Profitable thermal renovation of hotels to combat climate change and depletion of fossil fuels: The case of Cyprus

by

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To Costas and Eliel,
the two constants
in my variable life.

‘All that is impossible remains to be achieved.’
- Jules Verne -

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Abstract

Hotel buildings were identified as significant energy consumers. Within the theoretical framework of the thesis it was argued that climate change and increasing energy prices due to depletion of fossil fuels would cause pressure on hotel operations in Cyprus by increasing their cooling loads and operational costs.

The analysis was techno-socio-economic and the core aim was to evaluate the cost-effectiveness of selected energy saving strategies. These were in the form of building envelope upgrades, changes in indoor environmental criteria and introduction of renewable energy technology via solar air-conditioning to be implemented as part of the hotels' periodic scheduled building and systems upgrades with the aim of lowering their space conditioning energy costs and improving their profitability and competitiveness.

The applied methodology consisted of auditing of a case study hotel, energy consumption data collection both from a sample of hotels and industry-wide and a hotel guest survey. Thermal simulation of hotels in present and future climates was used to identify technically viable renovation strategies. Strategies found cost-effective were further checked for sensitivity to energy prices, hotel occupancy and climate.

The major findings of the thesis predict over 20% savings in space conditioning energy costs due to strategic building envelope upgrades, over 50% savings if in addition adjustments in thermal comfort criteria are included and over 80% savings if solar AC is added into the above. It was further found that with a minimal increase in room rates hotels could implement thermal renovation while maintaining or even increasing room income. A unique cost-efficiency indicator that measures profitability of the proposed energy saving strategies in terms of hotels' room income generation potential was developed in this thesis. Finally, if the suggested renovations were implemented on a mass scale, one quarter of Cyprus' national energy saving and renewable energy targets could be met.

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LIST OF ABBREVIATIONS

AC = air-conditioning

AHU = air handling unit

CTO = Cyprus Tourism Organisation

DHW = domestic hot water

DPB = discounted payback

EMS = environmental management system

EPBD = Energy Performance of Buildings Directive

ETC = evacuated tube collector

ETS = emissions trading system

FPC = flat plate collector

GHG = greenhouse gas emissions

GN = guest nights

h = hour

HVAC = heating, ventilation and air-conditioning

ITP = International Tourism Partnership

IRR = internal rate of return

LCC = lifecycle cost

LNG = liquidised natural gas

min = minute

NPV = net present value

PKM = passenger kilometre

PMV = predicted mean vote

POE = post-occupancy evaluation

pp = per person

PV = photovoltaic

PVT = photovoltaic-thermal

RH = relative humidity

s = second

SC = space conditioning

SIR = savings to investment ratio

SPB = single payback

toe = tonnes of oil equivalent

VAT = value added tax

WDD = Water Development Department (of Cyprus)

WTO or UNWTO = United Nations World Tourism Organisation

1 Chapter 1 - Introduction

1.1 Background

1.1.1 Tourism in the 21st century

The world total of international tourist arrivals has risen from a mere 25.3 million in 1950 to 806.8 million in 2005 indicating an average annual growth of 6.5% (WTO, 2007). Furthermore, the World Tourism Organisation predicts the figure to reach nearly 1.6 billion by 2020 from about 940 million in 2010 (WTO, 1999; 2011). Similarly, tourism revenue receipts have increased from US$2.1 billion to 682.7 billion over the same time period (WTO, 2007). Subsequently, it is obvious that tourism has become a key player in the world economy and the likelihood that many nations, poorer ones in particular, heavily rely upon.

Inevitably, the global economic growth and technological advances during the latter half of the 20th century have made long-distance travel possible and affordable for the masses. Low fossil fuel prices and the absence of aviation fuel taxation combined with fierce competition have further enabled the airlines to offer cheap flights to almost any destination imaginable. Not only is it possible to travel to far-away places but it has become somewhat of a ‘human right’ for people living in the post-industrialised world to travel and explore.

Tourist flows are subsequently expected to increase regardless of the fact that increasing fuel prices and environmental pressure are reshaping the industry. Fuel prices affect the tourism industry at every level from flight tickets to hotel room rates, restaurant bills, recreation expenses, shopping, etc. Climate change in turn affects tourism in two ways, on one hand by exacerbating the very problem due to emissions from its transport and accommodation components, and by altering the climate of the traditional destination countries on the other. In other words, flights and hotel energy use produce greenhouse gas (GHG) emissions that drive climate change and the impacts thereof cause overheating in hotel buildings, water stress, draughts, flooding, tropical storms, etc. at the destination end, thus feeding a vicious circle. Such changes in climate are expected to alter the patterns and seasonality of leisure travel especially in the Mediterranean where the summer temperatures may become uncomfortably hot. A shift in travel to cooler locations or to spring/autumn holidays in formerly popular summer destinations may result.

Incidentally, the tourism industry is not included in the national GHG inventories that all signatories of the Kyoto Protocol of the United Nations Framework Convention on Climate Change are required to produce annually (UN, 1998)[1]. Similarly, international flights are excluded from GHG inventories. In view of the fact that some 5% of global CO_2 emissions can be attributed to tourism, it is evident that such exclusion cannot continue (Davos Declaration, 2007). Subsequently, definite measures to reduce GHG emissions within the tourism industry are expected in the near future.

[1] It is noted that although tourism industry as such is excluded from the GHG inventories, the end-use sectors such as non-residential building energy use, local transportation, etc. are targeted.

1.1.2 External drivers

1.1.2.1 Climate change

As established above, climate change is expected to have a profound impact on the tourism industry in the future. It is therefore assumed to be an essential driver for energy saving in this study and subsequently it is important to define the term. In the usage of the Intergovernmental Panel on Climate Change (IPCC) the term 'climate change' refers to 'any change in climate over time, whether due to natural variability or as a result of human activity' (IPCC, 2007, p.2). In the context of this study the concept is narrowed down to refer only to human-induced greenhouse gasses, primarily CO_2 emissions that lead to gradual increase in the mean atmospheric temperatures and altered weather patterns. This definition is in line with the usage adopted in the United Nations Framework Convention on Climate Change (UN, 1992) that stipulates:

> *Climate change means a change of climate which is attributed directly or indirectly on human activity that alters the composition of the global atmosphere and which is in addition to the natural climate variability observed over comparable time periods.* (UN, 1992, p.3).

Temperature predictions in the Fourth IPCC Assessment Report for the small island regions are 'virtually certain' and they were given with 'very high confidence' (Mimura *et al.*, 2007). According to the scale of statistical uncertainty used by the IPCC, *'very high confidence'* denotes that at least 9 out of 10 chances are correct and *'virtually certain'* that an event has greater than 99% probability of occurrence (Parry *et al.*, 2007). In view of the above definitions and the general consensus on the effects of climate change in the Eastern Mediterranean, the climatological framework adopted in this thesis is justified.

It is further emphasised that measures to combat climate change are twofold. On one hand *adaptation* to climate change is necessary to deal in the short term with the impacts of changes that have already taken place due to historical emissions. On the other hand *mitigation* efforts are necessary to prevent or at least slow down further climate change. Such efforts include reducing fossil fuel based energy use in the long term. It is in this context that this study was conceived with an aim to evaluate how thermal renovation could be used to future-proof hotels in Cyprus against the negative impacts of climate change and increasing fossil fuel prices. The specifics of climate change in Cyprus are discussed in further detail in Chapter 2.

1.1.2.2 Depletion of fossil fuels

Depletion of fossil fuels causing price inflation was identified as another factor driving energy saving. In this study it is maintained that energy prices will continue to rise due to the fact that fossil fuel reserves are depleting and that at least the easily extracted 'cheap' oil supplies have to large degree already been exhausted. It is argued that the high oil prices at present are indeed a sign of a dwindling supply rather than any political or artificial inflation as was the case for example during the oil crises of the 1970s. A brief introduction to the 'peak oil' theory is given below so as to substantiate the premise of this study.

In 1956 an American geophysicist M. King Hubbert developed a theory, since then called the Hubbert Peak Theory, and used it to accurately predict that oil production in the United States, Alaska not included, would reach its peak between 1965 and 1970 (Hubbert, 1956). In the same study Hubbert predicted the world peak in oil production by writing:

> *If the world should continue to be dependant upon the fossil fuels as its principal source of industrial energy, then we could expect a culmination in the production of coal within the next 200 years. On the basis of the present estimates of the ultimate reserves of petroleum and natural gas, it appears that the culmination of world production of these products should occur within about half a century…* (p.27)

Literally speaking, half a century from the time when Hubbert made his prediction passed in 2006 and the debate about if and when oil will run out continues 50+ years on. Hubbert's protégé Kenneth Deffeyes predicted the peak to take place at the end of 2005 or early 2006 (Deffeyes, 2005). But as yet another prominent peak oil expert Matthew Simmons emphasised, the onset of a peak in oil production can only be verified in retrospect when the necessary production data is available (CNBC, 2007). There may still not be a universally agreed consensus whether the peak indeed was reached but the IEA stated in the *World Energy Outlook 2010* that global oil production indeed would peak one day, but that such a peak would be determined by factors affecting both demand and supply (IEA, 2010). In the same report IEA admitted that although oil production as a whole would continue to rise into the foreseeable future (2020 or 2035, depending on the scenario used), based on the most likely 'New Policies Scenario', conventional oil production (crude extracted from a well) already peaked in 2006 at production around 70 million barrels/day, as seen in Fig.1.1. Even with new oil field discoveries production is not expected to rise above an undulating balance at around 68-69 million barrels/day. The latest estimates by IEA indicate a significant shift in thinking as their previous estimates have been quite a bit more optimistic.

Figure 1.1 World oil production by type in the New Policies Scenario

Source: World Energy Outlook 2010 by International Energy Agency (2010)

The opponents of the peak oil theory often point out that one should not underestimate the power of future technological advancement in oil discovery and extraction nor the economical factors that will continue shaping the industry well into the future (Cambridge Energy Research Associates, 2006; Watkins, 2006). It has even been suggested that oil may not be exclusively of biogenic[2] origin, as generally believed (Tsatskin and Balaban, 2008). Tsatskin and Balaban argue that the modern petroleum science has provided compelling evidence that hydrocarbon genesis may also be abiogenic in origin. Such evidence includes findings of liquid and gaseous hydrocarbons in hydrothermal vents in the ocean, in meteorites and in the outer space. Even spontaneous oil well replenishment, such as the Eugene Island 330 well in the Gulf of Mexico, has been observed (Tsatskin and Balaban, 2008). What is indeed suggested by the multi-origin paradigm of hydrocarbon genesis is that hydrocarbons may not actually be finite in nature. Such a shift in paradigm would naturally have a major impact on exploration activities and hydrocarbon resource depletion estimation, though endless supply of abiogenic oil is yet to be found.

It can be concluded that regardless of the opposing views on the subject of peak oil, there is evidence that the oil extraction and production industry has already gone over marked changes and that large increases in production are not likely. Demand on the other hand is expected to increase due to aggressive industrialisation taking place in the developing nations such as China, India and Brazil. It is therefore assumed in this thesis that fossil fuel prises will continue to rise in the future and that energy saving measures, whether in the form of rational use of energy or by utilising renewable energy sources, are a way forward in protecting hotel operations against the financial implications due to energy price increases.

1.1.3 Hotel industry and guest comfort

It was established earlier that tourism travel is expected to increase in the foreseeable future. Naturally each travelling tourist will need temporary accommodation while away from home. Hotel accommodation was therefore chosen to be studied; in particular, how energy-efficiency improvements could be utilised to maintain income regardless of increasing operating costs driven by fuel price inflation and possible reduction in occupancy due to growing competition among tourist destinations or factors driven by climate change. Tourists and business travellers are notorious in demanding high levels of comfort while staying in hotels. Subsequently, the important role of hotels in defining and maintaining high comfort standards has been noted over the years.

The known history of guest accommodation dates back to 1800 B.C. when the Babylonian king set out standards for tavern owners in the Code of Hammurabi (McDonough *et al.*, 2001). McDonough *et al*. continue developing the historical timeline of hotel accommodation by pointing out that over the centuries hotels have been beacons in setting up new living and building standards. One good example of such pioneering trend setting was the introduction of modern plumbing complete with water closets and hot and cold water piping in the Tremont Hotel in Boston, Massachusetts in 1829, long before it became a standard in other types of buildings. Similarly, in 1904 New York City's St. Regis Hotel set a new standard by fitting its guestrooms with individually controlled heating and cooling units. More recent trends were set when the Hilton chain equipped its hotel rooms with television sets in 1951 and in 1991 when the Westin hotels introduced voicemail for their guests. Therefore, the 'civilizing' influence of hotels, as accurately

[2] Biogenic origin of hydrocarbons means that hydrocarbons are of organic, i.e. plant or animal origin, transformed via bacterio- and thermogenesis.

termed by McDonough *et al*., has been significant over the centuries or even millennia. It is in this spirit that hotel buildings were selected for this study, i.e. with anticipation that once again hotels could set a new standard for environmentally responsible, sustainable, energy- and water-efficient building operation.

The aspect of guest comfort relevant in this study is thermal comfort as it is directly linked to heating and cooling energy consumption. However, thermal comfort is not a universal state that can be obtained by a fixed temperature setting. Instead, it varies between individuals, nationalities, genders, age, seasons, time of the day and so on. Therefore, guests must have control over the room temperature settings in order to cater for the varying needs. Such individual control, however, opens up a door for energy wastage. Hence innovative ways must be found to maintain comfort by introducing indirect and invisible controls over the potentially energy wasting decisions and actions of individual guests. Furthermore, control over guest behaviour goes hand in hand with an efficient building envelope; it is certainly much easier to prevent guests from overheating or -cooling their rooms when the building envelope is built so that unwanted heat losses and gains are minimised. It is therefore maintained that thermal renovation is a reasonable starting point for hotels to take control over their energy consumption.

1.1.4 Cyprus as a case study

Cyprus, located at the north-eastern part of the Mediterranean basin is the third largest island in the Mediterranean Sea with an area of 9251 km^2 out of which 47% is arable, 19% forest and the remaining 34% uncultivated land (Water Development Department, 2011). The geographical location and a map of the island are shown in Fig. 1.2. As a semi-arid island Cyprus' climate can be characterised as temperate with hot, dry summers and cool winters. The island is prone to water shortages although the winter months are associated with sometimes heavy torrential rains causing flash flooding. Rains occur typically between the months of November and March. The average annual rainfall on the island is about 500 mm ranging from 300 mm in the central plain and the south-eastern parts of the island to 1100 mm on the Troodos mountain range. The population of the island in 2009 was estimated at 892400 (Statistical Service of Cyprus, 2011).

Island of Cyprus

Figure 1.2 Geographical location of Cyprus and a detailed map of the island

Source: (kypros.com, no date)

From the economy point of view Cyprus is characterised as a market economy dominated by the services sector with an 81.3% contribution towards the GDP[3], whereas only 16.4% is contributed by industry and construction and 2.3% by agriculture (Central Intelligence Agency, 2011). About one quarter of the contribution of the services sector is due to tourism and related activities including the operation of hotels and restaurants, rental car agencies, theme parks etc. Furthermore, 71% of the labour force is employed by the services sector and about 10% of total gainfully employed population for the production of GDP directly by the accommodation and food service activities (Statistical Service, 2010), much more if the indirect and spinoff activities, retail in particular, are included. To put it all in the context, the gross output and the value added of hotels and restaurants in 2008 were €1954.8 and €1012.1 million respectively at current market prices. Furthermore, 15.2% unemployment in 2009 (Statistical Service of Cyprus, 2010) among the workforce of the accommodation and food service sector in comparison to the total unemployment of 5.3% indicates that it is harder hit by unemployment than the other sectors.

Regarding energy consumption, the greatest share (52%) is taken by transport followed by residential (20%), tertiary sector (14%), industry (11%) and agriculture (3%) (Republic of Cyprus, 2007). Further, electricity accounts for 47% of the total energy consumption. Electricity consumption increased by about 80% during the period 1995-2005, mostly within the residential and tertiary sectors. Total energy and electricity consumption figures are shown in Fig. 1.3.

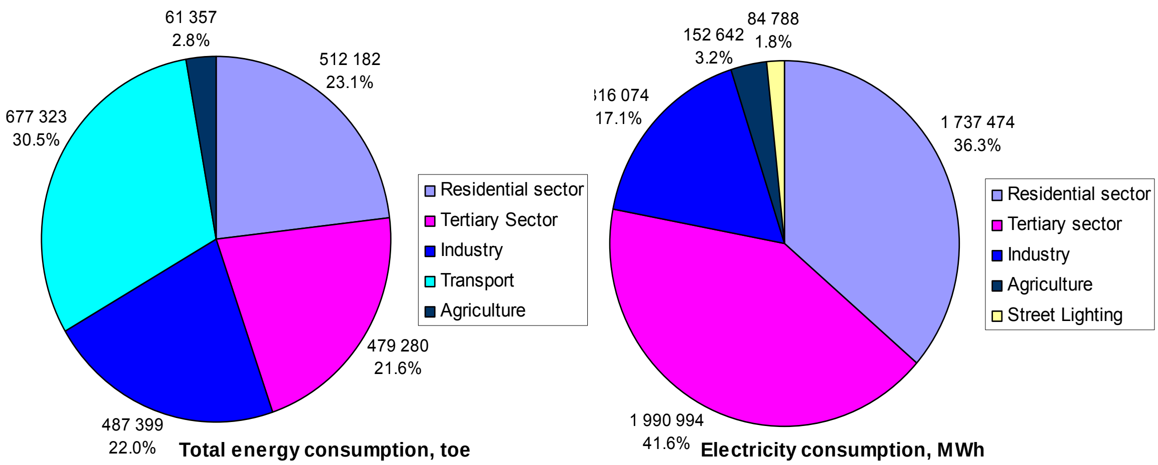

Figure 1.3 Total energy and electricity consumption in Cyprus

Sources: Compiled from National Energy Efficiency Action Plan (Republic of Cyprus, 2007) and Annual Report 2010 (Electricity Authority of Cyprus, 2011a)

Note: Transport excludes fuel consumption by aviation, shipping and the armed forces vehicles.

Due to the important contribution of tourism in the national income of the island, it is obvious that any disturbances in tourist flows have an immediate impact on the economic health. It is indeed observed that global crises, such as both Gulf wars and most recently the 2008 credit crisis negatively impacted tourist arrivals in Cyprus. In 2009 10.9% reduction in tourist arrivals and 16.7%

[3] For a frame of reference the GDP of Cyprus in 2009 was estimated at €16946.5 million and €21236 per capita (Statistical Service, 2010).

reduction in tourism receipts was recorded (Statistical Service of Cyprus, 2010). Therefore, a small country like Cyprus that so heavily relies on tourism as an income and employment generator is more vulnerable to the negative impacts of climate change and rising energy prices discussed earlier than a more mature economy with a higher level of economic diversification. It is subsequently concluded that Cyprus is a highly relevant country as a case study for an in-depth analysis of energy-efficient renovation of hotels as a means to lower their operational expenses and to remain competitive in the international tourism market.

1.2 Thesis aim and hypothesis

In addition to the needs to mitigate the impacts of climate change it is speculated that price increases in air travel due to fuel price inflation will cause tremendous pressure on the hotel sector to absorb all or part of the price increase in order to remain competitive to tour operators handling a large part of the tourist arrivals in Cyprus. Subsequently, hotels are left with a decision either to accept lower income or to take measures targeted at reducing their operational costs, heating and cooling energy costs in particular. Cyprus was selected as a case study because it represents a small island state largely dependent on its tourism income, yet vulnerable to many of the adverse effects attributed to climate change. In addition, Cyprus is solely dependent on imported fossil fuel which adds the elements of fuel supply insecurity and price vulnerability. Secondly, it is argued that it is economically prudent to renovate hotels as a precautionary measure against the negative drivers of climate change and rapidly rising energy prices. Improved energy-efficiency not only reduces heating and cooling energy costs of hotels but can also help in market repositioning by providing a greener and more eco-friendly holiday product. Such product differentiation is perceived to be vitally important in the future when competition for tourist arrivals will inevitably increase.

Therefore, the main aim of this study is:

to develop a methodology for evaluating the impacts of climate change and rising fossil fuel prices on space conditioning energy costs of hotels in Cyprus and to propose cost-effective thermal renovation strategies to combat such impacts.

The objectives of the study are:

1. To understand by literature review how climate change and depletion of fossil fuels would affect space conditioning energy consumption of hotels in Cyprus,
2. To assess by energy audit of a representative case study hotel, an energy consumption survey of a small sample of hotels and by analysis of an industry-wide dataset on hotel electricity use the current baseline of space conditioning energy consumption of hotels in Cyprus,
3. To evaluate by thermal simulation which energy-efficiency measures implemented in the form of building envelope improvements, thermal comfort criteria adjustments and introduction of renewable energy technology could be cost-effectively employed in existing

hotel buildings in order to reduce their space conditioning energy costs at present or in the projected future climates of 2050 and 2090,

4. To investigate by questionnaire survey to what extent the additional capital costs of implementing such measures could be offset by an increase in hotel room rates,
5. To develop and test a new economic efficiency indicator aimed at evaluating the viability of the proposed renovation strategies measured in terms of their income generation potential, and
6. To extrapolate the effects of cost-effective thermal renovation strategies to the entire hotel building stock of Cyprus by estimating the overall energy and operational costs savings potential and by developing recommendations for nationwide rational hotel building upgrade.

The hypothesis of this thesis is that a minimum of 20% savings in space conditioning energy costs can be realised by cost-effective thermal renovation of hotel buildings in Cyprus. By ‘thermal renovation’ it is meant that the chosen strategies target savings in space conditioning (SC), i.e. heating and cooling energy and costs. Subsequently, the focus is on building envelope upgrades and introduction of renewable energy technology for space cooling. In addition, the impacts of indoor environmental parameters, hereinafter referred to as ‘thermal comfort criteria’ are evaluated in regards to SC energy saving. 20% energy saving objective was selected in order to tie this study into the EU target of 20% improvement in energy-efficiency by 2020 (European Commission, 2011a). It is noted that much stricter targets for 2050 (88-91% CO_2 emissions reduction in the residential and services sectors) and beyond are proposed (European Commission, 2011d, Table 1, p.4) but this thesis was set out to address the immediate target and to explore if any additional energy savings were likely with the set of strategies studied in detail.

In addition, recommendations of practical measures for adapting to the future climate and reducing operational costs of hotels are made, aimed at the appropriate stakeholders planning and financing such projects.

The original contribution of this research lies in the methodology that systematically evaluates the cost-effectiveness of hotel renovation under the combined influence of three variables, namely the climate (present and regional climate model projections for 2050 and 2090), fossil fuel prices (incremental increase) and hotel occupancy (incremental decrease). No existing research was identified investigating energy-efficient renovation of any type of buildings, hotels included, with such a methodology. In addition and most importantly, a unique cost-efficiency indicator was developed to measure the profitability of the proposed energy saving strategies by relating the predicted energy cost savings to the hotels’ room income generation potential. This new indicator could radically change the way how techno-economic studies aiming at evaluating and ranking hotel energy-efficiency improvement projects were conducted and hopefully increase the uptake of implementation and encourage third-party financing for such projects. Although the methodology was tested in the Cypriot context, it was designed to be applicable in other countries with similar tourism dominated economic structures. It is therefore believed that this study fills a gap and contributes to knowledge on multiple levels by:

1. adding to the knowledgebase how to strategically employ building envelope renovation and renewable energy technology not only to reduce energy consumption and costs in hotels but also to increase their profits even during the amortisation period of such investments,
2. suggesting cost-effective mechanisms and priorities that could be effectively implemented on a policy level within the EU framework and energy saving targets,
3. developing a new cost-efficiency indicator that is more applicable to hotel operations than any existing indicator, and by
4. increasing understanding of the interdependencies between climate change, fossil fuel depletion and ultimately the survival of tourism-based economies in a wider scale.

It is noted that this study focuses on the economic rather than environmental impacts of climate change. The choice of focus was intentional in view of the fact that the decisions about hotel renovation and energy-efficiency upgrades are generally made based on perceived financial savings as a direct result. Climate change policies, on the other hand, are driven by environmental agendas that aim at reducing GHG emissions. Such policies typically also consider fuel security issues coupled with promotion of renewable energy but fundamentally they serve emissions reduction goals. Climate change, however, cannot be separated from economics. In the Stern Review climate change was identified as a unique challenge for economics, the 'greatest example of market failure' (Stern, 2006, p.1). The basic link between economic and environmental benefits is obvious though; every kWh of fossil-fuel-originated energy saved means reduction both in costs and in GHG emissions. It is argued, however, that in the future when fuel prices increase rapidly, financial savings per unit of energy grow steeply, whereas emissions savings will stay constant or even fall as technology advances and electricity generation becomes cleaner. On the flip side of the coin, renewable energy generation is typically considered to be more expensive than conventional fossil fuel energy, meaning that the efforts to use renewables that are justified environmentally may not be so economically. It is the premise of this study, however, that even alternatives that may not be economically feasible with the current or recent fossil fuel prices will be so in the scenarios where the negative drivers of climate change and increasing energy prices are factored in. Therefore, it is maintained that economic and environmental benefits are mutually supportive and that addressing the economic side leads into a true win-win situation.

1.3 Thesis structure

The thesis is divided in eleven chapters and the structure is shown in Fig. 1.4. The chosen study angle is techno-socio-economic and the related aspects are identified in the figure. The figure also shows the interface between the study and the theoretical framework underpinning it. In addition, the logical sequence of the methods employed is shown and the points where the study objectives are addressed are indicated.

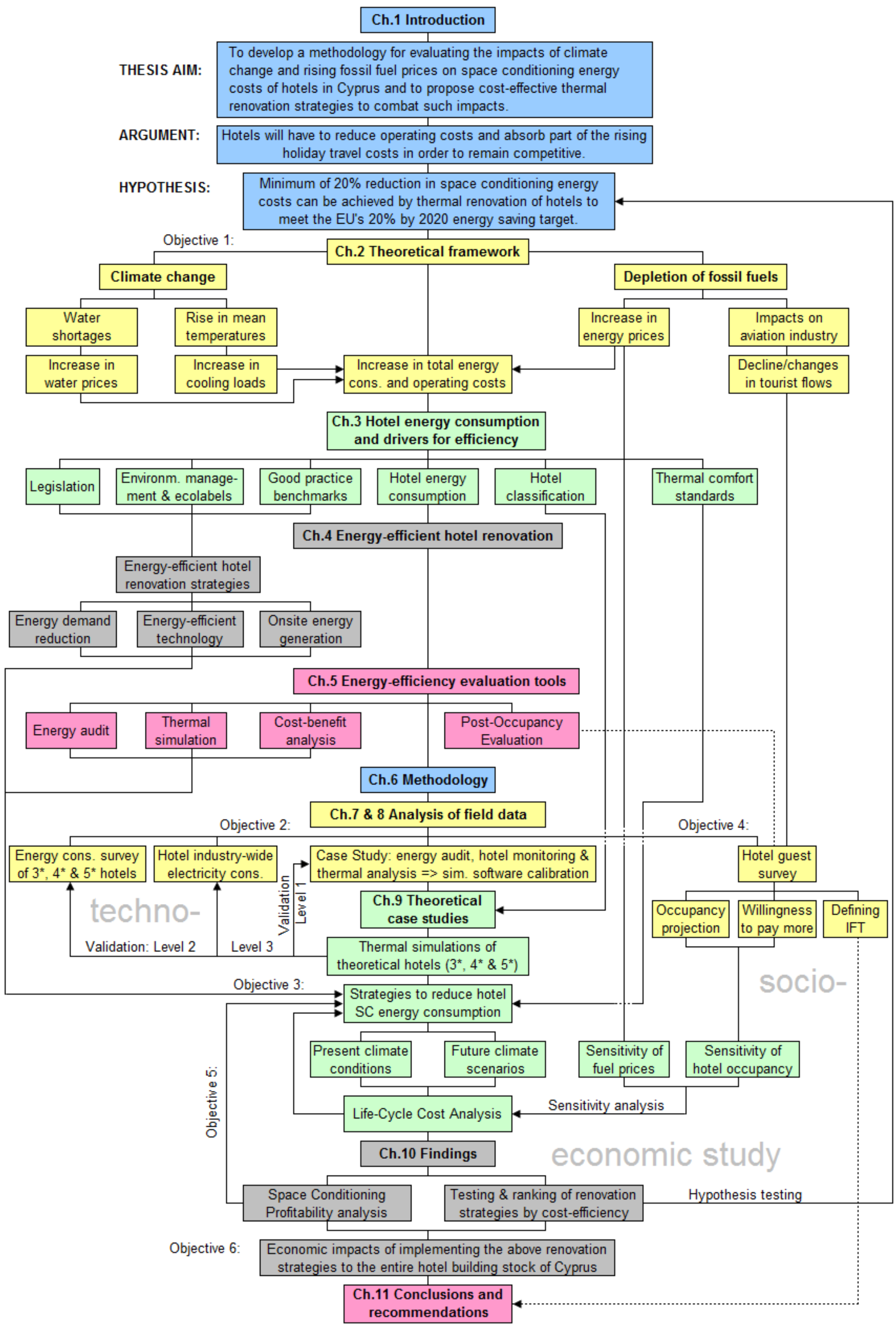

Figure 1.4 Thesis structure and methodology flow diagram

1.4 Conclusions

It was established in this chapter that the needs for hotel accommodation remain high as leisure travel is projected to grow globally. Tourists are known for demanding high levels of comfort when away from home. Therefore, hotels cannot lower their comfort standards but are rather forced to find other ways to reduce their operational costs using strategies that maintain guest comfort yet save energy. The need for energy saving becomes even more acute when the external drivers of climate change and rising energy prices are factored in. It was subsequently suggested that thermal renovation is a sensible way for hotels to adapt themselves against the negative impacts of climate change and rising energy prices. Cyprus was introduced as a case study because it represents a small island state largely dependent on tourism as an income and employment generator, yet vulnerable to many of the adverse effects attributed to climate change and it is entirely reliant on imported oil. In view of the urgent need to address the above issues this study was taken up to investigate the role of thermal renovation in hotel operations, room income generation in particular. In addition, it was of interest to observe the impact of such renovation on a mass scale in meeting the underlining energy saving targets of the EU.

2 Chapter 2 – Theoretical framework

1.1 Introduction

The purpose of this chapter is to firmly place this study within the chosen theoretical framework and it directly contributes towards Objective 1 *to understand by literature review how climate change and depletion of fossil fuels would affect space conditioning energy consumption of hotels in Cyprus*. The external drivers of climate change and depletion of fossil fuels were briefly introduced in the previous chapter but they are examined in more detail here. Climate change issues relevant to the island of Cyprus and fossil fuel reserve estimation and related uncertainties are discussed from an evidence-based point of view. But before tackling the above issues, the relationship between tourism and climate change is established and a brief introduction to research in that domain is given.

Aviation is discussed in this chapter with the aim to better understand where the industry is heading and if any fuel savings or operational efficiency improvements could be expected within the industry in the future that in turn could ease off the pressure on hotels to accept lower revenue.

2.1 Tourism and climate change research

2.1.1 Historical background of tourism and climate change research

The inherent relationship between climate and tourism has been recognised for a long time in the context of tourists selecting a holiday destination based on the climatic conditions the place has to offer. However, the connection between climate *change* and tourism has not been widely studied until recently (Viner, 2006). The first studies seeking for a link between tourism and climate change focussed on North American ski resorts with the potential of reduced snow cover and shorter ski season (McBoyle and Wall, 1992) and the vulnerabilities of wetland areas (Wall, 1998).

2.1.2 Tourism and climate change research and actions today

Tourism and climate change research was taken to a new level in 2003 when the WTO held the First International Conference on Climate Change and Tourism in Djerba, Tunisia. During the same year researchers who shared similar research interests established a network forum called eCLAT, i.e. Experts in Climate Change and Tourism (eCLAT, 2003). The above two incidences gave a healthy impetus for tourism and climate change research but Viner (2006) argues that still only a relatively small number of papers on the subject has been published. Subsequently, one of the objectives of eCLAT is to '*provide constructive advice to governments and stakeholders to aid them in their decision making process*' (eCLAT, 2003).

In 2007 the Second International Conference on Climate Change and Tourism was held in Davos, Switzerland. The conference culminated in a declaration that calls for action from the governments and international organisations, tourism industry and destinations, consumers as well as the research community (WTO *et al*., 2007). One of the actions called upon was for the tourism industry and destinations to promote and undertake investments in energy-efficiency and use of renewable energy resources with the aim to reduce the carbon footprint of the entire tourism sector. Implementation of climate-focused product diversification, repositioning of destinations and support systems together with fostering all-season supply and demand were among some of the means to tackle the challenge. The participants agreed that tourism would continue to be a vital component of the global economy, an important contributor to the Millennium Development Goals and an integral, positive element in the society. Therefore, future tourism must reflect a ‘quadruple bottom line’ of environmental, social, economic and climate responsiveness in order to be truly sustainable. A range of policies encouraging such ends are required. Such policies should aim at mitigating GHG emissions derived especially from the transport and accommodation activities, adapting tourism businesses and destinations to changing climate conditions, applying existing and new technology to improve energy-efficiency as well as securing financial resources to help poor regions and countries.

Therefore, this thesis by evaluating the impacts of climate change on hotel energy costs is well placed within the objectives of the subject-specific wider research community.

2.2 Environmental and economic key drivers

2.2.1 Climate change predictions in the Mediterranean region

The climate change assumptions used in this study are based on the projections laid out in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Parry *et al.*, 2007). Especially the work by Working Group II is relevant. The impacts of climate change relevant to Cyprus are covered in two chapters of the report written for different geographical areas, i.e. for the Mediterranean region of Europe (Chapter 12) and for small islands (Chapter 16).

2.2.1.1 Temperature predictions

The IPCC report includes seven climate model studies for the small islands regions, i.e. for the oceans and all studies projected increased surface air temperatures for the islands in question (Mimura *et al.*, 2007). Temperature increase is expected at ‘very high confidence’. More concisely, mean annual temperature increases of 0.60-2.19°C for years 2010-2039, 0.81-3.85°C for 2040-2069 and 1.20-7.07°C for 2070-2099 compared to the base period of 1961-1990 are predicted for the Mediterranean basin (Mimura *et al.*, 2007, p.694). It is noted that the predicted temperatures apply to open ocean surfaces rather than to land, suggesting that the actual land-based temperature changes may be even higher (Mimura *et al.*, 2007). In addition, warming in the Mediterranean is projected to be greater in summer than in winter.

Subsequently, the limitations of *global climate models* (GCMs) have been recognised especially in the context of small islands. As mentioned, GCMs tend to miss the land mass of islands due to the coarse resolution used, typically a few hundred kilometres, and treat them as oceans instead (Jones *et al.*, 2004). However, the thermal inertia of land mass is much lower and will warm much faster than the surrounding ocean. Therefore the need for *regional climate models* (RCMs) arises. Fig. 2.1 further clarifies the difference between global and regional climate models in and around the Mediterranean basin. But as can be seen, even an RCM with 100 km resolution cannot resolve the island of Cyprus. Therefore, further refinement in the model is necessary.

Figure 2.1 Comparison of global and regional climate model temperature increase predictions in and around the Mediterranean basin

Source: Met Office Hadley Centre (Jones *et al.*, 2004)

Temperature changes specifically in Cyprus have been studied by Price *et al.* (1999). They found out that the annual mean temperatures have increased approximately 1.3°C on the coast and 1°C inland over a century, approximately twice the observed globally averaged warming as reported by the IPCC. In addition, decrease in the diurnal temperature range (DTR) was observed varying from -0.5°C for an inland station to -3.5°C for a coastal station over the past century. Furthermore, there were major differences between the coastal and inland locations. Both the minimum and maximum daily temperatures have increased throughout the time series for inland, minimum at a larger rate than the maximum thus reducing DTR, but on the coast the reduction in DTR is all due to increase in minimum daily temperatures when actually the maximum daily temperatures have been reduced. Price *et al*. conclude that rapid urbanisation and land use changes alone cannot explain the profound warming tendencies observed on the island but that global climate change, whether natural or anthropogenic in origin, must be driving it.

2.2.1.2 Other impacts of climate change

The following impacts of climate change for the Mediterranean area are listed in the IPCC Fourth Assessment Report: reduced water availability, increased drought, severe biodiversity losses, increased forest losses, increased forest fires, reduced summer tourism, reduced suitable cropping areas, increased energy demand in summer, reduced hydropower, increased land loss in estuaries and deltas, increased salinity and eutrophication of coastal waters and increased health effects of heat waves (Alcamo *et al.*, 2007, p.558). Two of the listed effects above are of particular interest in the context of this study, namely reduced summer tourism and increased energy demand in summer. The report suggests that the more intense summer heat in the Mediterranean will cause a shift in tourism to further north and to higher mountainous regions. However, spring and autumn tourism is expected to increase. Such a shift in case of Cyprus would actually be positive as the island is currently suffering from high seasonality of tourism with increased stress on water and energy resources during the summer peak season. Up to 28% increase in summer cooling loads is predicted for the south-east Mediterranean region by 2030 and subsequently 10% decrease in winter heating (Alcamo *et al.*, 2007).

2.2.2 Fossil fuel future; is another energy crisis eminent?

Whether 237%[4] inflation in crude oil price in just four years between 2003 and 2007 is enough to onset a global energy crisis is an essential question. Some experts believe that the credit crunch and the global recession of late 2008 were in part due to high oil prices (Waters, 2010). But the 2008 credit crunch did not cause inflation on fossil fuel prices as in previous oil crises. On the contrary, oil prices came down, but as speculated by some experts, the post-crisis fossil fuel prices were kept artificially low. In any case, the prices are recovering fast and crude oil peaked at nearly $114 at the end of April 2011 (NYSE.TV, 2011a). Superficially speaking, there are many parallels between the 1970s oil crises and the recent and ongoing inflation of oil prices. Subsequently, the argument that over time oil prices would stabilise at a significantly lower price level than the current prices indicate would seem reasonable. However, there are some fundamentally different factors at play now that were not present in the global economy in the 1970s.

One such difference is the fact that whereas the 1970's oil crises had a reducing impact on global energy consumption, the 2008 oil price hikes did not. On the contrary, the world primary energy consumption continues rising and rose 1.2% between 2007 and 2008, a period leading to the recession (BP, 2011b). Oil consumption was reduced by 0.5% between 2007 and 2008 but has since rebounded and saw a 3.1% increase from 2009 to 2010 taking oil consumption to a record high. During the same period from 2009 to 2010 primary energy consumption rose 5.6%, the highest growth rate since 1973 (BP, 2011a).

A secondary issue to be considered in the context of high oil prices and the recent global recession is whether at least a slowdown is to be expected for example in the industrialisation process of China. The question is partly answered by the fact that in 2009 China's energy consumption surpassed that of the USA making China the world's largest energy consumer (IEA, 2010). Oil demand in China is projected to continue increasing and the transport sector is largely responsible for the growth (Nel and Cooper, 2008). To illustrate the growth volumes in question, car sales in China increased 100% between 2002 and 2003 (Wang, 2004 quoted in Nel and Cooper, 2008). Car ownership in China is expected to increase from 13 to 230 cars per 1000 people in the period 2000–2050[5] (European Environment Agency, 2007, p.407).

Subsequently, it is quite obvious that China will continue its industrialisation and motorisation process well into the foreseeable future. Moreover, China's increased dependency on imported oil will be integral with the process. Therefore, the energy security debate should include the future geopolitical dimension of oil sharing, i.e. new super consumers entering the energy market. Inevitably, as the oil supplies dwindle, there will be more competition for what is left. In such a context Williams makes a reference to 'resource wars' (2006, p.1075) and considers various scenarios where China and the US would be competing for Iraqi oil in varying levels of hostility.

Therefore, in view of the current global economic and geopolitical situation, the question whether the pre- and post-recession ultra or moderately high oil prices are a sign of a permanent

[4] From average crude oil price of $28.83 in 2003 to $97.26 in 2008 (BP, 2011b)
[5] For comparison, the current level of car ownership in OECD Europe is 390 cars/1000 people.

trend or just a local peak can be answered with confidence: the era of cheap oil is over. The fundamental difference between the current recession and the 1970s oil shocks is that the demand from the developing world is so high that oil prices have become increasingly insensitive to the laws of supply and demand. Even the most aggressive energy saving and alternative energy campaigns in the industrialised world would not reduce global demand to a point where market forces would adjust the prices, at least in the short term.

2.2.3 Transport and tourism: The aviation dilemma

2.2.3.1 Environmental impacts of aviation

Transport is an essential part of tourism as it provides the means for the required mobility. Whereas continental destinations can be reached by rail and road, island destinations can only be reached by air and sea. Further, the choice arriving by sea is typically limited to nearby locations subsequently making air transport the major means of entry for many remote islands. For instance, 91% of all tourist arrivals in Cyprus are estimated to be by air and the figure is projected to increase to 94% by 2020 (European Commission, 2006). Moreover, the environmental impact of tourism is estimated at 89% transport, 70-80% out of which is attributed to air travel (Peeters, 2007). Out of the remaining, 8% of GHG emissions are due to accommodation and 3% leisure activities and local transport at destination. Subsequently, it is evident that the environmental footprint of tourism in Cyprus is highly dominated by the transport component. Little if anything, however, can be done about the travel component at the destination end as tourists arrive on the island primarily by foreign airline carriers. Therefore, it is the premise of this thesis that the environmental responsibilities of the tourism industry of island destinations lay largely on energy and water efficiency improvements of the accommodation infrastructure. At the same time the tourism industry at large and the entire mankind should strive for decreasing the environmental footprint of travel, aviation in particular, although it is reminded that the focus should not be exclusively on aviation since after all it contributes only 2-2.5% of total CO_2 emissions globally (Lee, 2010).

The aviation industry has been in search for alternative fuels ever since the early 1970s energy crisis. Actually, the early model of jet engine was developed to be powered by hydrogen but the fact that the energy content of hydrogen per volume and weight was too low complicating fuel storage discarded it as a candidate for aircraft fuel (ICAO, 2007b). The options of alternative aircraft fuels are divided into two categories: drop-in and non drop-in fuels. Synthetic jet fuels manufactured from coal, natural gas, oil shale or tar sands, or other hydrocarbon feedstock using Fischer-Tropsch process are drop-in fuels and can be substituted directly for conventional fuels without any changes in aircraft or engines. Non drop-in fuels, in turn, require a completely new design of jet engines and they include cryogenic liquids such as liquid methane and liquid hydrogen. Cryogenic liquids are highly compressed and at very low temperature, thus complicating their handling and increasing their storage volume (ICAO, 2007b). In addition, major changes in the fuel distribution and ground transportation systems would be required (Hadaller and Daggett, 2007). Therefore, their adaptation into aviation does not look likely in the near future.

Subsequently, it appears that the best promise for reducing the environmental footprint of aviation lies in fuel efficiency and overall flight efficiency[6] improvements. At the moment modern aircraft achieve fuel efficiencies of 3.5 litres per 100 PKM and the next generation of aircraft target for less than 3 litres (Air Transport Action Group, 2007). However, flight volume is likely to increase at a much faster pace than any technical improvements could possibly cancel out its negative impacts. Therefore, a totally different approach in aviation is required in order to curb its environmental impacts. One such a concept is the 100-percent-solar-powered aircraft under development by Solar Impulse, a Swiss research and development company spearheaded by scientist-explorer Bertrand Piccard, the captain of the first non-stop hot-air-balloon-flight around the world in 1999 (bertrandpiccard.com, no date). The first manned test flight of the solar plane took place in 2010 and in July 2011 the plane made promotional flights in Europe to Paris and Brussels. A mission to fly around the world is scheduled for 2014. The International Air Transport Association (IATA), a representing body of some 240 airlines comprising 94% of scheduled international air traffic, is an institutional partner of Solar Impulse and supports the pioneering efforts towards zero-carbon aviation (IATA, 2008). IATA itself has set a strategic coal to make air traffic zero-carbon in 50 years time and to achieve carbon-neutral growth in the medium term (IATA, 2008). However, there are many technical obstacles to overcome before solar aviation becomes viable for passenger traffic. It is estimated that it will take over 40 years to be able to build a solar aircraft capable of carrying several hundred passengers. The current limitations are mainly due to heavy batteries required to store enough power during the daytime in order to enable night-time operation, thus limiting the aircraft's additional load carrying capacity. Nevertheless, although not a short-term solution to the aviation dilemma, the project does offer some tangible hope for zero-carbon skies for the future generations.

2.2.3.2 Economic impacts of aviation

As concluded above, it is highly unlikely that the industry were to accomplish any net emissions reductions in the short term. The main focus of this study, however, is to look at the financial implications that climate change and rising energy prices will have on tourism, either on its travel or accommodation component. As stated earlier, it is argued that the aviation industry cannot indefinitely continue absorbing the increasing fuel costs without increasing airfares. That in turn implies that different cost sharing and distribution formulae between the travel and accommodation components of package holidays are inevitable.

Airlines have an opportunity to try and pass some of the additional expenses either to individual tourists via increased airfares or in case of package holidays to negotiate with the tourist destinations a new formula of cost sharing. A triangular relationship between airlines, tourists and tourist destinations is shown in Fig. 2.2. It is noted that ultimately the choice of accepting a price increase in an airline ticket or a holiday package lies with an individual tourist. Similarly, an individual tourist will decide whether the increase is worth it for a given destination. At the same time the destinations must adapt to new climatic conditions caused by climate change and face challenges in thermal comfort and operational costs. In addition, climate change also applies direct

[6] Flight efficiency is influenced by efficient air control, route optimisation, capacity and load ratios, etc.

pressure on the aviation industry as the debate how to charge the true environmental costs from the industry will inevitably pick up momentum in national and international agendas. Therefore, it is believed that the aviation industry is at a brink of a major change.

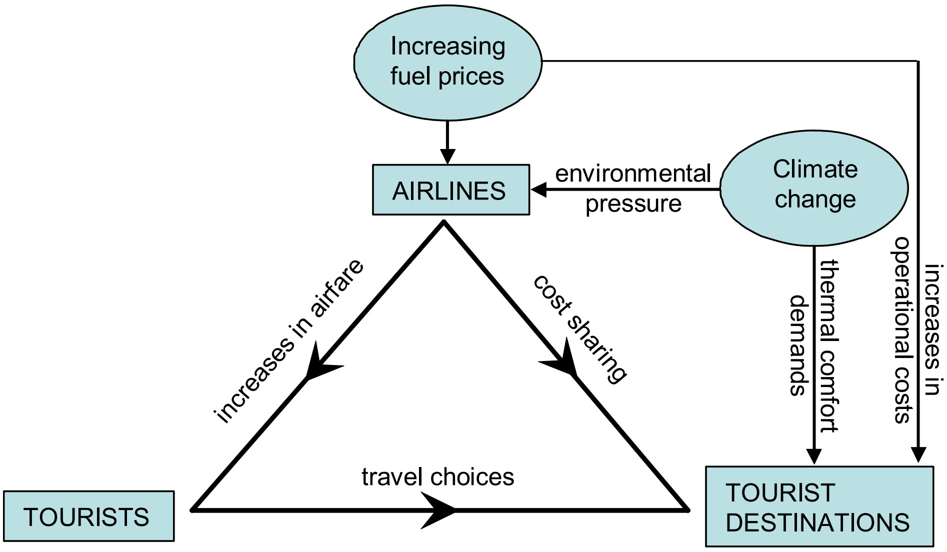

Figure 2.2 Relationship between airlines, tourists and tourist destinations

The above discussion on aviation is of essence because it is the premise of this thesis that in the competitive market of holiday travel, package holidays in particular, the accommodation sector must be prepared to absorb at least part of the price increase affecting the travel component, whether due to fuel price inflation or environmental costs. It is hypothesised that hotels have a window of opportunity to maintain profitability by reducing SC energy costs while remaining competitive to tour operators. How much increase in energy prices can be absorbed by hotels without eroding income is analysed later in this thesis.

2.2.4 Cooling energy needs of Cypriot hotels

In the context of this study, it is of interest to make a preliminary evaluation of the energy demands of the entire tourist accommodation building stock in Cyprus. Taking the total number of hotel beds of 88234 and converting it into building area using an average total gross area[7] of 55 m^2 per two-bed room (Ransley and Ingram, 2004), the gross area reaches 2.4 Mm^2. In an attempt to make a rough estimate for the total cooling load, benchmarks provided by the International Tourism Partnership (ITP, 2005) are used. (The ITP benchmarks are discussed in detail later in the thesis.) In addition, it is assumed that about 42%[8] of the annual electricity is consumed during the cooling season by air-conditioning chillers and the associated systems. Therefore, annual hotel cooling loads in the order of 82-178 GWh are to be expected nationwide[9]. Having in mind that the total electricity generation capacity on the island in 2009 was 4656 GWh (Electricity Authority of Cyprus,

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[7] Total gross area per room is the entire hotel gross area excluding parking divided by the number of guestrooms. 55 m^2 represents an average figure for economy and resort hotels.

[8] Average figure from hotel energy audits conducted in Cyprus as part of an EU funded project under the SAVE II Programme (CHOSE, 2001a).

[9] Electricity consumption figures used are taken from Table 3.8 as follows: 175 $kWh/m^2/yr$ for luxury serviced hotels and 80 $kWh/m^2/yr$ for small and budget serviced hotels. ‘High’ use assumed.

2010), hotel cooling alone could take up nearly 4% of the total electricity generation capacity. Subsequently, hotels are major consumers island-wide and by addressing hotel cooling, significant progress could be made towards the EU's 20% by 2020 target. Therefore, selecting hotel accommodation as the focus of this study and their cooling in particular, seems appropriate and most certainly massive energy saving measures are urgently needed to target hotel buildings in order to reduce their energy footprint and at the same time increase their overall profitability, competitiveness and ultimately the survival of the tourism industry in Cyprus.

2.3 Conclusions

This chapter was written in direct response to Objective 1*: to understand by literature review how climate change and depletion of fossil fuels would affect space conditioning energy consumption of hotels in Cyprus*. To begin with, the study was placed in the context of tourism and climate change research so as to tie it into an existing debate and a branch of research. As concluded, there is still quite little research done in the said domain and thus this study fills a gap in a wider context by addressing the relationship between hotel energy-efficiency and climate change.

The second part of the chapter examined the impacts of climate change in Cyprus. Evidence- and measurement-based studies were introduced to provide already recorded proof on climate change. As for the future climate predictions in Cyprus, it was demonstrated that the resolution of global climate models was too coarse; hence the need for regional climate models. Next, the economic drivers were examined. Global energy consumption was discussed in light of the past and present energy crises and it was concluded that depleting supply would not be able to meet the much greater increase in demand.

Aviation was considered as another economic driver that is believed to have major influence on the hotel operations in Cyprus in the future. The premise of this study is that in circumstances where the majority of tourist arrivals are of package holidays in nature, i.e. a lump sum is paid for transport and accommodation, hotels may have to absorb some or all of the increases in the travel component of the holiday package resulting from fuel price inflation. In order to substantiate the claim, aviation was examined in detail so as to understand if any fuel-efficiency or operational improvements could be expected from the industry itself. It was concluded that no major technical breakthroughs were to be expected in the near future and that on the contrary the operational costs of the aviation industry may rather rise if eventually policies were implemented requiring the true environmental costs of aviation to be borne by the industry.

Finally, the cooling energy needs of the entire tourist accommodation industry were estimated and they were related to the total electricity consumption on the island. It was subsequently concluded that targeting energy saving within the hotel industry had a good potential of bringing Cyprus as an EU member state closer to the 20% by 2020 energy saving goal.

In the next chapter a closer look is taken at hotel energy consumption as well as drivers for energy-efficiency improvements in hotels.

3 Chapter 3 – Hotel energy consumption and drivers for efficiency

3.1 Introduction

The purpose of this chapter is first of all to provide data and figures of typical energy consumption of hotels globally and in Cyprus in particular. Statistical details of the tourist accommodation industry in Cyprus are given also. Further, the hotel classification system in use in Cyprus is described. A brief introduction to the thermal comfort criteria applicable for hotels follows with a discussion how they could be adjusted to realise energy savings in SC. The above background information is provided in assistance to fulfilling Objective 2, i.e. to assess the current baseline of SC energy consumption of hotels and Objective 3 which requires preparation of thermal simulation models of 3-, 4- and 5-star hotels.

In the latter half of the chapter different drivers, both legislative and voluntary and their expected impetus for energy-efficiency improvements in hotels are discussed. Good practice benchmarks for hotel energy consumption are presented and they are compared to the reported energy consumption figures of hotels in Cyprus.

3.2 Energy consumption of hotels

3.2.1 Introduction

Since the World War II tourism has increased at an average annual rate of 6.5% (WTO, 2007). In particular, Asia and the Pacific (13% increase) and the Middle East (10% increase) have experienced a rapid increase in tourist arrivals (WTO, 2007). In a way, the WW2 gave an impetus for tourism development by setting up useful transportation infrastructure such as airports especially in many remote island locations and Alpine roads (Favero, 2007). As mentioned earlier, the total international tourist arrivals are expected to reach nearly 1.6 billion by 2020 (WTO, 2007). Therefore, it is inevitable that the hotel infrastructure must be developed so as to provide accommodation for the ever-increasing tourist flows.

There are over 300000 hotels worldwide (EUHOFA *et al*., 2001) and the number of hotels and similar establishments in Europe is estimated at over 216000 (Eurostat, 2007), about one half of them located in the Mediterranean countries (Dascalaki and Balaras, 2004). Furthermore, nearly half of the total hotel room capacity of the world is located in Europe with estimated 5.45 million beds (Hotel Energy Solutions, 2011). The operation of hotels is best described as 24/7 and therefore their energy consumption pattern differs from other non-residential buildings such as offices and schools that conform to daily and seasonal operating hours. Subsequently, the energy consumption of hotels ranks high within the tertiary sector[10] of buildings; in fact they are among the top four types of buildings for energy consumption after food production, sales and health care facilities (Hotel Energy Solutions, 2011).

Energy consumption in hotels depends on many factors, such as the service category, climatic

[10] Tertiary sector, aka the service sector, is characterised as providing services instead of end products. It is one of the three economic sectors, the others being the primary sector (agriculture, fishing, mining) and the secondary sector (manufacturing).

conditions, thermal quality of construction, efficiency of the heating/cooling plant, lighting and other energy consuming appliances in use. Ultimately the energy-efficiency of a particular hotel is influenced by staff and guest behaviour as even the most efficient systems can yield their maximum benefits only if operated correctly. The Mediterranean climate is demanding in a way that relatively large amounts of both heating and cooling energy are required. The energy demands are further increased due to the fact that a large portion of the hotel infrastructure was built to inferior thermal insulation standards. According to Dascalaki and Balaras (2004) nearly 70% of the Mediterranean hotels are more than 20 years old and typically hotels need either a partial or complete refurbishment in 15-25 years after construction. It can be concluded that a large portion of the Mediterranean hotel building stock is in urgent need of renovation. Such inevitable renovations give an opportunity for energy-efficiency improvements and indeed should be used as such. Legislation can effectively be used in facilitating energy-efficient upgrades of hotels and the EU Directive on energy performance of buildings (European Commission, 2003) is a good example of such a mechanism.

3.2.2 Energy use of hotels globally

Energy expenses make up the second largest expenditure after staff costs in hotel operations amounting to about 3-6%[11] of the total running costs (European Commission Directorate General for Energy, 1994). Therefore, regardless of the level of environmental consciousness of the hotel operators, energy cost savings are desired. In luxury serviced hotels the total energy consumption is divided approximately 50-50 between electricity and fossil fuel, whereas in mid-range serviced hotels electricity accounts for 27-28% and in small budget hotels for 25-28%.

The major energy consuming centres of a hotel are typically HVAC (50% of total energy), hot water production (15% of total energy), lighting (12-18% of total energy or 40% of electricity), electrical equipment (lifts, pumps, etc.), cooking (1-2 kWh per meal) and laundry (2-3 kWh per kilo of clothes) (European Commission Directorate General for Energy, 1994).

3.2.3 Energy use of hotels in Cyprus

Energy use of hotels in Cyprus was studied by Konis (1991). As a result of the study the baseline energy consumption of hotels was established from data consisting of 51 hotels that at the time represented 30% of all hotels and more than 50% of available tourist beds in Cyprus. The energy consumption figures correspond to an average for years 1983-88. Baseline energy consumption from the given time slice is of particular interest in this thesis as it falls within the reference period of 1961-90 typically used in climate modelling. Therefore, comparison to newer baseline energy consumption figures would make it possible to observe any increases in energy consumption due to climate change that has already taken place.

Newer baseline energy consumption figures were available from a study that audited five hotels in Cyprus (CHOSE Project, 2001a). As the study was completed in 2001 it is assumed that

[11] At first glance 3-6% may not seem like a large percentage but nevertheless is usually a large amount of money and an item to be tackled after optimisations in staff costs have been made.

the audits represent the energy consumption of the late 1990s. The baseline energy consumption from both studies is shown in Tables 3.1 and 3.2.

Hotel class	Total energy, kWh/m^2/yr	Electricity, kWh/m^2/yr	% Electricity	Total energy, kWh/guest night	Electricity, kWh/guest night
5-star	278.8	132.0	50.0	55.6	28.0
4-star	222.2	100.0	44.0	55.6	18.0
3-star	194.4	78.0	40.0	36.1	14.0
2-star	138.9	42.0	32.0	19.4	5.0
All	-	-	45.0	28.9	13.1

Table 3.1 Baseline energy consumption in Cypriot hotels (average for 1983-88)

Source: According to Konis (1991). Compiled from Tables 1.2.8 to 1.2.10.

Hotel class	Total energy, kWh/m^2/yr	Electricity, kWh/m^2/yr	% Electricity	Total energy, kWh/guest night[12]	Electricity, kWh/guest night
5-star	296.2	175.2	59.1	55.9	33.0
4-star	339.2	130.8	38.2	39.0	14.4
3-star	194.7	80.2	40.4	17.8	7.2

Table 3.2 Baseline energy consumption in Cypriot hotels (late 1990s)

Source: Compiled from data in *Energy Savings by Combined Heat, Cooling and Power Plants (CHCP) in the Hotel Sector - Energy Audits – Cyprus* (CHOSE Project, 2001a).

It can subsequently be observed that both total and electrical energy consumption have increased but electricity consumption in particular in the order of 30% for 5- and 4-star hotels from the mid 80s to late 90s. Unfortunately the newer audited sample was too small, only five hotels, to draw conclusions on general level. Especially the reported total energy consumption per unit area for 4-star hotels appeared high as it would be expected to be equal or less than that of 5-star hotels. However, a closer look into the gross area per room ratio of the audited hotels indicated that while the ratio was 84.0 m^2/room for 5-star hotels, it was only 59.3 m^2/room for 4-star hotels. Such a difference would explain the ‘anomaly’ in energy consumption per unit area. This observation highlights another key issue in energy audits, namely the importance of accuracy in reporting building areas. It was noted during the fieldwork of this research that the technical staff of hotels did not understand the need nor the importance of knowing the floor areas of their hotels. Any errors in reporting floor areas could subsequently cause discrepancies in baseline energy consumption figures. Furthermore, very high occupancy rates were reported by the audited hotels, up to 92% room occupancy whereas the national average is around 50%. Subsequently, the energy consumption figures shown per guest night are not indicative nationwide and are shown in Table 3.2 only to highlight this very point. The baseline energy consumption figures are compared to good practice benchmarks later in this chapter.

It is also important to establish the end-use energy consumption within hotels. Both studies

[12] Guest nights were not given in the study but they were estimated from the room occupancy rate and total number of beds. It was assumed that room occupancy = bed occupancy. Although it is not always the case, it is a reasonably good assumption for holiday hotels.

discussed above gave also a breakdown of energy consumption between the various energy centres of hotels. In addition, a typical breakdown of hotel end-use energy consumption was presented in a report evaluating the potential for introducing innovative energy technologies in the tourist sector (Nicolas E. Aristodemou Mechanical & Energy Engineering Consultants, 1999). The study presents a collated energy breakdown picture for a typical hotel by drawing data from four hotels specifically energy-audited for the project combined with additional audits done by the consultant before. Finally, end-use energy breakdown was also available for a 5-star hotel in Cyprus audited as part of a Master's dissertation (Stylianou, 2005). The findings of all four studies are presented in Figs. 3.1 to 3.5.

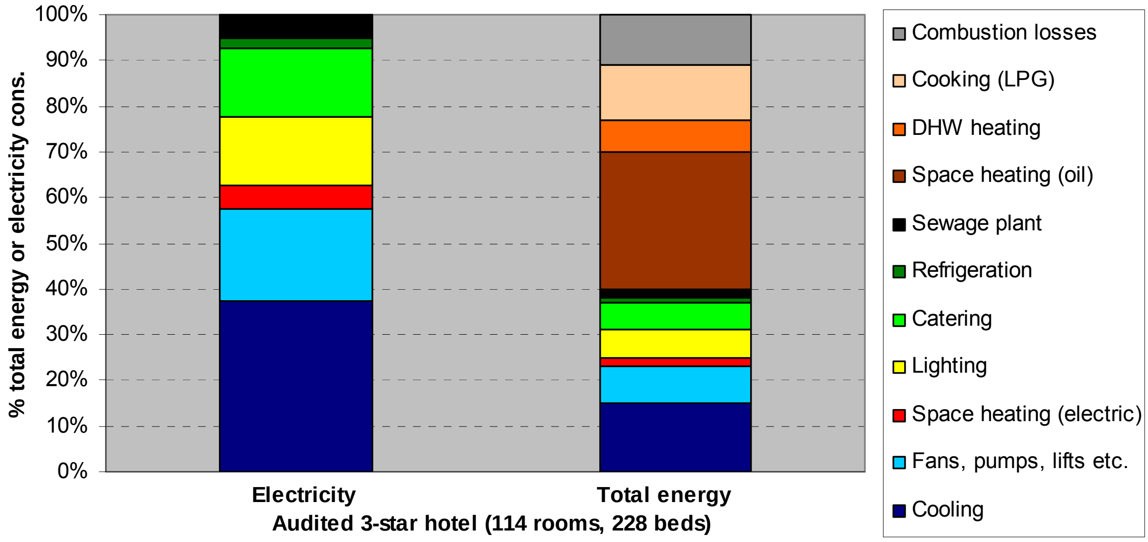


Figure 3.1 End-use energy consumption in an audited 3-star hotel in Cyprus

Source: According to Konis (1991). Compiled from Figure 4.2.5.

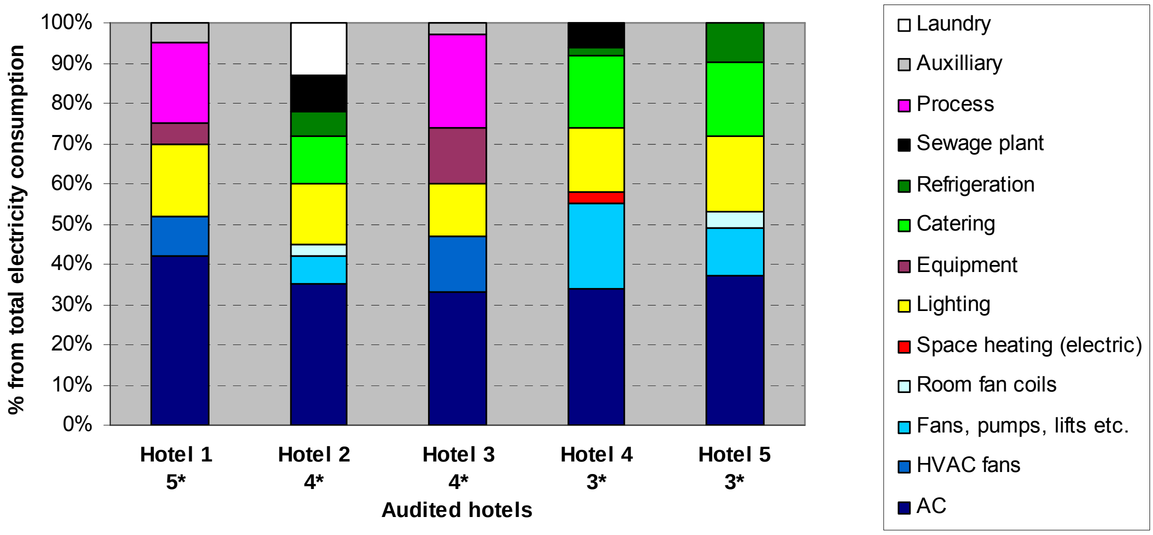


Figure 3.2 End-use electricity consumption in audited 3-, 4- and 5-star hotels in Cyprus

Source: Compiled from data in *Energy Savings by Combined Heat Cooling and Power Plants (CHCP) in the Hotel Sector - Energy Audits – Cyprus* (CHOSE Project, 2001a).

Note: Hotel 1: 350 rooms, 700 beds; Hotel 2: 342 rooms, 692 beds; Hotel 3: 350 rooms, 700 beds, Hotel 4: 114 rooms, 217 beds; Hotel 5: 199 rooms, 510 beds

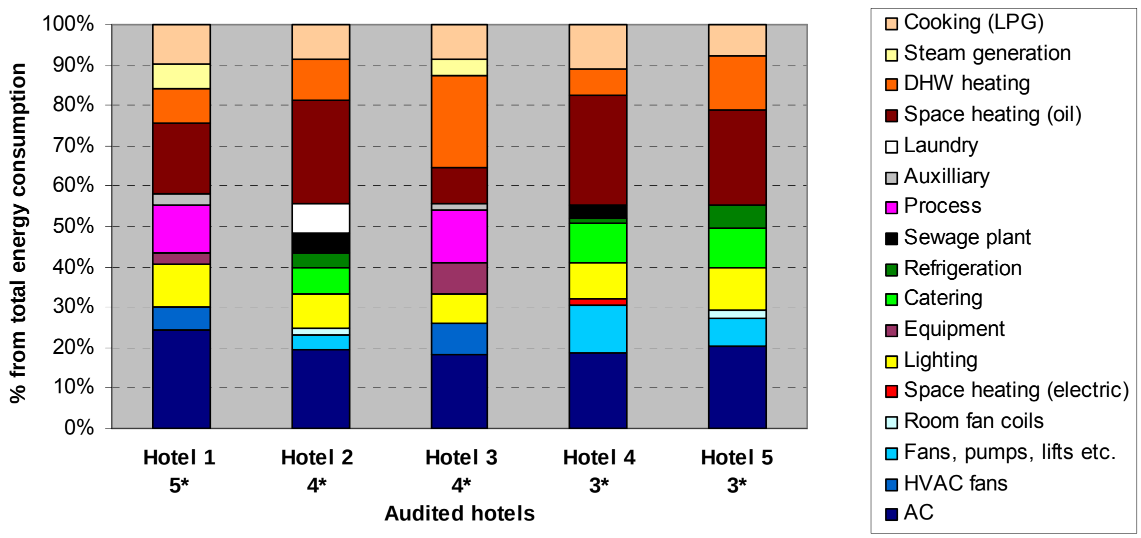


Figure 3.3 End-use energy consumption in audited 3-, 4- and 5-star hotels in Cyprus

Source: Same as for Fig. 3.2.

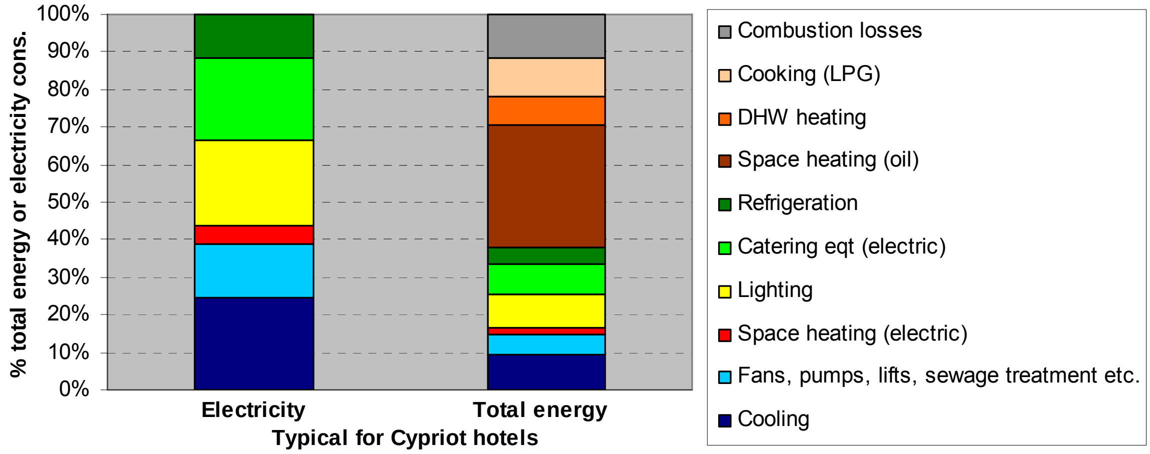


Figure 3.4 End-use energy consumption in typical hotels in Cyprus

Source: According to Aristodemou (Nicolas E. Aristodemou Mechanical & Energy Engineering Consultants, 1999). Compiled from Fig. 1. (5% solar water heating energy should be added to the total energy mix.)

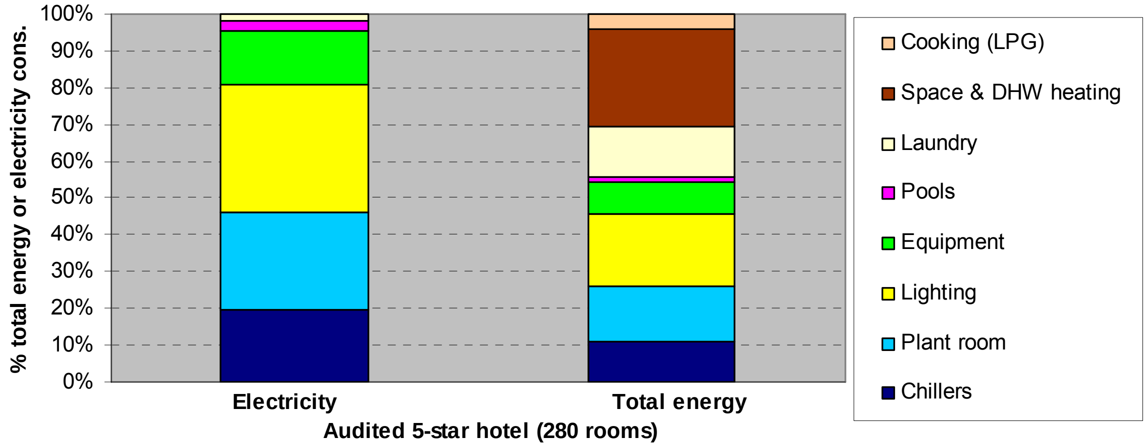


Figure 3.5 End-use energy consumption in a 5-star hotel in Cyprus

Source: According to Stylianou (2005).
Note: Baseline consumption of 246.2 kWh/m^2 energy and 141.4 kWh/m^2 electricity can be derived from the audit data or on guest night basis: 65.3 kWh/GN energy and 38.3 kWh/GN electricity.

It can be seen from Figs. 3.1-3.5 that the general energy consumption patterns from all four studies are similar, i.e. 10-25% of total energy used for cooling, 25-35% for space heating, 7-10% for DHW heating, 6-10% for lighting, 10-20% for fans, pumps, etc. and 8-12% for cooking by LPG in addition to 10% combustion losses. In Fig. 3.5 it can be seen that lighting energy takes a rather high percentage. It is possibly due to the fact that the hotel is much newer (built 2002) than the other audited hotels and may have lower SC energy consumption, thus changing the proportions of the energy centres. In general, when comparing baseline energy consumption figures from different studies the problem is that the reporting categories are not identical and make a direct comparison impossible. That was the case among the above studies as well. Nevertheless, the studies provided valuable insight in the energy consumption patterns of Cypriot hotels.

3.3 Existing hotel building stock in Cyprus

The total number of tourist accommodation establishments in Cyprus in June 2008 was as follows: 227 hotels, 211 classified hotel apartment complexes, 22 tourist villages and 418 other accommodation types such as tourist villas, traditional buildings, unclassified apartments, hotels without star rating, guesthouses and camping sites, taking the grand total to 878 (CTO, 2008e). The distribution of beds in the above tourist accommodation types is seen in Fig. 3.6. Furthermore, the distribution of hotels and hotel beds in 1- to 5-star hotels is shown in Fig. 3.7.

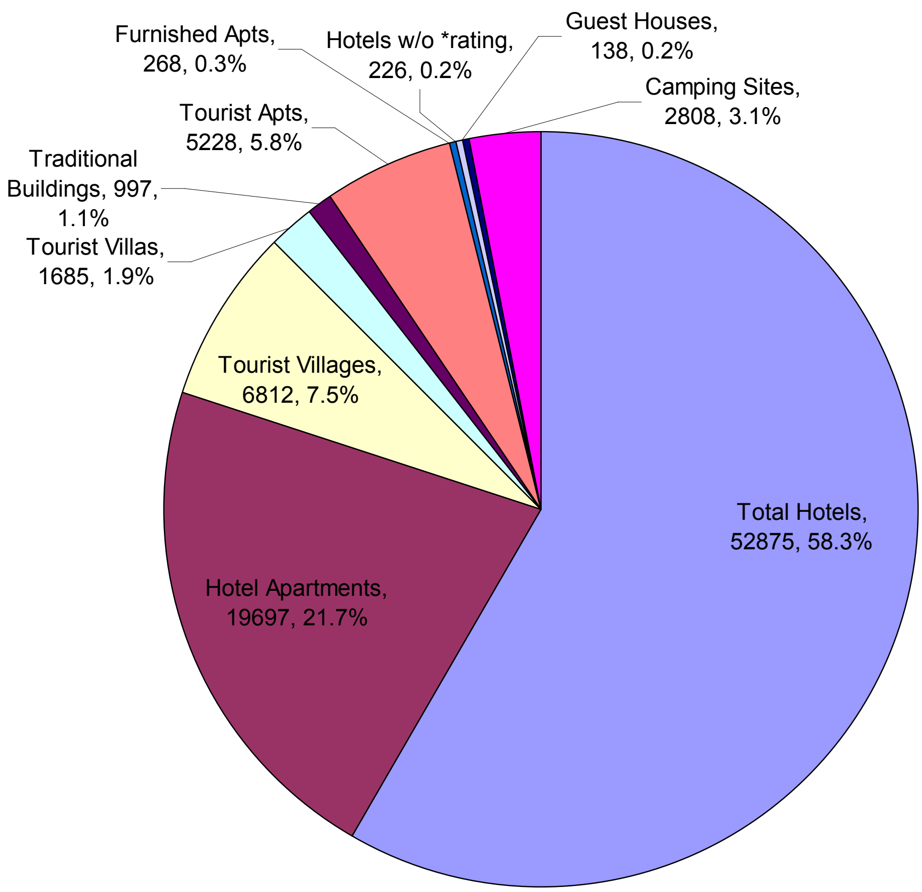


Figure 3.6 Number and distribution of beds in tourist accommodation in Cyprus
Source: CTO (2008e)

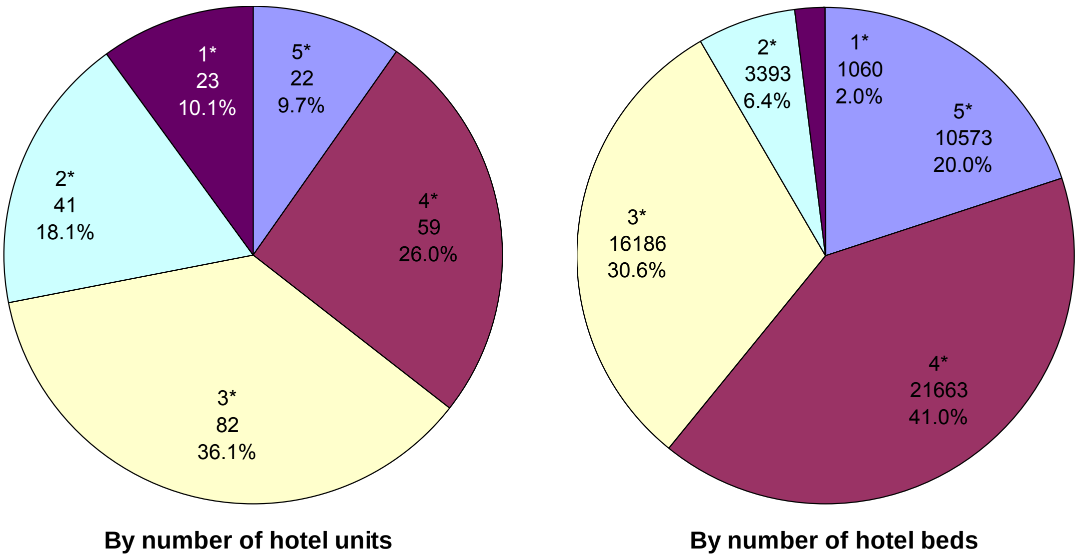


Figure 3.7 Number and percentage of 1- to 5-star hotels and hotel beds in Cyprus on 30.6.2008

Source: CTO (2008e)

It can be observed from Figs. 3.6 and 3.7 that hotels make up over 58% of all tourist beds. Furthermore, 4-star hotels, although second in number of units, offer the greatest amount of beds amounting to 41%. Hotel apartments, tourist villages and tourist apartments form another group providing 35% of tourist beds. Hotel apartments are fitted for self-catering and are in turn divided into three classes A, B and C. Tourist villages are in essence hotel apartments that are set in a self-confined, communal, landscaped environment offering the essential leisure and commercial facilities. Tourist apartments, in turn, typically offer basic accommodation and self-catering only. In view of the fact that the island's strategic plan for tourism targets to upgrade the tourism product by abolishing the self-catered type, the lower classes at least, and by upgrading hotel accommodation to 3- to 5-star class (CTO, 2002), the focus of this study is on 3-, 4- and 5-star hotels only. The requirements of the said hotel classes are given in the following section.

3.4 Hotel classification in Cyprus

3.4.1 Hotel classification and licensing criteria

Hotel classification in Cyprus is carried out according to criteria set forth in a specific law, the abidance of which is overseen by the Cyprus Tourism Organisation (Republic of Cyprus, 2005b). Requirements for a certain star rating include criteria such as minimum number of beds, minimum size of rooms and bathrooms, existence and size of balconies, amenities on site such as restaurants, pools, spas, hair dressers, etc. Licensing and inspection of the facilities is done by the CTO and the licence needs to be renewed every two years.

Table 3.3 shows the minimum number of beds required for each hotel class together with the actual number of units and beds and the average number of beds derived for each hotel class. As observed, all hotel classes offer significantly more beds than the minimum requirements. It is understandable from the financial point of view that the higher class hotels required to offer more luxury and facilities cannot do so for a small number of rooms.

Hotel category	No. of units	%	No. of beds	%	Min no. of beds	Avg no. of beds
5-star	22	9.7%	10573	20.0%	160	481
4-star	59	26.0%	21663	41.0%	100	367
3-star	82	36.1%	16186	30.6%	50	197
2-star	41	18.1%	3393	6.4%	25	83
1-star	23	10.1%	1060	2.0%	15	46
Total	227	100.0%	52875	100.0%	-	-
Total 3- to 5-star	163	71.8%	48422	91.6%	-	-

Table 3.3 Distribution of units and beds within hotel classes in Cyprus (30.6.2008)

Source: Compiled from data by CTO (2008e)

The distribution of rooms within 5-, 4- and 3-star hotels are shown in Figs. 3.8-3.10. Mean number of rooms with standard deviations were derived as follows: 242±69.06, 183±65.55 and 103±67.24 for each hotel class respectively.

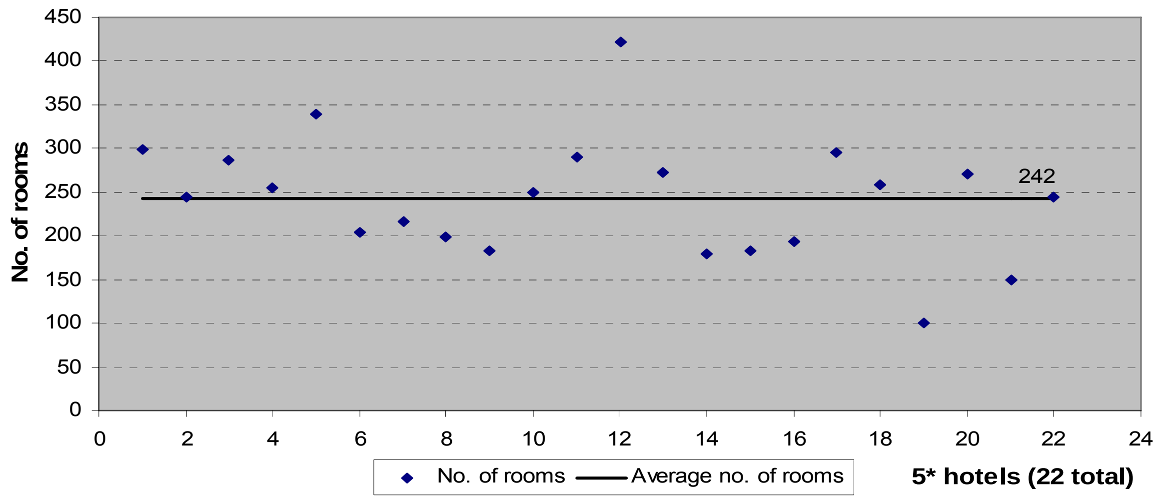


Figure 3.8 Distribution of units and beds in 5-star hotels in Cyprus (March 2008)

Source: Compiled from data by CTO (2008a)

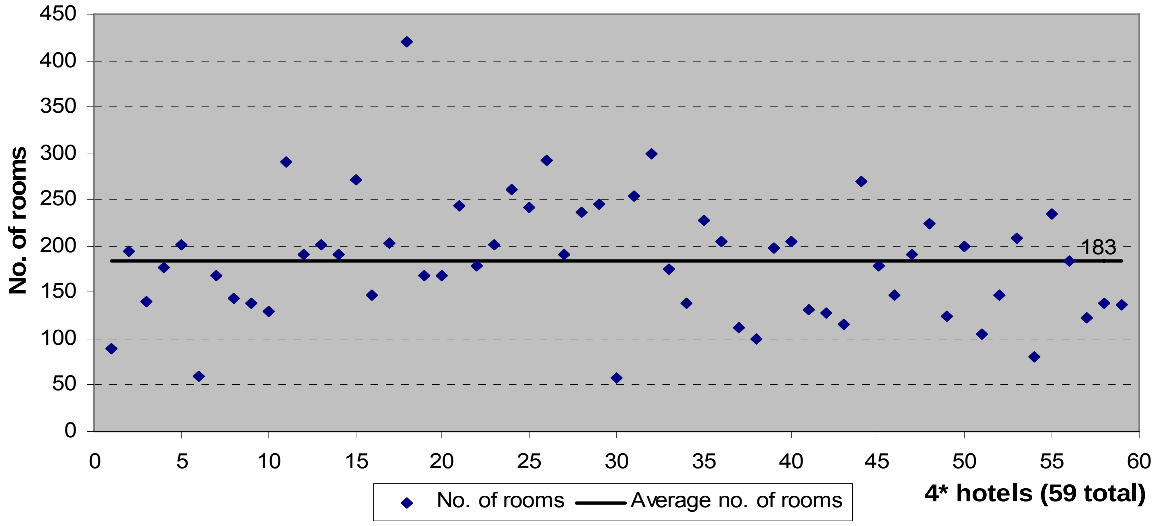


Figure 3.9 Distribution of units and beds in 4-star hotels in Cyprus (March 2008)

Source: Compiled from data by CTO (2008a)

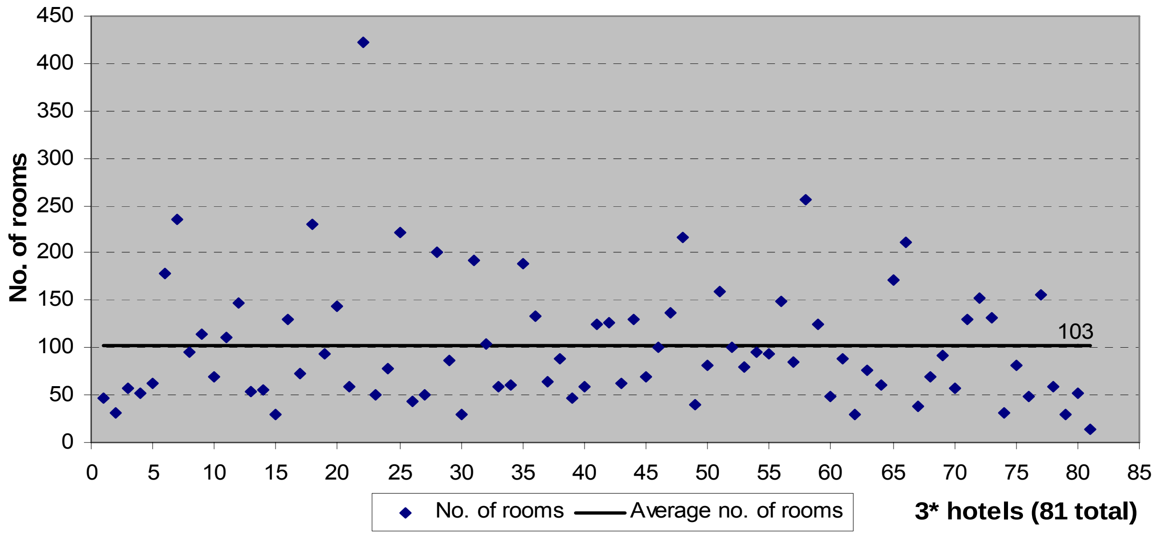


Figure 3.10 Distribution of units and beds in 3-star hotels in Cyprus (March 2008)

Source: Compiled from data by CTO (2008a)

3.4.2 General requirements for all hotel classes

The space requirements of the most essential hotel facilities as dictated by the regulations (The Law Commissioner of the Republic of Cyprus, 2005) are summarised in Table 3.4. In addition to conveying the minimum requirements, a calculation is presented in the table with an attempt to identify the number of rooms required for each hotel class so that their common areas would be similar in size (within ±10% or so). The relevance of the exercise becomes obvious later in the thesis when theoretical models are prepared for 3-, 4- and 5-star hotels. The additional constraint in the calculations was that the number of rooms in all hotel classes would have to fit into the same footprint and to form complete floors. After an iteration process the following combination yielded a satisfactory result: 5-star hotel with 180 rooms, 4-star hotel with 192 rooms and 3-star hotel with 210 rooms. The results are presented in Table 3.4 in relevant locations.

Amenity	5-star	4-star	3-star
Min number of beds	160	100	50
Min no. of single rooms	-	-	10% of total 3
Min no. of twin rooms	80	50	24
Calculated no. of beds	**360**	**384**	**399**
Calculated no. of rooms	**180**	**192**	**210** (189+21)
Lobby required	yes	yes	yes
Breakfast room required	yes	yes	yes
Dining room required	yes	yes	no (if provided, no separate breakfast room required)
Communal sanitary areas required	yes	yes	yes
Lounge required	yes	yes	yes
Bar required	yes	yes	yes
TV room required	yes	yes	no
Min area of TV room	≥1 m^2 per 8 beds		-
Min area of TV room for calculated no. of beds	**45.0**	**48.0**	**-**
Min area of multipurpose hall	≥0.3 m^2/bed ≥50 m^2	≥0.3 m^2/bed ≥50 m^2	≥0.25 m^2/bed ≥50 m^2
Min area of multipurpose hall for calc. no. of beds	**108.0**	**115.2**	**99.8**
Min area of ballroom/ conference room	≥ 1 m^2/bed		
Min area of ball/conf. room for calculated no. of beds	**360.0**	**384.0**	**399.0**
Cloakroom required for ballroom	yes	yes	yes
Shops required	barber/hair dressing, shop selling printed matter, tobacco, photographic mat., cosmetics, etc. folk art shop	barber/hair dressing, shop selling printed matter, tobacco, photographic mat., cosmetics, etc.	-
Sauna and athletic hall required	yes if no. of beds > 240		
Sauna and athletic hall re-quired for calc. no. of beds	**yes**	**yes**	**yes**
Indoor pool required	yes	yes	yes
Min area of indoor pool	≥80 m^2	≥70 m^2	≥60 m^2
Min area of single bedrooms	14 m^2	12 m^2	11 m^2
Min area of double bedrooms	**20 m^2**	**17 m^2**	**15 m^2**
Sanitary facility requirements for bedrooms	private complete bathroom†	private bathroom	50% rooms private b/r, 50% rooms private shower
Min area of bathrooms/shower rooms	**5.0 m^2**	**4.5 m^2**	**4.0 m^2**

Min side dimension of bedrooms	≥3.5 m	≥3.3 m	≥3.0 m
Min clear ceiling height	≥2.6 m	≥2.6 m	≥2.6 m
Min length of the wardrobe	≥1.5 m	≥1.5 m	≥1.2 m
Min width of the wardrobe	≥0.6 m	≥0.6 m	≥0.6 m
Min side dimension of balcony	≥1.5 m	≥1.5 m	≥1.2 m
Min area of balcony	3.5 m^2	3.5 m^2	3.0 m^2
Min width of corridors & main staircase	≥1.5 m	≥1.5 m	≥1.5 m
Min width of staircase if max 2 floors	≥1.2 m	≥1.2 m	≥1.2 m
Min width of 2nd staircase if min 2 floors	≥1.1 m	≥1.1 m	≥1.1 m
Min area of entrance lobby	2 m^2 for the first 40 bedrooms, 1.25 m^2 for each additional	2 m^2 for the first 40 bedrooms, 1.25 m^2 for each additional	1.5 m^2 for the first 35 bedrooms, 1 m^2 for each additional
Area of entrance lobby for calculated no. of rooms	**255.0**	**276.9**	**227.5**
Min area of lounge	2 m^2 for the first 40 bedrooms, 1.25 m^2 for each additional	2 m^2 for the first 40 bedrooms, 1.25 m^2 for each additional	1.5 m^2 for the first 35 bedrooms, 1 m^2 for each additional
Area of lounge for calculated no. of rooms	**255.0**	**276.9**	**227.5**
Combined area of lobby & lounge for calculated no. of rooms	If no wall between lobby and lounge, 30% area reduction allowed		
	0.7*(255.0+255.0)=	0.7*(276.9+276.9)=	0.7*(227.5+227.5)=
	357.0	**387.7**	**318.5**
Min area of bar	40 m^2	40 m^2	40 m^2
No. of communal toilets for avg no. of beds (men/women each)	1 toilet for 30 beds, separately for men & women		
	12	**13**	**13**
Min area of breakfast room	≥0.5*(no. of beds) m^2	≥0.5*(no. of beds) m^2	≥0.5*(no. of beds) m^2
	≥80 m^2	≥50 m^2	≥25 m^2
Min area of breakfast room for calculated no. of beds	≥0.5*(no. of beds) m^2	≥0.5*(no. of beds) m^2	≥0.5*(no. of beds) m^2
	180.0	**192.0**	**199.5**
Min area of dining room	≥1.5*(no. of beds) m^2	≥1.5*(no. of beds) m^2	≥(no. of beds) m^2
	≥240 m^2	≥150 m^2	≥50 m^2
Min area of dining room for calculated no. of beds	≥1.5*(no. of beds) m^2	≥1.5*(no. of beds) m^2	≥1*(no. of beds) m^2
	540.0	**576.0**	**399.0**
Area of combined breakfast & dining room for calculated no. of beds	-	-	399.0
Min area of kitchen	≥70% of dining room	≥70% of dining room	≥60% of dining room
	≥ 168 m^2	≥ 105 m^2	≥ 30 m^2
Min area of kitchen for calculated no. of beds	≥70% of dining room	≥70% of dining room	≥60% of dining room
	378.0	**403.2**	**239.4**

Table 3.4 Summary of requirements for 5-, 4- and 3-star hotels in Cyprus

Source: The Republic of Cyprus (2005a)

Notes: † By definition, a ‘complete bathroom’ includes a toilet basin with an automatic flushing apparatus, a bath-tub with cold and hot water mixer as well as a suitable, preferably movable, shower head, soap boxes, towel-racks, bathtub curtain, a washbasin with a suitable mixer, a shelf, two glasses, a mirror with lighting, general lighting, a special electric socket for a shaving appliance and a bidet or other sanitary article. 'Bathroom', in turn, includes all the above items except a bidet or other sanitary article.

Air-conditioning is mandatory by law (Republic of Cyprus, 2005a, Sect.43(1), p.25) in 5-, 4- and 3-star hotels and it must extend to all guestrooms and public spaces. Also, noise reduction forms an important part of hotel design. Subsequently, the separating walls between guestrooms shall be at least 150 mm thick. Corridor flooring material shall also be selected so as to reduce noise caused by walking, i.e. soft carpeting.

3.4.3 Summary of the functional area requirements of 3-, 4- and 5-star hotels

It can be concluded from Table 3.4 that 3-, 4- and 5-star hotels in Cyprus have very similar functional area requirements with the exception that shops and separate TV and dining rooms are optional for 3-star hotels. It is also noted that all three hotel classes offer banquet services as they are required to have ballroom and conference facilities. Therefore, it can be concluded that functionally there is little if any difference between the hotel classes. This is particularly true for the larger 3-star hotels. The fact is highlighted here as this may not be the case in other countries where 3-star hotels offer only basic services. There are, however, differences in the intensity of use of certain facilities such as the conference and ballrooms between the classes. The issue is discussed in greater detail later in the thesis.

In the EU's Thermie Programme for energy consumption purposes and benchmarking hotels were classified primarily by their size and the inclusion of some major features such as heating and cooling, laundry and an indoor swimming pool (European Commission Directorate-General for Energy, 1994). The following three hotel classes were derived:

- Large hotels (>150 rooms) with AC, laundry and indoor swimming pool,
- Medium-sized hotels (50-150 rooms) without laundry, with heating and AC in some areas, and
- Small hotels (4-50 rooms) without laundry, with heating and AC in some areas.

If the Cypriot 3-star hotels had to be put into one of the above categories, functionally they would more closely fit into the 'Large hotels' although their average number of rooms was derived at 103 from Fig. 3.10. Therefore, for further analysis in this thesis it is assumed that 3-, 4- and 5-star hotels in Cyprus are functionally equal with differences only in their intensity of use.

3.5 Thermal comfort standards

3.5.1 Introduction

The word 'comfort' is defined in a dictionary as *'cause of satisfaction, physical well-being, being comfortable'* (Concise Oxford Dictionary, 1981). Thermal comfort, therefore, is a measure of a person's level of satisfaction and well-being in a thermal environment. However, thermal comfort is not just a function of the air temperature of a given space but it is also influenced by other factors such as air movement, humidity, thermal radiation, the metabolic rate of a person, clothing worn, state of health, level of acclimatisation, age, gender, a person's body shape and the amount of subcutaneous fat and even the food and drink consumed (Szokolay, 2003). Since people are the users of buildings, it is natural that the indoor environment should offer comfort for all occupants at all times. The difficulty arises when buildings are occupied simultaneously by people with different thermal preferences and predispositions.

Subsequently, the engineering profession has been trying to define a universal standard measure of thermal comfort that could be used in the design of building services. The first such attempt was made by Houghten and Yaglolou in 1923 when they defined what was called the 'effective temperature' combining the effects of temperature, humidity, air movement and thermal radiation (Houghten and Yaglolou, 1923 quoted in Szokolay, 2003). Many similar attempts have been made since then but the most notable work in the area was perhaps done by Fanger who developed the concept of 'Predicted Mean Vote', PMV as a statistical measure of occupant satisfaction in an indoor space (Fanger, 1972) and defined as an index that predicts the mean value of the votes of a large group of persons on a 7-point thermal sensation scale[13]. The index is based on the heat balance of the human body where thermal balance is obtained when the body's internal heat production equals to the heat loss to the environment. It is therefore implied that when the human body is in equilibrium with its surrounding environment neither cool nor warm sensations are felt, referred to as 'neutral' in the thermal sensation scale. It is further maintained that in a moderate environment the human thermoregulatory system will automatically attempt to modify skin temperature and sweat secretion to maintain heat balance (British Standards, 2005). Subsequently, both the ASHRAE (Standard 55) and ISO (7730) have adopted the PMV as the method of measuring thermal comfort and occupant satisfaction in indoor environments (ASHRAE, 2004; British Standards, 2005).

The concept of thermal comfort, however, is surrounded by a vivid debate. The opponents of the PMV index maintain that the human body is adaptable to a much wider range of temperatures and internal conditions, depending on the outdoor ambient temperatures. The adaptive thermal comfort theory is mainly advocated by Nicol and Humphreys (2002; 2009) based on vast amount of field studies in different parts of the world. The main difference between the opposing schools of thought is that the PMV index is considered independent of outdoor temperatures and subsequently only measures thermal comfort in spaces using HVAC systems, whereas the adaptive thermal comfort criteria is dictated by the ability of the building occupants to seek for all possible means of improving comfort, i.e. adjusting clothing, opening windows, using window shading devices and such in addition to becoming more tolerant of warmer or cooler temperatures as a result of acclimatisation to a given climate.

The relationship between thermal comfort and energy consumption is of particular interest in this study. As discussed earlier, thermal comfort in a luxury hotel is one of the key components in guest satisfaction. Therefore, thermal comfort standards cannot be lowered in the name of energy saving without due consideration to guest satisfaction. However, this study does not take a stand

[13] Thermal sensation scale has the following points: hot (+3), warm (+2), slightly warm (+1), neutral (0), slightly cool (-1), cool (-2) and cold (-3) (British Standards, 2005)

on the above debate in regards to thermal comfort. The premise of this study is that hotels by default function as temporary residences where guests stay for a limited time; in Cyprus the average length of stay in 2007 was 10.0 days (CTO, 2008d). In addition, the majority of tourists come from much cooler climates, such as the UK, Central and Northern Europe, and are expected to experience a thermal shock to some degree upon arrival in Cyprus. Therefore, it is not likely that acclimatisation would take place with most tourists that come to the island for one- or two-week holidays. Subsequently, this study maintains that AC is required in hotel rooms and other common hotel facilities. In any case, as pointed out earlier, AC is required by law in 3-, 4- and 5-star hotels (Republic of Cyprus, 2005a). Therefore, the aim of this study is not to investigate if and how AC could be replaced by natural ventilation, but rather to identify ways to reduce hotel cooling loads not only via rational improvements of the building envelope and introduction of renewable energy sources but also by critical review of the thermal comfort design criteria that are used in hotels when dimensioning HVAC equipment and their operating profiles. The sections below present the requirements of three categories for which indoor environment can be designed. Temperature and ventilation criteria, in particular, are outlined.

3.5.2 Temperature criteria

Indoor environment is influenced by factors such as temperature, humidity, indoor air quality, lighting and acoustics. The minimum requirements do not vary only for different types of buildings but also for different categories of thermal comfort that can be implemented in a building. As seen in Table 3.5, acceptable temperatures vary considerably between categories I-III. For example, the minimum temperature in bedrooms for heating can be lowered by 3°C and maximum cooling temperature increased by 1.5°C when switching from category I to III. The impact of such changes in energy consumption is one of the evaluation criteria in the thermal simulations to follow later in this study.

Type of space	Category	Temperature range for heating, °C Clothing~1.0 clo[14]	Temperature range for cooling, °C Clothing~0.5 clo
Bedrooms (sedentary activity~1.2 met)[15]	I	21.0-25.0	23.5-25.5
	II	20.0-25.0	23.0-26.0
	III	18.0-25.0	22.0-27.0
Cafeterias, restaurants, conference rooms, offices (sedentary activity~1.2 met)	I	21.0-23.0	23.5-25.5
	II	20.0-24.0	23.0-26.0
	III	19.0-25.0	22.0-27.0

Table 3.5 Temperature ranges for hourly calculation of cooling and heating energy in three categories of indoor environment

Source: Compiled from BS EN 15251:2007 Table A.3, p.31 (British Standards, 2007)

[14] Clo is a measure of the insulation value of clothing. 1 clo=0.155 m^2K/W.
[15] Met refers to 'metabolic rate'. 1 met=58.2 W/m^2 and is the energy produced per unit surface area of a sedentary person at rest, the surface area of an average person being about 1.8 m^2 (British Standards, 1999).

3.5.3 Ventilation criteria

Similarly, ventilation requirements are divided into three categories. The purpose of ventilation is to remove pollutants originated both from the occupants (bio effluents) and the building itself. Buildings are further divided into three types based on the materials they are built of, i.e. Very low-polluting, Low-polluting and Non-low-polluting buildings. According to the above standard, a building is low-polluting if the majority of the materials used are low-polluting[16]. The minimum ventilation rates for each building type and category are shown in Table 3.6.

Type of space	Category	Floor area m^2/person	Ventilation rate, l/s/m^2							Added when smoking allowed[17]
			q_p	q_B	q_{tot}	q_B	q_{tot}	q_B	q_{tot}	
			for occupancy	for very low-polluting building		for low-polluting building		for non-low-polluting building		
Restaurants	I	1.5	7.0	0.5	7.5	1.0	8.0	2.0	9.0	-
	II	1.5	4.9	0.3	5.2	0.7	5.6	1.4	6.3	5.0
	III	1.5	2.8	0.2	3.0	0.4	3.2	0.8	3.6	2.8
Conf. rooms	I	2	5.0	0.5	5.5	1.0	6.0	2.0	7.0	5.0
	II	2	3.5	0.3	3.8	0.7	4.2	1.4	4.9	3.6
	III	2	2.0	0.2	2.2	0.4	2.4	0.8	2.8	2.0
Single offices	I	10	1.0	0.5	1.5	1.0	2.0	2.0	3.0	0.7
	II	10	0.7	0.3	1.0	0.7	1.4	1.4	2.1	0.5
	III	10	0.4	0.2	0.6	0.4	0.8	0.8	1.2	0.3

Table 3.6 Recommended ventilation rates for non-residential buildings with default occupant density for three categories of pollution from building itself

Source: Compiled from BS EN 15251:2007 Table B.2, p.34 (British Standards, 2007)

Ventilation criteria applicable in renovation projects would most likely have to assume that the building belongs to the 'non-low-polluting' category, because it not known in full what materials were used and it certainly cannot be guaranteed that nobody has ever smoked within its space – criterion for 'very low-polluting' building. Therefore, ventilation rates shown in the last highlighted column shall be used in the simulations to follow.

The above table lists ventilation criteria for spaces of mass assembly. The usage pattern of hotel guestrooms in contrast is more like the one in residential bedrooms and living rooms. Subsequently, the per-person ventilation requirements are similar. Table 3.7 indicates the minimum

[16] The definitions are given in Appendix I.

[17] Based on the assumption that 20% of occupants are smokers smoking 1.2 cigarettes/hr at emission rate of 44 ml CO/cigarette.

requirements applicable for hotel rooms. It is noted that the airflows per person and per m^2 cannot be added directly. Therefore, the ventilation rate due to building pollution is calculated for a typical room size of 23.1 m^2 (room + bathroom)[18]. The code does not stipulate how to combine the two sources of pollution though. It is optional either to add the values, select the larger of the two or a value between the highest ventilation rate requirement and the value based on addition. Unless national regulations dictate otherwise, the designer is empowered to make an informed decision and simply report the criteria. The decision made in this study was to initially use ventilation rate of 25 l/s that is reportedly used as a design criterion in Cypriot hotel rooms and incidentally places the value between a low-polluting building in Category I and the combined impacts for people and building emissions for non-low-polluting buildings in Category III[19]. Further simulations were made by adjusting the ventilation rate within the non-low-polluting building group. Reduction down to 18.5 l/s was possible within Category III.

Type of space	Cate-gory	Airflow per person, l/s/person	Airflow for building emissions pollution					
			Very low-polluting building		Low-polluting building		Non-low-polluting building	
			l/s m^2	per room*	l/s m^2	per room*	l/s m^2	per room*
Non-residential buildings	I	10	0.50	11.6	1.00	23.1	2.00	46.2
	II	7	0.35	8.1	0.70	16.2	1.40	32.3
	III	4	0.20	4.6	0.40	9.2	0.80	18.5

Table 3.7 Recommended ventilation rates for non-residential buildings for three categories of pollution from the building itself

Source: Compiled from BS EN 15251:2007 Table B.3, p.35
* Room + bathroom size 23.1 m^2.

3.5.4 Proposed changes to the thermal comfort criteria in this study

In summary, the preceding discussion on thermal comfort criteria according to the European Standard EN 15251:2007 was given as the necessary background information for the thermal simulations later in the thesis. As concluded, it is allowable to adjust the temperature set points as well as ventilation rates and still meet the standard but in a lower, more permissible category. It is therefore the intention of this study to quantify the energy saving potential due to such adjustments.

It is further noted that the ventilation criteria used when the hotels were designed permitted smoking. A law banning smoking in all public spaces came into force recently[20] and thus an opportunity to revise and reduce ventilation requirements arises. However, it is emphasised that ventilation is done for a reason to maintain high indoor air quality. Therefore, any changes in ventilation rates should be done only if good indoor air quality can be maintained. In order to

[18] Size of room used in sample calculations in Appendix II.
[19] For two people per room in a non-low-polluting building in Cat. III, ventilation rate=2x4+18.5=26.5 l/s
[20] Strictly enforced since 1 January 2010; earlier law from 2002 was largely not enforced at all.

assure good air quality, measurements should be taken to make sure that the air pollutants do not exceed the permissible limits. Such an audit done in a 4-star hotel in Portugal revealed that the air pollutant levels were too high in some areas due to insufficient ventilation rates and poor air filtration effectiveness in the AHUs (Asadi *et al.*, 2011). Therefore, each hotel renovation should be evaluated individually in regards to the potential of lowering ventilation rates. If high ventilation rates are required, heat recovery ventilation systems should be considered in order to minimise heat losses. Naturally, heat recovery ventilation should be considered for any ventilation rates especially if a complete ventilation system overhaul is in order. It is, however, outside the scope of this study to quantify energy savings due to such upgrades.

3.6 Legislative drivers for energy-efficiency in hotels

3.6.1 EU Energy Performance of Buildings Directive

Traditionally hotel renovations have been driven by the need to replace natural wear and tear or to change the image and the aesthetic characteristics of the place. However, more recently energy-efficiency upgrades and renovations have also been carried out and good practice case studies are published for example in the trade magazine *Green Hotelier* (Green Hotelier, 2008). New legal impetus for hotel renovation was given by the introduction of the EU directive on energy performance of buildings (European Commission, 2003) and its implementation in the legislation of the member states. The directive was revised in 2010 (European Commission, 2010) and is already fully incorporated into the local legislation in Cyprus. The aspects of the directive that bear direct importance on hotels have to do with major renovations of non-residential buildings with total useful area larger than 1000 m^2. It is dictated that all such buildings are obliged to consider energy-efficiency improvements in their upcoming major renovations[21]. In view of the above, practically all hotel buildings within the European Union are now bound by the directive and its practical implications.

Furthermore, boilers and AC systems will need to be inspected regularly. Boilers with an effective rated output greater than 100 kW will need to be inspected at least every two years. Similarly, AC equipment shall be inspected at regular intervals, frequency to be decided by each member state. The inspection shall include an assessment of the system efficiency and sizing compared to the cooling requirements of the building. Appropriate advice is to be given to the building occupants but with no mandatory corrective action clause. Consequently, the gap between recommendation and implementation has raised wide criticism and EuroACE, an action group for energy-efficiency in buildings, has been lobbying for the modification of the directive in respect to making HVAC equipment efficiency upgrades mandatory for public sector and non-residential buildings, assuming they are cost-effective to implement (European Alliance of Companies for Energy Efficiency in Buildings, 2008). However, it appears that the latest recast of the directive still leaves the issue on voluntary basis and in the hands of the member states.

[21] 'Major renovation' is defined in the directive as renovation where either the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated, or where more than 25% of the surface of the building envelope undergoes renovation.

In addition, the directive dictates that public access buildings will have to post an energy certificate for public view. It is anticipated that the mandatory certification process will have a positive impact on energy-efficiency improvements because of the negative image that a poor energy rating would give to a property.

3.6.2 Local legislation and building code

As mentioned, the Directive 2010/31/EU has already been implemented in the local legislation in Cyprus. A law came into force on 23 December 2007 (Republic of Cyprus, 2006) dictating, among other things, that all new building permit applications shall have to meet the minimum criteria for elemental U-values as follows:

- external walls: $U \leq 0.85$ W/m^{2}K,
- roof and exposed floors: $U \leq 0.75$ W/m^{2}K,
- openings: $U \leq 3.80$ W/m^{2}K and
- walls to unheated spaces: $U \leq 2.00$ W/m^{2}K.

In addition, thermal insulation is required to wrap around the entire building envelope in order to control thermal bridging. Therefore, cavity infill insulation on wall sections between columns, a typical construction practice in Cyprus, is no longer allowed.

Further ministerial orders were issued in 2009 to complete the implementation of the directive. Regarding U-values, the elemental U-values as listed above were kept unchanged but limits for U-mean value where the U-values of the entire building[22] are averaged out were introduced as follows:

- residential buildings: $U_m \leq 1.3$ W/m^{2}K and
- non-residential buildings: $U_m \leq 1.8$ W/m^{2}K.

The inclusion of limits for U-mean applies additional control for buildings with large glazing ratios; both wall and window elements may have to meet more stringent U-values in order to meet the U-mean value.

Since 1 January 2010 it became mandatory to certify all residential and since 1 September 2010 all non-residential new and existing buildings (Xichilos and Hadjinicolaou, 2010). New construction is required to have B-rating as a minimum in order to qualify for a building permit. As for the local adaptation of HVAC equipment inspection, all AC systems ≥250 kW capacity must be inspected every 3 years and the first inspection must be completed by the end of 2011 (Xichilos and Hadjinicolaou, 2010). Consequently, every hotel in Cyprus is subject to AC inspections. Boiler inspection is on voluntary basis.

The above heat transfer coefficients may look rather poor in comparison to the values adopted by many other EU member states. However, for Cyprus the leap to the new legislated U-values is colossal in view of the fact that the recent practise yielded U-values in the order of 1.5 W/m^{2}K for

[22] Floors and roofs are not included in the U-mean calculations.

walls, 3.4 W/m^{2}K for beams and columns and 5.4 W/m^{2}K for single-glazed aluminium-frame windows. The new legislation is significant also in regards to large commercial refurbishments such as hotels. Accordingly, their future renovation efforts will eventually upgrade the entire hotel building stock to at least to the current code requirements[23].

3.6.3 EU energy-efficiency obligations

As mentioned in several contexts earlier, the overall driving force in this thesis is the EU's 20% by 2020 energy-efficiency improvement target. In the EU's *Energy Efficiency Plan 2011* it is stated that the greatest energy saving potential lies in buildings (European Commission, 2011a). Residential and tertiary sectors are estimated of having 21% potential for cost-effective energy saving EU-wide (European Commission, 2011b), most of it to be attributed to energy-efficiency in SC, DHW and cooking[24]. It is further estimated that about 13.4% of the energy saving potential is achievable with current policies but that new policy measures may have to be implemented to realise the rest.

The Plan does not specifically address hotels, although they do belong to the tertiary sector, but addressing them as a priority would seem beneficial for Cyprus as a member state trying to meet its energy saving obligations. In the framework of the Plan all member states are required to deliver their individual commitments as stated in their National Energy Efficiency Action Plans (NEEAP). Cyprus has committed to 10% energy savings by 2016 (European Commission, 2011c). The NEEAPs are subject to the European Commission's assessment in 2013 and should it become obvious that the overall target of 20% energy savings by 2020 were not likely to be met, further binding measures would be implemented. Therefore, in anticipation that the grip of the EU's legislative arm will tighten in regards to definite measures to be taken towards improved energy-efficiency, it is proposed that thermal renovation of hotels would take the front seat in Cyprus the soonest. Hotels could truly lead the way in becoming energy-efficient because they have the potential to partly finance their renovations by increased room income. Similar mechanisms or opportunities do not exist for any other building type, either commercial or residential. This issue is discussed in great detail later in the thesis as it forms the fundamental basis for the development of the new cost-efficiency indicator and the original contribution thereof.

3.7 Voluntary drivers for energy-efficiency in hotels

3.7.1 Environmental management and eco-labelling schemes of hotels

Environmental management system (EMS) is defined as '*part of an organisation's management system used to develop and implement its environmental policy and manage its environmental aspects*' (British Standards, 2004, p.2). Hotel operations are ideal candidates for EMS implementation as they have vast environmental impacts from energy and water consumption

[23] There are no separate U-values specified for building upgrades and renovation. Therefore, it is implied in this thesis that any hotel renovation targeted for improved energy-efficiency would at least meet the current code requirements and if possible, exceed them.
[24] 78% of total energy needs of the tertiary sector within the EU are attributed to SC, DHW and cooking, the remaining 22% to electric appliances and lighting.

to solid waste and wastewater generation. A successful EMS program, however, requires a firm commitment from the management to the employee level. Setting up an EMS program is not a one-off event but rather an ongoing process. Further, maintaining an efficient EMS program requires continuous follow-up and action. The process is founded on the principles of Total Quality Management (TQM) following a sequence of actions called Plan-Do-Check-Act (PDCA), briefly described as follows:

- Planning by establishing the objectives and processes necessary to deliver results in accordance with the organisation's environmental policy,
- Doing by implementing the processes,
- Checking by monitoring and measuring processes against environmental policy, objectives, targets, legal and other requirements, and reporting the results, and
- Acting by taking actions to continually improve performance of the environmental management system (British Standards, 2004, p.vi).

The above process allows and mandates continuous improvement to the established program so as to maximise the benefits, both environmental and financial, from it. It is emphasised that financial benefits are to be expected from a well-designed environmental plan because its primary goal is to save resources, including energy, water, consumables such as detergents, soaps, shampoos, etc. and to reduce waste, such as packaging material, spoiled food, bottles, cans, etc. In addition, some sorted recyclable waste such as aluminium cans, glass, paper, plastic or even used cooking oil can be sold for extra income. Therefore, an EMS can and should be viewed as an income-generating factor rather than an overhead item in the hotel operations. A study comparing the performance of hotels in Spain suggested that indeed the hotels that had environmental management programs in place also performed better financially (Molina-Azorín *et al.*, 2009).

However, many obstacles for implementing an environmental management program in hotels exist. The following were identified as some of the main reasons: 1) lack of knowledge and skills, 2) lack of professional advice, 3) uncertainty of outcome, 4) certifiers/verifiers, 5) lack of resources, and 6) implementation and maintenance costs (Chan, 2008). It can be concluded from the list of reasons that the first four out of the six reasons have to do with educating the staff and the last two with resources, either human or financial. It therefore becomes obvious that educating staff on the implementation and benefits of such a program, financial and otherwise, is of paramount importance and possibly the only real barrier that needs to be overcome in order for environmental management programs to become more popular within the hotel industry.

It is recommended that any major hotel renovations in Cyprus were implemented in the context of a wider scope of conformity with international eco-labels such as the EU Flower. Although this study focuses primarily on SC energy conservation, it is emphasised that the greening efforts of hotels should not stop there. In any case, the tangible financial savings are largely realised from energy and water conservation. When the overall environmental program produces financial savings, adoption of non-revenue-producing, purely environmental measures also becomes easier and more feasible. Therefore, it is the premise of this study that maximising the financial savings in energy and water will promote environmental sustainability both directly and indirectly via increased willingness to implement complimentary measures.

3.7.2 Good practice benchmarks

As a starting point, hotels that do not have yet an operational EMS in place could compare measured resource consumption and waste generation against industry-wide good practice benchmarks[25]. Such benchmarks are published by many authorities, most notably by CIBSE and the International Tourism Partnership. Benchmarks provided by CIBSE are applicable for the UK or similar standard of construction and climate only, whereas the ITP gives benchmarks for three distinct climate zones, namely temperate, Mediterranean and tropical. The values for the Mediterranean climate are adopted as the benchmarks for this study as shown in Table 3.8.

Energy source	**Excellent**	**Satisfactory**	**High**	**Excessive**
	Luxury serviced hotels (~400 rooms), kWh/m²/yr			
Electricity	<140	140-150	150-175	>175
Other energy	<120	120-140	140-170	>170
TOTAL	<260	260-290	290-345	>345
	Midrange serviced hotels, kWh/m²/yr			
Electricity	insuff. data	70-80	80-90	>90
Other energy	insuff. data	190-200	200-230	>230
TOTAL	insuff. data	260-280	280-320	>320
	Small & budget serviced hotels, kWh/m²/yr			
Electricity	insuff. data	60-70	70-80	>80
Other energy	insuff. data	180-200	200-210	>210
TOTAL	insuff. data	240-270	270-290	>290

Table 3.8 Benchmark values for electricity and other energy consumption in typical Mediterranean hotels

Source: Compiled from *Sustainable hotel: siting, design and construction*, Table 11, p.116 (International Tourism Partnership, 2005)

It is now possible to compare the baseline energy consumption of Cypriot hotels to international benchmarks as given in Table 3.8. It is noted that the hotel classification system is different in Cyprus from that used in the benchmarks. It is therefore assumed that 4- and 5-star hotels belong to the ‘luxury serviced hotels’, 3-star hotels to the ‘midrange serviced hotels’ and 2-star hotels to ‘small & budget hotels’ as far as the comparison to the benchmarks is concerned. It is observed that the Cypriot hotels compare quite favourably to their Mediterranean counterparts. However, the benchmark figures given for luxury serviced hotels assume somewhat larger hotels than the 5- and 4-star hotels in Cyprus with 242 and 183 rooms on average respectively. It subsequently highlights a problem in benchmarking having to do with the lack of international

[25] Benchmarking denotes comparing performance metrics, such as energy/water consumption to industry best or typical values but no conformance is required. Eco-labels and environmental certification use benchmark performance as criteria for qualification.

uniform standards in hotel classification that would make such comparisons reliable. Nevertheless, the comparisons are shown in Tables 3.9 and 3.10.

Hotel class	Total energy, kWh/m^2/yr		Electricity, kWh/m^2/yr		Comparison made to
	Cyprus	Benchmark evaluation	Cyprus	Benchmark evaluation	
5-star	278.8	satisfactory	132.0	excellent	Luxury serviced hotels
4-star	222.2	excellent	100.0	excellent	-“-
3-star	194.4	insuff. data	78.0	satisfactory	Mid-range serviced hotels
2-star	138.9	insuff. data	42.0	insuff. data	Small & budget serv. hotels

Table 3.9 Cypriot hotel energy consumption (mid 1980s) vs. benchmark values

Hotel class	Total energy, kWh/m^2/yr		Electricity, kWh/m^2/yr		Comparison made to
	Cyprus	Benchmark evaluation	Cyprus	Benchmark evaluation	
5-star	296.2	satisfactory	175.2	excessive	Luxury serviced hotels
4-star	339.2	high	130.8	excellent	-“-
3-star	194.7	insuff. data	80.2	high	Mid-range serviced hotels

Table 3.10 Cypriot hotel energy consumption (late 1990s) vs. benchmark values

3.8 Conclusions

In this chapter the typical hotel energy consumption was discussed and the baseline energy consumption of Cypriot hotels representing the mid 1980s and late 1990s was presented. A detailed description of the hotel classification system in place in Cyprus was given.

Thermal comfort criteria were discussed and it was noted that some adjustments could be made within the criteria still staying within permissible indoor environmental parameters. The possible adjustments in temperature settings and ventilation rates were identified for further analysis in the thesis.

In the latter part of the chapter both legislative and voluntary drivers influencing energy-efficiency in hotel operations were discussed. Finally, good practice benchmarks for hotel energy consumption were presented and they were compared to the baseline energy consumption of Cypriot hotels derived from existing literature.

This chapter was written in order to provide background information for fulfilling Objectives 2 and 3 by establishing the literature-based energy consumption baselines of Cypriot hotels (Objective 2) and by describing the hotel class requirements to be used in the design and simulations of the theoretical hotel models (Objective 3).

In the following chapter energy-efficient hotel renovation is discussed and strategies for further study are selected.

4 Chapter 4 – Energy-efficient hotel renovation

4.1 Introduction

It is the premise of this thesis that hotels can take control over their profitability by investing wisely on energy-efficiency. But what exactly entails ‘wise investment’? First of all, it is important to distinguish between energy-efficient *design* as in new construction and energy-efficient *renovation* as in upgrading existing buildings. When designing for energy-efficiency, more options are available as the designer can start to innovate from a clean sheet of paper. However, when a building already exists, the options are more limited, as the site or the orientation of the building may not be optimal for passive or active solar exploitation for instance. Therefore, the interventions analysed in this thesis are chosen from measures that are applicable for building renovation.

The purpose of this chapter is to introduce strategies that can be used in hotel energy-efficiency improvements and to select the most applicable ones to hotel renovation in Cyprus for further analysis. The chapter thus addresses Objective 3 by providing background information on energy-saving renovation strategies.

4.2 Existing research on energy-efficient hotel renovation

Before looking at the individual renovation strategies that can be utilised in hotel building thermal upgrades, a brief review of research done in the field is given. The review is not meant to be exhaustive but rather to identify some major research efforts taken in the context of systemic approach to hotel energy-efficiency improvements. Therefore, research or case studies addressing a single measure are not included here but such studies are referenced elsewhere in the thesis when appropriate.

The earliest undertaking identified in the said field is a doctoral thesis by Konis (1991) titled: *Energy management and conservation in the hotel industry of Cyprus: a systematic modelling approach*. The study was conducted from the energy management point of view utilising a soft systems approach but an energy consumption database of hotels in Cyprus was established as part of the study in order to serve as technical background for the analysis. The study methodology also included a hotel guest survey in addition to interviews with various stakeholders of hotel operations, such as hotel managers, chief engineers, designer architects, mechanical consultants, etc. as the human factor was an important contributor in the soft systems modelling. The study concluded that there was a scope in the range of 10-20% for energy conservation in the Cypriot hotel industry by modifying user habits, controlling hotel energy demand, remodelling existing technology and by introducing new energy-efficient technology.

Another highly relevant study was taken up under the European Commission Directorate-General for Energy Thermie program and titled: *Rational use of energy in the hotel sector* (1994). The report disseminated as a result of the study is a detailed introduction into hotel energy issues, gives benchmark energy consumption figures and has a discussion on strategies that can be used to save energy in hotel operations. Relevant case studies were included for demonstration purposes.

The need for developing suitable computerised tools for evaluating the energy performance of hotels was recognised and subsequently a computer program XENIOS was developed in the framework of the European Commission's Altener Program (Dascalaki and Balaras, 2001; 2004). The program is available free of charge as a web download. The program can be used as a follow-up to a walkthrough energy audit for a preliminary, first assessment of where and how to integrate the most cost-effective, energy-efficient renovation practices, technologies and systems. It was developed for the Mediterranean climate and was tested in four countries: Greece, Italy, Spain and France. The XENIOS audit methodology itself is based on two existing methodologies developed in previous European research projects for apartment buildings (EPIQR) and for office buildings (TOBUS). As for limitations of the program, standard climate is used for all four countries. Secondly, the costs database was developed for Greece and by now is over ten years old. Nevertheless, the project and the software development were a massive step forward in raising awareness in hotel energy consumption and saving issues.

More recent efforts taken up evaluating the energy-efficient renovation potential of hotels in Greece and Cyprus include a study called LowEHotels, i.e. Low Energy Hotels in Southern Europe co-funded by the European Commission's Sixth Framework Program (Gramkow, 2009). The project was divided into two phases. The first phase was to demonstrate how energy consumption of hotels could be reduced by implementing existing good practice such as building envelope insulation, efficient boilers, window replacement, shading, etc. together with integration of renewable energy in the building systems such as solar water heating, photovoltaics and solar assisted cooling. The second phase was to introduce innovative solutions by utilising new innovative technology and advanced control systems to efficiently cool the building with a minimal consumption of primary energy. Thermal simulations indicated that with a combination of building fabric improvements, lighting upgrade, ceiling fans and heat recovery up to 26.2% reduction in cooling and 4.8% reduction in heating energy consumption could be achieved. A combination of keycard electrical switches in guestrooms, ceiling fans, reflecting blackout curtains in guestrooms, external shading measures and lighting upgrade would yield up to 64% reduction in cooling and 5% increase in heating energy consumption (Bindels *et al.*, 2009). It is noted that the two examples were simulations for two specific 3-star hotels in Greece and do not necessarily represent typical energy saving potential. In addition, the economic viability of the measures was not studied. The second phase aimed at demonstrating renovation measures that could achieve an energy reduction of more than 50%, therefore pushing the envelope beyond existing and future legislation. In particular, an innovative roof renovation system was to be developed. Computer modelling and a test rig laboratory model were made to optimise the properties of the roof system but at the time of writing no data was available of the practical demonstration and monitoring of the roof system.

Another study investigated renovation measures and their efficiency to reduce CO_2 emissions in two hotels in the UK in 2030 as part of the Carbon Vision Buildings Programme (Taylor *et al.*, 2010). The two hotels represented an old historic converted city hotel and a purpose-built newer hotel. Thermal simulations were used to model various renovation strategies and their sequential implementation in order to cut the hotels carbon emissions by 50% from a 2005 baseline. Weather data used for 2030 was morphed from a 1995 TRY by using published algorithms to take into account the effects of predicted climate change. Energy-efficiency measures such as heat recovery ventilation, wall insulation, triple-glazing, air-tightness improvements, switching from electric heating to gas or from conventional gas to a condensing boiler, reduction in small power and lighting and installation of solar-thermal water heating were investigated. A set of measures that would meet the carbon cutting target was identified for both hotel types and it was concluded that cutting carbon emissions in half was possible with existing technology. However, no cost analysis was done in the study and it remained unclear how feasible such renovation measures would be on a mass scale. The study is very relevant in the context of this thesis because it also included sensitivity analysis where the effects of hotel occupancy in a future climate were observed. Subsequently, the simultaneous effects of two of the three sensitivity variables proposed for analysis in this thesis (climate, fuel prices and hotel occupancy) were studied. However, building renovation aimed at lowering carbon emissions or reducing operational costs must be cost-effective to gain momentum. Subsequently, this thesis intends to address that aspect. It is also highlighted that by reducing carbon emissions the energy consumption is not always reduced at the same rate. It was noted in the abovementioned study that interventions that resulted in 50% reduction in carbon emissions yielded only 25% savings in energy consumption[26]. Therefore, it is concluded that while it is important to establish ways to reduce carbon emissions, it is equally important to study ways to reduce energy consumption in absolute terms and most importantly to find cost-effective ways to achieve both goals in unison.

The most recent undertaking aimed at improving hotel energy-efficiency in Europe was a project spearheaded by the United Nations' World Tourism Organization (UNWTO) and supported by the EU's Intelligent Energy Europe program (Hotel Energy Solutions, 2011). The main goals of the project were to increase energy-efficiency by 20% and the use of renewable energy by 10% in small and medium scale hotels (SMEs) across the 27 European Union member states. Hotel Energy Solutions is in line with the EU targets and the Davos 2007 process seeking ways to alleviate the tourism industry's impact on climate change. The project therefore aimed at reducing hotels' operational costs while increasing their competitiveness, acting on customer demand, increasing staff motivation and improving overall sustainability of the tourism and lodging industry. A web-based toolkit was developed as part of the project where hotels can input their energy consumption and compare their current energy use to similar enterprises. The tool provides support in ranking practical and cost-effective energy-efficiency and renewable energy investment options. A carbon footprint calculator is also provided for evaluating the environmental impacts.

In conclusion, no existing research were identified where the simultaneous impacts of climate change, energy prices and hotel occupancy were considered in predicting energy consumption and the cost-effectiveness of hotel building adaptation measures thereof. The impacts of future climate and hotel occupancy were studied by Taylor *et. al* (2010) as discussed before and sensitivity analysis of energy prices and cost-effectiveness of building renovation is commonplace in techno-economic evaluation but no other research has been identified where the three variables of climate,

[26] Due to a switch from electric to gas heating, carbon savings grossly exceeded energy savings.

fuel prices and occupancy were investigated simultaneously. It would subsequently appear that this thesis is well placed within its theoretical framework to fill a gap in hotel energy-efficiency research.

4.3 Energy saving strategies in hotels – the building component

The following sections briefly discuss some of the typical strategies that can be implemented in buildings in order to improve energy-efficiency. The strategies are divided in three categories as follows: 1) measures to reduce energy consumption, 2) energy-efficient technology and 3) onsite micro-generation of energy. Some of the strategies are analysed further later in the study in order to evaluate their technical and economic viability as renovation strategies in Cypriot hotels.

4.3.1 Measures to reduce energy consumption via passive means

4.3.1.1 Building envelope

4.3.1.1.1 Introduction

Building envelope that includes the exterior walls, roof, floor, windows and doors are in constant communication with the external weather conditions on one hand and internal loads on the other. Therefore, the purpose of the envelope is to protect against unwanted external exposure, such as wind, rain, excess sun, dust, noise, etc. yet to allow beneficial communication between the interior and exterior spaces via windows for fresh air and ventilation, natural daylight and pleasant views. However, due to lack of building regulations regarding the thermal performance of buildings plus the adaptation of modern construction methods over their bioclimatic vernacular counterparts, the existing hotel buildings in Cyprus are poorly equipped to face the environmental challenges they are exposed to. Building envelope upgrades are therefore a logical way not only to extend the buildings' usable service life but also to make them more energy-efficient.

It is also useful to define the Cypriot hotel building typology as it directly contributes to prioritising the building envelope improvement measures. Hotels are typically maximum 6-7 stories high including a basement floor. Width-to-height ratios in the order of 4-5:1 are typical. No tower-type hotel construction exists as they have not been allowed due to visual and seismic concerns.

Below a brief introduction to the main components of the building envelope, i.e. windows and doors, walls and roof is given.

4.3.1.1.2 Windows and doors

A typical hotel window in Cyprus constitutes a single-glazed panel in a sliding-type aluminium frame without thermal break, yielding a U-value of about 5.42 W/m^2K. Sliding or hinged glass-aluminium doors are also the standard for openings between the hotels' common indoor and outdoor areas, whereas automated glass sliding doors are typical as main entrance doors to resort hotels. Some hotels have already upgraded to double-glazing. The U-value of such 'conventional' double-glazing, as referred to in this thesis, is around 3.00 W/m^2K. Low-emissivity, gas filled, insulated frame double-glazing hereinafter called 'high-performance' window systems have not penetrated into the hotel industry of Cyprus yet. It is therefore one of the parallel aims of this thesis to study the impact of high-performance window replacement in comparison to conventional double-glazing both in their thermal performance and cost-effectiveness.

High-performance double-glazed windows are now available with U-values in the order of 1.1-1.6 W/m^2K depending on the coatings on the glazing and the material of the frame. In cooling dominated climates they take advantage of a highly reflective low-emissivity silver coating on the inside face of the outer glass pane and a gas-filled (typically argon) 12-15mm gap between the panes. The working principal is that the metal coating of the outer pane reflects a large portion of sunrays back to the atmosphere, thus reducing the overheating potential by direct sunlight on the window. The principal is reversed in heating dominated climates by placing the reflective coating on the outer surface of the inner pane where its purpose is to reflect heating energy that attempts to escape from the building back to the heated space. Such coatings are available in sputtered and pyrolytic, or as commonly referred to as soft and hard types depending on the method how the coating is applied to the glass. The coatings act selectively to the wavelengths attempting to cross the pane by blocking the entry of near-infrared radiation in the incident solar energy if solar control is its objective or by admitting it to enter the building but blocking its escape if heating efficiency is of primary importance.

While the glazing industry has made such remarkable progress over the past 30 years, the challenge remains to fit the high-performance glazing into frames that would not null out the benefits. Aluminium is the material of choice for window frames in Cyprus. It has proven to be a long-lasting and virtually zero-maintenance material. However, the conventional way frames are made renders them as thermal bridges. Local manufacturing efforts have failed to correctly incorporate thermal breaks into the frame designs.

Wood as a window frame material is time-tested but not applicable[27] for the climate of Cyprus except in small developments that seek for a traditional look and are willing to accept the added maintenance that comes with it. Aluminium-gladded wooden frames are a viable option as they offer the best of the both materials: warm and natural material for the interior and zero-maintenance material for the exterior. However, although popular in Scandinavia, they have not yet penetrated into the Cypriot market but may become an option in the future.

The most promising frame material for high-performance windows at the moment in Cyprus is uPVC. Several vendors represent German-made brands in Cyprus and they are very competitive in prices. The earlier generation of uPVC windows demonstrated problems in use such as warping of the frames due to high surface temperatures under sunlight. The lessons, however, have now been learnt and the materials used for Cyprus and the Middle Eastern market have been greatly improved to perform in the demanding solar environment. As a window frame material uPVC behaves much like wood in terms of its U-value as well as its look. Windows with uPVC frames are available in Cyprus with a U-value of 1.2 W/m^2K and are therefore considered as the best option for hotel renovations at the moment.

[27] Due to high solar irradiation that destroys wood unless repeatedly retreated (twice a year).

4.3.1.1.3 Walls

Hotel buildings in Cyprus are typically constructed with reinforced concrete frame structure and perforated clay brick infill walls. No thermal insulation on walls is used as there were no building regulations regarding thermal performance until 2007. Walls consisting of horizontally perforated clay bricks (200 mm thick) according to EN 771-1:2003 Specifications for Masonry Units - Part 1: Clay Masonry Units (British Standards, 2003) with sand-cement render outside and high-density plaster inside have a U-value of about 1.45 W/m^2K (Energy Service, 2007). It is noted that at column and beam locations the U-value of the wall is increased to 3.35 W/m^2K due to thermal bridging.

In view of the fact that the current target U-values for openings and walls are 3.8 and 0.85 W/m^2K respectively, 30% reduction in heat loss through windows, 41% reduction through walls at infill and 75% reduction through the building frame are possible[28]. Therefore, wall insulation is proposed as a renovation measure to control heat gain and loss. Moreover, external insulation is advocated because internal insulation would decouple the thermal mass present in the walls. Subsequently, the application of external wall insulation can be implemented as part of a routine periodic façade refurbishment but with the added benefit of improved energy-efficiency. The simplest way of application is considered in this thesis, i.e. mechanically attaching expanded polystyrene or polyurethane board insulation to the wall and plastering and painting the surface. The method has been tried and tested in the cold climates of Scandinavia and found to be durable and long-lasting. In Cyprus the technology has been around for less than ten years and naturally there are concerns of durability under the strong solar irradiation. However, in the context of this study it is assumed that the maintenance requirements of such walls would be similar to conventional plastered brick walls. It is therefore assumed that repainting and minor crack repairs are needed every seven years. The insulation thickness can vary and just 25 mm of EPS insulation would be required to meet the code requirements. However, it is argued that it is prudent to go beyond the building code when such a major renovation measure is taken. The issue is discussed in further detail later in the thesis.

4.3.1.1.4 Roof

The roof and floors of hotels are cast-in-place concrete slabs, the roof slabs most often uninsulated and protected only against water and moisture penetration by a 4-5 mm thick bituminous felt. Some hotels may have a lightweight screed applied between the slab and waterproofing to facilitate drainage slopes and to serve as thermal insulation. Therefore, roof improvements should be considered in major renovations as recent research has indicated that for example reflective roof coatings can have a sizable impact on building cooling loads; 15-32 kWh/m^2 annual decrease is reported in various locations around the Mediterranean basin (Synnefa *et al.*, 2007). Similar findings were reported on a cool roof study conducted in California (Akbari *et al.*, 2005).

Roof insulation, however, has pros and cons. A commonly known negative side effect of roof

[28] The issue is illustrated with a simple steady-state calculation in Appendix II.

insulation is that it traps heat into the roof slab in summertime and cannot take full advantage of the cooling potential of long wave radiation of the clear night sky. Subsequently to address the said problem, a model of an innovative roof construction for hotel buildings was developed in an EU demonstration project LowEHotels mentioned earlier. The objective of the roof innovation was to find ways for excess heat to be dissipated through an insulated roof to cool it off quicker during summer nights. Various configurations were modelled incorporating a grid of vertical piping connecting the roof slab into the ambient air via a metal plate used as a heat exchanger (Paurine and Maidment, 2009a; 2009b; Ryan and Burek, 2009). At the time of writing no results were yet made public as of the implementation and monitoring of the system.

However, the effectiveness of any roof treatment is highly influenced by the building typology. Naturally a single-storey building is greatly exposed to the atmosphere through its roof whereas a multi-storey building communicates through its roof to a directly lessening degree with an increasing number of floors. To illustrate the point: a 6-storey building that goes through a roof renovation and as a result is able to cut the top floor energy consumption in half would see only 8.3% energy savings overall, assuming that all floors had equal energy consumption, whereas the same measure would benefit a single-storey building by 50% energy savings. Although not insignificant, roof measures in multi-storey buildings may not be of the highest priority especially when limited funds are available for energy-efficiency improvements.

Another reason that makes roof insulation difficult in Cypriot hotels is that the HVAC equipment such as chillers and their piping, packaged AC units, fan inlets/outlets, etc. are typically located on the building roof. In addition, satellite antennas and solar collector fields, if installed, are located on the roof. It makes it difficult to treat the roof slab in any methodical manner. Especially the application of insulation that would have to be waterproofed from the top would be virtually impossible around all the equipment and pipes in place. The problem is illustrated in Fig. 4.1.

Figure 4.1 Typical view of a hotel roof indicating congested HVAC installations

Subsequently, roof insulation of the hotel main buildings is not investigated as one of the renovation strategies in this thesis. Roof insulation is applied in the auxiliary areas (that extrude out of the main building) where applicable in the simulation models as explained later. Wherever applicable, 100 mm of EPS insulation board is applied to the concrete slab and waterproofed with 5 mm bituminous felt with a total U-value of 0.30 W/m^{2}K.

4.3.1.1.5 Air-tightness

Window and door openings are typically poorly sealed in Cypriot hotels. Sliding doors and windows tend to be loose and don't seal tightly against their sash. But the most obvious problem is the lack of thresholds under doors. It is not customary to provide thresholds in Cypriot buildings in general, hotels being no exception. Therefore, doors have to be slightly undercut in order to be able to drag along the floor to open. A simple measure to improve air-tightness is to seal windows and doors and of course if a complete window and door replacement is chosen, special care must be taken to ensure correct installation. In addition, doors with thresholds should be specified for replacement.

Window and door sealing is studied as a low-cost energy-efficiency measure in the thermal simulations later in the thesis.

4.3.1.1.6 Thermal mass

Thermal mass is of vital importance in reducing peak cooling loads in hot climates. Building elements such as concrete or masonry walls, floor and roof slabs, masonry partition walls, etc. can store heat due to their high thermal capacity. Night-time natural ventilation is usually all that is needed to purge the stored heat if a minimum of 10°C diurnal temperature variation is available (Balaras, 1996). Cyprus qualifies in that regard. The problem with hotels, however, is that their operation continues late into the evening hours, therefore not rendering the common spaces empty and ready for natural cooling. The cooling loads are still high in early evening as indoor restaurants, bars, lobbies and lounges have to be cooled, whereas an office building would be empty in the evening by the time its thermal storage capacity has been saturated and could therefore be amply naturally ventilated.

Hotels in Cyprus have a relatively high thermal mass due to the concrete and masonry construction method, although they do not possess the mass that vernacular buildings with 0.5 m adobe mud brick walls had. Ceilings are considered as the most effective place for thermal storage as hot air rises up. Cypriot hotel room ceilings are usually exposed concrete with plaster, therefore fit for thermal storage. Similarly, plastered clay-brick walls are fit for heat storage since wallpaper or soft wall coverings are not used. Therefore, the baseline construction is considered adequate in thermal mass.

Phase change materials can offer tangible benefits in the thermal performance of buildings and their primary application in building renovation would be to add thermal storage to lightweight construction. However, their post-application to already heavy-mass buildings is not obvious, whereas new construction could take full advantage of them. Therefore their mass implementation in Cypriot hotel renovations is not advocated and they are not investigated further in this thesis.

4.3.1.2 Passive ventilation and cooling

Nocturnal ventilation in dry hot climates can have a profound impact on reducing cooling loads. Santamouris *et al.* (1996) found that 56% of cooling load reduction is possible using ventilation rate of 6 hourly air changes in Greece. Night-time ventilation in hotels is not feasible in all circumstances though. Issues such as noise, air pollution, security, insects, etc. may prevent effective night-time ventilation and ultimately, the guest cannot be forced to sleep with an open window. Additionally, effective cross ventilation in hotel rooms is not possible as windows face one direction only. Therefore, the quoted savings may be somewhat theoretical unless innovative ways were developed so that cross ventilation into the corridor were made possible. Openings into the corridor, even if air grilles only, can seriously jeopardise sound proofness of guestrooms and may therefore not be applicable for larger hotels especially. Further, they may also violate fire codes. An open window with a ceiling fan may assist in night-time cooling especially on the windward side of the building. However, as the aim of this study is to focus on strategies that do not require behavioural change, window opening and fan use are not investigated further.

4.3.1.3 Solar shading

Solar shading plays an important role in the overheating protection of buildings. It is particularly efficient to shade windows against incident solar irradiation but protecting walls and roofs is of significant importance as well. Santamouris *et al*. (1996) found out that solar shading can reduce hotel cooling loads by 30% in Greece. Thermal insulation on the walls and roof also act as 'shading' for the inner surfaces and volumes. However, in the context of this study solar shading is understood to include items such as curtains and window covers, i.e. louvers, awnings and the shading provided by permanent structural components such as balconies, eaves or veranda covers. The typology of Cypriot hotels offers by default a horizontal protection for all guestroom windows by the balcony above. The 1.2-1.5 m extension of the balcony dictated by the building standard is adequate in blocking the high noon/before/after southern sun from reaching the windows. Naturally, depending on the orientation of the building, early morning or late afternoon solar irradiation may be incident on the windows and additional measures to prevent unwanted heat gains may be necessary. The most applicable solution is louvered window covers. The simplest models of them have fixed fins at a downward sloping angle that lets in some diffuse light but no direct irradiation. More sophisticated models have swivelling fins that can be manually adjusted to a desired position to let in light or to block it completely. They are also useful at night for nocturnal ventilation as they can give privacy and security while still letting air in and out.

It is assumed in the simulations that the guestrooms are fitted with thick curtains and that built-in sun protection is provided by the balcony slabs above the guestrooms. The large restaurant and bar windows are typically protected by canopies built in front of them. It is a standard feature in Cypriot hotels to have covered outdoor sitting and dining areas close to the building and the canopies inadvertently protect also the windows of the building. Additional window shading features were not studied in this thesis.

4.3.2 Measures to reduce energy consumption via active technology

4.3.2.1 Energy-efficient lighting

The International Hotels Environment Initiative (1993) estimates the lighting needs of hotels at 15-25% of total electricity consumption. Further, in a EU's Thermie Action program it was estimated that up to 40% of hotel electricity consumption, depending on hotel class, and 12-18% of total energy is consumed by lighting (European Commission Directorate General for Energy, 1994). Required lighting levels vary depending on the zone or area to be lit. For a frame of reference, lighting levels in guestrooms are typically 10-20 W/m^2 and 15-30 W/m^2 for general service areas, yielding total lighting related annual electricity consumption in the order of 25-55 kWh/m^2 (European Commission Directorate General for Energy, 1994). Similarly, Santamouris *et al*. (1996) found out that artificial lighting in Greek hotels consumes about 24.5 kWh/m^2 or 9% of the total energy consumed. CIBSE (2004) provides annual energy benchmarks for lighting in hotels as follows:

- Luxury hotels: 40 kWh/m^2 good practice, 70 kWh/m^2 typical
- Business/holiday hotel: 35 kWh/m^2 good practice, 65 kWh/m^2 typical
- Small hotels: 35 kWh/m^2 good practice, 55 kWh/m^2 typical

The most suitable and efficient light source should be selected for each application. The choice depends on various criteria, such as efficiency, colour temperature, colour rendering index, lamp life and emission mode (European Commission Directorate General for Energy, 1994).

Hotels impose many challenges for lighting design. First of all, due to the 24-hour operation, certain areas must be lit at all times, such as the corridors and lobby. Secondly, some areas, such as the lounge and restaurants require atmospheric lighting that was not so easy to accomplish with the first generation of energy saving lights such as the cold-toned fluorescent tubes. However, the latest models of compact fluorescent lamps come in warmer colour tones and with much improved colour rendering abilities as well as in many shapes that mimic the tungsten filament lamps. Even for spotlights either a compact fluorescent or a LED alternative is now available.

Obviously lighting energy needs can be further reduced by taking full advantage of natural daylight which in the Mediterranean is in ample supply. However, it is not within the scope of this study to evaluate the energy saving potential due to natural daylight as it is highly dependent on the orientation and architecture of the buildings as well as the correct use of lighting controls, either manual or automated. It was concluded that the theoretical hotel models used for evaluating building envelope improvements were not fit for assessing natural daylight potential in a manner that it could be extrapolated to the entire hotel building stock of Cyprus.

In the simulations to follow, it is assumed as a baseline that a hotel has already to a large degree switched to energy-efficient lighting, except for some halogen spotlights and special chandeliers. The energy saving potential of lighting is considered to be so well known and easily calculated that it is not included as a renovation strategy in the thermal simulations that follow, as the focus of this study is on SC energy consumption.

4.3.2.2 Energy-efficient equipment

Upgrading outdated, energy-wasting equipment with new efficient models has a two-fold impact on energy-efficiency. First of all, efficient equipment uses less electricity thus lowering total consumption. Secondly, it produces less heat and therefore can have a reducing impact on cooling loads. Typical equipment that contribute into internal loads in a hotel are TVs and minibar refrigerators in guestrooms, computers, printers, copy and fax machines in the offices, washing machines and ironing stations in the laundry and dishwashers, cookers, ovens, etc. in the kitchen. Equipment upgrades should be planned so that the old, inefficient ones are replaced with the most efficient, A-rated models.

Regarding small power equipment, 11% energy savings were possible in the Saunders Hotel Group by replacing equipment such as refrigerators, clock radios and TVs in guestrooms and computers and fax machines in offices by Energy Star-qualified[29] products (Energy Star, 2007).

Equipment replacement is not studied further in this thesis that focuses on SC energy consumption.

4.3.2.3 Energy-efficient boilers and chillers

In a large portion of Cypriot hotels that were built in the 1980s or early 1990s the boiler and chiller systems may soon be reaching their service life. System replacements would then become timely and an opportunity would arise to upgrade for the latest and most energy-efficient technology. The opportunity could be used for correct up-to-date load analysis and sizing of the new equipment also. Konis (1991) found out from interviews with electro-mechanical consultants that the hotel building loads were seldom calculated and that systems were sized empirically thus leading to over-sizing and part-load operation that yield poor efficiencies. The situation was made worse by consultants representing certain equipment and obviously getting higher commission for larger equipment.

Regarding chillers, it was observed that many hotels in Cyprus have a rather mixed supply of cooling as the hotels have been built in phases. But it is also clear that the thermal comfort needs have changed over the lifetime of the buildings thus necessitating additional comfort cooling. Subsequently, the cooling plant of a typical hotel consists of many different chillers, packaged and split units resulting in a fleet of cooling equipment of different technology, efficiency, age and manufacture. As a result, cooling energy management becomes overly complicated. Later in the thesis the application of solar air-conditioning is advocated but even if a hotel chooses to install solar AC, a need for conventional backup or a supplemental system still remains. Therefore, the most inefficient chillers should be retired first and the newer and more efficient ones kept as a supplemental system. Chiller renovation is an alternative; the compressors of inefficient reciprocating and standard models of scroll type chillers can be replaced by compressors using

[29] Energy Star is a seal of approval by the United States Department of Energy that is given to products that demonstrate 25-50% lower energy consumption than their conventional counterparts.

magnetic bearing technology for nearly 40% improvement in the integrated part load value (IPLV)[30] (Energy Star, 2008b).

An HVAC system upgrade would be a good time to re-evaluate the size requirements for fans and pumps also. Most induction motors that drive pumps reach their peak efficiencies when about 75% loaded and are less efficient when fully loaded. Therefore, pumps should be sized so that much of their operating time is spent at or close to their most efficient part-load factor (Energy Star, 2008b). Therefore, variable speed or volume pumps or AHUs should be used to replace single-speed and on/off type pumps and air handlers. It is noted that the power required to operate a pump motor is proportional to the cube of its speed, i.e. a 10% reduction in motor speed would reduce energy consumption by 27%[31] (Energy Star, 2008b). A hotel case study in Hawaii including chiller plant replacement with high-efficiency units and new chilled water pumps, both with variable frequency drives, resulted in 23.8% reduction in annual energy consumption and a payback of 3.43 years (Green Hotelier, 2004). Another hotel switched to variable speed demand ventilation in the kitchen, reduced fan electricity by 62% and rendered annual energy savings of over 76 MWh, yielding a payback of less than one year (Bohling and Fisher, 2004).

As discussed earlier, boiler and AC system inspections are now dictated by the EU's EPBD directive (European Commission, 2010). It is therefore to be expected that hotel owners and operators will become more aware of the inherent inefficiencies of the old heating and cooling installations and that as a result an increased uptake of system replacements will follow. Conventional boiler and chiller replacements are not investigated further in this study as introducing renewable energy is given priority.

4.3.2.4 Heat recovery for water heating

Significant energy savings in water heating are possible if appropriate heat recovery systems are put in place. 'Free' hot water can be obtained from the cooling and refrigeration equipment by using double-bundled heat exchangers in the chillers or plate heat exchangers in the condenser-cooling loop. Similarly, gray water heat recovery equipment used with showers can save 50-60% of water heating energy with a two-year payback (Energy Star, 2007). Preheating water has the added benefit that it can double or triple the first-hour capacity of water heaters. Furthermore, heat recovery can assist in preheating water any time of the day unlike solar-thermal that is limited to the sunlight hours and whatever hot water storage capacity is available. Utilising waste heat via heat recovery offers additional benefits. If for example the waste heat of freezers and refrigerators is used for water heating, the COP of the refrigeration equipment is improved simultaneously via lower condensing temperatures.

The application of water-to-water heat pumps was investigated in a hotel in Hong Kong by using heat rejected by the HVAC system as the heat source (Yu and Chan, 2006). A mean coefficient of performance of 1.75 for the system was observed and with the investment and energy

[30] IPLV is a measure used to evaluate the efficiency of chillers under a variety of operating load conditions, i.e. it is a weighted average of efficiency measurements at various part-load conditions. It is measured as kW power required per ton of cooling produced, i.e. in SI units kWe/3.517 kWc.
[31] Calculated as: $1-0.9^3=0.27=27\%$

price structure in place, a two-year payback was achieved. In the same hotel an air-to-water heat pump was installed for swimming pool heating with an average COP of 2 and a payback just over two years.

Heat recovery and heat pump technology should be considered case by case for hotel renovations but it is not investigated further as a priority strategy in this thesis.

4.3.2.5 Building management systems

It is virtually impossible to effectively control the optimal operation of large hotels without the help of a building management system (BMS). BMS allows the control of equipment and lighting as well as monitoring energy consumption centrally and even remotely. Cooling and heating thermostat settings in the various zones of the hotel can be set or overridden via the system. Also, functions such as start-up of chillers can be programmed into the system and concurrent start-up of all major equipment can be prevented thus shaving off sudden demand surges that would lead to penalties by the electrical utility. Power factor correcting devices, mandatory for large commercial facilities, can also be incorporated into the BMS. Automatic metering of electrical sub-meters, oil, gas and water meters can be achieved using a BMS and standard monitoring and targeting software. Nowadays the metering and analysis software have become more affordable and increasingly reliable (CIBSE, 2004). Demand patterns and consumption profiles are readily available from the system. Faults and atypical consumption can therefore be caught early before excessive energy wastage or extensive damage to the plant and auxiliaries due to faults or equipment malfunction is caused. The importance of systematic and frequent analysis cannot be overemphasised because the downside of monitoring systems is often due to excessive print-outs and incomprehensible data. BMS systems can be implemented as a refurbishment provided the necessary sub-meters and sensors are installed. Wireless technology is available that greatly simplifies installation and reduces the needs for extensive wiring (Oksa *et al.*, 2008).

BMS is not analysed further in this study as control strategies were excluded from the study objectives.

4.3.2.6 Energy control devices

Energy saving measures in hotels can be implemented at every department. Guestrooms are typically a large consumer. Key-card control that switches off the AC and lights when a guest is not in the room is an example. A hotel in America installed a key-card system for an investment of $120000 and just a 10-month payback and 10% overall energy savings (Energy Star, 2007). Other measures suitable for guestrooms include intelligent room HVAC controls that are programmed to go to setback mode with a higher temperature in summer and lower in winter when the occupancy sensor recognises that the room is unoccupied. Such intelligent installations can be further programmed so that the response time to return to the guest comfort temperature does not exceed a set value, say 8 minutes for example (Telkonet Inc., 2006). In order to guarantee the response time, the system is self-adjusting during the unoccupied hours that for a hotel room could be as long as 10-16 hours daily. In both cases, such overriding control by the hotel management provides significant energy savings without decreasing guest comfort in any way. Similarly, lighting in public areas can be controlled by occupancy or daylight sensors. Occupancy sensors are also appropriate for meeting rooms, public toilets and back-of-the-house areas. But as stated earlier, control strategies are outside the scope of this study.

4.3.3 Onsite micro-generation of energy

4.3.3.1 Combined heat and power and trigeneration

The feasibility of combined heat, cooling and power, CHCP, in European hotels was investigated in an EU project (CHOSE Project, 2001b). Out of the five participating countries of Cyprus, Greece, Italy, Portugal and Sweden, only Italy had a suitable economic structure in place to make CHCP installations cost-effective yielding payback periods of 2.5-4.1 years. An average payback of 8.4 years was calculated for hotel CHCP installations in Cyprus, thus rendering them non-feasible. However, CHP installations without the cooling capability showed greater promise even in Cyprus with a projected payback of 3.9-4.7 years. The study further demonstrated the sensitivity of the economic results to factors such as fuel and electricity prices and possible subsidies for the initial investment. In Cyprus, for example a 30% subsidy on the initial cost would reduce the payback of a CHCP investment from 8.4 to 4.2 years. Similarly, a 20% reduction in LPG price in Cyprus would result in a payback of 3-4 years. In another feasibility study a CHP application for a hotel in Cyprus was found to be very promising with a 3.2-year payback (Papamarcou and Kalogirou, 2001). However, it is noted that subsidies on LPG have been removed since the above two feasibility studies and LPG price has increased fivefold whereas electricity price has increased less than threefold. Therefore, CHP investments may no longer be feasible.

CHP systems have been successfully installed in many hotels in heating dominated climates. In the UK special supply and operation arrangements are available that make it possible for hotels to acquire a CHP system with zero initial investment. In such arrangements the vendor installs the system at its own cost and sells the produced energy to the hotel at a discounted price to recover the investment costs (Discount Energy Purchase scheme) (ENER•G Combined Power, 2007). Similar contractual structure has been used in Cyprus for desalination plants and should be considered for CHP applications as well.

CHP is not evaluated further in this study as without heavy subsidies on LPG they are not feasible. However, the issue of viability of CHP systems should be reevaluated in the near future as at the time of writing it has just been confirmed that Cyprus has substantial deep-sea natural gas reserves in its territorial waters. A local gas supply may make CHP installations more viable in the future. Also the viability of bio-fuel-fired CHP systems (Keppo and Savola, 2007) and especially that of centralised units that could serve the needs of several hotels should be appraised.

4.3.3.2 Renewable energy generation

4.3.3.2.1 Solar potential in Cyprus

Solar energy generation has a high potential in Cyprus due to the island's geographical location and favourable climate. On average, Cyprus receives 1450-1934 kWh/m^2 of solar radiation per year depending on the location (Meteorological Service of Cyprus, 2006b). It is noted that the highest solar radiation is received at the coastal areas, coinciding with the large tourist developments, whereas the mountainous regions receive a lesser amount. Daily solar radiation varies from 1.79 kWh/m^2 in December to 8.08 kWh/m^2 in June.

It is concluded that Cyprus has an extremely favourable climate for solar applications, either solar-thermal or photovoltaic. Fig. 4.2 is provided as a frame of reference in order to see how Cyprus scores globally in solar potential. The map divides the world in six zones based on the month of the lowest solar radiation. It is reported that even during the cloudiest winter months (December and January), an average of 5.5 hours of bright sunshine is available in the lowland and nearly 4 hours on the highest mountains (Meteorological Service of Cyprus, 2006a). Subsequently, most of the island of Cyprus falls to the second most favourable solar radiation zone (5.0-5.9 hours of sunshine) globally.

Figure 4.2 World solar insolation map showing the amount of solar energy in hours received each day on an optimally tilted surface during the worst month of the year

Source: OkSolar.com (no date)

4.3.3.2.2 Solar PV vs. solar-thermal

Solar potential can be used either for solar-thermal applications or for photovoltaic power generation. Solar-thermal technology on the island is mature and cost-effective but photovoltaic power generation is in its infancy and expensive as such. In this study PV power is not perceived a viable option for hotel upgrades mainly due to the fact that with the current PV panel efficiencies, large panel areas would be required to generate a reasonable fraction of the electricity needs. Suitable space for panels is generally limited and the placement of PV panels is in direct competition with the placement of solar-thermal panels. Therefore, it is maintained that it is more economical to utilise the available space for solar-thermal panels and solar air-conditioning application rather than for PV power generation. It was also the finding of the Tarbase project in the UK evaluating the energy and carbon saving potential of non-domestic buildings that drastic cost reductions and technical efficiency improvements of PV and small-scale wind turbines would have to happen for such technologies to become an economical micro-generation strategy throughout the entire non-domestic building stock. The reasons were that the roof-to-floor area ratios are quite small in multi-story commercial buildings to generate any appreciable amount of electricity while the energy intensity of non-domestic buildings was high (Jenkins *et al.*, 2010).

Naturally building wall-integration remains an option for the placement of PV. The end walls in typical Cypriot hotels may be suitable for PV integration, provided the orientation of the hotel is appropriate. However, the vertical placement of panels would greatly reduce their efficiency in latitudes where 27° is the ideal tilt angle for PV panels for optimised output. In general, the greatest benefits of building-integrated photovoltaics are achieved if they offset part of the costs of the conventional building components such as roofs or walls that they replace. In a hotel renovation that would, however, not be the case as the panels would be installed on top of an existing wall. Wall-integrated PV is a great way to increase the visibility of a building's green intentions and by all means should be considered but it is maintained in this thesis that unless the costs are drastically reduced and panel efficiencies greatly improved, PV in large commercial facilities such as hotels in Cyprus can only have an image-building role. It is reminded that the aim of this thesis is to identify the bottom-line strategies that could be implemented with limited financial resources yielding the maximum savings in SC energy costs without eroding the hotels' income. The position taken is in sync with the findings of a study done for the Greek hotel sector. Although PV power generation was successfully implemented in a hotel complex in the Greek island of Paros, after a rigorous economic analysis the authors concluded that there was no incentive for a PV system except in some remote areas, such as the Greek islands, where the cost of electricity was high and the local utility grids were overloaded and prone to shortages especially during the tourist season (Bakos and Soursos, 2002). However, the non-tangible benefits associated with a PV system installed in the said hotel had reportedly been very positive in branding the hotel with ecotourism.

The ideal renewable energy system for Cypriot hotels would be hybrid phovoltaic-thermal collectors (PVT) that produce both electricity and hot water. Maximising the electric and thermal output has been the greatest design challenge regarding hybrid collectors. It appears that maximising one would lower the efficiency of the other function. But it has been reported that per unit area a hybrid panel produces more energy than the combined energy of separate PV and thermal panels of same total area (Charalambous *et al.*, 2007). Therefore, hybrid solar is indeed a promising technology that would address installation space limitations in a sensible manner. The major obstacle for greater market uptake has been the price. In a study in the Netherlands a comparison was made by a reference system that would produce the same amount of electricity and heat as a 25 m^2 array of PVT (Bakker *et al.*, 2005). The PVT system was found out to be only 6% more expensive than the reference system when the fixed costs for both systems were assumed to be equal[32]. It is noted that 33 m^2 total area would have been required if the PV and solar-thermal panels were to be employed separately to match the energy output of a 25 m^2 PVT array. It subsequently appears that even the economics of PVT systems is no longer an obstacle

[32] Unit costs for PVT panels: 590/m^2 panels only and 790/m^2 including installation.

for greater market penetration. However, they are not commercially available in Cyprus at present but offer a great promise for future exploitation of solar energy in Cyprus and beyond.

4.3.3.2.3 Solar-thermal technology

Cyprus is the world leader in solar-thermal systems with the world's largest solar collector installed capacity per capita of 657 kW_{th} per 100000 population (IEA, 2008). According to the statistics published by the European Solar Thermal Industry Federation, the total operational installed capacity of solar-thermal systems in Cyprus in 2007 was 437640 kW_{th} or 625200 m^2 (ESTIF, 2008). However, although the domestic sector has embraced the solar-thermal technology with approximately 90% coverage of houses and 80% coverage of apartment buildings, only about one half of hotels are currently using solar-thermal water heating (Papastavros, 2007) even if payback periods for hotel SHW systems are reported at about 4.7-6.9 years (Kassinis, 2006; Pharmaconides, 2006).

The greatest barrier for the expansion of solar-thermal technology is the high initial investment costs. ESTIF has prepared an action plan at the European level for promoting solar-thermal technology with the following focus areas: regulations, financial incentives, awareness and promotion, improving market structures via EU market integration and research and development activities (ESTIF, 2003). A good example of strict regulation is the so called 'Barcelona model' in Spain that makes solar-thermal installations mandatory in new buildings and in major renovations (ESTIF, 2003). The success in implementing solar-thermal technology in countries like Germany and Austria, although not even particularly sunny in comparison to the Southern Europe, is an example of political will and efficient financial incentives. Greece on the other hand has a well-established market base for solar-thermal technology without any financial support from the government. Argiriou and Mirasgedis (2003) discuss the evolution of the solar-thermal market in Greece and show with economic analysis that the benefit-cost ratio of such systems has increased from a mere 0.72 in 1980 to 1.10 in 2000 without the help of financial incentives. Of course the initial market was established due to heavy subsidies during the 1980s but has since then become mature and self-supportive.

The Cyprus government has set up a financial incentives structure as a result of harmonising with the European Union renewable energy generation targets. Currently subsidies for solar-thermal applications are available for both domestic and commercial sectors. Hotel water heating systems qualify for a 30% subsidy for eligible costs[33] with a maximum grant amount of €75000. Similarly, solar assisted space heating and cooling systems qualify for 35% subsidy with a €75000 maximum grant (Republic of Cyprus, 2011).

4.3.3.2.4 Solar air-conditioning

Solar air-conditioning is the natural evolution to solar-thermal technology as the same collector field to produce hot water is used to run a chiller generating chilled water for space cooling. Solar

[33] Eligible costs constitute the difference between installing the proposed energy saving and a conventional equipment/component with an expectation that a minimum of 10% energy saving will be realised with the more expensive energy-efficient equipment/component.

AC was identified as an ideal candidate to introduce renewable energy into the hotel energy mix as the peak demand of cooling coincides with the peak production of solar heat. The technology itself is mature although its commercial uptake has been low due to unfavourable economics. It was chosen to be analysed as one of the hotel thermal renovation strategies in this thesis and with special interest to evaluate its cost-effectiveness. The author has written a literature review article that was published in the International Journal of Sustainable Energy titled: *Solar air conditioning and its role in alleviating the energy crisis of the Mediterranean hotels* (Naukkarinen, 2009). The paper in its entirety is included in Appendix III. Therefore, only a brief description of the system chosen for further analysis, namely absorption cooling is provided here.

An absorption chiller consists of a generator, condenser, absorber and an evaporator. Water as the refrigerant and lithium bromide, a nontoxic salt, as the absorbent are used as a working pair. In the generator the solution boils, refrigerant vapour is separated and it flows to the condenser while the concentrated solution flows to the absorber. In the condenser latent heat is removed from the condensed water vapour and rejected to a cooling tower while the refrigerant liquid flows to the evaporator where it boils and removes heat from the chilled (5-7°C) water circuit. The refrigerant vapour is attracted to the absorber where it is absorbed by the concentrated lithium-bromide resulting in a diluted solution that returns to the generator and the cycle is repeated. Typically driving temperatures >80°C are required but some manufactures have models that run at temperatures >68°C (Yazaki Energy Systems Inc., 2010). The working principle of absorption chiller is illustrated in Fig. 4.3.

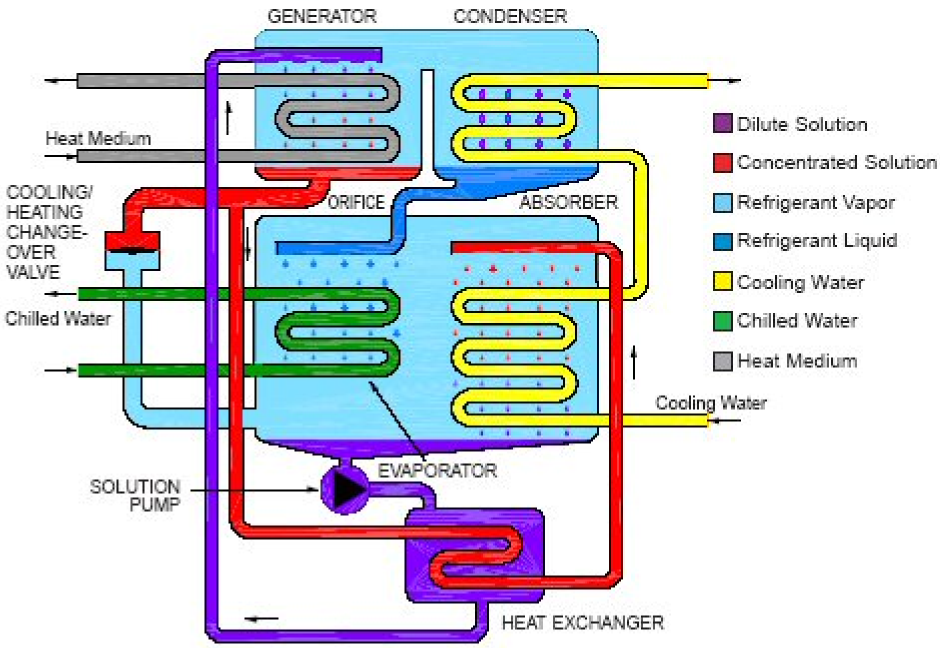


Figure 4.3 Working principle of absorption chiller

Source: (Yazaki Energy Systems Inc., 2010)

4.3.3.2.5 Wind power potential in Cyprus

On-shore wind energy potential in Cyprus is considered small to moderate with some areas with mean wind velocities in the range of 5-6 m/s and few areas in 6.5-7 m/s (Papastavros, 2007).

Initial studies on off-shore wind energy potential have indicated that the near shore sea depth[34] increasing the installation costs of wind turbines with only moderate wind speeds makes offshore installations financially ineffective (Papastavros, 2007). Consequently, onshore wind energy is expected to take the lead in renewable electricity production and the projection for 2010 was approx. 4.6% of total electricity generation. The island's first wind park was inaugurated in March 2011 with 82 MW capacity and several other wind parks are under construction at the moment. The renewable energy target of 2010 was not met but there is a momentum to the right direction.

Decentralised small-scale wind turbines are not considered viable due to the marginal nature of wind resources on the island. It is a more prudent strategy to focus on centralised wind power generation and a great idea for hotels to purchase green electricity in the future when it becomes available after more wind parks are commissioned.

4.3.3.2.6 Biomass utilisation potential in Cyprus

The potential contribution of biomass to the electricity generation in Cyprus is expected to be 1.2%. Possible resources include agricultural and forest residues, municipal solid waste, sewage water sludge and a considerable potential of energy crops including traditional herbaceous or short rotation woody crops (Papastavros, 2007). Chronic and recent particularly serious water shortages may render cultivation of energy crops unfeasible though. One application has been approved for a 35 MW solar-thermal power plant using biomass as a backup fuel (CERA, 2011). In addition, eight power generation units using biomass/biogas are already in operation with a total installed capacity of 3555 kW and total production of 19.8 GWh (Electricity Authority of Cyprus, 2010). As for hotel applications, boilers using ground olive pits, a local biomass source, are already available but they are not investigated further in this study.

4.4 Rational energy use in hotels – the behavioural component

4.4.1 Good housekeeping practices

Housekeeping practises can have a significant impact on hotel energy and water consumption. Therefore, environmental awareness training for the hotel staff is important and it is required for compliance with many EMS and eco-label schemes. Such training brought down energy usage by 5% at the Tokyo Bay Hilton hotel (Short, 1999). Energy-saving measures where housekeeping can play a major role include switching off lights, heating or cooling in unoccupied guestrooms or stores, closing curtains during summer to prevent overheating, etc. For example, turning fluorescent lights off for 12 hours daily can extend their expected calendar life by 75% to nearly seven years (Energy Star, 2007).

A lighting tune-up is a housekeeping measure that can bring in substantial benefits. Just cleaning the lighting fixtures alone may boost fixture light output from 10% in enclosed fixtures in clean environments to over 60% in open fixtures located in dirty areas. If occupancy sensors and photocells are installed, a simple calibration can restore their correct operation reducing the energy used by the lighting systems in those areas by 50% or more (Energy Star, 2008a). Swimming pool

[34] 30m depth at 300m from the shore

cover is another way to save 50-70% on the pool's energy use, 30-50% on its makeup water and 35-60% on its chemicals (Energy Star, 2007).

In addition, the front desk staff can help reduce energy costs by booking rooms in clusters so that only occupied building areas or wings need to be space conditioned to guest comfort levels. Rooms on top floors, at building corners and facing west (in summer) or north (in winter) can be the most energy-intensive to heat or cool and therefore should be rented last.

It is important that the right climate for resource saving and efficiency is communicated from the top management down to all staff levels. The importance of setting up an environmental program was discussed earlier and it is now widely accepted that they bring tangible financial benefits to hotels (Molina-Azorín *et al.*, 2009). Involving the whole hotel staff in energy and water saving activities related to their work tasks is the right way forward. In some cultural contexts a strong management-driven top-down approach is more appropriate (Chan and Hawkins, 2012) whereas a reward-based system may work better in another.

A study was done on the Greek island of Crete where hotel managers were interviewed about their knowledge and willingness to implement energy saving measures and renewable energy systems in their hotels (Zografakis *et al.*, 2011). It was concluded that 87.5% of hotel managers agreed or fully agreed that efficient energy management can indeed increase hotel profits. While one would expect the share to be 100%, it is nevertheless promising that the attitudes are changing. 20 years prior it was reported by Konis (1991) while conducting interviews of hotel managers in Cyprus how some managers were under the impression that high energy costs were of no consequence because they were tax-deductible and actually increased net profits.

4.4.2 Guest awareness

Guests should be invited to participate in the hotel's energy and water saving campaigns. Although many technologies exist that reduce energy and water consumption, at the end of the day if they are misused, no savings are achieved. For example, even energy-efficient lighting wastes electricity if left on unnecessarily. Similarly, a bathtub can be filled with a low-flow faucet although it may take longer to do so. Therefore, it is of vital importance to try and capture the attention and cooperation of the guests. Experience from many hotels shows that guests welcome invitations to energy and water saving campaigns. For example towel rack hangers and sheet changing cards asking guests to use their towels and linens more than once have been a great success with over 70% guests participating and 5% savings in laundry-related utilities costs ("Green" Hotels Association, 2008).

A good way to inform guests and to disseminate information about the hotel's environmental program is to have leaflets in the rooms briefly explaining what the hotel's goals are and how guest participation can help. It is also an opportunity to relate the desired energy saving activities in a way that the guests can continue implementing them at home for financial benefits. Within the project Hotel Energy Solutions (2011) discussed earlier a lot of ready dissemination material was prepared that can be just printed out and placed in the rooms for guests' perusal.

In techno-economic studies the human aspect is often ignored as it is difficult to predict, model or measure but it is ultimately the key that determines the success or failure of energy-efficiency improvements that rely on behavioural change.

4.5 Conclusions and strategies selected for further evaluation

This chapter addressed Objective 3 by providing background information on energy saving renovation strategies. It was the intention to introduce typical renovation strategies that could be implemented in hotel upgrades. An attempt was made to introduce a wide array of measures. They were presented in three categories starting with measures targeted for energy demand reduction, secondly energy saving via efficient equipment upgrades and finally onsite energy generation either by more efficient use of fossil fuel or by introducing renewable energy technology. The applicability of the measures for Cypriot hotels and the intention to investigate them further in this thesis was noted regarding each measure. A summary of measures for further analysis is presented in Table 4.1.

It was noted that user behaviour (both guest and staff) is of vital importance in the total energy savings as discussed and substantiated by case studies but it is presumed to be over and above the bottom-line energy savings that this thesis was set out to identify. Other researchers have studied the energy management issues of Cypriot hotels with an emphasis on the human factor by the means of soft systems analysis (Konis, 1991). Therefore it appeared appropriate to concentrate on the hard aspects in this thesis. Subsequently, the focus of this thesis was chosen to be on building envelope renovation and introduction of renewable energy in the form of solar-thermal technology targeted to reduce SC energy consumption. The defining factor for addressing the building envelope was the fact that it is something that hotels have to renovate periodically in any case. Window replacement and façade upgrade stood out as the measures of choice since it was established that the majority of the hotel building stock was at the age that major renovations were in order. The element of improved energy-efficiency was introduced into these common strategies.

Changes in the internal environmental, i.e. thermal comfort criteria as discussed in Chapter 3 were also chosen for further investigation. As argued earlier, there was room within the code requirements to adjust the temperature thermostat settings for both heating and cooling, and their impact on SC energy consumption was of interest. Similarly, ventilation rates could be lowered as smoking is no longer permitted in any public spaces in Cyprus.

Finally, solar AC was selected from the renewable energy technologies discussed because it is a logical extension to solar-thermal technology that is mature and well known in Cyprus and because the same solar collector field required to heat water for driving the chiller can also be used for space heating in winter and for DHW heating year around. In addition, solar AC truly addresses the peak cooling loads as the maximum demand and available solar irradiation happen simultaneously. Regardless of the obvious benefits, solar cooling is virtually nonexistent on the island. Hence, it was a parallel aim of this study to evaluate its economic viability in hotel renovations.

The chosen strategies are summarised in Table 4.1.

Renovation strategy	Present value	Code requirement	Proposed value
Wall insulation	U=1.45 kWh/m^{2}K	U=0.85 kWh/m^{2}K	U=0.30 kWh/m^{2}K
Windows, convent. 2-glazed, alumin. frame	U=5.42 kWh/m^{2}K (1-glazed alumin.)	U=3.80 kWh/m^{2}K	U=3.00 kWh/m^{2}K
Windows, HP 2-glazed, uPVC frame	U=5.42 kWh/m^{2}K (1-glazed alumin.)	U=3.80 kWh/m^{2}K	U=1.20 kWh/m^{2}K
Roof insulation	U=2.88 kWh/m^{2}K	U=0.75 kWh/m^{2}K	U=0.30 kWh/m^{2}K
Temperature setting heating (Cat. II)	T=23°C rooms T=22°C other areas	T=20-25°C rooms T=20-24°C other areas	T=20°C rooms T=20°C other areas
Temperature setting cooling (Cat. II)	T=25°C	T=23-26°C	T=26°C
Temperature setting heating (Cat. III)	T=23°C rooms T=22°C other areas	T=18-25°C rooms T=19-25°C other areas	T=18°C rooms T=19°C other areas
Temperature setting cooling (Cat. III)	T=25°C rooms T=24°C other areas	T=22-27°C	T=27°C
Ventilation rate (Cat. III) rooms	Q=25 l/s	Q≥18.5 l/s	Q=18.5 l/s
For ventilation in other areas, see Table 9.4			
Solar air-conditioning	N/A	N/A	N/A

Table 4.1 Energy saving strategies chosen for further analysis

While this chapter looked at the possible renovation strategies, the following chapter will investigate what tools can be used later in the thesis to measure their efficiency both in technical and economic terms.

5 Chapter 5 – Energy-efficiency evaluation tools

5.1 Introduction

The purpose of this chapter is to introduce the tools used in the fieldwork and data collection as well as in the technical and economic analyses in this thesis. The chapter therefore addresses Objectives 2, 3 and 4 by providing background information on energy auditing (Objective 2), thermal simulation (Objective 3) and guest surveys (Objective 4).

5.2 Energy audit

Energy audits are performed in order to collect information about the building's general condition, the condition of its HVAC systems and its energy and water consumption. The information can then be used to identify measures for energy and cost savings and reduction of GHG emissions. It is recommended by CIBSE (2004) that energy audits were undertaken regularly, every 3-5 years. The procedure proposed below is loosely based on the recommendations by CIBSE (2004).

An energy audit process starts typically with the collection of energy consumption data such as electricity and fuel bills for establishing the typical monthly energy consumption patterns. Several years of data should be compared to check if any changes have taken place. This constitutes a preliminary audit and actually should be done as a routine part of energy monitoring. A site survey follows. A site survey can be *comprehensive* or *concise*. A comprehensive survey deals with specified areas or items in depth whereas a concise survey is more superficial. The following items should be covered in an energy survey in the chosen level of detail:

- *building construction*: wall and roof construction type, insulation levels if any, windows, air infiltration, ventilation type, acquiring building floor plans if the building area is not known amended with in-situ measurements as needed, etc.
- *usage patterns*: typical hotel occupancy on monthly basis, schedules of occupancy in guestrooms, public spaces and the back-of-the-house areas, control strategies in place, temperatures and humidity maintained in various areas, lighting (audit of wattage and operating pattern)
- *main building services*: HVAC plant, DHW heating system (solar or fossil fuel based)
- *electric lighting*: quality, illuminance, luminance efficiency, daylight potential, control systems, etc.
- *energy supply and flows within the building*: fans and pumps, insulation of hot water and steam pipes and air ducts, evidence of leakage, etc.
- *plant room*: state and condition, insulation of boilers, chillers, tanks, pipe work, recovery of condensate, plant efficiency checks, etc.
- *small power*: TVs, hair driers, etc. in guestrooms, catering equipment, office equipment, gym and spa equipment, etc.

- *energy management*: review of hotel's energy management, monitoring and target setting, investment and maintenance plan or if no plan is in place, help in establishing one
- *building performance*: comparison to standard benchmarks
- *identification of opportunities*: energy and cost savings with recommendations for action.

It may be necessary to monitor the indoor environmental parameters, i.e. temperatures and humidity, in the key areas to check if they are in line with the thermostat settings. In addition, it would be valuable to get some user feedback in regards to thermal comfort and lighting, noise etc. levels in the different functional areas of the building, although user surveys are not part of a standard energy audit but are rather administered as post-occupancy surveys. A detailed breakdown of energy end-uses as a result of the energy survey should be produced identifying the major energy centres and the base load.

Regarding the timing of an energy audit, equipment should be observed in use, i.e. heating systems in winter and cooling systems in summer, although general information like plant capacities, condition, insulation levels, etc. can be gathered even outside the plant's operating season. It is also wise to time energy audits before major renovations so that up-to-date data can be used in planning the renovation project. After a major renovation project an energy audit is a must but it is actually called commissioning in such circumstances. A building that was never commissioned properly to begin with requires *retrocommissioning* (Energy Star, 2008b). The timing aspect also concerns the actual time of the day when the data collection takes place. The site visits should be timed so that the least amount of disturbance is caused to the normal hotel operation, both to guests and staff but the key staff must be available for consultation and access to the areas of interest.

Energy audit of the case study hotel was taken up in this thesis and it was conducted within the framework of the procedure outlined above.

5.3 Thermal simulation

To fulfil the study objectives, comparison of different renovation strategies in terms of the relative change in their energy consumption and costs was required. Thermal simulation stood out as a sensible way to evaluate building performance as hotel buildings are too complex for any simplified or manual evaluation methods. Furthermore, thermal simulation made it possible to evaluate the impacts of climate change on the building energy consumption, an investigation that was central to the methodology of the thesis.

It is recognised that at best thermal simulation represents an approximation of the reality. With so many variables to consider when modelling a building, an accurate replication of the reality is never fully possible. Whereas building materials and theoretical heat flows could be modelled somewhat realistically, modelling user behaviour such as window or curtain opening, guest-controlled room thermostat settings, etc. would certainly be impossible especially in case of large hotels capable of hosting 1000+ people at any given moment. Therefore, it was considered imperative to calibrate the thermal simulation model against a monitored and measured case study hotel. Calibration gives an opportunity to adjust the hard-to-know input parameters such as user patterns, infiltration, incident loads, etc. until a reasonable match between the measured and modelled output is reached. It is in this context that this study proposes to use thermal simulation in building performance evaluation. Once the baseline energy consumption is well matched between the actual and modelled, simulating renovation strategies becomes a relatively benign and robust way of evaluating their impact on energy efficiency. The danger in thermal simulation is when attempting to measure energy consumption in absolute terms.

5.3.1 Requirements for the thermal simulation software

Having established the above purpose of thermal simulation, a question arose: what software to use? Many simulation software packages are available, both commercially and in public domain. The first decision to be made was to decide whether the program should be based on steady state or dynamic analysis. In view of the fact that parameter calibration against actual measured energy consumption and weather data was planned as part of the methodology, the choice was clear: the software had to employ dynamic analysis. Dynamic analysis, in turn, can utilise two different methods of calculation, namely response function method (time and frequency response) or finite volume conservation method i.e. numerical method (Clarke, 2001). The selection between the two alternatives in the context of this study was not obvious. Both methods have merits and are suitable for handling the dynamic interactions occurring within buildings. However, Clarke (2001) insists that the numerical method is superior especially when emulating reality and testing prototype buildings, whereas the response function method, although mathematically elegant and the outcome of many years of accumulated research and development essentially had emerged in response to the need to introduce dynamic considerations into manual methods. However, as stated above, the aim of the simulations in this study was not to emulate reality to the level of accuracy referred to by Clarke. Subsequently, it was decided that either method would be suitable for the purpose.

5.3.2 Comparison and selection of thermal simulation software

The selection criteria for simulation software to be used in this study were set and the simulation package was expected to demonstrate the following features or capabilities:

1. Full geometric description of building components, i.e. walls, roofs, floors, windows and doors
2. Unlimited number of surfaces, zones, systems and equipment
3. Heat balance calculation with simultaneous calculation of radiation and convection at each time step
4. Element conduction solution method either time response factor or finite difference/volume
5. Internal thermal mass considered
6. Insolation analysis[35] by computing distribution at each hour/time step

[35] Insolation analysis studies the impact of incident solar radiation on a building. Insolation refers to the wide spectrum radiant energy from the sun which strikes an object or surface, including both the direct component (sunshine) and the diffused component from the visible sky (skylight).

7. Controllable window blinds
8. Airflow via windows
9. Natural ventilation (pressure and buoyancy driven)
10. Hybrid natural and mechanical ventilation
11. Window opening for natural ventilation controllable
12. Multizone airflow simulation
13. Simulation of solar thermal collectors
14. Calculation of building power loads
15. Validation of software

To assist in software selection, a study comparing 20 prominent building simulation software programs was used as a starting point (Crawley *et al.*, 2005). The study compared the programs with regards to their way of handling general modelling features such as zone loads, building envelope and daylighting, infiltration, ventilation and multizone airflow, renewable energy systems, electrical systems and equipment, HVAC systems, HVAC equipment, environmental emissions, economic evaluation, climate data availability, results reporting, validation and user interface, links to other programs and availability. The purpose was merely to list and report the capabilities of the programs, not to pass judgement on their goodness or badness, to validate them nor to rank them in any order. The abovementioned 20 simulation programs were considered and compared against the selection criteria set forth for this thesis. The results are shown in Table 5.1 and as indicated, the two programs that met all the criteria were ESP-r and IES<VE>.

The final selection between ESP-r and IES<VE> was made considering the following aspects:

- user-friendliness
- input/output interface
- flexibility to simulate nonstandard conditions
- suitability to energy consulting services, i.e. possibility of being an industry standard

It was concluded that ESP-r as a primarily research software and widely validated as such, was somewhat difficult to use. In addition, its input and output interfaces are underdeveloped and cannot be compared to the interfaces available in commercial software packages such as IES<VE>. As for the flexibility in simulating nonstandard conditions, ESP-r would be clearly the choice as it is an open-code program that can be supplemented by user-defined systems. IES<VE>, in turn, is closed-code and cannot be modified as such. It is reemphasised that the aim of this study is to evaluate the energy saving potential of various renovation strategies, primarily architectural. Therefore, detailed modelling of mechanical systems is not of interest and is outside the study objectives. The main objective of the thermal simulations was to quantify the relative differences between strategies rather than to accurately determine the exact energy consumption. In addition, this study aims to develop a methodology of evaluating the impacts of climate change and rising energy prices on hotel energy costs with the notion that the methodology could be used by practising engineers and architects in real-life hotel renovation projects. Thermal simulation forms a major part of the proposed methodology and as such has to utilise software tools that are readily available and within the capabilities of practitioners. It was concluded that IES<VE> had become somewhat of an industry standard in the UK with a growing clientele also in the USA and Australia. Therefore, IES<VE> was selected for this study.

	Selection criteria	BLAST	Bsim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
1	Full geometric description (walls, roofs, floors, windows, skylights, doors)	yes	yes	yes	yes	yes	-	yes	-	yes	yes	yes	-	yes	yes	yes	yes	yes	yes	yes	yes
2	Unlimited number of surfaces, zones, systems and equipment	-	yes	yes	-	yes	-	-	-	yes	yes	yes	yes	yes	yes	yes	yes	-	yes	yes	yes
3	Heat balance calculation with simultaneous calc of radiation and convection at each time step	yes	yes	yes	yes	-	yes	-	-	yes	yes	yes	-	yes	yes	yes	yes	yes	yes	yes	yes
4	Element conduction solution method either time response factor or finite difference/volume	yes	-	yes	yes	-	yes	-	yes	yes	yes	yes	yes	-	yes	yes	yes	yes	yes	yes	yes
5	Internal thermal mass considered	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	-	yes	yes	yes	yes	yes	yes	yes	yes
6	Insolation analysis by computing distribution at each hour/time step	yes	-	-	yes	-	-	-	-	yes	yes	yes	-	-	-	yes	-	-	-	-	-
7	Controllable window blinds	-	yes	yes	yes	yes	-	yes	-	yes	yes	yes	-	yes	yes	yes	-	yes	yes	-	yes
8	Airflow via windows	-	-	-	-	yes	-	-	-	yes	-	yes	-	-	-	yes	yes	yes	yes	-	yes
9	Natural ventilation (pressure and buoyancy driven)	-	yes	-	-	-	-	-	-	yes	-	yes	-	-	yes	yes	yes	yes	yes	-	yes
10	Hybrid natural and mechanical ventilation	-	yes	-	-	-	yes	-	-	-	-	yes	-	-	yes	yes	yes	-	yes	-	yes
11	Window opening for natural ventilation controllable	-	-	yes	-	-	yes	-	-	yes	-	yes	-	-	-	yes	-	yes	yes	-	yes
12	Multizone airflow simulation	-	yes	-	-	-	-	-	-	-	-	yes	-	-	yes	yes	-	yes	yes	-	yes
13	Simulation of solar thermal collectors	-	-	yes	-	yes	-	-	yes	yes	-	yes	-	-	-	yes	-	-	yes	-	yes
14	Building power loads	yes	-	yes	yes	yes	-	yes	yes	yes	yes	yes	yes	-	yes	yes	yes	-	yes	-	yes
15	Validation	yes	yes	yes	yes	-	-	-	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

Table 5.1 Simulation software selection criteria[36]

5.4 Cost-benefit analysis

5.4.1 Analysis methods

The economic viability of the proposed thermal renovation strategies in this study is evaluated using the lifecycle cost concept but there are several methods that each addresses a slightly different aspect of the proposed investment. First of all, it is important to distinguish between profitability and economic efficiency. An investment is profitable if it yields benefits or savings in excess to the costs incurred. However, economic efficiency is measured how much profit is generated, ideally maximising profits that in the context of building renovation denotes selecting the most profitable alternative. Economic efficiency is therefore defined as a '*situation in which (with the given state of technology) it is impossible to generate a larger welfare total from the available resources*' (BusinessDictionary.com, 2008). However, *profitability* in this thesis is measured in terms of hotels' ability to generate room income after implementing energy-efficiency

[36] It is noted that the newest versions of some of the simulation software compared here may already have included features that at the time of the software comparison were not available.

improvements. Cost-effective measures that in addition increase room income are considered *profitable*. The mechanism is discussed further in several contexts as it forms the original contribution of this thesis.

Another factor that needs to be considered in economic evaluation is the time value of money. Therefore, the future returns of an investment must be discounted in order to reflect the value of the future savings or income in their present value that is lower due to inflation and loss of interest on the capital. The time span that is required to pay back the initial investment as well as the rate at which the investment is discounted are of vital importance and they directly dictate to the profitability and economic efficiency of a renovation alternative.

Gorgolewski (1995) discusses the applicability of various methods used in the economic evaluation of energy-efficiency improvements and concludes that economic optimisation of the chosen measures and their correct prioritisation in implementation lead to the maximum fuel cost savings per unit of investment. However, how to select the most profitable and therefore economically the most efficient alternative, is a matter of preference. The following is a list and brief description of some of the common economic evaluation methods that were considered in this study.

Simple and discounted payback calculations are the most basic measures of the amount of time it takes to recover the initial investment in capital. As such the methods are popular and widely used although they are not valid for comparing multiple, mutually exclusive project alternatives nor for ranking them. Ranking by payback favours short-term solutions and does not capture the lifecycle benefits of project alternatives, especially the ones that happen beyond the payback period (Gorgolewski, 1995). The merits of payback calculations lie in their simplicity and they are warranted to be used as screening methods for projects that are so clearly economical that a fuller lifecycle cost treatment would be uneconomical and unwarranted (Boussabaine and Kirkham, 2003). However, payback period is a common criterion in the hotel industry's investment decisions. Therefore, in this study paybacks were calculated as an initial test tool and an additional indicator after economic optimisation had been carried out using other more suitable methods.

Net Present Worth (NPW) or Net Present Value (NPV) is defined as the difference between the present value of all revenues and costs incurred. NPW analysis is therefore a measure of profitability where NPW>0 indicates that profits in excess of costs are generated. NPW analysis is useful in sizing projects but does not rank them well because it does not compare the size of the investment to savings generated and therefore does not distinguish between two alternative investments, different in size but generating equal savings. The NPW method is also called **Net Benefits (NB)** or **Net Savings (NS)** method since the revenues are often due to the operational cost savings from implementing energy saving measures (CRES, 2000).

Savings to Investment Ratio (SIR) is a measure that compares savings over the study period or the service life in present value to the investment required to make the savings possible. By definition, SIR>1.0 denotes that a project is suitable for economic justification (Boussabaine and Kirkham, 2003). By inspection, the greater the SIR, the more profitable a project is. It is to be noted though that the project with the lowest lifecycle cost is not necessarily the one with the highest SIR. Therefore, SIR analysis is not applicable for choosing projects but is well suited as a ranking tool for comparing mutually exclusive projects when limited amount of funds are available (Boussabaine and Kirkham, 2003).

Internal Rate of Return (IRR) represents the minimum interest rate that the invested money would have to earn elsewhere to be a better investment (CIBSE, 2004). It is defined as the discount rate at which the NPV of the project reduces to zero. Another way of looking at it would be to state that IRR is the discount rate at which the discounted payback period equals to the project service life or the study period.

Life-Cycle Cost (LCC) is defined as the '*sum of all recurring and one-time (non-recurring) costs over the full life span or a specified period of a good, service, structure, or system. It includes the purchase price, installation cost, operating costs, maintenance and upgrade costs, and remaining (residual or salvage) value at the end of ownership or its useful life'* (BusinessDictionary.com, 2008). If the LCC of a refurbishment is less than the LCC of the original building, the investment is considered profitable, and cost-effective if in addition its LCC is lower than that of any other alternative aiming to achieve the same objective, making it the best alternative to be implemented.

5.4.2 Methods chosen for further use in the present thesis

The above methods are summarised in Table 5.2 and their intended use in this study is stated.

Evaluation method	Equation	Criterion	Intended use in this thesis
Simple Payback Period (SPB)	$CF_0 = \sum_{k=1}^{Y} CF_k$ or $Y = \frac{CF_0}{A}$	Y << N	Rough preliminary screening of renovation alternatives.
Discounted Payback Period (DPB)	$CF_0 = \sum_{k=1}^{Y} \left[\frac{CF_k}{(1+d)^k}\right]$	Y < N	Preliminary sensitivity analysis on the effects of the discount rate on payback period.
Net Present Worth (NPW)	$NPW = \sum_{k=1}^{N} \left[\frac{CF_k}{(1+d)^k}\right] - CF_0$	NPW ≥ 0	Used in DPB and IRR calculations.
Savings to Investment Ratio (SIR)	$SIR = \frac{\sum_{k=0}^{N} \left[\frac{S_k}{(1+d)^k}\right]}{\sum_{k=0}^{N} \left[\frac{I_k}{(1+d)^k}\right]}$	SIR > 1	Ranking of independent renovation alternatives against their initial investment costs.
Internal Rate of Return (IRR)	$\sum_{k=1}^{N} \left[\frac{CF_k}{\left(1+d_r\right)^k}\right] = CF_0$	d_r to fulfil the equation	To establish the upper ceiling value for the discount rate.
Life-Cycle Cost (LCC)	$LCC = \sum_{k=0}^{N} \left[\frac{AC_k}{(1+d)^k}\right]$	LCC = the least possible	Ranking of independent renovation alternatives against their life-cycle costs.

Table 5.2 Economic evaluation methods and their intended use in this study

Legend to Table 5.2:

- CF_k is the net cash flow in year k, k going from 0 (the year of the initial investment) to N (study period or service life of the equipment, component, etc.)
- Y is the year when the accumulated net cash flow equals to the initial investment
- A is the annual net cash flow when it is known that the net cash flow is constant throughout the study period
- d is the discount rate, i.e. the interest rate that the initial investment would yield if invested otherwise
- S_k is the savings at year k
- I_k is the investment at year k, k=0 denoting the initial investment and $1 \leq k \leq N$ referring to costs, such as maintenance costs, occurring during the study period or lifetime of the equipment, component, etc.
- AC_k is the annual costs in year k including energy, maintenance, etc.

5.5 Post-Occupancy Evaluation

5.5.1 What is post-occupancy evaluation?

Post-occupancy evaluation is generally understood to mean evaluation of a building's performance after it has been constructed and commissioned for use and habited by its occupants. The latest trends regarding POE include a framework called soft landings. It consists of five main stages: 1) inception and briefing, 2) design development, 3) preparation for handover, 4) initial aftercare and 5) longer-term aftercare. The central idea is that the designer and the contractor would not simply walk away when a building project is finished but would stay close to the building owner and users for realising the building's full potential and helping out solving problems especially during the initial commissioning (Bordass and Leaman, 2011). From such a working relationship new professionals, better buildings and happier occupants would emerge.

Post-occupancy evaluation is not a rigid method but rather a recommended framework that can be implemented in various ways as seen fit. POE surveys, however, usually include an energy assessment and an occupant survey. Water consumption analysis and fabric air-tightness tests, if needed, can also be included and further diagnostics tests prescribed as dictated by the case (Leaman *et al.*, 2010).

A POE survey can be conducted at any stage in a building's life but it is of particular importance during the commissioning stage when the mechanical and electric systems are being tuned up, typically during the first year of a building's life. Occupant surveys can then guide in fixing problems related to thermal comfort, lighting, noise, etc. However, during the commissioning stage the occupants may be more forgiving and less critical of nuisances that are perceived to be temporary, especially if the building in concern is a high profile 'green' building (Paevere and Brown, 2008). In such cases it would be good to repeat the survey after a couple of years when the newness of the building has worn out. However, there is a general tendency for people to be more tolerant with the so-called 'green' buildings than their conventional counterparts (Leaman, 2007).

POE can also be used to try and match actual and modelled energy consumption. A multi-storey office building was carefully surveyed for its lighting and small power consumption using POE methodology and as a result it was possible to match the actual energy consumption of the building with dynamic thermal simulation within 3% (Menezes *et al.*, 2009). The authors identified the need for further research using similar methodology to develop evidence-based benchmarks for buildings. Indeed, similar methodology was used in this thesis to calibrate the thermal simulation model in an attempt to close the performance gap between the modelled and monitored energy consumption. It is encouraging to observe that other researchers have used the method with good results.

5.5.2 Designed vs. actual building energy consumption

There has been growing concern recently that buildings, even the flagship, award-winning, sustainable ones, do not actually perform in use as they were designed to or as demonstrated by simulations. This is particularly embarrassing with buildings that have been awarded an environmental label or certification and have gained high publicity and visibility. A re-analysis of LEED-certified[37] buildings concluded that while on average they used 18-39% less energy per floor area than their conventional counterparts, 28-35% of LEED buildings actually used more energy than their conventional counterparts (Newsham *et al.*, 2009). The findings highlight the problem with certifications such as LEED because they give credit to simulated instead of measured energy performance. The study further concluded that the measured energy performance had little correlation with the level or the number of energy credits given during certification, i.e. that counter to popular belief, a LEED Platinum building did not save more energy than a LEED Silver building. Scofield (2009) analysed the same data used by Newsham *et al.* using a different way of calculating the energy intensity of the buildings and measuring energy consumption by source rather than by site energy and found out that the energy consumption of LEED buildings was no less than that of conventional buildings. His finding highlights the danger of using LEED certification as a mitigation measure against carbon emissions. LEED credits can be collected for measures such as providing bicycle racks and showers for employees that have nothing to do with reducing energy consumption. Therefore, although the intentions of such certifications are good, caution should be applied when extrapolating energy or carbon savings from them. It is argued that building eco-labelling and certification should apply only to real performance rather than to design intentions. Or at the very least, in order to maintain a certified status, real energy consumption data should be presented after the first year of operation and periodically thereafter.

5.5.3 Collecting building user feedback in this thesis

The methodology of this thesis did not include a post-occupancy evaluation in the conventional sense of the concept. An energy audit of the case study hotel was performed instead without a formal survey of the hotels users, i.e. staff and guests. However, informal discussions with the hotel staff revealed issues of concern, thermal comfort in particular, and they are discussed wherever appropriate within the thesis. In addition, the usage patterns, occupancy schedules, lighting timing, etc. were established through in-depth discussions with various staff members, augmented by personal observations. So, in this respect the tasks of an energy audit and POE overlap.

[37] LEED stands for Leadership in Energy and Environment and the certification is administered by the US Green Building Council.

In addition, a hotel guest survey was conducted island-wide with an objective to get building user feedback on a general level rather than for a particular building. Thermal comfort issues were part of the guest survey with the intention to understand for instance whether guests used AC and why. However, the survey touched many other aspects that would not normally be included in a POE questionnaire. The survey and its objectives are discussed in detail later in the thesis but the survey's multiple purpose is highlighted here.

5.6 Conclusions

In this chapter the tools used in the fieldwork and data collection as well as in the technical and economic analyses were introduced. The chapter therefore addressed Objectives 2, 3 and 4 by providing background information on energy auditing (Objective 2), thermal simulation (Objective 3) and building user surveys (Objective 4).

It was established that buildings benefit from periodic energy audits as they can identify problems of energy wastage and act on them promptly. But when it comes to proposing cost-effective remedies for the problems identified in the energy audit, simplified hand calculations are not enough when dealing with complex buildings like hotels. Therefore, it was concluded that it is best to utilise the data collected from an energy audit as calibration data. The accuracy of thermal simulation can be greatly improved as the hard-to-know parameters can be calibrated until the modelled and measured energy consumption and indoor environmental parameters match. It was in this context that thermal simulation was proposed to be used in this thesis.

The methods most applicable for the economic evaluation of energy-efficient building renovation were discussed and their intended use in this thesis was stated.

Furthermore, it was concluded that POE was invaluable as it provides feedback from the building users, an aspect that is overlooked in a traditional energy audit. The performance gap, a worrying trend that buildings consume substantially more energy in reality than what they were designed for, was discussed and the role of POE and the soft landings framework in helping to bridge the gap. It was concluded that soft landings was the mode of operation where the building industry should be heading.

In the next chapter it is described in detail how the tools discussed in this chapter were used in the applied methodology of this research.

6 Chapter 6 – Methodology

6.1 Introduction

In this chapter the main aim and the research objectives introduced in Chapter 1 are discussed in greater depth. Further, the methods employed in data collection and analysis are presented. The specific application of the evaluation tools introduced in the previous chapter are discussed and a step-by-step outline of the methodology is presented.

6.2 The aim and objectives of the study

The main aim of this study was *to develop a methodology for evaluating the impacts of climate change and rising fossil fuel prices on space conditioning energy costs of hotels in Cyprus and to propose cost-effective thermal renovation strategies to combat such impacts.* Fulfilling the aim was undertaken by assigning detailed objectives that each advanced the development of the said methodology.

The objectives in detail are as follows:

6.2.1 Objective 1

Objective 1 was *to understand by literature review how climate change and depletion of fossil fuels would affect space conditioning energy consumption of hotels in Cyprus*.

The objective was undertaken by reviewing relevant studies on the impacts of climate change on small islands and specifically studies reporting observation-based changes in the climate of Cyprus. Similarly, studies and figures on oil production, consumption, resource and reserve estimation, price fluctuation, past and present energy crises and the politics behind them were reviewed in order to conclude that the current high oil prices were not due to temporary, politically motivated price manipulation but rather due to steeply increasing demand coupled with uncertain supply.

6.2.2 Objective 2

Objective 2 was *to assess by energy audit of a representative case study hotel, an energy consumption survey of a small sample of hotels and by analysis of an industry-wide dataset on hotel electricity use the current baseline of space conditioning energy consumption of hotels in Cyprus*.

The objective was undertaken, first of all, by conducting a detailed energy audit of a 4-star hotel. Secondly, energy consumption data was collected from a small but representative sample of 3-, 4- and 5-star hotel buildings in Cyprus and thirdly, a hotel industry-wide electricity consumption dataset was used to calculate the per-guest-night baseline electricity consumption for the entire hotel building stock of Cyprus. The actual energy consumption of the case study hotel was validated against the sample of 3-, 4- and 5-star hotels while their electricity consumption was validated against the industry-wide baseline. Further, the information gathered from the energy audit was used in calibrating the thermal simulation model of the case study hotel. The calibrated model in turn was used as a template in constructing theoretical models of hotels. As a result of simulations, it was possible to derive the baseline SC energy consumption of 3-, 4- and 5-star hotels from their theoretical models.

6.2.3 Objective 3

Objective 3 was *to evaluate by thermal simulation which energy-efficiency measures implemented in the form of building envelope improvements, thermal comfort criteria adjustments and introduction of renewable energy technology could be cost-effectively employed in existing hotel buildings in order to reduce their space conditioning energy costs at present or in the projected future climates of 2050 and 2090*.

The objective was undertaken by thermal simulations of theoretical case study hotels at present and in future climates. Several renovation strategies targeting building envelope improvements, adjustments in thermal comfort criteria and introduction of solar cooling were simulated and their cost-effectiveness was evaluated. In addition, increase in energy prices and incremental reduction in hotel occupancy were factored into the econometric model in three climate scenarios for joint sensitivity analysis.

6.2.4 Objective 4

Objective 4 was *to investigate by questionnaire survey to what extent the additional capital costs of implementing such measures could be offset by an increase in hotel room rates*.

The objective was undertaken by conducting a hotel guest survey in order to map out tourists' willingness to pay more for their holiday experience in Cyprus in the future when the external drivers of climate change and fuel price inflation may force increases in package holiday prices.

6.2.5 Objective 5

Objective 5 was *to develop and test a new economic efficiency indicator aimed at evaluating the viability of the proposed renovation strategies measured in terms of their income generation potential*.

The objective was undertaken by comparing the room income per guest night of the renovated cases to that of the base case. Any modification made to the hotel building in any combination of the external conditions (climate, oil price and occupancy) that would yield income greater than that of the base case, would be considered profitable.

6.2.6 Objective 6

Objective 6 was *to extrapolate the effects of cost-effective thermal renovation strategies to the entire hotel building stock of Cyprus by estimating the overall energy and operational costs savings potential and by developing recommendations for nationwide rational hotel building upgrade*.

The objective was undertaken by calculating the total energy savings per room for each renovation strategy in each hotel class and multiplying the savings in energy and financial terms by the total number of rooms. Subsequently, an action plan for upgrading the hotel building stock and revamping the image of the product they offer was developed.

6.3 Research methodology

6.3.1 Introduction

This study consists of four distinct aspects: 1) technical data collection and analysis regarding hotel energy consumption, 2) analysis of energy-efficient renovation strategies, 3) hotel quest survey and analysis and 4) economic analysis. Items 1 and 2 form the technical, item 3) the social and item 4) the economic aspect of the study. This thesis can therefore be characterised as a techno-socio-economic study on the impacts of climate change and rising fuel prices on hotels and their SC energy costs in Cyprus.

The relationship between the technical, social and economic aspects of the study is shown in Fig. 6.1. The pyramid shown indicates the interfaces between the three aspects and how they frame the feasibility of hotel renovation strategies. First of all, the interface between technical and social aspects consists of tourists' perceptions on various technologies, such as AC. Any guest-controlled technical systems, such as lighting for example, are only as efficient as the user makes them to be, therefore clearly defining the techno-social relationship. Tourists or hotel guests are also the key in accepting new thermal comfort criteria that aims at reducing hotel energy consumption. The socio-economic interface, in turn, is defined by the tourists' willingness to pay more in the future for their holiday experience in Cyprus, whereas the techno-economic interface indicates the cost-effectiveness of the proposed renovation strategies of hotels. Cost-effectiveness is evaluated in terms of the various stakeholders' ability to absorb costs and the return on their investment. As indicated in the pyramid, a window of opportunity is created between the three interfaces for operational cost control of hotels.

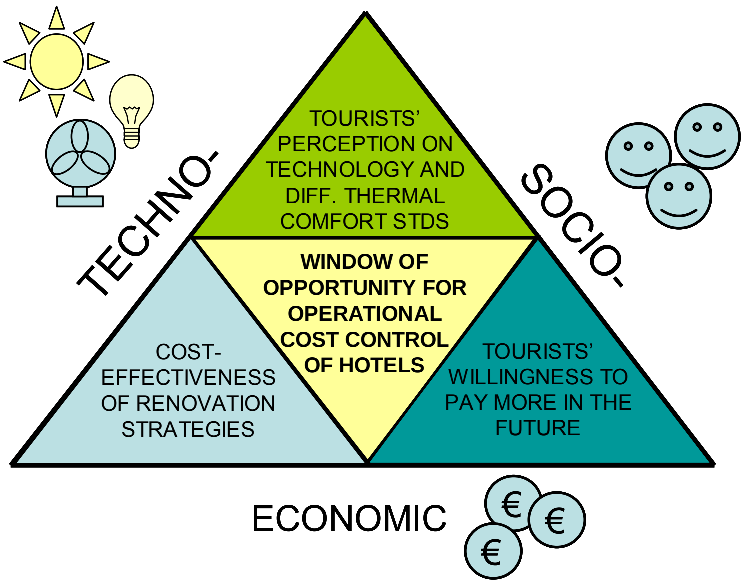


Figure 6.1 Pyramid structure indicating the interfaces between the techno-, socio- and economic aspects of the study

6.3.2 Primary data collection

6.3.2.1 Introduction

Primary data for this study was collected in three different ways: 1) a typical 4-star hotel was selected as a case study for a detailed energy audit, 2) energy consumption data of a small sample of 3-, 4- and 5-star hotels was collected, and 3) a hotel guest survey was conducted. The following paragraphs explain the methods of data collection in detail.

6.3.2.2 Energy audit and monitoring of a case study hotel

For detailed monitoring of electricity consumption and temperature and humidity variation within the various facilities of the building, a typical 228-room 4-star full-service hotel was selected as a case study. 4-star hotels represent the most common accommodation type in Cyprus accounting for 41% of all hotel beds and 26% of all accommodation types (CTO, 2008e).

Temperature and humidity data loggers were installed in the hotel in order to establish the typical temperature and humidity range in which the various facilities of the hotel operate, i.e. to identify their daily and seasonal maximums and minimums. The following areas were monitored: one guestroom (bedroom, bathroom and balcony separately), kitchen, laundry, lobby, staircase (unconditioned space) and outdoors (opposite façade to the guestroom balcony). The purpose of the outside temperature and humidity monitoring was to establish any microclimate variations around the hotel building.

6.3.2.2.1 Temperature and humidity measurements

Monitoring was done using data loggers Tinytag Ultra 2 (TGU-4500), Tinytag Transit (TG-0050) and Tinytag eXtra (TGX-3580) manufactured by Gemini (Gemini Data Loggers, 2006). TGX-3580 units are weatherproof and were used outdoors. All loggers were programmed to take one recording an hour. An hourly recording interval was chosen to match the climate and output data resolution typically used in thermal simulations. The dataloggers used are shown in Fig. 6.2. Temperature and humidity measurements were continued for one full year (January-December 2007) for a complete picture of the yearly variations.

Figure 6.2 Dataloggers Tinytag Ultra, Tinytag eXtra and Tinytag Transit

6.3.2.2.2 Electricity sub-metering

Electrical sub-meters were installed as part of this research on four AC chillers, kitchen (normal and emergency lines), laundry and one guestroom. The consumption of a fifth chiller was estimated to be the same as its pair; the two chillers serve a conference room and work approximately equal loads and their combined consumption was taken as double of the one. Readings were recorded manually on a weekly basis and they were combined into monthly data. The electricity consumption of the guestrooms was derived by multiplying the recorded consumption of one guestroom by the total number of rooms.

6.3.2.2.3 Lighting and electrical equipment survey

It was not possible to isolate all energy consumption end-use groups with a sub-meter. For example the hotel lighting was served by so many different electrical circuits that it would have been impractical to install a sub-meter into every circuit. In addition, there was no consolidated knowledge of the systems nor detailed electrical as-built drawings available. As many hotels in Cyprus, the case study hotel was built in phases and had been extended and remodelled in several occasions. Therefore, lighting installations had changed over time and no detailed records were kept of the changes. Therefore, a thorough walkthrough audit was taken as the method to assess the lighting fixtures in place. The technical staff of the hotel assisted in determining the usage time and patterns.

Similarly, the electricity consumption of all electrical equipment such as ceiling fans, office equipment, gym equipment and those used in catering was estimated from the equipment rating and usage patterns as reported by the hotel staff.

6.3.2.2.4 Weather data collection

Besides the outdoor temperature and humidity measurements in two locations with data loggers, official weather data for the year 2007 from the nearest weather station, Larnaca Airport located about 15 km away from the case study hotel, was acquired. The weather station recorded data for all necessary parameters required by thermal simulation except solar irradiation, i.e. temperature (dry bulb), relative humidity, wind speed, wind direction and cloud cover were obtained from the weather station data. Solar irradiation was subsequently derived using the ASHRAE Clear-Sky Model (ASHRAE, 2005, Ch.14). Further, a Cyprus-specific model was used to estimate diffuse irradiation. The weather data thus compiled was converted to a suitable format compatible with the chosen thermal simulation software[38] by using a weather file converter offered as an auxiliary program with the EnergyPlus thermal simulation software (EnergyPlus by US Department of Energy, 2010).

The actual weather data was used in the simulations of the case study hotel in order to match the measured internal conditions to those derived by simulation. The purpose of the exercise was to assist in the calibration of the input parameters such as thermostat settings. Parameter calibration was perceived of paramount importance in order to ensure the robustness of the simulation software and the reliability of the results.

[38] The chosen simulator IES<VE> uses the same format for weather files as the EnergyPlus software.

6.3.2.3 Energy consumption survey of hotels

A survey with questions about the size, age, service class, construction standard, occupancy patterns and consumption of electricity, fossil fuels and water was targeted for 3-, 4- and 5-star hotels. The questionnaire was analysed using Excel spreadsheet and the case study hotel was compared to the mean values derived from the analysis. The purpose of the comparison was to first establish that the case study hotel represented an ‘average’ within the heterogeneous sample of hotels since it was later used as a template in constructing theoretical models of 3-, 4- and 5-star hotels. Secondly, the survey results were aggregated for the three hotel classes for direct comparison to the industry-wide data.

6.3.3 Hotel guest survey

In the conceptual techno-socio-economic framework of this study it was necessary to assess the social aspect or the ‘soft dimension’ influencing cost-effectiveness of hotel renovations. Subsequently, a hotel guest survey was conducted. It was essential to the study to establish how much more tourists would be willing to pay for holidays in Cyprus in the future. It is the premise of this study that the external drivers of climate change and rising energy prices will have a negative impact on tourist flows and subsequently in hotel occupation. Either a reduced number of tourists will have to pay a premium for a holiday in Cyprus or the hotels will have to accept lower profits. It was of great interest to assess how energy-efficiency improvement of hotels could give leverage against such profit losses. The findings from the questionnaire were subsequently used in the profitability analysis when evaluating the impact of hotel room rates in the cost-effectiveness of the renovation strategies.

The survey questionnaire was inspired by the needs for post-occupancy evaluation of buildings as discussed in the previous chapter. It is noted that POE is done for a specific building and the findings are applicable for that building only. The guest survey therefore was not a post-occupancy survey in the traditional sense as it was not targeted at evaluating the particular hotel buildings that the guests were staying at, but rather to draw conclusions on a general level. Subsequently, useful information was collected regarding thermal comfort for example. The aim was to see how and why guests use certain technologies such as AC and to assess if there was a way to challenge such use with innovative renovation measures.

6.3.4 Secondary data collection – industry-wide dataset on hotel electricity use

Electricity consumption figures of hotels for the year 2007 were available from the local utility. The data was presented as monthly consumption and charge figures for each consumer separately. It was subsequently possible to aggregate the consumption for the various classes of hotels and by applying the official occupancy figures published by the CTO (2008b; 2008c), it was possible to derive consumption per room and per guest night. It was not possible to determine electricity consumption per unit area as the floor areas of the hotels were not known.

6.3.5 Thermal simulation of the case study hotel and calibration of the model

The inherent uncertainty in thermal simulation lies within the accuracy of input parameters.

Subsequently, parameters such as infiltration and air flows, not to mention user-controlled activities such as window opening are difficult to define accurately. Therefore, in order to gain confidence in the robustness of the thermal simulations done in this study, the case study hotel was modelled and the simulated energy consumption and internal environmental parameter results were compared to the actual measured data. The simulations were iterated with adjusted input parameters until a good agreement between the simulation results and the measured data was reached. Actual weather data from the Larnaca airport weather station for the year 2007 was used so as to eliminate the weather bias. The calibration process therefore provided an opportunity to evaluate the sensitivity of the results to certain input parameters.

Once an acceptable match with the measured data was reached, the input parameters were fixed and the values thus defined were used to construct a theoretical model of the 4-star hotel that was subsequently used as a template for making the models of 3- and 5-star hotels. The premise was that the case study was carefully selected to represent a typical Cypriot hotel in terms of its age, type of construction, size and thermal performance. It is therefore believed that the calibration of the model provided a robust way to ensure a reasonable level of accuracy in the simulations of the theoretical hotel models.

6.3.6 Design and validation of theoretical case study hotel models

Theoretical case studies were used to investigate the impacts of various renovation strategies on the three most common hotel types. Methodology using theoretical case studies was selected over real case studies for the following reasons: a) the typology of 3- to 5-star hotels in Cyprus is quite uniform and clearly defined in the legislation that is used as a basis for the licensing of hotels, therefore making it easy to define a typical, average size hotel in each class, b) absence of any building regulations concerning thermal performance further promotes homogeneity among the building stock and c) the aim of theoretical case studies was to elevate the investigations above actual cases, location/orientation bias and operational mishaps to a theoretical level that would give a basis for extrapolation of the results and findings to the entire hotel building stock in Cyprus. Theoretical case studies and the findings thereof were validated on multiple levels against the data collected from real hotels of similar class participating in the energy consumption survey and from the industry-wide dataset on electricity consumption.

6.3.6.1 Design of theoretical hotels

Design of the theoretical hotels was done by first slightly modifying the layout of the real case study hotel model so as to remove any unique architectural features that may not be present in all hotels. Secondly, all facilities were placed within the same footprint[39]. Floor areas, space volumes, windows and doors of the various functional zones were kept the same as in the real case study hotel model. Slight modifications were unavoidable due to the changes in the floor plan. One floor each representing guestrooms of 5-, 4- and 3-star hotels were placed in the model.

[39] The case study hotel had a separate building for the indoor pool and its basement floor footprint was different from that of the upper floors.

6.3.6.2 Validation of the theoretical hotel models

The theoretical case study models were validated on three levels; at first against the real case study hotel via the calibration of its simulation model, secondly by validating the real case study hotel against the sample of hotels participating in the energy consumption survey and lastly by validating the sample of hotels against industry-wide electricity consumption. It was subsequently shown that the bottom-up approach chosen for the study to begin data collection and investigations from a detailed audit of one representative hotel, then extracting data from a sample of 3-, 4- and 5-star hotels and finally analysing secondary data collected on industry level worked well in defining theoretical models of hotels of different class. It is emphasised that the theoretical models were prepared to be used to predict energy savings due to energy-efficiency improvements. They were not meant to be used for measuring energy consumption in absolute terms.

6.3.7 Future climate scenarios

Future climate files were not readily available within the IES<VE> software package. Therefore, future climate had to be predicted from regional climate model runs. A regional climate model PRECIS was used for the simulation and IPCC SRES A1B scenario[40], i.e. a 'medium' emissions scenario was assumed. The model coordinates and resolution (25x25 km) were selected so as to produce accurate enough output for the town of Larnaca for years 2050 and 2090. The raw weather data produced by the climate model was further converted to a suitable format compatible with the requirements of the simulation software.

6.3.8 Thermal simulation of renovation strategies

The theoretical hotel models were used in thermal simulation to predict energy savings due to an array of renovation strategies in three climates, i.e. the present and the climates of 2050 and 2090, and the predicted energy savings were assessed and compared.

6.3.9 Simulation of solar AC

The cooling potential of solar AC was simulated using specialist software SolAC (Henning and Albers, 2004). It was possible to optimise the area requirements of solar collector fields, thermal storage and chiller size. By comparing the solar chiller output to the overall cooling requirements and the solar collector winter output to the heating requirements, solar fractions of cooling and heating were derived. Hence, it was possible to predict energy savings due to the solar system.

6.3.10 Cost-benefit analysis and economic evaluation

The cost-effectiveness of the renovation strategies was tested with various indicators discussed in Chapter 5. To begin with, all renovation strategies simulated previously were analysed for their SPB, DPB, SIR and LCC using an applicable discount rate. The preliminary analysis gave an indication which strategies were likely to be cost-effective at present and how it would change in future climates. The influence of the discount rate was investigated next. It was of interest to establish the ceiling values of discount rates for the renovation strategies by calculating their IRR.

[40] The reasoning behind selecting the SRES A1B scenario is discussed in greater depth in Chapter 9.

6.3.11 Sensitivity analysis

Besides being tested in three climates, i.e. at present and in the climates of 2050 and 2090, the variables of energy prices and hotel occupancy were introduced into the econometric model for joint sensitivity analysis. To begin with, the relationship between crude oil and end-use energy prices had to be established. For electricity the relationship between crude oil price and electricity generated was obvious since at present almost 100% of the island’s total electricity generation of 1118 MW[41] comes from heavy fuel oil or diesel. Therefore, a straightforward relationship between fuel oil prices and the unit price of electricity could be established by using a formula published by the local electricity authority. It was not the aim of this study to forecast oil prices as such but rather to evaluate the economic viability of the renovation strategies over a wide range of them. As for heating oil, the relationship between crude oil and heating oil prices in Cyprus was established from historical time series.

Regarding hotel occupancy, a wide range of reduction in occupancy was factored into the analysis. Since the analysis in this thesis was done on per-guest-night basis, occupancy had a direct impact on the room income generation potential. Therefore, it was of interest to see how reduction in occupancy would impact the overall cost-effectiveness of the renovation strategies. Subsequently, a cost-efficiency matrix where all three variables, i.e. climate, energy prices and hotel occupancy analysed simultaneously in all possible combinations was produced and it was possible thereafter to determine the external boundaries of cost-effective renovation.

It was concluded from the analysis that cost-effectiveness alone was not enough to justify hotel renovations as even cost-effective measures could still mean reduction in room income during the amortisation period of the measures. Therefore, the need for a new and unique indicator was established; an indicator that would assess if decrease in room income was to be expected as a result of the renovation measure.

A flow chart showing the logic of the sensitivity analysis is presented in Fig. 6.3. As seen from the figure, the objective was to derive the SC energy costs for the base case and renovation strategies at present and in future climates of 2050 and 2090. Sensitivity variables of hotel occupancy and oil price were introduced into the econometric model. Hotel occupancy was taken as an indication of how many guest nights a hotel sells annually whereas the end-use energy prices, as explained above, would be dictated by the oil price. Subsequently, the annual SC energy costs equation was derived as follows:

$$\text{Space conditioning energy costs, €} = \text{Guest nights sold} \cdot \text{Space conditioning requirements, kWh/GN} \cdot \text{End-use energy price, €/kWh}$$

Hotel SC energy costs could subsequently be evaluated in various combinations of climate, hotel occupancy and oil prices.

[41] It is noted that 188 MW of the total installed generating capacity is gas turbines using diesel oil as a fuel but will be switched to liquefied natural gas as soon as supply is made available on the island. LNG supply is expected to arrive in mid-2014 (Electricity Authority of Cyprus, 2010).

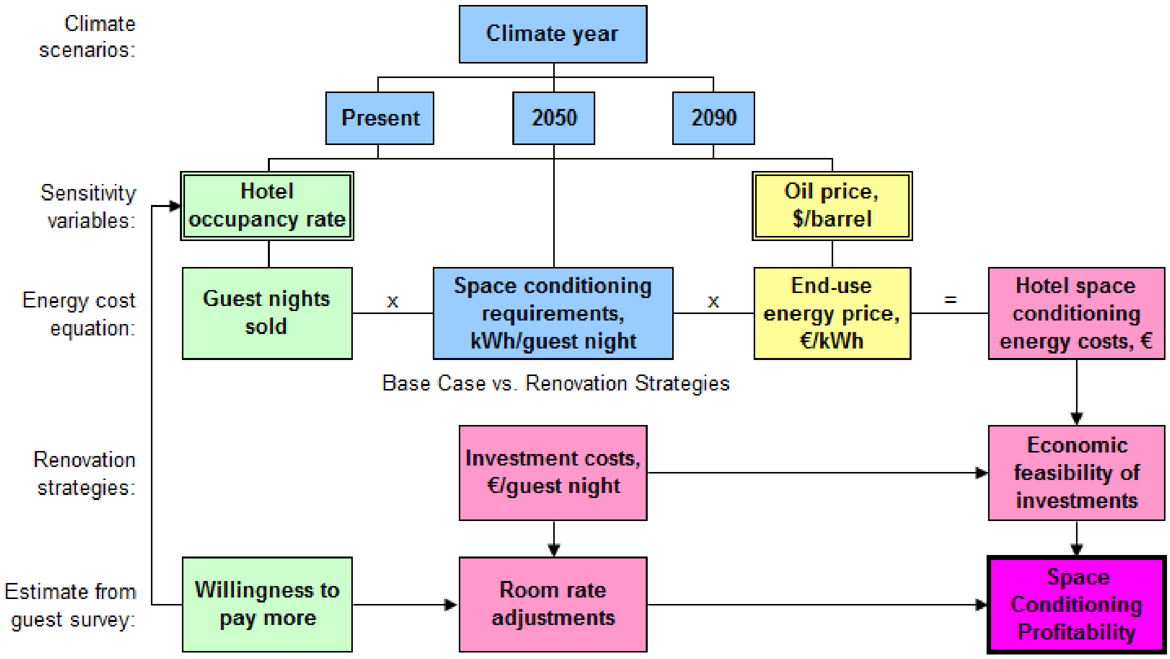


Figure 6.3 Flow chart of the sensitivity analysis

6.3.12 Defining a new economic indicator

At the final level of the analysis a new indicator ***Space Conditioning Profitability*** **(SCP)** was introduced. The concept implies heating and cooling efficiency but in financial terms. Since the term *efficiency* often denotes technical performance, the concept of profitability was introduced for the indicator that measures change in room income due to improved energy-efficiency. The concept should not be confused with the overall profitability of hotel operations that would require parameters such as labour, purchases (food, consumables, etc.), maintenance, capital and many other costs to be factored in. Profitability in this case is limited to SC energy costs only, hence the name. Strictly speaking room 'income' would also need to reflect other fixed and variable expenses such as housekeeping, maintenance and positive revenue items such as mini bar sales, telephone calls made, paid TV channel use, etc. But in the context of this study *room income* is narrowed down to mean room revenue after SC energy and investment costs have been deducted from it.

In order to derive the SCP, the room income per guest night for the base case (as-is construction, present climate, current oil price and occupancy) was calculated. Similarly, the room income was calculated for the proposed energy-efficiency improvements and their variants with the changing variables of climate, oil price and occupancy. Each strategy's SCP was then taken as the ratio of the income it generates to that generated by the base case. Subsequently, SCP is a unit-less indicator with a value close to one. Values greater than one would indicate that the strategy was profitable as more income per guest night would be generated as a result of it. Sensitivity analysis was extended to evaluate how SCP would be influenced by external factors and what circumstances would be the most favourable for maximising it.

In this chapter the methods employed in data collection and analysis were discussed and a step-by-step description of the work done was provided. In the following two chapters the methods are applied in the fieldwork and the results are presented.

7 Chapter 7 – Analysis of field data: Technical aspect

7.1 Introduction

The original idea was to conduct this research using the *top-down* methodology, i.e. by collecting energy consumption data from a large number of Cypriot hotels and narrowing the focus from there downwards to individual hotel types. Data collection to that extent was attempted but unfortunately there was no willingness from the hotels to participate in such a survey. 559 hotels and hotel apartment complexes were contacted either by email or by fax and invited to fill out a short survey form asking for energy and water consumption figures and other technically relevant information about the hotel buildings. The survey form was designed so that it could be filled out electronically and emailed back as completed. Even a call centre was engaged to follow up on the hotels in an attempt to encourage participation. It was initially hoped that at least 100 hotels would participate so as to collect a statistically significant sample. However, only 13 hotels chose to participate thus not making the sample size significant nor allowing the top-down methodology to be used.

Due to the above, the *bottom-up* method of analysis was applied instead. A typical hotel was selected as a case study and audited in detail. A simulation model of the hotel was created and it was calibrated against the monitored and measured data of the case study hotel. The results were further related to the sample of hotels that participated in the survey. In addition, a large dataset of electricity consumption covering the entire hotel industry of Cyprus was available for the top level referencing, thus allowing the single case study to be validated and triangulated from bottom up.

This chapter was written in direct response to address Objective 2.

7.2 Hotel case study

7.2.1 General details and occupancy statistics

A typical 4-star hotel with 188 rooms and 40 bungalows was selected as a case study for this research. What makes the hotel ‘typical’ is its size close to the national average (183±65.55 rooms) and the fact that it was built in the eighties, therefore representing the construction standards of the period when the majority of existing hotels in Cyprus were built. The said construction standards include single-glazing and no thermal insulation on the building envelope. An areal view of the hotel is shown in Fig. 7.1 and an elevation view in Fig. 7.2.

Figure 7.1 Areal view of the case study hotel

Source: www.googlemaps.com

Figure 7.2 South-west elevation of the case study hotel

The first task was to establish the total covered area of the hotel. The information was not readily available and subsequently required a detailed study utilising available architectural drawings complemented with in-situ measurements. The floor areas were further divided into conditioned and unconditioned space. The areas are summarised in Table 7.1. The floor plans are presented in Figs. 7.3-7.7 and in larger size in Appendix IV.

Space	**Area, m²**	**Conditioned area, m²**	**Un-conditioned area, m²**
Basement:			
Corridor (front-of-the-house)	235.3		235.3
Executive meeting room	52.5	52.5	
Seminar room	42.1	42.1	
Kid's club	8.4	8.4	
Hair dressing	39.7	39.7	
Public toilets	24.3		24.3
Public toilets (Conference Centre)	44.8		44.8
Gym	192.3	192.3	
Aerobics	34.6	34.6	
Massage	15.9		15.9
Gym store	6.1		6.1
Spa - Total	55.8		55.8
Changing rooms	52.6		52.6
Hallway from gym to squash court	98.5		98.5
Squash court	48.6		48.6
Games rooms	45.5		45.5
Restaurant	283.7	283.7	
Restaurant service area	26.3		26.3
Administration offices - Total	252.0	252.0	
Office store	33.3		33.3
Server room	15.3	15.3	
Lift wells	19.8		19.8
Stairwells	85.8		85.8
Corridor (back-of-the-house)	216.5		216.5
Main kitchen	223.5		223.5
Cold storage and working stations	192.8	192.8	
Dry storage	158.6		158.6
Chef's office	7.9	7.9	
Laundry	144.9		144.9
Laundry storage	34.0		34.0
Staff restaurant	48.2	48.2	
Staff changing rooms	74.8		74.8

Maintenance office			12.4		12.4
Chief engineer's office			15.7	15.7	
Misc. office space			22.9		22.9
Misc. storage space			22.3		22.3
Misc. service areas			7.1		7.1
Mechanical room			160.1		160.1
Boiler room			14.6		14.6
Plumbing room			15.8		15.8
Refuge room			29.6		29.6
Basement - Total			**3114.9**	**1185.2**	**1929.7**
Ground floor:					
Reception & lobby			462.5	462.5	
Lobby shops			64.4	64.4	
Lounge			267.1	267.1	
Breakfast cafeteria			245.0	245.0	
Service area			123.9		123.9
Open area above restaurant			90.7	90.7	
Main Bar			195.5	195.5	
Bar kitchen & storage			32.4	32.4	
Public toilets			30.8		30.8
Concierge			8.2		8.2
Lift wells			19.8		19.8
Stairwells			85.3		85.3
Ground floor offices			27.8	27.8	
Conference centre hallway			85.6		85.6
Conference centre main hall			627.8	627.8	
Conference centre small hall			94.6	94.6	
Second kitchen			39.1		39.1
Indoor pool house			260.6		260.6
Ground floor - Total			**2761.1**	**2107.8**	**653.3**
Floors 1-4:	**No.**	**m^2**			
Floors 1-4 corridors	4	197.5	790.0		790.0
Guestrooms - Typical	184	18.5	3404.0	3404.0	
Guestroom bathrooms	184	4.0	736.0		736.0
Guestrooms - Suite	4	36.9	147.6	147.6	
Suite bathrooms	4	7.4	29.6		29.6

Lift wells	4	15.8	63.2		63.2
Stairwells	4	87.2	348.8		348.8
Floors 1-4 - Total:			**5519.2**	**3551.6**	**1967.6**
Bungalows:					
Bungalow - Typical	38	26.5	1007.0	1007.0	
Bungalow bathroom	38	4.5	171.0		171.0
Bungalow - Suite	2	44.3	88.6	88.6	
Bungalow suite bathroom 1	2	4.5	9.0		9.0
Bungalow suite bathroom 2	2	5.4	10.8		10.8
Bungalows - Total			**1286.4**	**1095.6**	**190.8**
Grand Total			**12681.6**	**7940.2**	**4741.4**

Table 7.1 Breakdown of floor area in the case study hotel

Figure 7.3 Key plan of the case study hotel

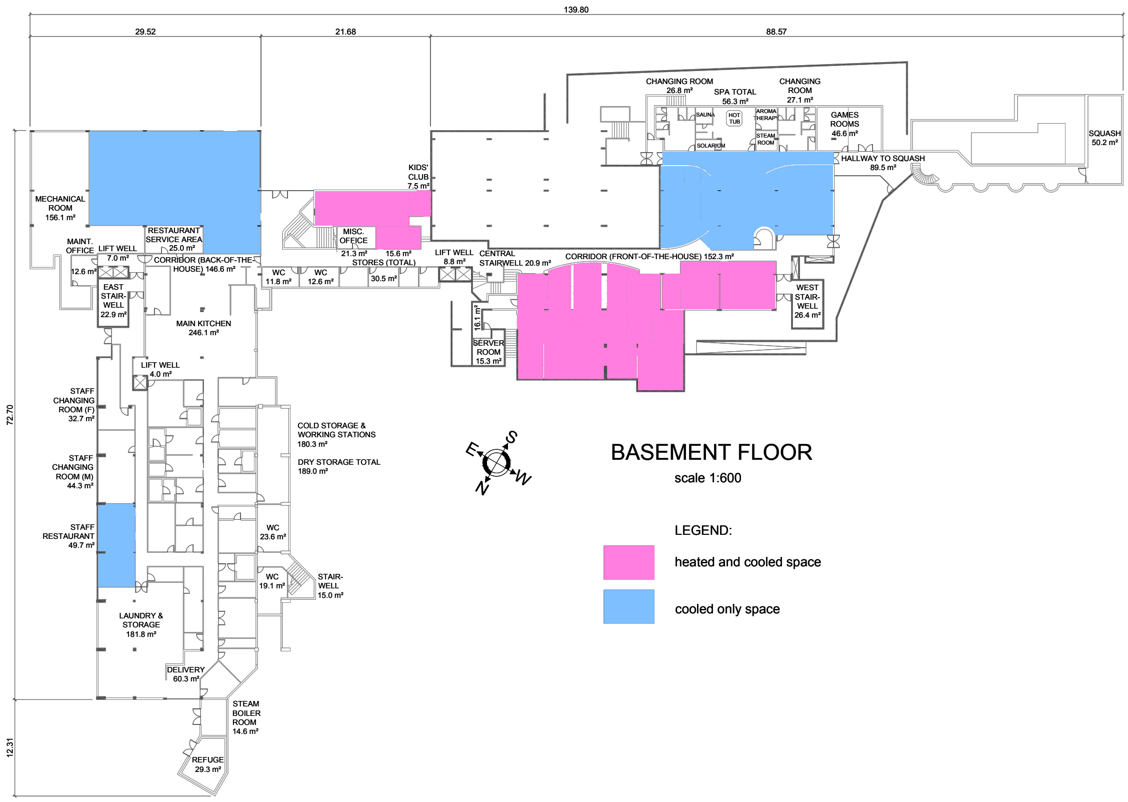


Figure 7.4 Basement floor plan – Case study hotel

Figure 7.5 Ground floor plan – Case study hotel

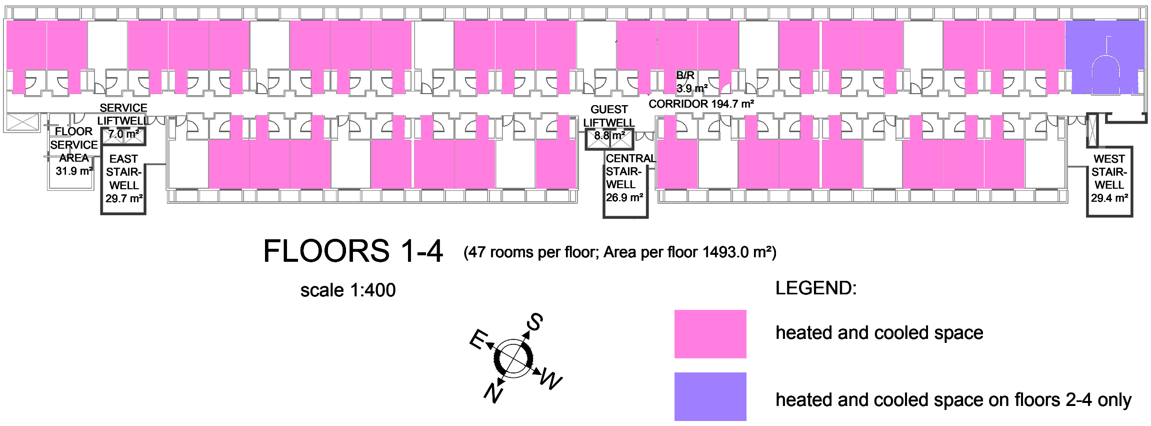


Figure 7.6 Floors 1-4 plan – Case study hotel

Figure 7.7 Bungalows floor plan – Case study hotel

The functional floor area distribution was compared to that of the international industry practice. The hotel had the following distribution: guestrooms 55.1%, public areas 29.8% and service areas 15.1%[42]. According to Ransley and Ingram (2004) resort hotels typically have a breakdown of 70%, 16% and 14% for guestrooms, public and service areas respectively. Convention hotels in turn follow 65-20-15 split. Therefore, it appeared that the case study hotel was more generous in the allocation of public spaces. However, a closer analysis indicated that the minimum size of guestrooms in Cyprus is substantially smaller than the international reference sizes. As shown in Table 3.4, the minimum net area of 4-star guestrooms, including bathroom is 21.5 m^2, some 40% less than in resort hotels (36 m^2) or 33% less than in convention hotels (32 m^2) internationally. In

[42] The distribution was calculated on the gross area basis.

any case, what is important in this thesis is that Cyprus has well-defined criteria for hotel classes with minimum area requirements, as discussed in Chapter 3, thus making the hotel building stock highly homogenous. Therefore, a comparison to international practice was made for a frame of reference only.

It is also useful to relate the total gross area of the hotel to the number of rooms for comparison to international practice. The case study hotel yielded 66.9 m^2/guestroom for the main hotel building and 61.5 m^2/guestroom including the bungalows. The reference values given for resort and convention hotels are 72 m^2 and 70 m^2 respectively. As observed, the case study figures are again somewhat less, although by a smaller percentage than the area distribution analysed before.

During 2007[43] the hotel operated at an average occupancy of 73.8% as seen in Table 7.2.

Month	Occupancy, %	Guest nights
January	39.0	4437
February	43.0	4419
March	58.0	6599
April	69.0	7597
May	80.0	9102
June	95.0	10460
July	96.0	10922
August	98.0	11149
September	99.0	10900
October	95.5	10865
November	67.5	7432
December	45.0	5120
Avg / Total	**73.8**	**99000**

Table 7.2 Occupancy and guest nights in the case study hotel in 2007

7.2.2 Energy audit

7.2.2.1 Temperature and humidity monitoring

Dataloggers were installed in the hotel in order to monitor the daily and seasonal variations in temperature and humidity. The guestroom logger was installed at ~2 m height and partially hidden behind the curtain. The bathroom logger was placed above the false ceiling in the mechanical space. A gap was left in the ceiling for unobstructed air movement in front of the logger sensor.

The loggers in the other monitored areas were placed as deemed appropriate. The kitchen and laundry loggers were positioned at central areas of circulation but away from direct heat flow from cooking equipment or dryers and ironing stations. A secure location in the lobby wall, hidden from a direct view, was selected for the lobby data logger. In the staircase a high wall location was selected. The staircase provided a unique opportunity to monitor temperature and humidity variation in an unconditioned space to establish a baseline for the free-running conditions of the

[43] Year 2007 is used throughout this study as the year of monitoring and data collection.

building. Finally, the outdoor data loggers were placed so as not to be in direct sunlight. The logger in the balcony on the south-eastern side of the building was placed on the wall underneath the floor slab of the balcony above, about 13 m above ground level. The other logger on the north-western side of the building was placed on the wall of the back-of-the-house areas, about 5.5m above ground level.

The microclimatic temperature and relative humidity measurements together with the data from the Larnaca Airport weather station are shown in Figs. 7.8 and 7.9. It is observed that up to 5°C higher temperatures are expected on the south-eastern side of the building compared to those recorded by the weather station. It is noted with interest that on the north-western side of the building up to 10°C higher temperatures were recorded. It is possible that the early summer, late afternoon sun was incident on the logger thus warming it up non-proportionally. As for the relative humidity measurements, it can be seen that the on-site measurements exhibit a wider range of humidity. It is suspected that high humidity pockets were created around the loggers that were protected by the various building components causing a delay in clearing away humidity unlike in a weather station that would be unobstructed from all sides. There is no clear explanation why zero and close to zero humidity is recorded by the on-site loggers, whereas the lowest value recorded by the weather station is about 12%.

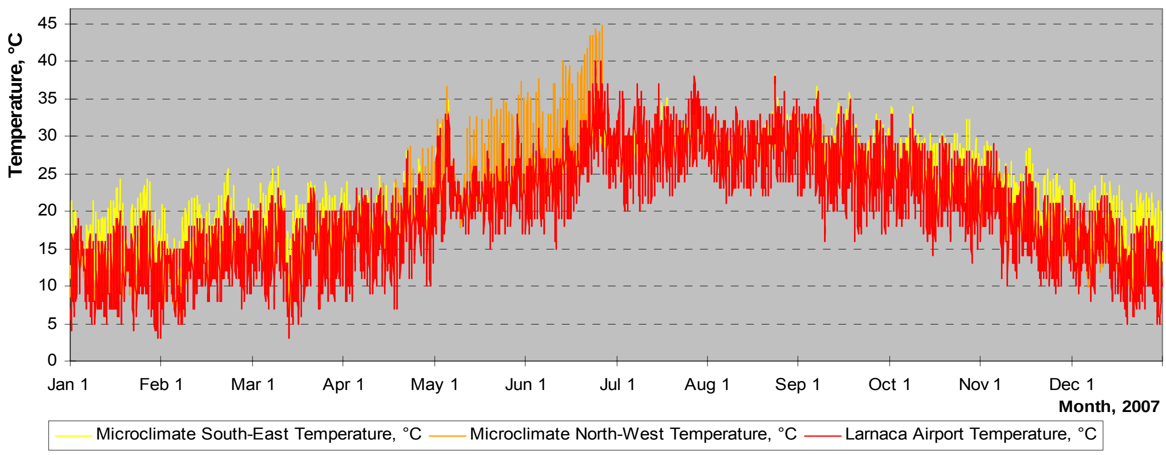


Figure 7.8 Ambient temperature from the Larnaca Airport weather station and as measured on the case study hotel site in 2007

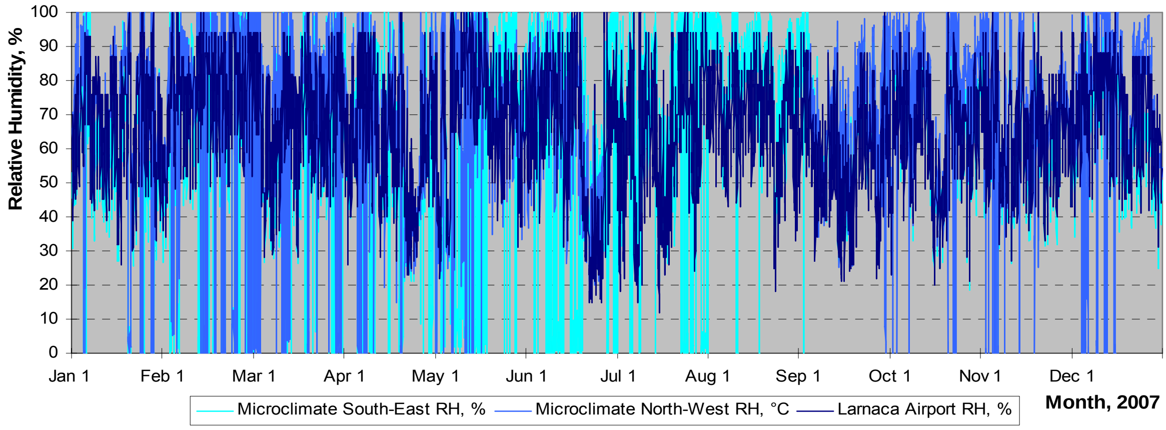


Figure 7.9 RH from the Larnaca Airport weather station and as measured on the case study hotel site in 2007

7.2.2.2 Electricity consumption monitoring

Monthly electricity bills were available but the hotel had no means to disaggregate the consumption. Therefore, it was deemed necessary to install electrical sub-meters in the major power centres. All sub-meters electricity consumption is shown in Fig. 7.10, AC chillers in Fig. 7.11, kitchen in Fig. 7.12 and laundry in Fig.7.13.

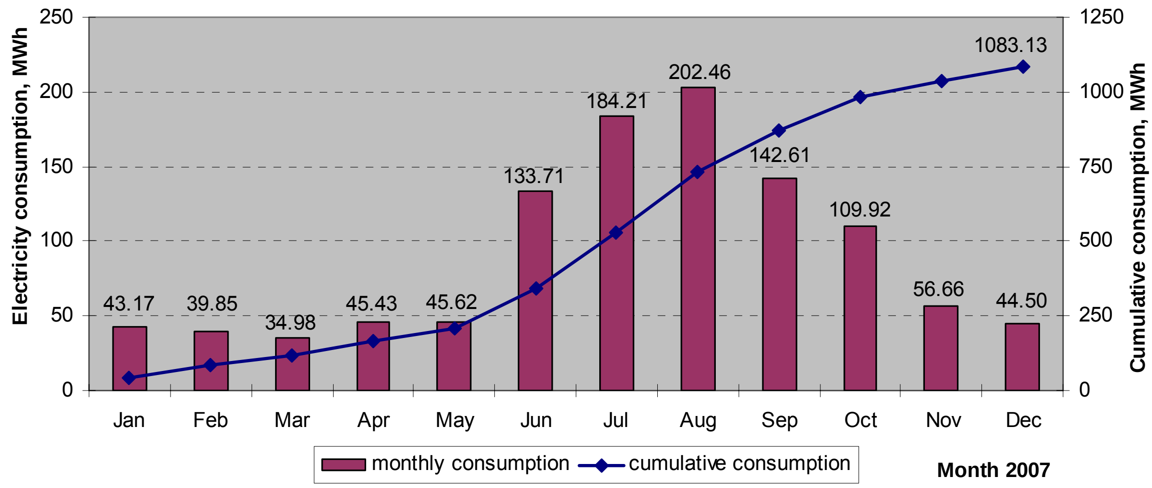


Figure 7.10 All sub-meters monthly and cumulative electricity consumption in 2007

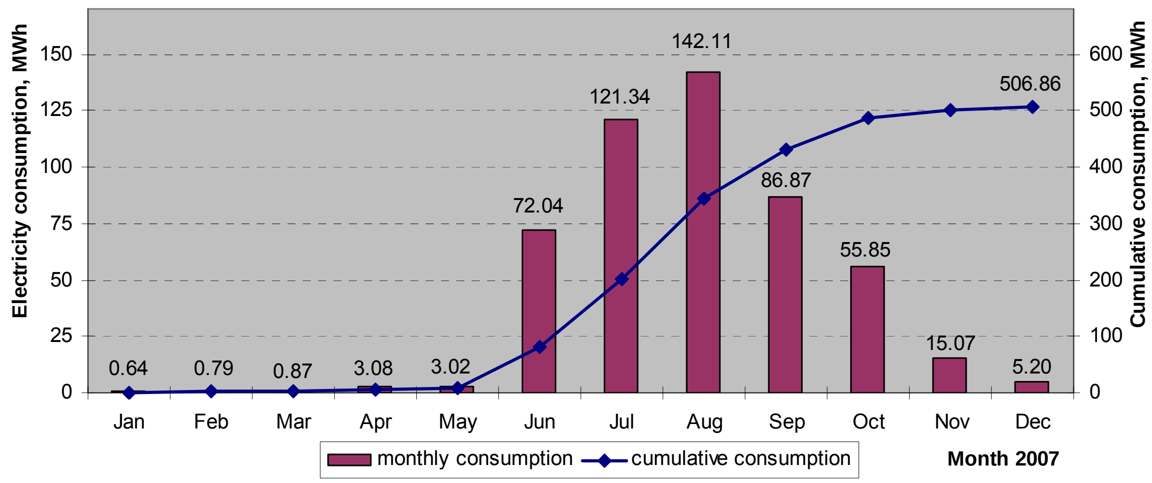


Figure 7.11 AC chillers monthly and cumulative electricity consumption in 2007

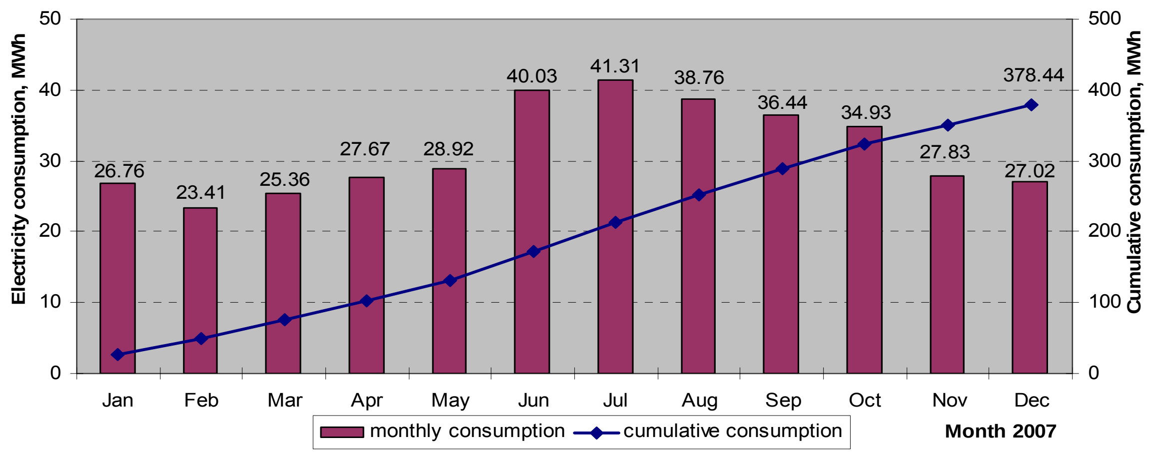


Figure 7.12 Kitchen monthly and cumulative electricity consumption in 2007

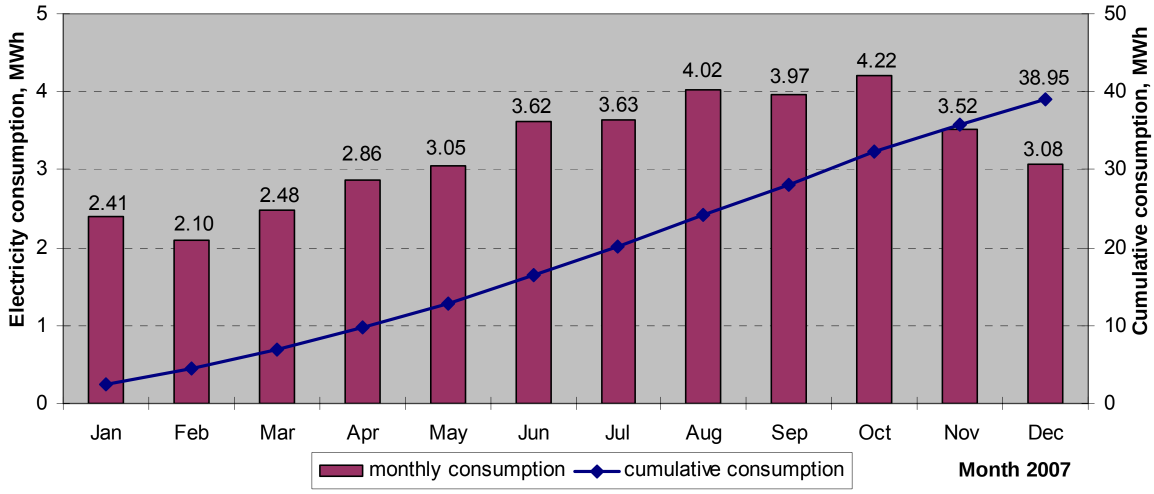


Figure 7.13 Laundry monthly and cumulative electricity consumption in 2007

Finally, the guestrooms electricity consumption is shown in Fig. 7.14. The consumption was derived by extrapolating the recorded consumption of one guestroom to the total number of rooms, taking into account that the main hotel with 188 rooms operates year around, whereas 40 additional bungalows[44] are in use for six months only. It was assumed that the consumption pattern and the occupancy rate of the monitored room was representative of the entire hotel.

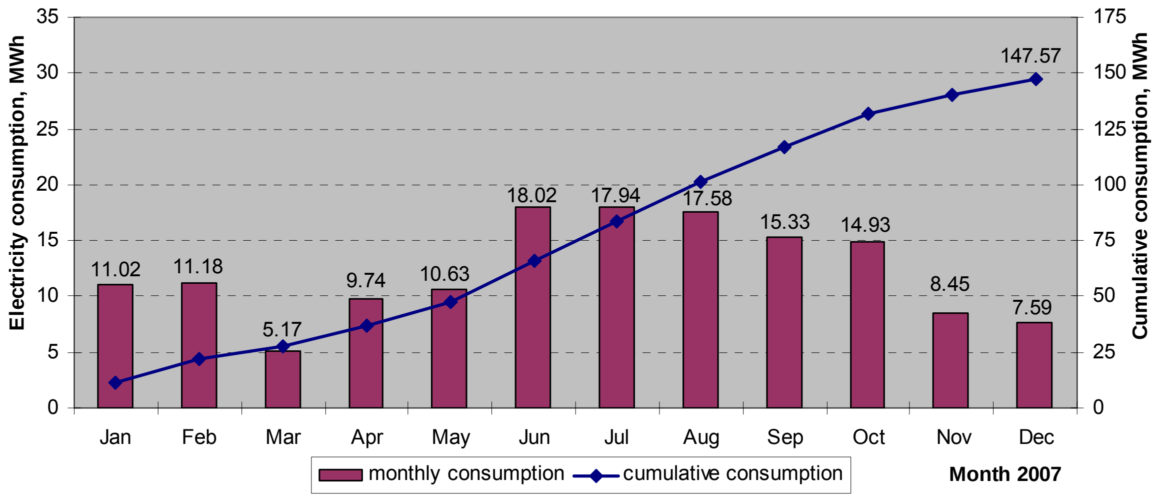


Figure 7.14 Guestrooms monthly and cumulative electricity consumption in 2007

Metered electricity consumption was compared to the actual electricity bought from the utility. Table 7.3 shows the monthly consumption and the associated costs yielding an average electricity cost of €0.139/kWh. It was noted that what was thought to represent major electricity consumption within the hotel, turned out to represent only 26%-49% of the total, depending on the month as shown in Fig. 7.15. As seen, during summer months the sub-metering arrangement was able to capture about one half of the total electricity consumption, whereas during winter only about one

[44] The bungalows are slightly larger than the standard rooms (31 vs. 23 m^2) and are fitted with a tea kettle that is not provided in the standard rooms. Otherwise the rooms are comparable. It is noted that the AC load was not measured via the sub-meter.

quarter. Subsequently, other major power centres were identified. One such was the pumps used for circulation of air, domestic water, sewage and swimming pool water. Similarly, lighting was identified, yet it was not possible to isolate it with a reasonable arrangement of sub-meters. Finally, it is noted that the electricity consumption of the kitchen represented only the main kitchen, whereas the hotel had another kitchen used during summer and five bars serving hot and cold drinks and snacks. In addition, several packaged AC units had been added to the hotel over the years to better serve areas that the main chillers were not able to serve, thus making the sub-metered chiller consumption data only a partial representation of the total demand by AC. Therefore, it was logical and necessary to estimate the electricity consumption of the additional facilities and to combine it with the sub-metered data.

Electricity consumption in 2007				
Month	**Consumption, kWh**	**Cost, Cy£[45]**	**Cost, €**	**Avg unit cost, €/kWh**
January	157680	10360.46	17701.90	0.112
February	127260	8074.88	13796.75	0.108
March	148570	1816.05	3102.91	*
April	157350	10315.12	17624.43	0.112
May	243860	16376.63	27981.13	0.115
June	332110	32016.18	54702.89	0.165
July	410720	39341.12	67218.29	0.164
August	408060	39131.15	66859.54	0.164
September	337410	33672.17	57532.32	0.171
October	290490	22183.57	37902.88	0.130
November	199400	16294.76	27841.25	0.140
December	160300	11607.91	19833.29	0.124
TOTAL	**2973210**	241190.00	**412097.58**	**0.139**

Table 7.3 Electricity consumption and cost in the case study hotel in 2007

(Reproduced from the monthly electricity bills provided by the hotel)

* Compensation for overcharges from year 2006 was credited in March 2007. Therefore, the monthly unit price for March would not be a true figure.

[45] In 2007 Cyprus was still using its own currency, Cyprus pound. Cyprus joined the Euro Zone in January 2008 and the official exchange rate was fixed at 1Cy£=€1.7086. 15% VAT included in the price.

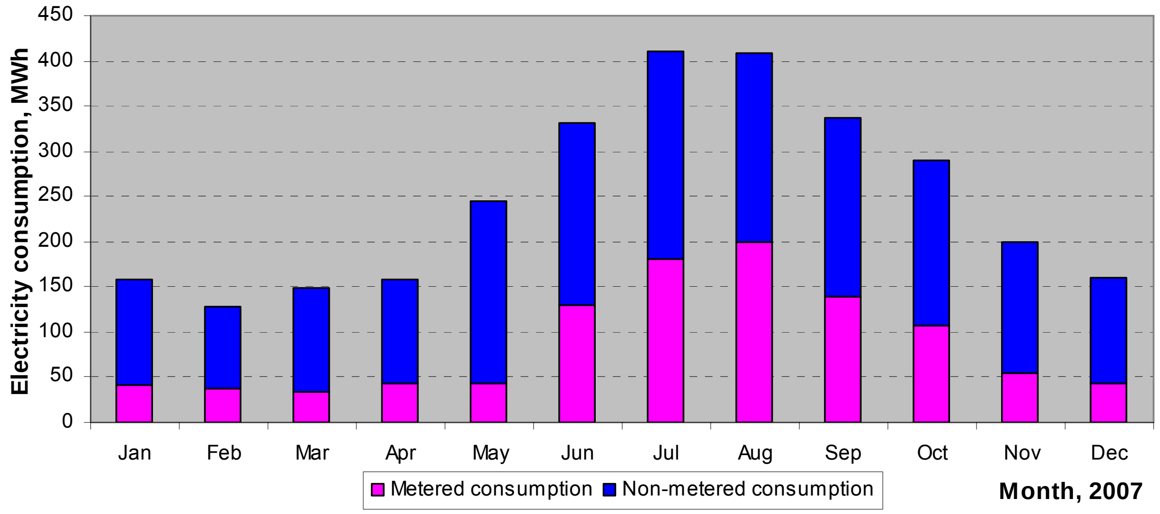


Figure 7.15 Metered vs. non-metered power consumption in 2007

Detailed energy audit of the hotel followed where all facilities were appraised for their lighting and equipment electricity consumption. The hotel staff was consulted for defining the usage patterns of the equipment and lighting. Lamp wattage and equipment power ratings were recorded and the total yearly electricity consumption was calculated. After all the audited data was compiled, it was possible to establish a reasonably accurate estimate of the electricity consumption within the hotel. Figs. 7.16 and 7.17 summarise the electricity consumption as recorded and calculated, identifying the major power centres, in absolute and relative terms.

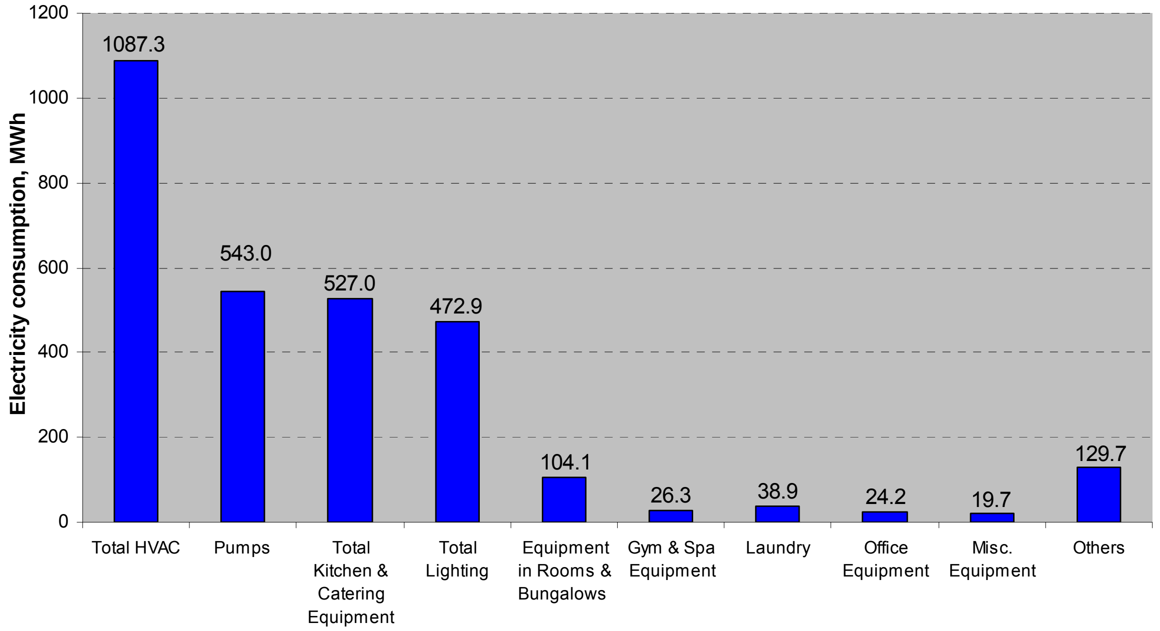


Figure 7.16 Major power centres of the case study hotel in 2007

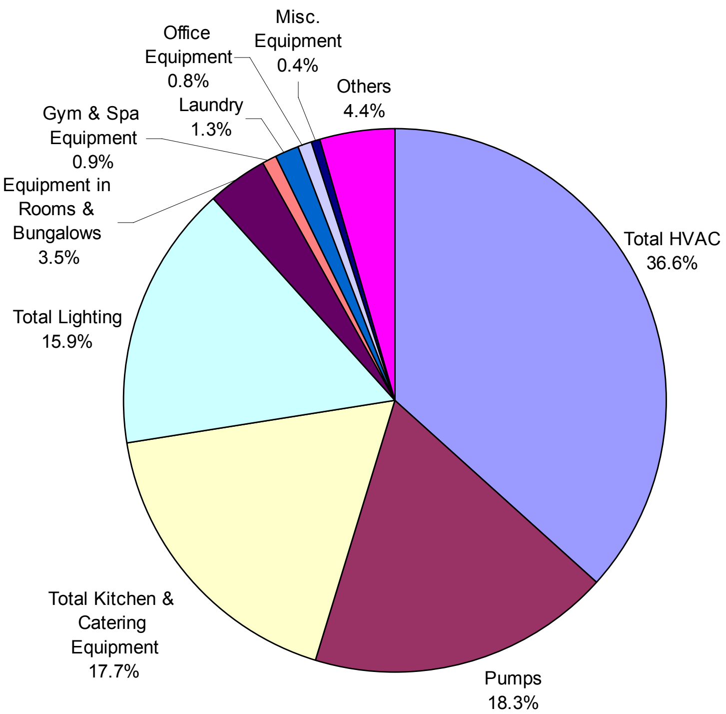


Figure 7.17 End-use electricity consumption of the case study hotel in 2007

7.2.2.3 Heating energy consumption analysis

Besides the electricity consumption monitoring described above, data was collected for space and DHW heating and water consumption. The hotel has two boilers with a nominal capacity of 870000 kcal/h, i.e. approx. 1000 kW each. The boilers are oil-fired and their nominal oil consumption is listed at 95.4 kg/h while producing hot water at 80-85°C. Both boilers are from the mid-90s and for calculation purposes their efficiency is assumed at 0.80. One of the boilers is operating nonstop, whereas the other boiler is fired to assist when consumption is high, usually for at least a few hours daily. Heating oil consumption can be seen in Fig. 7.18. The total yearly consumption of 204.72 m^3 yields about 1736.0 MWh in energy and corresponds to €171545 annual costs in 2007.

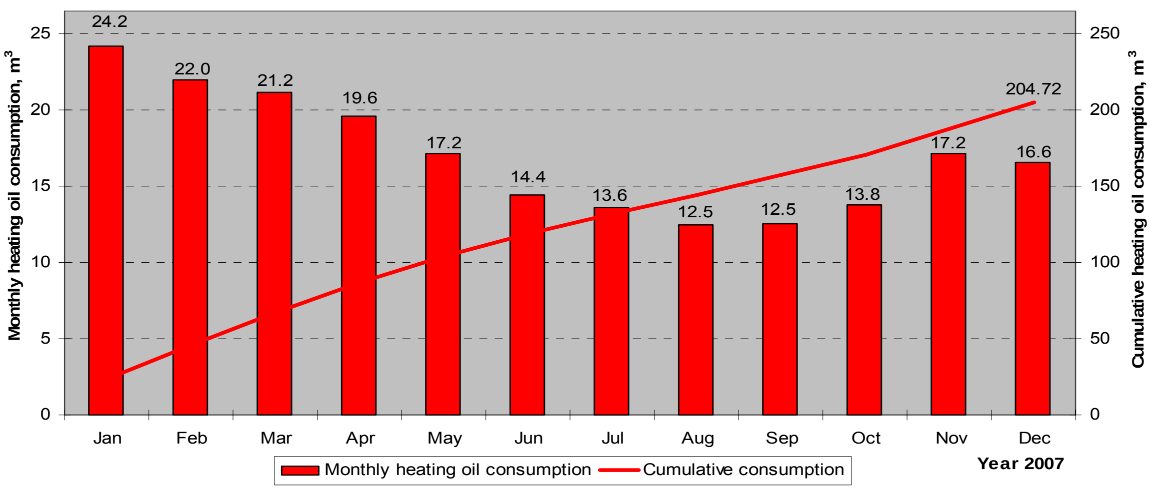


Figure 7.18 Heating oil consumption of the case study hotel in 2007

The DHW consumption had to be estimated as the hotel had no means to monitor and record it. Iterations in the thermal simulations were done in order to arrive at 225 litres per occupied guestroom, i.e. 112.5 litres/GN. In the iterations the amount consumed per GN was varied until the monitored and simulated heating oil consumption during the summer months, when no space heating was necessary, was reasonably matched.

7.2.2.4 LPG energy consumption analysis

LPG is used for cooking and its annual consumption is shown in Fig. 7.19. 33.72 tonnes of LPG were consumed in 2007, 435.5 MWh in energy terms, for €25896.

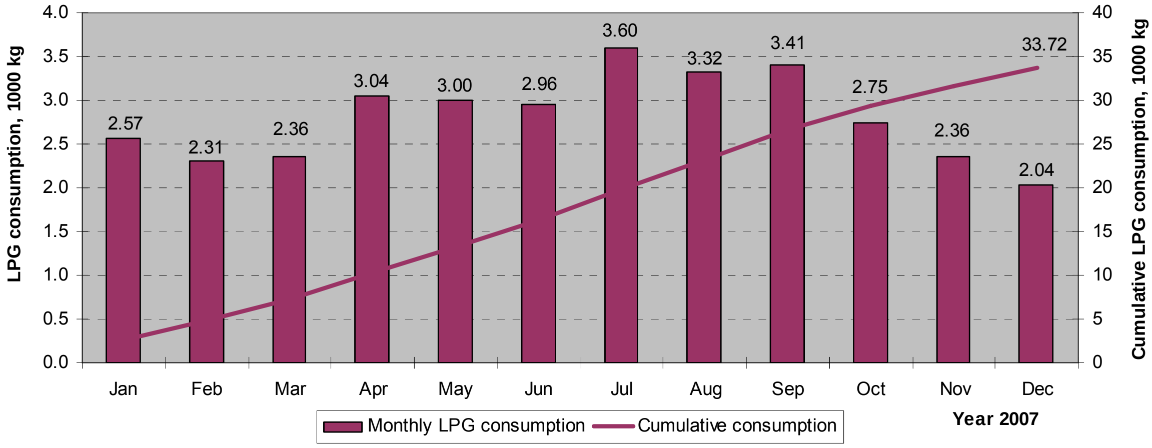


Figure 7.19 LPG consumption of the case study hotel in 2007

7.2.2.5 Breakdown of total energy consumption

It is now possible to analyse the energy use by fuel as shown in Fig. 7.20. It is noted that nearly 58% of the energy consumption is due to electricity.

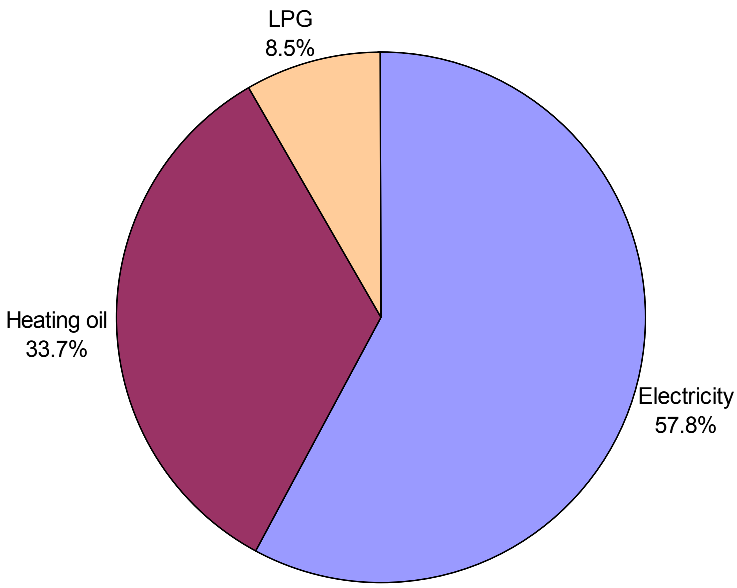


Figure 7.20 Breakdown of total energy consumption of the case study hotel in 2007

7.2.2.6 Summary of the energy audit

The energy audit included detailed monitoring of the internal environmental parameters of the key areas of the hotel. Further, two outdoor locations were monitored for micro-climate comparison. In addition, electrical sub-meters were installed in the major power centres of the hotel and data was recorded for one year. Detailed walk-through audit and a desk study was done to define the end-use electricity consumption breakdown. Monthly and annual heating energy consumption was established from fuel oil bills. Similarly, energy consumption due to LPG was established. Subsequently it was possible to derive the total energy consumption breakdown within the hotel resulting in 57.8% electricity, 33.7% heating oil and 8.5% LPG.

The data derived from the energy audit was used in the calibration of the thermal simulation model prepared for the hotel. Issues related to the preparation of the thermal simulation model are discussed in the next section.

7.2.3 Thermal simulation model considerations of the case study hotel

Simulation model of the case study hotel was prepared in order to try and match the hotel building's actual thermal behaviour and energy consumption. The model was used to calibrate some of the input parameters, such as thermostat settings and infiltration. It is reminded that defining the exact usage pattern of a hotel is an impossible task. Each guest and staff member has a unique way of using the hotel. Consequently, when in full occupancy, the hotel would have over 500 people using the building concurrently. If a large function, such as a wedding reception is organised during full occupancy, the simultaneous number of users could reach over 1000. Therefore, it is obvious that any attempt to define the usage patterns of buildings like hotels is a rough estimate at its best. The following is a brief discussion of the main parameters and the initial assumptions made in order to define the first set of input values.

7.2.3.1 Guestroom occupancy, door opening, lighting and equipment usage

Occupancy in the guestroom is assumed to denote two people sharing the room. In contrast to the occasional single occupancy there are also families of up to four people sharing a room; therefore two people is taken as an average. For a frame of reference, in ASHRAE hotel design guidelines, typical occupancy of resort hotel guestrooms is assumed at 1.9-2.4 people (ASHRAE, 2007).

The room is assumed to be occupied for 13 hours a day. This assumption is in broad agreement with the findings from a hotel guest survey conducted in Cyprus where the time spent in the room was eight hours between 18:00-8:00 and three hours between 8:0018:00 (Konis, 1991). Hotel guests and the occupied room are assumed to conform approximately to the following schedule:

- 9:00-10:00 TV on (morning news, children's cartoons), bathroom lights on
- 9:00-11:00 morning washing activities (including room cleaning)
- 9:00-9:15 balcony door half open

- 10:00 leaving the room for breakfast (room door open for 1 min)
- 10:00-12:00 cleaning by housekeeping (room & balcony doors open for 15 min; housekeeping to turn off all lights upon finishing room service)
- 17:00 returning to the room, TV and 50% of lights on
- 17:00-18:00 showering, hair drying, etc.
- 18:45-19:00 balcony door half open
- 19:00 leaving the room for dinner, TV off, 50% of lights stay on, (room door open 1 min)
- 23:00 returning to the room (room door open for 1 min), TV and all lights on
- 24:00 lights and TV off
- 0:00-24:00 heating (mid Nov-mid Apr), cooling (May-Oct)
- heating set point 23°C, cooling set point 25°C
- ventilation (25 l/s) when the fan coil unit is on

Heating, cooling and ventilation are scheduled as follows:

- 0:00-24:00 heating (mid Nov-mid Apr), cooling (May-Oct)
- heating set point 23°C, cooling set point 25°C
- ventilation (25 l/s) when the fan coil unit is on

Further, it is assumed that the bathroom door stays open at all times except when in use, i.e. two time slots (9:00-10:00 and 17:00-18:00) allocated for morning washing and showering activities. A purpose-built gap between the bathroom door and its frame allowing 1% air exchange is assumed. As for other room use parameters, curtains are assumed to be closed during the direct sunlight hours.

Lighting in the room consists of two table lamps, two wall lamps and a lamp above the entrance door. The bathroom is fitted with three halogen spotlights and the balcony has an outdoor light. All lamps are 11 W compact fluorescent type, except the halogen spotlights, 35 W each. Lights are assumed to be on 5 hr/d except the outdoor light that is on 3 hr/d. Total wattage of 61.6 W[46] for the room and 105 W for the bathroom are included in the simulations.

Sensible and latent heat components calculated in Appendix V shall be used in the simulations for the one-hour time slot from 17:00-18:00. Summertime conditions apply to May-October whereas wintertime to November-April.

Internal gains caused by occupancy and electrical equipment are presented in Table 7.4.

[46] 66 W in total but reduced to 61.6 W when the outdoor light power consumption is extended over five hours for ease of simulation.

Source of gain	Activity	Heat gain, W		Remarks
		Sensible	Latent	
Guestroom:				
Person (one)	sleeping	53	27	assuming 2 m^2 of skin area[47], 40 W/m^2 total heat generation[48] and 2:1 sensible:latent ratio
Person (one)	seated, light activity	70	45	
Hot water	showering	94	322	summertime[49]
-"-	-"-	89	195	wintertime[50]
Mini bar	refrigeration	42	-	
TV	in use	100	-	
Hair dryer	in use	850	-	10 min daily
Vacuum cleaner	in use	1600	-	2 min daily
Power outlets	in use	21	-	phone/i-Pod charger, laptop etc. (5+16)W; one hour daily
Bungalow:				
Person (one)	sleeping	53	27	assuming 2 m^2 of skin area, 40 W/m^2 total heat generation and 2:1 sensible:latent ratio
Person (one)	seated, light activity	70	45	
Hot water	showering	94	322	summertime
Mini bar	refrigeration	42	-	
TV	in use	100	-	
Hair dryer	in use	850	-	10 min daily
Vacuum cleaner	in use	1600	-	2 min daily
Power outlets	in use	21	-	phone/i-Pod charger, laptop etc. (5+16)W; one hour daily
Kettle	tea/coffee making	2000	-	10 min daily

Table 7.4 Internal heat gains within the case study hotel

7.2.3.2 Common areas occupancy, lighting and door opening

Common areas of the hotel, such as the reception/lobby, lounge, bar, restaurants, public toilets, gym and the indoor pool all carry different occupancy patterns that need to be defined for the thermal simulations. Subsequently, the following paragraphs summarise the occupancy and usage assumptions made. The estimates for sensible and latent heat due to occupancy are taken from ASHRAE Handbook of Fundamentals, Table 1, p.18.4 (2009) unless otherwise noted.

[47] 2 m^2 is an estimate of the skin area of an average person with 1.85 m height and 85 kg weight according to DuBois surface area formula (ASHRAE, 2009, p.9.3).
[48] From ASHRAE Handbook of Fundamentals (2009, Table 4, p.9.6)
[49] 75 W sensible and 70 W latent heat added for one person walking/standing in the shower
[50] -“-

Reception & lobby

- main entrance door opening schedule:

- 8:00-18:00 60 openings/h; duration of each opening 10 s => door open 16.67%/h
- 18:00-24:00 40 openings/h; duration of each opening 10 s => door open 11.11%/h
- 24:00-8:00 5 openings/h; duration of each opening 10 s => door open 1.39%/h

- occupancy schedule:

- 8:00-18:00 50 people/h (walking & standing); sensible heat 75 W, latent heat 70 W pp
- 18:00-24:00 30 people/h (walking & standing); sensible heat 75 W, latent heat 70 W pp
- 24:00-8:00 5 people/h (walking & standing); sensible heat 75 W, latent heat 70 W pp

- equipment schedule:

- 8:00-17:00 2 computers w/ monitor (190 W each)
- 0:00-24:00 2 computers w/ monitor (190 W each)

- lighting schedule:

- 0:00-24:00 306 W fluorescent, 105 W incandescent/halogen light
- 7:00-10:00 and 16:00-1:00 232 W fluorescent, 11660 W incandescent/halogen light

- ventilation schedule:

- 6:00-2:00 2000 l/s

Lobby shops

- doors opening schedule:

- 9:00-17:00 doors open 100%/h
- 17:00-9:00 doors closed

- occupancy schedule:

- 9:00-17:00 2 people/h (walking & standing); sensible heat 75 W, latent heat 70 W pp
- 17:00-9:00 no activity

- lighting schedule:

- Shop 1: 0:00-24:00 890 W incandescent/halogen light (display lights)
- Shop 2: 9:00-17:00 332 W fluorescent light
- Shop 3: 9:00-17:00 44 W fluorescent light

Lounge

- lounge-to-veranda entrance door opening schedule:

- 2:00-8:00 door closed
- 8:00-12:00 30 openings/h; duration of each opening 10 s => door open 8.33%/h
- 12:00-18:00 60 openings/h; duration of each opening 10 s => door open 16.66%/h
- 18:00-2:00 80 openings/h; duration of each opening 10 s => door open 22.22%/h

- occupancy schedule:
  - 8:00-18:00 20 people/h (seated, light activity); sensible heat 70 W, latent heat 45 W pp
  - 18:00-24:00 40 people/h (seated, light activity); sensible heat 70 W, latent heat 45 W pp
  - 24:00-8:00 no activity
- equipment schedule:
  - 0:00-24:00 2 computers w/ monitor (190 W each)
- lighting schedule:
  - 14:00-2:00 550 W fluorescent, 9540 W incandescent/halogen light
- ventilation jointly with the reception & lobby

Lounge bar (within the lounge)

- equipment schedule:
  - 0:00-24:00 cold display unit (218 W); sensible heat 218 W
  - 0:00-24:00 ice maker (917 W); sensible heat 917 W
  - 0:00-24:00 freezer (150 W nameplate power => 60 W continuous consumption[51]); sensible heat 60 W
  - 0:00-24:00 refrigerator (367 W); sensible heat 367 W
  - 0:00-24:00 juice mixer/cooler (180 W); sensible heat 180 W
  - 8:00-22:00 espresso machine (3275 W nameplate power => 491 W continuous consumption[52]); sensible heat 491 W
  - 8:00-22:00 espresso machine (1100 W nameplate power => 150 W continuous consumption); sensible heat 150 W
  - 8:00-22:00 coffee dispenser (1800 W nameplate power => 900 W continuous consumption[53]); sensible heat 900 W
  - 14:00-15:00[54] orange juicer (60 W); sensible heat 60 W
  - 15:00-16:00 ice coffee mixer (130 W); sensible heat 130 W
  - 16:00-17:00 blender (300 W); sensible heat 300 W
  - 8:00-22:00 dishwasher (1410 W[55]); sensible heat 308 W, latent heat 1058 W[56]

Main Bar

- bar-to-veranda entrance door opening schedule:
  - 1:00-8:00 door closed
  - 8:00-18:00 8 openings/h; duration of each opening 10 s => door open 2.22%/h
  - 18:00-1:00 60 openings/h; duration of each opening 10 s => door open 16.67%/h

[51] Usage factor for freezers/refrigerators of 0.4 applied, CIBSE Guide A (2007, p.6-8).
[52] Usage factor for espresso machines of 0.15 applied, ASHRAE (2009, Table 5A, p.18.8).
[53] Usage factor for equipment maintaining constant temperature of 0.5 applied, CIBSE Guide A (2007, p.6-8).
[54] One hour total daily usage time assumed and applied as one time slot in the simulations.
[55] Assumed that 30 racks/d washed at 0.66 kWh per rack.
[56] 25/75% split assumed between sensible and latent heat produced by unhooded dishwashers

- occupancy schedule:
  - 1:00-18:00 negligible activity
  - 18:00-1:00 30 people/h (restaurant, light activity); sensible heat 71 W, latent heat 71 W pp
- equipment schedule:
  - 0:00-24:00 beer cooler (385 W); sensible heat 385 W
  - 0:00-24:00 beer cooler (15 W); sensible heat 15 W
  - 0:00-24:00 3 draught taps (385 W each); sensible heat 1155 W total
  - 0:00-24:00 water cooler, cold only (12 W); sensible heat 12 W
  - 0:00-24:00 juice mixer/cooler (180 W); sensible heat 180 W
  - 0:00-24:00 ice maker (1600 W); sensible heat 4000 W (COP=2.5 (CIBSE, 2007, p.6-10))
  - 0:00-24:00 2 freezers (150 W nameplate power => 60 W continuous consumption each); sensible heat 120 W total
  - 0:00-24:00 refrigerator (371 W); sensible heat 371 W
  - 0:00-24:00 refrigerator (367 W); sensible heat 367 W
  - 0:00-24:00 refrigerator (688 W); sensible heat 688 W
  - 0:00-24:00 refrigerator (760 W nameplate power => 304 W continuous consumption); sensible heat 304 W
  - 15:00-1:00 espresso machine (3275 W nameplate power => 491 W continuous consumption); sensible heat 491 W
  - 15:00-1:00 coffee dispenser (1800 W nameplate power => 900 W continuous consumption); sensible heat 900 W
  - 15:00-1:00 sand heater for Greek coffee making (500 W); sensible heat 500 W
  - 15:00-16:00 blender (300 W); sensible heat 300 W
  - 16:00-2:00 dishwasher (1160 W); sensible heat 290 W, latent heat 870 W (20 racks/d washed at 0.58 kWh/rack)
  - 22:00-23:00 microwave oven (1000 W); sensible heat 1000 W (1 h/d total time assumed)
- lighting schedule:
  - 16:00-2:00 2028 W fluorescent, 6910 W incandescent/halogen light
- ventilation schedule:
  - 18:00-2:00 2460 l/s

Breakfast cafeteria

- cafeteria-to-patio entrance door opening schedule (May-October):
  - 7:00-11:00 100 openings/h; duration of each opening 10 s => door open 27.78%/h
  - 11:00-18:00 20 openings/h; duration of each opening 10 s => door open 5.56%/h
  - 18:00-24:00 10 openings/h; duration of each opening 10 s => door open 2.78%/h
  - 24:00-7:00 door closed

- cafeteria-to-patio entrance door opening schedule (November-April):
  - 7:00-11:00 10 openings/h; duration of each opening 10 s => door open 2.78%/h
  - 11:00-16:00 16 openings/h; duration of each opening 10 s => door open 4.44%/h
  - 16:00-7:00 door closed
- occupancy schedule:
  - 7:00-11:00 80 people/h[57] (restaurant sitting + hot food); sensible heat 80 W, latent heat 80 W pp
  - 11:00-18:00 10 people/h (restaurant sitting + hot food); sensible heat 80 W, latent heat 80 W pp
  - 18:00-7:00 negligible activity
- equipment schedule:
  - 0:00-24:00 juice mixer/cooler (1800 W); sensible heat 1800 W
  - 0:00-24:00 ice maker (1600 W); sensible heat 4000 W
  - 0:00-24:00 freezer (150 W nameplate power => 60 W continuous consumption); sensible heat 60 W
  - 0:00-24:00 4 refrigerators (200 W nameplate power => 80 W continuous consumption each); sensible heat 320 W total
  - 6:00-22:00 2 espresso machines (1600 W nameplate power => 240 W continuous consumption each); sensible heat 480 W total
  - 6:00-22:00 coffee maker (3500 W nameplate power => 1750 W continuous consumption); sensible heat 1750 W
  - 6:00-22:00 tea machine (63 W); sensible heat 63 W
  - 7:00-11:00 3 milk warmers (3200 W each => 1600 W continuous consumption); sensible heat 4800 W
  - 7:00-11:00 toaster (3300 W nameplate power => 1551 W continuous consumption); sensible heat 1551 W (Usage factor=0.47 (ASHRAE, 2009, Table 5A, p.18.8))
  - 10:00-10:30 orange juicer (60 W); sensible heat 60 W
  - 10:00-11:00 modular stove unit (1000 W); sensible heat 1000 W
  - 7:00-11:00 6 food warmers (gas burning); estimated sensible heat 6000 W total
  - 0:00-24:00 6 refrigerators (2568 W total); no sensible heat gain applied as the refrigerators are located in a storage room adjacent to the cafeteria
- lighting schedule:
  - 6:00-18:00 484 W fluorescent, 245 W incandescent/halogen light
- ventilation schedule:
  - 7:00-13:00 1500 l/s

[57] Taking the average occupancy of 73.8% for the main hotel rooms (188) for 12 months and 93.9% for the bungalows (40) for 6 months with two people sharing a room, average number of hotel guests becomes 315. When distributed over 4 hrs, the figure becomes ~80.

Main restaurant

- restaurant-to-patio door opening schedule (May-Oct):

• 18:00-20:00 100% open

• 20:00-22:00 50% open

• 22:00-24:00 100% open

- restaurant-to-patio door opening schedule (Nov-Apr):

• 0:00-24:00 closed

- occupancy schedule:

• 19:00-22:00 60 people/h (restaurant sitting+hot food); sensible heat 80 W, latent heat 80 W pp

• 22:00-19:00 negligible activity

- lighting schedule:

• 18:30-23:00 132 W fluorescent, 7460 W incandescent/halogen light

- ventilation schedule:

• 19:00-21:00 1100 l/s

Public toilets

- toilet door opening schedule:

• 8:00-24:00 60 openings/h; duration of each opening 5 s => door open 8.33%/h

• 24:00-8:00 negligible activity

- occupancy schedule:

• 8:00-24:00 30 people/h (walking & standing); sensible heat 75 W, latent heat 70 W pp

• 24:00-8:00 negligible activity

- equipment schedule:

• 8:00-24:00 hand dryer (2600 W); assumed 30 uses of 20 s each per h => 433 W power consumed and sensible heat generated

- lighting schedule:

• 8:00-24:00 420 W incandescent/halogen light (840 W total activated with timer; lights assumed to be on a total of 8 h/d)

- ventilation schedule:

• 0:00-24:00 150 l/s

Gym and spa

The gym and spa consist of facilities for weight training, cardio exercise, aerobics, massage, aromatherapy, solarium, sauna, steam bath and a hot tub. In addition, changing rooms with showers are provided. There are a total of five showers and it is assumed that each shower is used twice per hour during the opening hours of the facility. Further, each shower session is assumed to last for 10 minutes, subsequently rendering the showers in use for 20 min/hr, i.e. 33% of the time.

The sensible and latent heat flows are then assumed to be continuous at 33% intensity for easier application in the simulations. Sensible and latent heat loads were estimated using the same methodology as for the guest bathroom, derived in Appendix V. Ventilation rate for the shower booths was specified at 30 l/s and was used in the simulations. The following assumptions were made for the calculations: 1°C temperature rise from 27° to 28°C with 30% rise in relative humidity from 65% to 95% for summertime (May-October) and 1°C temperature rise from 18° to 19°C with 30% rise in relative humidity from 65% to 95% due to shower in wintertime (November-April). High and low initial temperatures for summer and winter respectively were assumed due to the fact that the changing rooms are unconditioned and are expected to overheat in summer and be cold in winter. For the same reason humidity was expected to be at the high end year around, unlike the much lower humidity levels observed for the guest bathroom in winter due to heating of the room.

Using the Psychrometric Chart No.1 (ASHRAE, 2009, Fig.1, p.1.11) in Appendix V, the following results were derived: 45 W sensible and 702 W latent heat gains in summertime, 46 W sensible and 415 W latent heat gains in wintertime. Heat rates of 75 W sensible and 55 W latent due to occupancy were added to the above figures for standing/walking as per ASHRAE (2009, Table 1, p.18.4). Subsequently, sensible loads became 120 W and 121 W and latent loads 757 W and 470 W in summer and winter respectively. Scaling down the above figures to 33% intensity as discussed above, the final values to be used in the simulations became: 40 W sensible and 252 W latent heat gains in summertime, 40 W sensible and 157 W latent heat gains in wintertime.

Evaporation from the hot tub is a significant source of sensible and latent gains into the spa space. Furthermore, maintaining the tub water at 38°C requires a continuous heat supply. The methodology used to estimate evaporation from pools and hot tubs is discussed in detail in Section 7.2.3.5 in the context of the indoor swimming pool. Therefore, only the assumptions made and results are presented here as follows:

- Ambient temperature in the spa=27°C in summer, 18°C in winter
- Relative humidity=60%
- Hot tub water temperature=38°C
- Air velocity on the surface water=0.127 m/s
- Surface area of the tub=3.6 m^2

With the above assumptions, the evaporation rate for the tub was calculated at 0.664 kg/hr·m^2 in summer and 0.798 kg/hr·m^2 in winter. Relating the rate to the water surface area, evaporation became 2.4 and 2.9 kg/hr in summer and winter respectively. Evaporation causes latent heat gain within the spa space. It is assumed that the supplied heat required to maintain constant water temperature equals to the latent heat loss. The latent heat components were calculated as 1.61 kW for summer and 1.93 kW for winter. Sensible gain from the hot tub is considered negligible compared to the latent gain. Similarly, sensible gain from the tub water circulation pump is ignored as the pump is remotely located.

Steam bath is a facility where relative humidity is maintained at 100% and temperature at about

45°C. The power rating of the hotel's steam generating equipment was 6 kW. It was assumed that while in operation, the entire power capacity was converted into latent heat. Naturally, when the system is 'cold started', power is needed to reach the desired temperature, thus creating a sensible heat component, but once the operating temperature has been reached, the system generates a latent gain only. Subsequently, latent load from a steam bath is significant and contributes to the gains of the surrounding spaces via door opening, i.e. the more traffic between the spaces, the more steam escapes out of the bath.

The spa facility also includes a sauna room. The difference between a sauna and a steam bath is that whereas a steam bath maintains a relatively low temperature at high humidity, a sauna provides dry heat at a higher temperature. For the sake of the simulations, it was assumed that the heat gain from the sauna is all sensible, i.e. 8 kW of sensible heat. It is noted that also latent heat is released in saunas when water is thrown onto the stove for steam, but the latent component was not considered in the simulations. It is further noted that 100% efficiency is assumed for both steam bath and sauna equipment. Furthermore, both the steam bath and sauna operate for eight months a year, 12 hours a day.

The following assumptions were made for the steam bath and sauna regarding door opening and heat gains:

- door opening schedule:
  - 8:00-20:00 10 openings/h; duration of each opening 5 s => door open 1.39%/h
  - 20:00-8:00 door closed, no activity
- equipment schedule:
  - 8:00-20:00 steam bath (nameplate power 6000 W); 1.77 kW latent heat[58]; Oct-May
  - 8:00-20:00 sauna; (nameplate power 8000 W); 2000 W sensible heat[59]; Oct-May

It is noted that heat gains due to occupancy in the steam bath and sauna were not included in the simulations as they are negligible compared to the gains from the facilities themselves.

The remaining areas of the gym and spa were assumed to conform to the following schedule regarding door opening, occupancy and equipment use:

- entry and changing room door opening schedule:
  - 8:00-20:00 10 openings/h; duration of each opening 5 s => door open 1.39%/h
  - 20:00-8:00 door closed
- occupancy schedule:
  - 8:00-20:00 10 people/h (exercising); 210 W sensible, 315 W pp latent heat

[58] 1.77 kW represents the average of the calculated latent heat components for summer and winter due to water evaporation.
[59] Experimentally derived usage factor of 0.25 used.

- 8:00-20:00 10 people/h (showering); 40 W sensible and 252 W latent heat (May-Oct), 40 W sensible and 157 W latent heat (Nov-Apr) (five showers total => two people per shower per hour, the above figures representing continuous heat production)

  20:00-8:00 no activity

equipment schedule:

- 8:00-20:00 hot tub (nameplate power 3500 W); 1610 W (May-Oct), 1930 W (Nov-Apr) latent heat
- 8:00-20:00 five treadmills + one filvibe machine (1492 W each); 6 hr/d i.e. 50% utilisation => 4476 W total; 447.6 W sensible heat (10% friction for heat generation)
- 8:00-20:00 two TVs (100 W each)
- 0:00-24:00 one large and one small refrigerator (500 W combined)
- 0:00-24:00 water cooler (91 W)
- 8:00-20:00 computer with monitor (190 W)
- 0:00-24:00 fax machine (28 W)

lighting schedule:

- 8:00-20:00 gym main areas 171 W fluorescent, 7754 W incandescent/halogen light
- 8:00-20:00 spa 11 W fluorescent, 1590 W incandescent/halogen
- 9:00-18:00 aromatherapy room 210 W incandescent/halogen (business days only)
- 9:00-18:00 solarium 11 W fluorescent (Nov-Apr business days only)
- 9:00-12:00 solarium lamp 1500 W (Nov-Apr business days only)
- 8:00-20:00 changing rooms 248 W fluorescent (each)
- 0:00-24:00 44 W fluorescent (exit lights)

ventilation schedule:

- 8:00-20:00 2110 l/s (gym), 120 l/s (spa area), 200 l/s (changing rooms, each)
- 9:00-18:00 30 l/s (aromatherapy room)

Hair dresser's

- door opening schedule:
  - 8:00-18:00 8 openings/h; duration of each opening 5 s => door open 1.11%/h
  - 18:00-8:00 door closed
- occupancy schedule:
  - 8:00-18:00 4 people/h (seated, light work); sensible heat 70 W, latent heat 45 W pp
  - 18:00-8:00 no activity
- equipment schedule:
  - 8:00-18:00 hair dryer (15 min/h); sensible heat 250 W

- lighting schedule:
  - 8:00-18:00 11 W fluorescent, 1905 W incandescent/halogen light
  - 18:00-8:00 lights off
- ventilation schedule:
  - 9:00-18:00 130 l/s

Executive meeting room

- door opening schedule (two events a week):
  - 8:00-16:00 10 openings/h; duration of each opening 5 s => door open 1.39%/h
  - 16:00-8:00 door closed
- occupancy schedule:
  - 8:00-16:00 20 people/h (seated, light work); sensible heat 70 W, latent heat 45 W pp
  - 16:00-8:00 no activity
- lighting schedule:
  - 8:00-16:00 66 W fluorescent, 320 W incandescent/halogen light
- ventilation schedule:
  - 8:00-16:00 200 l/s

Kids' club

- door opening schedule:
  - 9:00-13:00 10 openings/h; duration of each opening 10 s => door open 2.78%/h
  - 13:00-9:00 door closed
- occupancy schedule:
  - 9:00-13:00 10 people/h (moderately active office work); sensible heat 56 W, latent heat 41 W pp[60]
  - 13:00-9:00 no activity
- lighting schedule:
  - 9:00-13:00 66 W fluorescent light

Seminar room

- door opening schedule (two events a month):
  - 8:00-16:00 10 openings/h; duration of each opening 5 s => door open 1.39%/h
  - 16:00-8:00 door closed
- occupancy schedule:
  - 8:00-16:00 20 people/h (seated, light work); sensible heat 70 W, latent heat 45 W pp
  - 16:00-8:00 no activity

[60] Adult male values of 75 W sensible and 55 W latent reduced to 75% values applicable for children (ASHRAE, 2009, Table 1, p.18.4)

- lighting schedule:
  - 8:00-16:00 72 W fluorescent, 320 W incandescent/halogen light
- ventilation schedule:
  - 8:00-16:00 100 l/s

Stairwells and Corridors

Stairwells and corridors are unconditioned spaces in the case study hotel. Therefore, no occupancy was applied to them. On the ground floor the stairwells connect to conditioned spaces such as the breakfast cafeteria and the bar but the traffic was considered minimal and the door opening between these spaces was taken as 5 openings per hour.

Lighting, however, is a significant power consumer, especially since the lights are expected to be on for 24 hours daily, as no timers nor motion sensors are in place. The following is assumed for stairwells:

- door opening schedule:
  - 7:00-1:00 5 openings/h; duration of each opening 5 s => door open 0.69%/h
  - 1:00-7:00 minimal activity
- lighting schedule (east and west stairwells):
  - 0:00-24:00 402 W fluorescent light
- lighting schedule (central stairwell):
  - 0:00-24:00 266 W fluorescent light

Corridors on guestroom floors are unconditioned spaces as well. Guestroom door opening to the corridors was accounted for with the room door opening schedule. Door opening between stairwell and corridor was not considered important as both spaces were unconditioned. Similarly to stairwells, lighting in the corridors was expected to be on continuously. The following was assumed for floors 1-4 corridors:

- lighting schedule:
  - 0:00-24:00 705 W fluorescent light

Lighting in the basement corridor differs from lighting on the guestroom floors and is detailed as follows:

- lighting schedule:
  - 0:00-24:00 524 W fluorescent, 2775 W incandescent/halogen light

7.2.3.3 Conference centre occupancy, lighting and door opening

The conference centre operating within the hotel hosts different types of events. The centre has its own entry, although it is also accessible from the main hotel. It is assumed, however, that the majority of guests enter the centre by using the centre’s own entry.

For the sake of the simulations, the events are grouped as ‘day events’ and ‘night events’. Day events are typically conferences, seminars, exhibitions or workshops running either full or half a day. Lunch is usually served as part of the event. Night events, in turn, are generally receptions, such as weddings, company parties, etc. and include a dinner and dancing. The night events require more preparation and decorating. The preparation activities include carrying in tables and chairs, place setting, flower arrangement, bringing in and setting up musical instruments and hi-fi equipment, etc. Lighting and AC needs may thus need to be extended beyond the actual event so as to provide the optimal conditions for the working crews, perishable flowers and such. The hotel estimated that approximately six events per month are organised. It was further assumed that the split between day and night events was 50-50. Summer months (Jun-Oct) were assumed to have two events per week, whereas winter months (Nov-May) one event per week adding up to 72 events a year. The following assumptions were made for each type of event:

- main entrance door opening schedule (day events; three events per month):
  - 8:00-9:00 100 openings/h; duration of each opening 5 s => door open 13.89%/h
  - 9:00-16:00 10 openings/h; duration of each opening 5 s => door open 1.39%/h
  - 16:00-17:00 100 openings/h; duration of each opening 5 s => door open 13.89%/h
  - 17:00-8:00 door closed
- occupancy schedule (day events):
  - 8:00-17:00 100 people/h (theatre, matinee); sensible heat 65 W, latent heat 30 W pp
  - 13:00-14:30 lunch catering for 100 people; sensible heat 9 W, latent heat 9 W pp
  - 17:00-8:00 negligible activity
- lighting schedule (day events):
  - 7:00-19:00 (4896 W fluorescent, 19410 W incandescent/halogen) 67% lights on
- ventilation schedule (day events):
  - 8:00-17:00 1700 l/s[61]
- main entrance door opening schedule (night events; three events per month):
  - 14:00-19:00 10 openings/h; duration of each opening 20 s => door open 5.55%/h
  - 19:00-1:00 100 openings/h; duration of each opening 5 s => door open 13.89%/h
  - 1:00-14:00 door closed
- occupancy schedule (night events):
  - 14:00-19:00 10 people/h (heavy work); sensible heat 170 W, latent heat 255 W pp
  - 19:00-1:00 500 people/h (moderate dancing & eating); sensible heat 90 W, latent heat 160 W pp
  - 1:00-14:00 negligible activity
- lighting schedule (night events):
  - 14:00-19:00 (4896 W fluorescent, 19410 W incandescent/halogen) 40% lights on
  - 19:00-1:00 (4896 W fluorescent, 19410 W incandescent/halogen) 100% lights on

[61] Ventilation adjusted to occupancy at 17 l/s per person conforming to Category II with smoking allowed as per Table 3.10.

- ventilation schedule (night events):
  - 19:00-1:00 8500 l/s
- Conference centre hallway lighting schedule:
  - 18:00-19:35 2088 W fluorescent light (8 h/event averaged over 365 d/yr)
- Conference Centre public toilets lighting schedule:
  - 0:00-24:00 509 W fluorescent light (365 d/yr)

7.2.3.4 Back-of-the-house areas occupancy, lighting and usage patterns

Back-of-the-house areas include all areas of the hotel that are used by the staff but not meant for guest access. Such areas include the administration offices, staff restaurant and changing rooms, storage areas, mechanical room, laundry and the kitchen. It is noted that the kitchen was not included in the overall thermal simulations. Also, areas such as storage and mechanical room were excluded, as they are unconditioned spaces and therefore do not contribute to the SC loads of the hotel. The laundry room, on the other hand, although not a conditioned space and as such excluded from the simulations, presented an interesting area where extreme heat and cold plague the working environment depending on the season. Temperature and humidity in the laundry room were monitored and the maximum temperatures recorded reached 41.4°C (with 46% RH) and the maximum RH 95% (with 36.7°C temperature) in July. The lowest recorded temperature in January was 19.8°C (34% RH) and as such did not appear excessively low. But it is emphasised that the data logger was purposely placed so as to be exposed neither to direct heat from the machines nor outside air from open doors and windows. Consequently, it is reasonable to assume that the extreme temperatures in the various work stations of the laundry were even more extreme than indicated by the measured data. The above conclusion is highly analogous to the testimonies given by the staff working in the laundry who complained about the extreme temperatures and low thermal comfort within the space.

The following paragraphs list the assumptions made for the various back-of-the-house areas.

Administration offices

- office entry door opening schedule:
  - 7:30-8:30 20 openings/h; duration of each opening 5 s => door open 2.78%/h
  - 8:30-16:30 5 openings/h; duration of each opening 5 s => door open 0.69%/h
  - 16:30-18:30 20 openings/h; duration of each opening 5 s => door open 2.78%/h
  - 18:30-7:30 door closed
- occupancy schedule:
  - 8:00-17:00 20 people/h (moderately active office work); sensible heat 75 W, latent heat 55 W pp
  - 17:00-8:00 negligible activity
- equipment schedule:
  - 8:00-17:00 9 computers with monitor (190 W each)

- 0:00-24:00 3 laser printers (67 W average consumption each; active 2 h at 369 W, on standby 7 h at 71 W, in sleep mode 15 h at 25 W)
- 0:00-24:00 2 fax machines (57 W average consumption each; active 2 h at 350 W, 'ready' 22 h at 30 W)
- 0:00-24:00 copy machine (168 W average consumption; active 2 h at 800 W, on standby 7 h at 260 W, in sleep mode 15 h at 40 W)
- 0:00-24:00 water cooler (91 W)

- lighting schedule:
- 8:00-18:00 3356 W fluorescent, 2125 W incandescent/halogen light
- 0:00-24:00 33 W fluorescent light

- ventilation schedule:
- 8:00-17:00 380 l/s

GM office

- office entry door opening schedule:
- 8:00-17:00 6 openings/h; duration of each opening 5 s => door open 0.83%/h
- 17:00-8:00 door closed

occupancy schedule:
- 8:00-17:00 2 people/h (moderately active office work); sensible heat 75 W, latent heat 55 W pp
- 17:00-8:00 negligible activity

- equipment schedule:
- 8:00-17:00 2 computers with monitor (190 W each)
- 0:00-24:00 laser printer (67 W average consumption; active 2 h at 369 W, on standby 7 h at 71 W, in sleep mode 15 h at 25 W)
- 0:00-24:00 fax machine (57 W average consumption; active 2 h at 350 W, 'ready' 22 h at 30 W)

- lighting schedule:
- 8:00-18:00 648 W fluorescent light
- 18:00-8:00 lights off

Kitchen

Kitchen electricity consumption was monitored via a sub-metered circuit but kitchen lighting was included in the simulations for contribution towards total electricity consumption. Internal gains and ventilation were not included.

- lighting schedule:
- 6:00-22:00 7872 W fluorescent light
- 0:00-24:00 44 W fluorescent light

Second kitchen (summertime May-October use only)[62]

- equipment schedule:

- 0:00-24:00 2 food cooling units (320 W nameplate power => 160 W continuous consumption)
- 0:00-24:00 refrigerator (444 W)
- 0:00-24:00 refrigerator (405 W)
- 0:00-24:00 3 refrigerators (367 W)
- 0:00-24:00 freezer (185 W nameplate power => 74 W continuous consumption)
- 0:00-24:00 water cooler (91 W)
- 12:00-18:00 Bain Marie food warming unit (3000 W nameplate power => 2070 W continuous consumption)
- 12:00-16:00 gas oven/steamer with electric fan (350 W; fan and controls only)
- 13:00-17:00 grill (320 W)
- 13:00-16:00 plate warmer (400 W nameplate power => 200 W continuous consumption)
- 13:00-19:00 dishwasher (1160 W) (assuming 20 racks/day washed at 0.58 kWh/rack)

- lighting schedule:

- 18:00-22:00 360 W fluorescent light (May-Oct)
- 13:00-22:00 80 W fluorescent light (May-Oct)

Laundry, delivery & refuge

Laundry, delivery and refuge electricity consumption was monitored via a sub-metered circuit but their estimated lighting contribution was included in the simulations as reasoned earlier for the kitchen.

- lighting schedule:

- 6:00-22:00 laundry 936 W, delivery 180 W and refuge 288 W fluorescent light

Staff restaurant

Staff restaurant operates 365 d/yr.

- door opening schedule:

- 7:00-12:00 40 openings/h; duration of each opening 5 s => door open 5.56%/h
- 12:00-14:00 60 openings/h; duration of each opening 5 s => door open 8.33%/h
- 14:00-18:00 40 openings/h; duration of each opening 5 s => door open 5.56%/h
- 18:00-7:00 door closed

- occupancy schedule:

- 7:00-12:00 5 people/h (sitting; no food); sensible heat 71 W, latent heat 71 W pp
- 12:00-14:00 30 people/h (sitting + hot food); sensible heat 80 W, latent heat 80 W pp

[62] No heat gains were applied in the second kitchen as it is an unconditioned space.

- 14:00-18:00 5 people/h (sitting; no food); sensible heat 71 W, latent heat 71 W pp
- 18:00-7:00 no activity

- equipment schedule:
  - 0:00-24:00 refrigerator (688 W)
  - 0:00-24:00 water cooler (91 W)
  - 8:00-18:00 air-conditioning (May-September)

- lighting schedule:
  - 7:00-1:00 180 W fluorescent light

Staff changing rooms (one for male, one for female staff)

Only lighting was included in the simulations as the changing rooms are unconditioned and not connected to any conditioned spaces.

- lighting schedule:
  - 6:00-13:00 and 15:00-2:00 180 W fluorescent light

Chief Engineer's office

- office entry door opening schedule:
  - 7:30-15:30 3 openings/h; duration of each opening 10 s => door open 0.83%/h
  - 15:30-7:30 door closed

- occupancy schedule:
  - 7:30-15:30 1 person/h (mod. active office work); sensible heat 75 W, latent heat 55 W pp
  - 15:30-7:30 no activity

- equipment schedule:
  - 7:30-15:30 one computer with monitor (190 W)

- lighting schedule:
  - 7:30-15:30 216 W fluorescent light

7.2.3.5 Indoor pool: considerations for thermal simulations

Natatoriums in general are a challenging environment from the building services point of view due to their inherent high humidity and subsequent condensation problems. In addition, user thermal comfort requirements dictate high levels of control in terms of humidity, air quality and air and pool water temperatures. According to ASHRAE (2007), the ideal relative humidity for swimmers is 50-60%. It is further recommended that the pool water in hotel pools is maintained at 28-30°C and the air temperature within the pool space 1-2°C above the water temperature but not higher than the comfort threshold of 30°C (ASHRAE, 2007, p.4.6).

The conditions of the indoor pool and the pool house of the case study hotel are not controlled to the degree recommended by the ASHRAE guidelines above. The pool house is neither heated nor cooled. The pool water, however, is heated during the winter months to about 28°C. The indoor pool is located in a separate building, although connected to the main hotel via a corridor at the basement level. The same building hosts toilet facilities, one shower and a squash court.

Since the pool building is an unconditioned space, it would not appear to be necessary to include it in the simulations as it does not contribute to the SC loads. However, since the pool itself is heated, it does contribute to the heating load. In addition, the evaporation from the pool is significant and has an impact on water consumption. Therefore, the pool house was included in the simulations. The sensible heat gain from the pool was simulated by representing the body of water as a room maintained at a constant temperature and the water surface as a single-pane window with the following properties: transmittance=1, absorptance=0, reflectance=0 and refractive index=1. In addition, a low surface resistance, 0.01 m^2K/W, was applied to the downward facing side of the window. It was not possible to directly simulate the latent heat component generated by evaporation from the pool. Therefore, evaporation was calculated independently and the results were used as an input parameter in the simulations. Appendix VI shows the evaporation calculations but the key input parameters and results are summarised as follows:

- Ambient temperature in the pool house=18°C (winter condition)
- Relative humidity=60%
- Pool water temperature=28°C
- Air velocity on the surface water=0.127 m/s
- Surface area of the pool=52.2 m^2
- Wetted area (assuming 50 cm splash boundary around the pool)=70.4 m^2

With the above assumptions, the evaporation rate for the pool was calculated at 0.298 $kg/hr{\cdot}m^2$. Applying the rate to the actual pool area, evaporation became 15.6 and 21.0 kg/hr for actual water surface and wetted areas respectively. It is noted that a minimal wetted area around the pool increases evaporation by 35%. As evaporation is primarily fuelled by the heat in the water itself, it has a cooling effect on the pool water. Therefore, continuous heat needs to be supplied to the water in order to maintain the desired temperature. The heat supply required to maintain the water pool temperature was calculated at 10.5 and 14.2 kW for actual water surface and wetted areas respectively. Incidentally, the amount of heat supplied equals to the latent heat loss.

In summertime it was assumed that the pool water and the ambient air temperatures were in equilibrium at about 28°C although the pool was not heated. By keeping other input parameters unchanged, the evaporation rate was calculated at 0.178 $kg/hr{\cdot}m^2$, yielding evaporation of 9.3 and 12.5 kg/hr for actual water surface and wetted areas respectively. Consequently, the latent heat losses became 6.3 and 8.5 kW.

The pool house is well naturally lit due to high glazing ratio. The hotel estimated that artificial lighting was required in the building on average for 2 hours daily over the entire year. The same building also hosts a squash court that is lit on demand. In the simulations, the lighting hours were distributed over the darker winter months but the squash court lighting was distributed over the whole year as follows:

- lighting schedule:
  - 16:00-21:00 99 W fluorescent, 800 W halogen light (November-March); pool house
  - 20:00-21:00 432 W fluorescent light (12 mo/yr); squash court

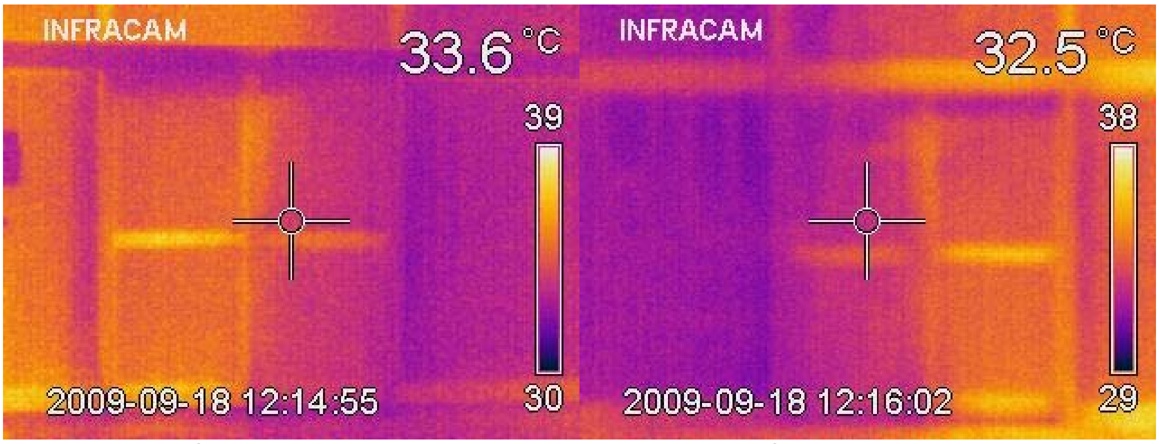
7.2.3.6 Infiltration considerations

Infiltration can be a significant cause for energy loss especially in older buildings built to no standards of air-tightness. Some 30 W/m^2 heat loss due to infiltration in guestrooms could be expected (EngineeringToolBox.com, no date)[63]. Possible paths for infiltration are cracks in the building envelope, ventilation ducts, chimneys and poorly sealed window and door frames. Although it is easy to identify problem areas in air-tightness, it is difficult to quantify infiltration without elaborate pressure testing. For the purpose of the calibration simulation, infiltration was assumed at 0.5 ach in all air-conditioned and 5 ach[64] in all naturally ventilated spaces such as the stairwells and the laundry. No additional window opening schedules were included in the naturally ventilated spaces as the chosen air change represents it.

Infiltration around windows and doors was of particular interest. By inspection, the hotel demonstrated poor air-tightness around openings. Visible air gaps around and below doors especially were noted, as can be seen in Fig. 7.21. Fig. 7.22 shows the same doors via the lens of an infrared camera highlighting another issue, namely high heat conductance through aluminium frames. As can be noted, the surface temperature of the door frame is higher inside the air-conditioned space rather than outside. It indicates that the space behaves like a ‘greenhouse’ overheating at least the areas nearby windows.

[63] Assuming 15-20°C temperature difference (indoors/outdoors) and 2.6 m room height.
[64] 5 ach is a typical value used for modelling window opening in a naturally ventilated room (IES, no date).

Figure 7.21 Double doors of the case study hotel model showing poor air-tightness



from inside from outside

Figure 7.22 Infrared pictures of the same doors as in Fig. 7.21

It subsequently became obvious that openings were a major weak point in the building envelope. For the sake of the calibration simulations, crack coefficients around the openings were taken from Orme *et al.* (1994) (quoted in IES, no date-b, p.13) as the most severe ones as follows:

- Sliding windows (non-weather-stripped): 0.37 l·s^{-1}m^{-1}Pa$^{-0.6}$
- Hinged external doors (non-weather-stripped) 1.4 l·s^{-1}m^{-1}Pa$^{-0.6}$
- Internal doors (non-weather-stripped) 2.0 l·s^{-1}m^{-1}Pa$^{-0.6}$

To illustrate the significance of infiltration around openings, the simulation was repeated by changing the crack coefficient values to indicate weather-stripped windows and doors with the following values:

- Sliding windows (weather-stripped): 0.079 $l \cdot s^{-1} m^{-1} Pa^{-0.6}$
- Hinged external doors (weather-stripped) 0.082 $l \cdot s^{-1} m^{-1} Pa^{-0.6}$

No changes were made with internal doors. The findings were interesting as at first glance they seemed to contradict common sense. Namely, energy savings were predicted in heating but not in cooling. As a matter of fact, slight increase in cooling energy would result from weather-stripping the openings. In absolute terms, 8277 kWh reduction in heating oil corresponding to about €737 financial savings using the 2007 average price of €0.089/kWh[65] representing 0.5% annual heating oil expenses. Chillers energy demand in turn would increase by 303 kWh and €42 in financial terms using the average electricity price of €0.139/kWh as calculated in Table 7.3. Subsequently, net savings in the order of €695 would be expected.

It can be concluded that weather-stripping alone would not contribute significant energy savings, although it is a measure that can be implemented at very low cost yielding a payback of possibly less than a year, especially if in-house maintenance staff is utilised in the installation at times when they are not otherwise busy. Another interesting conclusion that can be made from the above analysis is the role of nocturnal cooling in the given climate. The increase in cooling energy demand can be explained by the fact that less *uncontrolled* infiltration around the openings would not allow as much heat to be expelled at night, therefore increasing the demand during the day. With this added knowledge an intelligent system could naturally increase *controlled* air change at night to take advantage of the nocturnal cooling potential. It could be implemented either mechanically utilising the free-cooling potential of the ventilation system or manually by opening windows at night. Window opening can also be automated with a thermostat control but it would require a proper infrastructure to be in place. Such strategies can be part of an intelligent energy management system and should be studied in detail when planning for major hotel renovations. However, it is beyond the scope of this study to quantify the impacts of control systems.

7.2.3.7 Building envelope considerations

Properties to the building construction elements were assigned as detailed in Table 7.5. U-values were calculated by the simulation software using the EN-ISO method.

[65] The calorific value of the heating oil was taken as 10.6 kWh/l (CIBSE, 2004, p.A-5) and the boiler efficiency was assumed at 0.80.

Building element	U-value (W/m^2K)	Material	Location
Windows, single-glazed	5.42	aluminium frame	throughout the hotel
External doors	2.86	aluminium+glazing	throughout the hotel
Entrance doors	5.52	frameless thick glass	main entrance
Guestroom doors	2.19	wood, solid	guestrooms
Internal doors	2.33	wood, hollow core	guestroom bathrooms, throughout the hotel
Internal doors	2.86	aluminium, non-insulated	back-of-the-house areas
Internal glazing	3.69	wooden frame	meeting room
External wall, 22cm	2.26	clay brick, plastered on both sides	throughout the hotel
External structural wall, 21cm	3.00	reinf. concrete, plastered inside	stairwells
Glass block wall, 10cm	3.20	glass block	indoor pool house
Underground wall, 21cm	0.69	reinf. concrete, plastered inside	basement floor
Sauna wall 25cm, external underground	0.40	reinf. concrete, glass wool, pine panel	sauna
Sauna wall 16cm, internal	0.66	plaster, perforated clay brick, glass wool, pine panel	sauna
Internal walls, 12cm	2.17	clay brick, plastered on both sides	throughout the hotel
Internal walls, 22cm	1.61	clay brick, plastered on both sides	basement, selected areas
Internal structural wall, 22cm	2.26	reinf. concrete, plastered on both sides	basement, selected areas
Indoor pool wall, 21cm	0.17	reinf. concrete, tiled inside	indoor pool
Ground slab, 25cm	0.37	reinf. concrete, screed, tile	ground floor
Roof slab, 21.6cm	2.88	plaster, reinf. concrete, bitumen felt with stone chippings	main hotel upper floor, restaurant
Roof slab+false ceiling, 82.6cm	1.10	acoustic tile, cavity, reinf. concrete, bitumen felt with stone chippings	conference centre
Roof slab+false ceiling, 90.0cm	0.58	pine panel, glass wool, cavity, reinf. concrete, screed, tile	sauna (underground under a tiled patio)
Floor/ceiling, 26cm	1.40	carpet, screed, reinf. concrete, plaster	guestrooms
Floor/ceiling, 26cm	1.79	tile, screed, reinf. concrete, plaster	breakfast cafeteria
Floor/ceiling, 26cm	1.85	marble, screed, reinf. concrete, plaster	reception & lobby, lounge
Floor/ceiling, 85cm	1.39	aluminium sheet tile, cavity, reinf. concrete, screed, tile	guestroom bathrooms

Table 7.5 Construction element details used in the calibration simulations of the case study hotel

7.2.3.8 Summary of the considerations for thermal simulations

The usage patterns described earlier allowed the preparation of schedules that were needed in the thermal simulations. Each modelled space required a schedule for the usage of its lighting, heating/cooling/ventilation, door/window opening and occupancy. For a sizable, multiuse building such as a hotel, the task of defining its usage pattern is enormous and as discussed earlier, at best a guess of the typical use can be derived. The usage patterns stated above were based on conversations with the hotel staff as well as personal observations. They are not claimed to be 'universal' but they do represent typical use of Cypriot resort hotels. Similarly, the assumptions for infiltration and crack coefficients were in line with the quality of construction that the hotel represented by visual inspection. As for the actual construction elements, the case study hotel was a good representative of the construction standards of the 1980s, thus capturing a large segment of the existing hotel building stock in Cyprus. The ultimate check of the validity of the assumptions was to see how closely the actual energy consumption could be matched by simulation.

The simulation model is shown in Fig. 7.23.

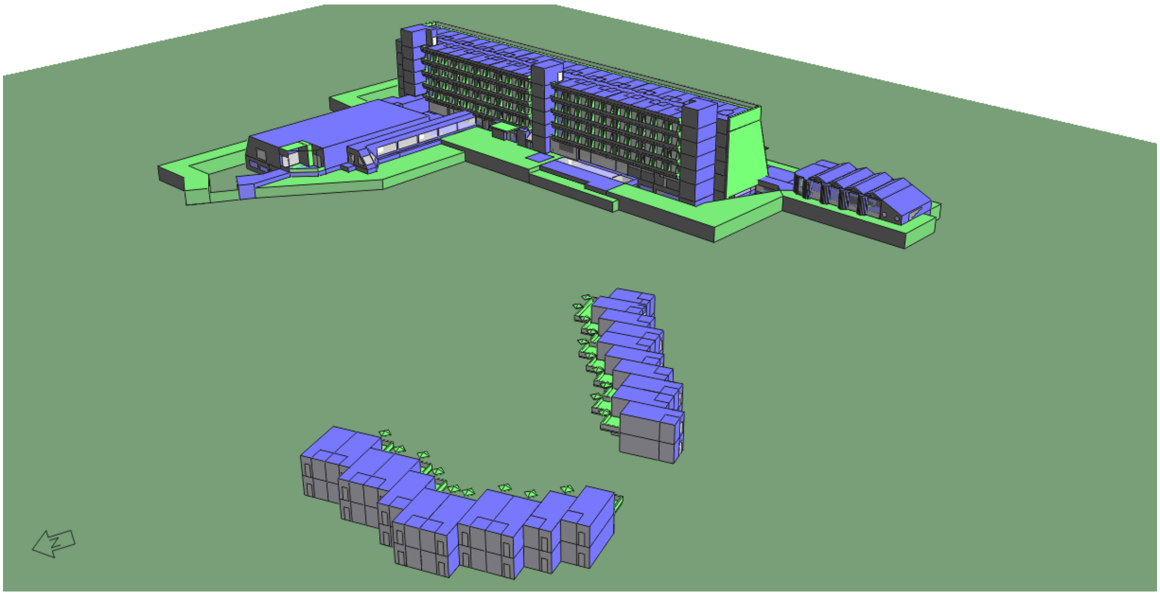


Figure 7.23 3D view of the case study hotel model

7.2.4 Weather data used in the case study thermal simulations

The decision to use the case study hotel as a calibration model required the actual weather data to be used in the simulations. The IES<VE> simulation software comes with a weather file for the Larnaca Airport; a WYEC file distributed by ASHRAE. WYEC stands for *Weather Year for Energy Calculations* and is the result of a research project by ASHRAE with a mission to improve the weather files used in thermal simulations (Crow, 1980; 1983). The main aim in developing WYEC weather data was to produce data sets with more typical weather patterns than either a single representative year or an assemblage of months, a practise of the previous generation of TRY (Typical Reference Year) weather data that tended to shave off the weather extremes by default (Crawley and Huang, 1997).

While the WYEC file was exactly what was needed in the simulations of the theoretical hotel cases, the calibration model required to be accompanied by a weather file with actual measured meteorological data for the place and time. Larnaca Airport as the nearest weather station was selected and hourly data available online (Weather Underground, 2011) was downloaded for the year 2007. The only complication was that the station does not record solar irradiance, only sunlight duration. Therefore, the solar irradiance had to be estimated. ASHRAE Clear-Sky Model (ASHRAE, 2005, Ch.14) was used to calculate the direct normal irradiance. The model utilises equations of the sun's position based on its orbital geometry and the geographical location over a solar year. Location-specific parameters to account for the optical depth of the air mass due to local conditions such as elevation, precipitable water content and aerosols in the atmosphere are built into the equations. Subsequently, the direct normal irradiation can be readily obtained. It is possible to obtain also the diffuse irradiation but a different method was chosen in this study. Jacovides *et al*. (2006) outline a procedure, specifically derived and tested for Cyprus, that correlates diffuse to global irradiation. Empirical correlations were developed to establish a relationship between the hourly diffuse fraction, k_d and the hourly clearness index, k_t using hourly global and diffuse irradiation measurements on a horizontal surface. High level of accuracy was obtained with the proposed third-order polynomial equation. Therefore, the said equation was used to estimate the amount of diffuse irradiation. Once the diffuse horizontal irradiation was calculated, it was straightforward to derive the global irradiation component. Cloud cover observations from the weather station data were included to accompany the clear sky irradiation estimates in the final weather file. Subsequently, specific weather data for the year 2007 was now at hand to be used for the calibration simulations. The data had to be converted to a specific format in order to be compatible with the simulation software. A suitable program for the conversion was available from the US Department of Energy (EnergyPlus by US Department of Energy, 2010).

7.2.5 Simulation results vs. empirical measured data

To evaluate the robustness of the model, simulation results were compared to the actual monitored or estimated electricity and heating energy consumption. Fig. 7.24 compares the estimated and simulated electricity consumptions. As seen, lights and equipment electricity match well on monthly basis. The systems electricity tends to be overestimated in winter and underestimated in summer. However, it balances out annually. When comparing the total cumulative electricity consumption, the simulated was 4.6% higher than the estimated. Similarly, heating energy consumption shown in Fig. 7.25 was compared to the actual fuel-bill-based figures and it was noted that the simulated was 4.4% higher than the actual.

It is noted that the sensitivity of the results was tested as several rounds of iterations were necessary to arrive at the above figures; namely the thermostat settings of various spaces were adjusted so as to match with the monitored output from the dataloggers. The initial aim was to match the actual energy consumption within 10% by simulation. Therefore, match within 5% was considered extremely good and subsequently no further input parameter adjustments were perceived necessary.

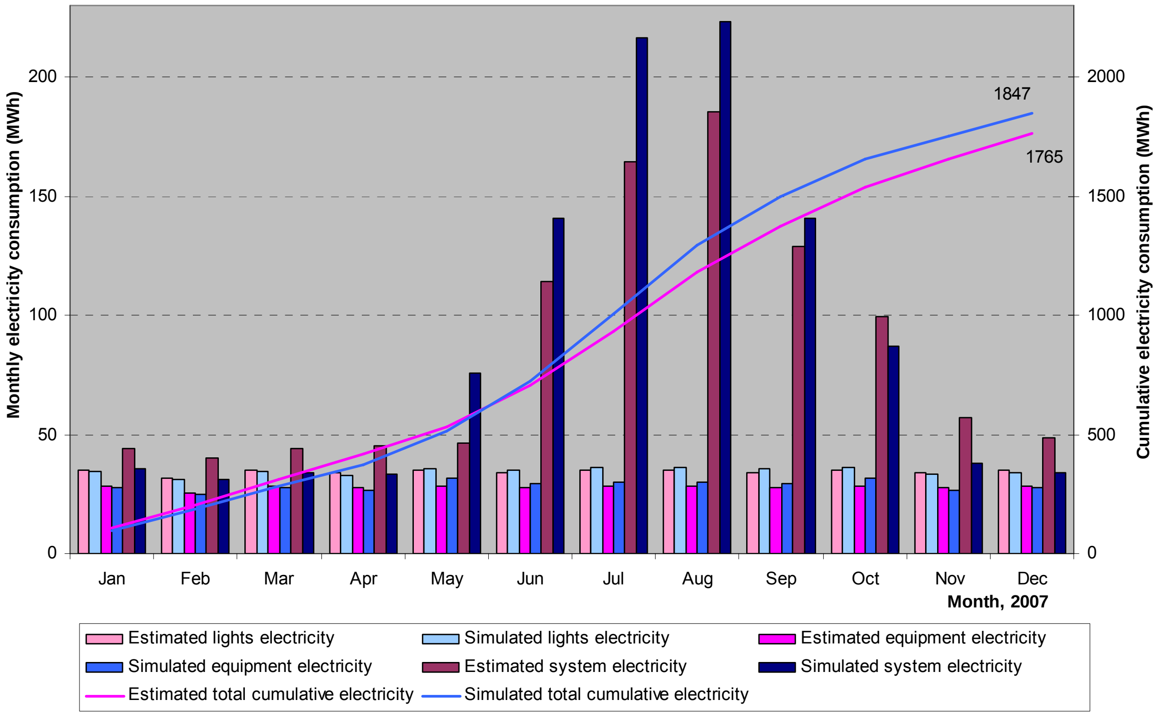


Figure 7.24 Estimated vs. simulated electricity consumption of the case study hotel model in 2007

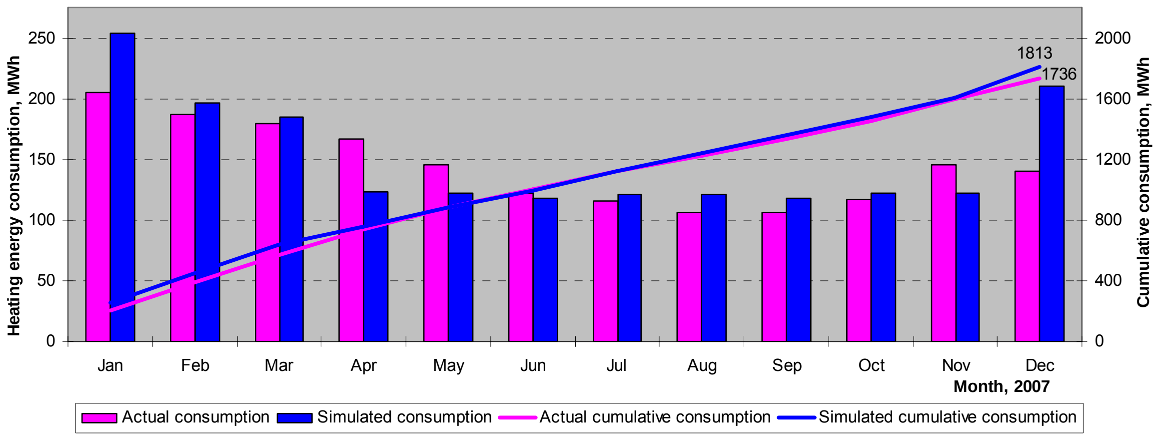


Figure 7.25 Estimated vs. simulated heating energy consumption of the case study hotel model in 2007

7.2.6 Free-running of the hotel building

Although not of importance in the energy consumption of the hotel, it was of interest to see how well the simulation model could match the free-running behaviour of the building. As reported before, temperature and humidity measurements were recorded in the stairwells. Comparison to the simulated values is shown in Figs. 7.26-7.28.

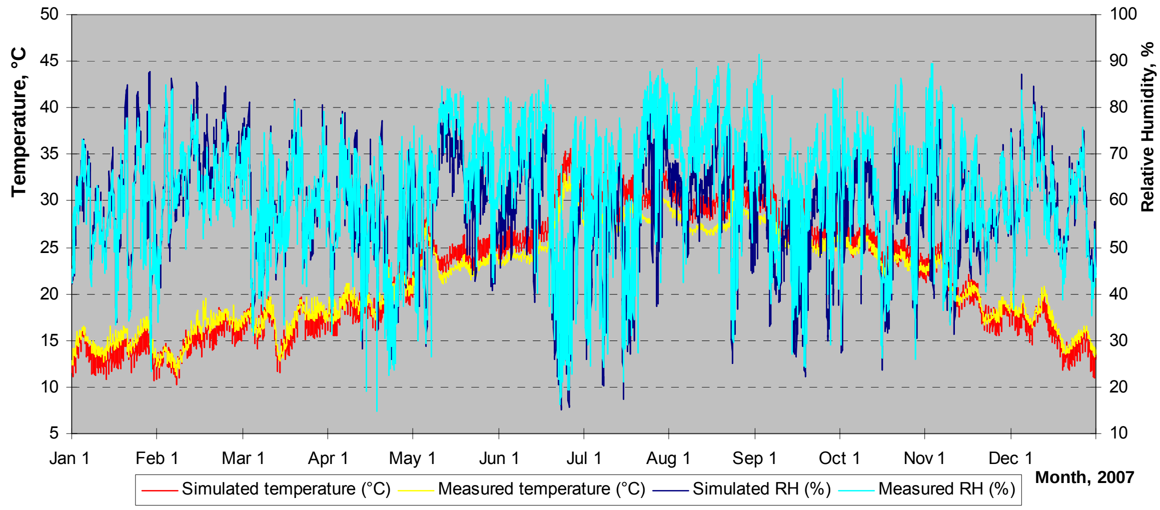


Figure 7.26 Measured vs. simulated temperature and RH in the stairwell of the case study hotel in 2007

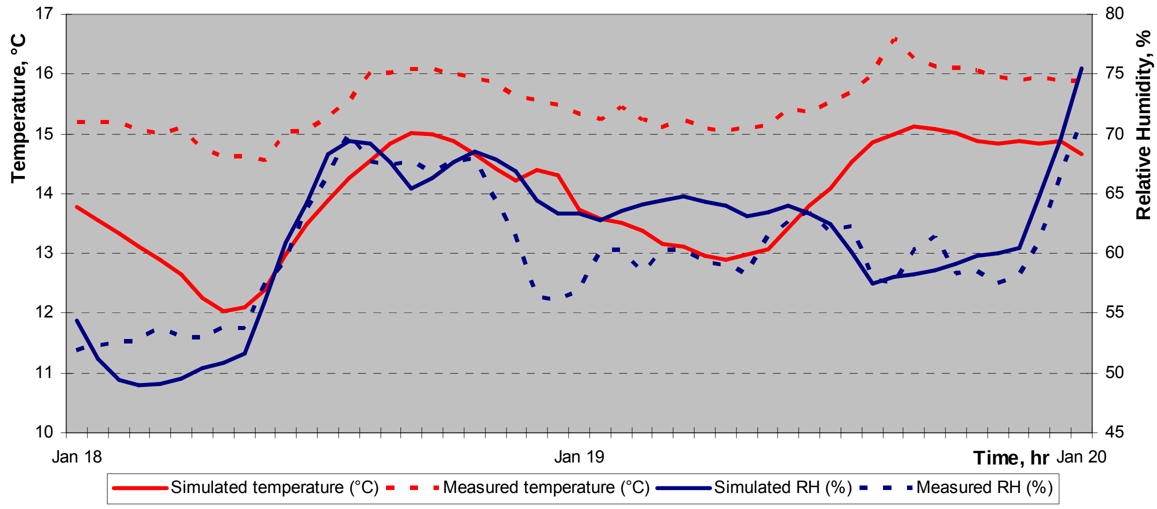


Figure 7.27 Typical winter day – measured vs. simulated temperature and RH in the stairwell of the case study hotel in 2007

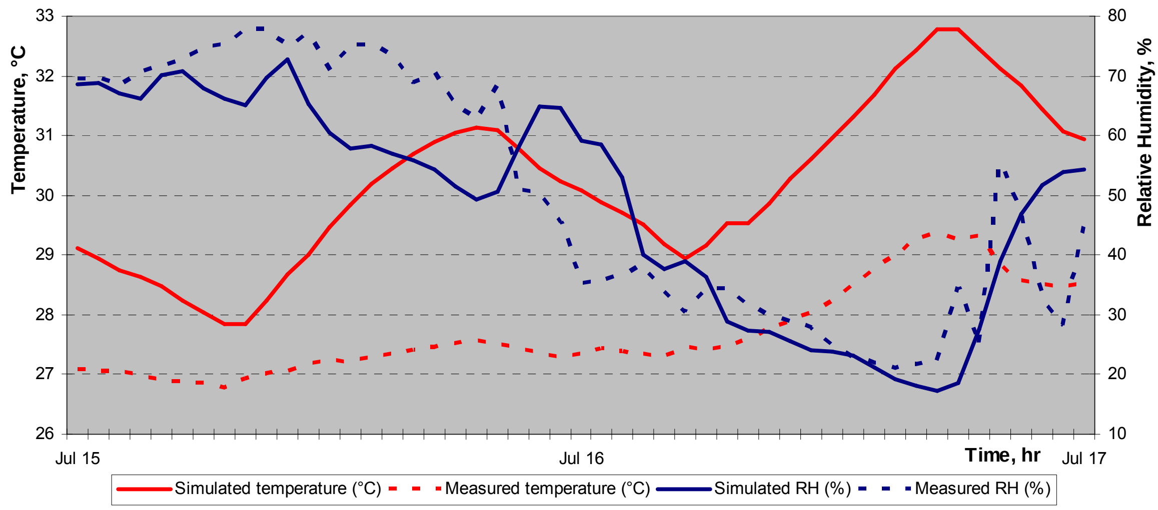


Figure 7.28 Typical summer day – measured vs. simulated temperature and RH in the stairwell of the case study hotel in 2007

It can be observed from the above figures that humidity is quite well matched by simulation. The simulated temperature though tends to be below the measured in winter and the opposite in summer. It could indicate that the model utilises less thermal mass than the actual building component, thus responding more quickly to ambient temperature variations. In addition, overheating in summer may indicate that the air change assumed to model naturally ventilated space may underestimate the actual window opening and especially the nocturnal cooling of the space. However, since the stairwells of the hotel are unconditioned spaces, no further adjustments were made in the model to provide a closer match. What is of importance though is to note the temperature bracket that a free-running building in the given climatic conditions would have, i.e. 10.3-35.6°C.

7.3 Hotel energy and water consumption survey

As explained earlier, 13 hotels participated in the energy and water survey. Two entries did not have enough information and were subsequently rejected. Therefore, eleven entries were included in the analysis. The survey questionnaire can be seen in Appendix VII.

7.3.1 Analysis of the energy and water consumption survey

The questionnaire was analysed using Excel spreadsheets. Statistical analysis with specialist software such as SPSS was not perceived appropriate since the sample size was not statistically significant, i.e. less than 30 entries were available for analysis. The purpose of the analysis was to establish mean values for the most important parameters and to compare them to the case study hotel. A close match would be considered an indication that the case study hotel represented a typical hotel and further that the theoretical models derived from it were a good template for approximating the energy consumption of 3-, 4- and 5-star hotels in Cyprus.

The descriptive statistics of the survey are shown in Table 7.6. Out of the eleven hotels, four were 5-star, three 4-star and four 3-star. The survey mean year built, number of rooms and number of beds were all within 10% of the case study hotel statistics. There was a noted difference in the treated area though. Although it was clearly stated that the treated area was of interest, it appears that in some cases the total area of the hotel may have been given, judging by the wide distribution of the values. In addition, three hotels did not give any information for the area. It highlights a common problem that hotel floor areas are often not known and further, that the importance of knowing them is not understood. Subsequently, the floor area of the case study had to be assessed from incomplete architectural plan series complemented with in-situ measurements. Such an exercise may have proven to be more than the participating hotels were willing to do. Therefore, it was concluded that the mean area derived from the survey was not a reliable figure and could not be compared to the case study hotel nor used in benchmarking energy consumption.

Comparison of the facilities indicated that the case study hotel had more bars and restaurants than the mean value. As for swimming pools, the case study hotel had more outdoor pools but a smaller indoor heated pool than the survey average. Health club was present in nine hotels and all but one had conference facilities. In-house laundry was present in seven hotels.

Construction detail-wise, it appeared that some of the survey hotels had already upgraded to double-glazing, although three hotels still had single-glazing. All hotels reported aluminium-frame windows and only one recently renovated hotel had them with a thermal break. Wall construction was a standard plastered single-leaf brick for all hotels except for one hotel built in 2005 that had an insulated cavity wall. Similarly, roof construction was a standard concrete slab. Four hotels had insulated roofs, the others were non-insulated.

Annual energy consumption comparison pointed out that the electricity consumption was a close match. Heating fuel volume for the case study was substantially higher but it was because the survey mean was lowered by two hotels that had solar hot water covering 30-50% of their hot water needs. When the hotels with solar-assisted water heating were excluded, the mean heat generation became an extremely close match with the case study.

In water consumption the case study was below the survey mean. It was noted with great interest that only three hotels knew or were able to estimate their hot water consumption. This information was not available for the case study hotel either and had to be estimated by trial and error in the calibration simulations, as discussed earlier.

The questionnaire also asked the hotels to report what energy and water saving features were already in place. The list of items and the mean is shown in Table 7.6. The mean value was calculated by assigning 0-value for ‘no’ and 1 for ‘yes’. It is noted that all hotels reported having energy saving light bulbs covering 30-80% of total lighting.

Solid waste and recycling practices were also asked about in the survey but not enough information was provided to calculate means and make comparisons.

	Mean	Case Study	% difference
General			
Star rating	4.0	4	0.0%
Year built	1986.8	1984	-0.1%
No. of rooms	241.5	228	-5.6%
No. of beds	489.4	456	-6.8%
Total treated area, m^2	13545.0	7940.2	-6.4%
Average annual occupancy rate, %	60.3	73.8	22.4%
Guest nights sold annually	99219.0	99000	-0.2%
Facilities			
Restaurants, no. of	2.0	3	50.0%
Bars, no. of	2.0	4	100.0%
Swimming pools, total area, m^2	498.9	554	11.0%
Heated swimming pools, total area m^2	124.5	52.2	-58.1%
Lifts	5.7	4	-30.2%
Health club	0.8	yes (1)	22.2%
In-house laundry	0.6	yes (1)	57.1%
Conference rooms, total area m^2	906.9	722.4	-20.3%
Construction details			
Single-glazing w/ aluminium frame	0.3	yes (1)	
Double-glazing w/ aluminium frame	0.7	no (0)	
with thermal break	0.2	no (0)	

Uninsulated brick wall with plaster,	20.8	22	6.0%
Concrete slab roof, thickness, cm	22.4	20	-10.8%
insulated, insulation thickness, cm	7.0	no	
Annual energy consumption			
Electricity, kWh	2834195	2973210	4.9%
Load entitlement, kVA	940.00	1000	6.4%
Average annual load factor	0.53	0.42	-20.8%
Average annual power factor	0.96	1.00	4.4%
Heating fuel, litres	159414.4	204722	28.4%
Heat generated, kWh	2166424.7	2170053	0.2%
Solar hot water	0.2	no (0)	
Annual water consumption			
Total domestic water, m^3	45727.8	40715	-11.0%
Hot water, m^3	11333.3	11162[66]	-1.5%
Irrigation water, m^3	13813.8	13235	-4.2%
Volume of toilet flush, l/flush	6.9	8	16.4%
Flow rate of shower heads, l/min	8.9	8	1.4%
Flow rate of water taps, l/min	7.9	6	-24.3%
Energy/water saving features			
Energy saving light bulbs	1.0	yes (1)	
% total	50.0	39.2	-21.6%
Key card control	0.5	no (0)	
Occupancy sensors for lights	0.2	yes (1)	
Building Energy Management System	0.6	no (0)	
Special window shading devices	0.4	no (0)	
Grey water recycling	0.2	no (0)	
Dual-flush toilets	0.2	no (0)	
Water saving showerheads	0.6	no (0)	
Water saving taps	0.6	no (0)	
Waterless urinals	0.0	no (0)	
Automated water taps	0.3	yes (1)	
Annual consumption comparison parameters			
Electricity per guest night, kWh/GN	28.6	30.0	5.1%
Heating energy per guest night, kWh/GN	21.8	21.9	0.4%
Domestic water per guest night, l/GN	460.9	411.3	-10.8%
Total water per guest night, l/GN	600.1	544.9	-9.2%

Table 7.6 Summary of the hotel energy and water survey vs. the case study hotel

The most important part of Table 7.6 is the last section where the energy and water consumption was calculated per guest night. As pointed out earlier, the unit area comparison could not be accurately made within the survey due to ambiguities in the reported floor areas. Therefore, the comparison was done per guest night which is the most appropriate way to evaluate energy consumption in the context of this study since it was used throughout the thesis in distributing room income, SC energy and investment costs. It can subsequently be seen that both electricity and heat energy consumption of the case study hotel were within 6% of the survey mean. Water consumption in turn was within 10% of the survey mean.

Electricity consumption was further evaluated for all three hotel classes separately. The results are shown in Table 7.7. The derived consumption per guest night is ready for comparison to the

[66] Estimated by the author.

electricity consumption of hotels from the industry-wide dataset derived later in this chapter.

	Hotel category		
	3*	4*	5*
Average number of rooms	179	233	309
Average number of beds	380	462	618
Average annual occupancy rate, %	68.3	61.9	56.8
Average number of guest nights sold annually	88625	104435	109865
Electricity per guest night, kWh/GN	**20.7**	**40.4**	**47.9**

Table 7.7 Electricity consumption of the surveyed 3-, 4- and 5-star hotels

7.3.2 Summary of the energy and water consumption survey

It is subsequently concluded that the case study hotel fitted well into the small sample of hotels participating in the energy and water survey. It was comparable in terms of size, class, age, function, construction standards and most importantly in its annual energy and water consumption. Its heating energy consumption was 0.4% and electricity consumption 5.1% higher than the survey average. Water consumption was within 10% of the survey average. Therefore, the case study hotel represents an 'average' hotel among 3-, 4- and 5-star hotels. It was important to establish that the hotel indeed was an average in terms of its energy consumption because later in the thesis it was used as a basis to construct theoretical models of 3-, 4- and 5-star hotels. Subsequently, calibration against the case study hotel gave a good starting point for theoretical hotel modelling.

Finally, the survey hotels were compared to the entire hotel population of Cyprus in regards to their electricity consumption. The details are presented in the next section.

7.4 Hotel electricity consumption – analysis of industry-wide data

The purpose of the analysis of the industry-wide electricity use of hotels was to compare the consumption of the sample of hotels participating in the energy and water consumption survey to the industry averages so as to confirm that they indeed well represented hotels in their own categories among the entire hotel population. Electricity consumption figures from the local utility for the year 2007 were available for a total of 329 tourist accommodation establishments. The figures were consolidated and class averages were calculated on per-guest-night basis. It is noted that the only additional data available for the establishments was the number of rooms and beds; information such as floor areas, year built, annual operation periods, etc. were not obtainable. Occupation rates for the entire tourist accommodation population were available from the CTO (2008b; 2008c). Therefore, it was possible to calculate the mean number of guest nights in each class and derive electricity consumption per guest night for an industry average. It was not possible to do similar analysis for heating fuel and water consumption because such data was not available centrally as there are many water utilities, some hotels may use private boreholes and heating fuel is bought independently from numerous private vendors. However, electricity consumption is the central component in this study because it is hypothesised that climate change will increase cooling loads and subsequently electricity consumption in order to power AC. Therefore, industry-wide comparison of electricity use was considered sufficient for validating the sample of hotels participating in the energy and water consumption survey as typical Cypriot hotels.

A summary of the electricity consumption statistics are shown in Table 7.8. The table also displays the electricity costs for later discussion. For completeness, all accommodation types are included although the specific interest is in 3-, 4- and 5-star hotels. All 5-star, 96.6% of 4-star and 81.0% of 3-star hotels were included in the summary, thus providing a near-perfect[67] sample.

Accommodation type	No. of units	Gross no. of rooms	Annual room occu-pancy, %	Gross no. of beds	Annual bed occu-pancy, %	Annual guest nights	Load entitle-ment, kVA	Electr. cons. in 2007, MWh	Amount paid in 2007, €	Average unit price, €/kWh	Load entitlement, kVA		Electricity per guest night	
											per room	per bed	cons. kWh	price, €
1* Hotels	2	71	8.89	135	10.08	4967	200	274.6	€35 975	0.1310	2.8	1.5	55.3	7.24
2* Hotels	20	1155	28.60	2183	24.71	196888	2585	3387.0	€446 353	0.1318	2.2	1.2	17.2	2.27
3* Hotels	68	7699	42.17	14666	44.37	2375166	23347	40971.8	€5 296 777	0.1293	3.0	1.6	**17.3**	**2.23**
4* Hotels	57	10553	54.60	20937	53.04	4053319	40130	88687.4	€11 319 569	0.1276	3.8	1.9	**21.9**	**2.79**
5* Hotels	23	5400	54.58	10597	52.32	2023688	29420	83127.5	€10 541 694	0.1268	5.4	2.8	**41.1**	**5.21**
Hotel Apts Cat. A	67	6935	44.22	13711	53.61	2682920	26493	44443.1	€5 869 146	0.1321	3.8	1.9	16.6	2.19
Hotel Apts Cat. B	73	3229	28.03	6666	30.11	732603	10231	11306.5	€1 476 824	0.1306	3.2	1.5	15.4	2.02
Hotel Apts Cat. C	10	249	37.76	530	28.33	54804	1280	1202.4	€162 450	0.1351	5.1	2.4	21.9	2.96
Tourist Apts	9	363	21.04	850	18.76	58203	1791	2172.7	€276 135	0.1271	4.9	2.1	37.3	4.74
TOTAL:	**329**	**35654**	**46.10**	**70275**	**47.49**	**12182560**	**135476**	**275573.0**	**€35 424 924**	**AVG: 0.1286**	**3.8**	**1.9**	**22.6**	**2.91**

Table 7.8 Summary of the industry-wide hotel electricity consumption in 2007

Comparison of the annual per guest night electricity consumption between the sample of the hotel energy and water survey and the industry-wide dataset indicated the following:

- 3* hotels: 14.0 vs. 17.3 kWh per guest night (-19.1%)
- 4* hotels: 24.7 vs. 21.9 kWh per guest night (+12.8%)
- 5* hotels: 43.0 vs. 41.1 kWh per guest night (+4.6%)

It can be concluded that the 3-star hotels participating in the energy and water consumption survey demonstrated lower than industry standard per guest night electricity consumption. It is most certainly due to a higher occupancy rate that lowers per-guest-night consumption. Mean occupancy rate of 68.3% was derived from the survey for 3-star hotels, whereas the industry averages were 42.17% and 44.37% for gross room and gross bed rates respectively. Also, the 3-star hotels participating in the survey were above average in size (mean number of rooms of 179 vs. 103 industry-wide) subsequently benefitting from the economies of scale regarding per-guest-night electricity consumption. 4-star hotels participating in the survey reported above industry average electricity consumption. It is most likely due to the fact that all participating hotels had a year around operation, whereas many hotels particularly in the 4-star category are open for the summer season only, subsequently lowering the annual industry average of their electricity consumption. As for the 5-star hotels, their electricity consumption matched the best with the industry average. 5-star hotels are typically open year around and thus do not have a similar bias as 4-star hotels.

In summary, it can be concluded that the case study and the small sample of hotels

[67] *Near-perfect* here denotes a sample that includes over 90% of the population.

participating in the energy and water survey represent well the three classes of hotels of interest. The observed discrepancies are explainable and overall the match between the survey sample and the industry average was still within an acceptable variance of ±20%. The validation hierarchy is summarised in Fig. 7.29.

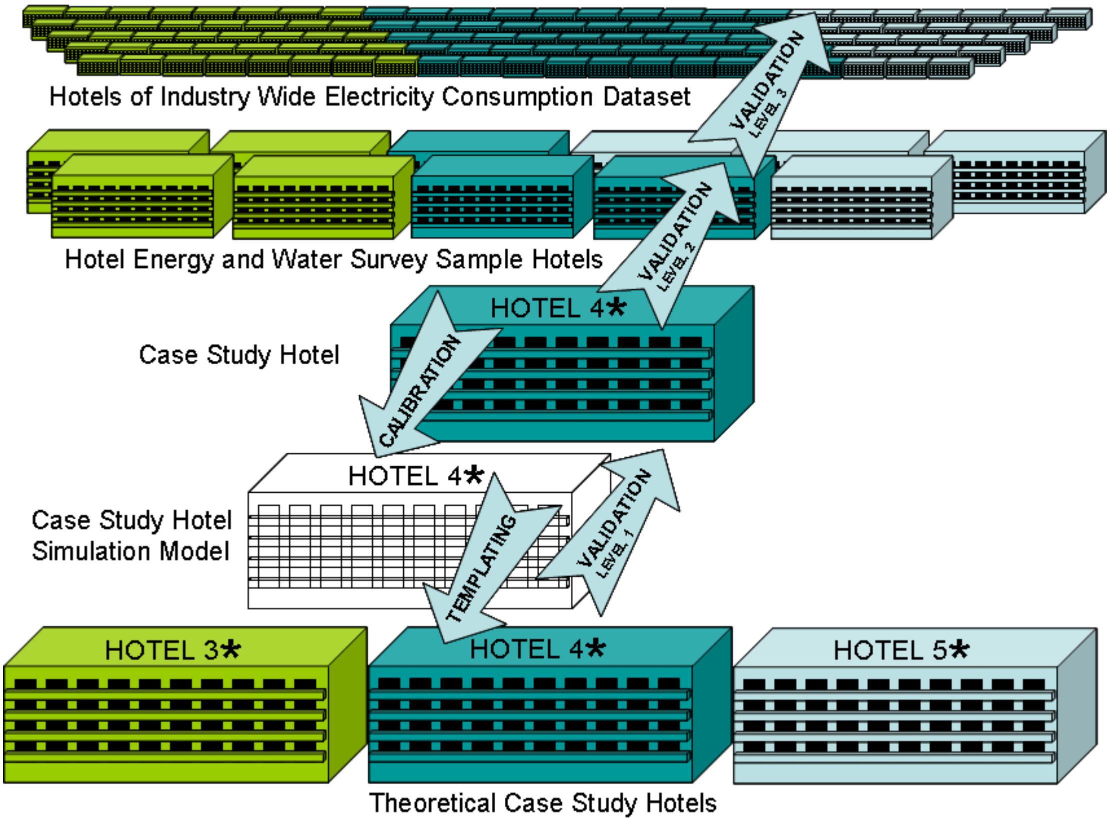


Figure 7.29 Three levels of validation of the theoretical hotel models

7.5 Conclusions

In this chapter field data was analysed. The results of the detailed energy audit of the case study hotel were presented and the sub-metered and carefully estimated electricity consumption was used to identify the major power centres of the hotel. Next, a thermal simulation model of the case study hotel was built to closely match the geometry and construction of the actual hotel. Schedules of usage patterns and occupation were prepared according to input from the hotel staff and personal observations. The case study hotel model was subsequently calibrated against the actual hotel to a very close match, within 5% of heating and electricity consumption.

The next step was to compare the case study hotel to a sample of hotels. The case study was found to be an 'average' hotel in terms of its energy consumption among 3-, 4- and 5-star hotels and a good representative of typical hotels in Cyprus. Further, the sample of surveyed hotels was found to represent well the average electricity consumption when compared industry-wide. Subsequently, it was concluded that the case study hotel can be used as a basis for preparing theoretical hotel models for 3-, 4- and 5-star hotels. Theoretical hotel models and thermal simulations to identify energy efficient-thermal renovation strategies are discussed in Chapter 9 but before that the hotel guest survey results are presented in the next chapter.

8 Chapter 8 – Analysis of field data: Social aspect

8.1 Introduction to the hotel guest survey

Hotel guest survey was conducted in order to provide input for the social aspect of the three-faceted 'techno-socio-economic' study. An estimate of an acceptable package holiday price increase was needed in order to fulfil Objective 4 for further use in the economic analysis. Therefore, the main interest was to quantify the guests' willingness to pay more for their holiday experience in Cyprus in the future when the climato-economic factors would force inflation on package holiday prices. In addition, the survey questionnaire was designed to offer building user feedback on thermal comfort preferences. The survey questionnaire is presented in Appendix VIII.

8.2 Conditions of data collection

For data collection, 139 hotels were approached by email and invited to participate in the survey, representing 61.2% of all hotels in Cyprus. The questionnaire was sent electronically with an invitation message and the hotel staff was asked to print it out, photocopy it in sufficient quantities and place it in the guestrooms before the arrival of new quests. A box was to be provided where the guests could return the form in complete anonymity. The survey was scheduled to run for summer 2006 and winter 2006-2007. Five hotels chose to participate. Three 4-star and two 3-star hotels provided a total of 458 completed questionnaire forms. 20 forms were rejected as they did not contain enough information and subsequently 438 forms were entered into the analysis.

Five out of the 139 hotels invited to participate in the survey represent 3.6% sample size in terms of the number of hotels contacted. It is more important, however, to look at the sample size in terms of the tourist population that the survey could have potentially reached. In 2006 2400919 tourists visited Cyprus out of which 1799570 between May and October (CTO, 2007) when the data was collected[68]. In order to determine how many of them were reached by the survey, a linear relationship is assumed between tourist beds and tourist arrivals. Hotels provide 58.3% of the tourist beds (Fig. 3.6). Therefore, 139 hotels represent 35.7% of all beds. Subsequently the population size became 857128 and the response rate 0.07%.

The participating hotels themselves were analysed to see how well they represented typical hotels in their respective classes. The two 3-star hotels had 60 rooms in one and 130 rooms in the other. Mean number of rooms in 3-star hotels was derived earlier at 103±67.24[69]. Therefore, the two participating hotels represented below and above average size 3-star hotels, both within the standard deviation. Similarly the 4-star hotels were found to have 198, 205 and 235 rooms respectively. The mean number of rooms in 4-star hotels was derived at 183±65.55, making the participating hotels above average in size and within the standard deviation. All hotels were officially rated and registered by the CTO, thus assuring that they provided the services expected from them. It was subsequently concluded that the participating hotels indeed represented typical

[68] Incidentally all participating hotels were catering for summer tourism only. Therefore no winter tourists were reached by the survey.
[69] Defined in Section 3.4.1.

hotels in their class and were unbiased in participating in the survey. In addition, they all catered for tourists from the UK, the main target group of the survey. UK tourists were selected as a target group because they are by far the largest homogenous group representing 53.1% of all tourist arrivals, whereas no other country reaches even the 10% mark. For completeness the tourism statistics are provided as follows: Scandinavians 9.6%, Russians 6%, Greeks 5.8%, Germans 5.7%, Be-Ne-Lux countries 2.3%, Switzerland and France 1.7% each, Ireland 1.5%, Israel 1.4%, Austria and USA 1.0% each, the other countries making up the remaining 9.2% with less than 1% each[70]. Also, the UK tourists were expected to respond positively to a survey by a British university conducted in their native language.

8.3 Sample size and the sampling strategy

Although the response rate was low, the sample size itself (438) was large for a robust statistical analysis. There was no bias in selecting the sample; the decision to participate in the survey was left to the hotels and was not influenced in any way. Moreover, all guests in the participating hotels had equal access to the survey questionnaire. If any bias were present, it could be that the subject matter of the survey was conceived more important by some hotel managers than others. If such a bias indeed existed, it was exactly the type of hotels or their management that this study was designed to guide in their efforts to reduce energy consumption and thus give them a competitive advantage.

The analysis of the questionnaire was done using SPSS[71] software (Nie *et al.*, 1968). The questionnaire can be seen in Appendix VIII.

8.4 Descriptive statistics of the survey

As the first undertaking in analysing the survey data, descriptive statistics were established and Table 8.1 was produced. It is noted that in the table complete statistics are shown only for ordinal and scale variables. Only sample size statistics are shown to nominal variables as they cannot be measured by the statistical instruments.

Parameters	N	Missing	Median	Mean	Std. Deviation	Min Value	Max Value	Sum
Q1 Country of residence	438	0	n/a	n/a	n/a	n/a	n/a	
Q2 Port of origin	438	0	n/a	n/a	n/a	n/a	n/a	
Q2_1 Distance travelled (km)	438	0	7000	6876.71	937.38	4600	18600	3012000
Q3 Size of party	438	0	2	2.66	1.10	1	5	1163
Q4 Duration of stay	437	1	14	10.98	3.73	1	28	4797
Q5 Classification of stay	436	2	n/a	n/a	n/a	n/a	n/a	

[70] 2007 statistics (CTO, 2008e) used here but the general distribution is similar every year.
[71] SPSS stands for the *Statistical Package for the Social Sciences*.

Q6 Purpose of visit	436	2	n/a	n/a	n/a	n/a	n/a	
Q7 Age	396	42	46	45.86	13.59	16	80	
Q8 Times in Cyprus (incl. this visit)	419	19	2	2.63	1.64	1	5	
Q9 Yearly income (€)	321	117	47500	47515.58	21033.82	5000	77500	
Q10 Price of holiday package (€)	378	60	1636	1921.99	1061.11	74	8820	726512
Q11 Money spent while in Cyprus (€)	383	55	1102	1376.96	1140.65	0	10292	527376
Q12 Annual holiday budget (€)	348	90	1	1.74	0.93	1	4	
Q12_1 Holiday budget monetary value (€)	299	139	5417	6619.20	4127.76	417	25833	
Q13 Holiday travel frequency	418	20	3	3.32	0.77	1	4	
Q14-1 Importance of price (1-5 Likert)	421	17	4	4.00	1.04	1	5	
Q14-2 Importance of climate	425	13	5	4.49	0.82	1	5	
Q14-3 Importance of nature	420	18	4	4.02	0.91	1	5	
Q14-4 Importance of culture	417	21	4	3.57	1.05	1	5	
Q14-5 Importance of food	422	16	4	4.28	0.82	1	5	
Q14-6 Importance of people	417	21	4	4.26	0.88	1	5	
Q14-7 Importance of green credentials	417	21	4	3.53	1.13	1	5	
Q15 Environmental consciousness	420	18	5	4.10	1.10	1	5	
Q16 AC/heating on/off at night	424	14	n/a	n/a	n/a	n/a	n/a	
Q16_1 AC on/off at night	426	12	1	0.74	0.44	0	1	
Q16_2 heating on/off at night	0	438	n/a	n/a	n/a	n/a	n/a	
Q17 Concerns about climate change	422	16	4	3.81	1.02	1	5	
Q18 Change in travel due to climate change	416	22	3	2.65	1.20	1	5	
Q19 Willingness to pay more	395	43	5	10.71	9.30	0	100	
Q20 Value for money	420	18	4	3.77	0.91	1	5	
Q21 Willingness to visit Cyprus again	425	13	1	0.96	0.20	0	1	
Hotel category	438	0	3	3.16	0.36	3	4	

Table 8.1 Descriptive statistics of the hotel guest survey from SPSS analysis

8.4.1 Summary of results for questions 1-13

Q1: UK tourists contributed 92.9% of the survey response followed by Germany at 2.5%. The remaining contributions came from Czech, Polish, Irish, Dutch and American tourists.

Q3-6: The mean travel party size was 2.66 persons with 10.98 days mean length of stay. Purpose of the visit was almost exclusively holidays; no business nor conference guests participated. 67.6% of guests were staying on bed & breakfast basis, 27.4% on half board and 3.9% on full board. Accommodation only was selected by three guests only.

Q7: The mean age of the participating guests was 45.86±13.59.

Q8: While about one third of the guests were first-time visitors, nearly one quarter had been in Cyprus for four or more times before. This finding is of vital importance as tourist loyalty will play a significant role in the future market segmentation of the Cypriot tourism product.

Q9: The mean total household income was €47515.58±€21033.82.

Q10-11: Price of the holiday package had a wide variation from €74 to €8820 with a mean at €1922±€1061 and money spent while in Cyprus at €1377±€1141. However, the figures needed to be adjusted to the travel party size and duration of stay in order to be comparable. Per person price allocation presented a problem because large travel parties such as families usually include children that may be staying for free in the hotel and may have paid a reduced airfare. However, for the analysis the total revenue from the holiday package price was divided by the total number of guests (both values under the sum column in Table 8.1) and further divided by the mean length of stay, thus yielding an average daily holiday price of €56.91. Similarly the money spent daily while in Cyprus was derived at €41.30.

Q12-13: Annual holiday budget measured in monthly salaries was used to calculate its monetary value. The mean annual holiday budget was derived at €6619.20±€4127.76, with a high standard deviation as can be expected. It was also of interest to see over how many trips abroad the annual holiday budget was distributed. Subsequently, the mean value for annual holidays abroad was 3.32±0.77 thus placing it between once or twice a year.

8.4.2 Environmental and thermal comfort variables

While the first half of the questionnaire was set to establish some general demographics and statistics regarding the guests, the latter half was to explore their attitudes about climate change, thermal comfort, etc. A series of questions mapped out the guests' selection criteria regarding holiday destinations. The importance of the parameters was measured in 1-5 Likert scale and yielded the results shown in Table 8.1. It can therefore be summarised that climate scored the highest importance at 4.49±0.82 followed by food at 4.28±0.82, people at 4.26±0.88, nature at 4.02±0.91, price at 4.00±1.04, cultural heritage at 3.57±1.05 and hotels' green credentials at 3.53±1.13. It is noted that all of the listed criteria were perceived 'important', i.e. scoring above 3 in the given scale.

The next three questions mapped out the guests' environmental attitudes. The first question in the series measured differences in the guests' environmental practices while at home and on holiday. As discussed earlier, it is generally observed that hotel guests are wasteful in their water and energy consumption. Therefore, it was out of curiosity that the question was set forth for the guests to answer. Surprisingly, the question scored high at 4.10±1.10 indicating that there was not much difference how such issues were viewed at home and on holiday. Some guests commented that the lack of infrastructure made for example recycling impossible, therefore indicating that there was a desire to do more than what was actually possible. (The guests' comments are discussed in detail later.)

The next question in the series was of particular interest in order to find out the guests' preferences regarding air-conditioning. 73.9% preferred AC at night. A typical reason given was that an open window did not provide the desired thermal comfort levels but also that an open window let in insects or undesired noise from outdoors. Security issues were also noted.

As for the guests' attitudes about climate change, it scored 3.81±1.02. Regarding to what degree they expected their holiday travel patterns to change due to climate change: 2.65±1.20. It can subsequently be concluded that the guests were somewhat concerned about climate change but did not anticipate much change in their holiday travel due to it.

8.4.3 Willingness to pay more in future, visit Cyprus again and value for money

The final group of questions dealt with the guests' willingness to pay more in the future, perceived value for money and willingness to visit Cyprus again. As seen in Fig. 8.1, 55.2% of guests were willing to pay up to 10% more, 32.7% 10-20%, 7.6% 20-30%, 0.8% 30-40%, 1.3% 50% and 0.3% double or more. The option for 0% was not originally given but some guests wrote down explicitly that they were not willing to pay any extra. Therefore in the analysis a category for 0% was created so as to reflect correctly on the mean and standard deviation. The mean thus became 10.71%±9.30%.

Another parameter expected to have high correlation with the willingness to pay more, namely *Value for money* yielded a score of 3.77±0.91 placing the mean in-between 'average' and 'good'.

The final question before space for additional comments asked the guests to indicate their willingness to visit Cyprus again. 96.0% were willing to return to Cyprus in the future.

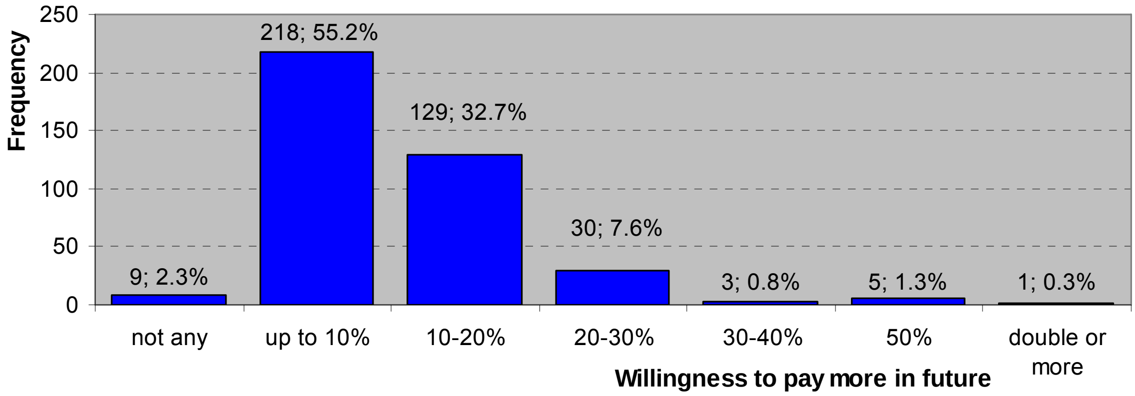


Figure 8.1 'Willingness to pay more in future' frequency and distribution

8.5 Correlation study and regression analysis

The primary research question set for the survey to answer was:

How much of an increase in package holiday prices can be passed onto tourists?

The question was approached by regression analysis where all variables correlated to the *Willingness to pay more* –variable were entered into a linear regression model generator in order to see how well they together could predict the willingness to pay more. Correlations were first identified by bivariate correlation testing using Kendall's correlation coefficients. Two-tailed significance testing was used and the significant correlations both at 0.01 and 0.05 level were noted. The correlations are discussed below in detail (Kendall's tau_b correlation coefficient given in parenthesis).

Weak correlations were identified to Age (0.088), Importance of food (-0.091), Price paid for the holiday package (-0.095), Preference with AC at night (-0.097), Annual holiday budget (-0.099), Willingness to visit Cyprus again (0.100), Concerns about climate change (0.101), Duration of stay (-0.104) and Money spent while in Cyprus (-0.107). Stronger correlation was found to Importance of price (-0.175), Value for money (0.193) and Size of travel party (-0.202). It is plausible to expect that tourists staying longer who had already paid more due to the length of their stay plus had spent more extra money while on the island would be less willing to pay more in the future; thus the negative correlations. It is worth mentioning here that the price of the holiday package by itself indicated correlation to the length of stay (0.354) and extra money spent while in Cyprus (0.433), although not as strong as one would expect, possibly due to the quite irregular holiday package pricing practises. Annual holiday budget, when measured in months of income showed a negative correlation to willingness to pay more. This would indicate that guests that spend a larger portion of their annual income for holidaying were less willing to pay more. Interestingly, the derived variable Holiday budget monetary value did not show any correlation to the willingness to pay more. The weak positive correlation with age suggested that with increasing age people were willing to pay more. Importance of food demonstrated a negative correlation to willingness to pay more. The correlation is difficult to interpret and may be due to coincidence. Preference with AC suggested that guests who chose to sleep with AC, would be less willing to pay more. This correlation may be due to coincidence as well. Positive correlation with concerns about climate change would indicate that with increasing concern people acknowledge the premiums that would have to be paid due to fuel or pollution taxation (aviation) and increasing operational costs at the destination, and would be willing to bear some of the added costs. Also, the willingness to visit Cyprus again positively influenced the guests' willingness to pay more.

The above twelve variables were entered into a linear regression model generator. Using stepwise regression only four variables met the entry criteria and were passed into the model. Summary of the statistical analysis is shown on Table 8.2. As a result, the model can explain only 15.5% of the willingness to pay more (adjusted R^2 of model 4).

Model	Predictors	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	Size of party	0.287	0.082	0.079	8.287
2	Size of party, Value for money	0.340	0.116	0.109	8.149
3	Size of party, Value for money, Importance of price	0.380	0.144	0.135	8.031
4	Size of party, Value for money, Importance of price, Duration of stay	0.409	0.167	0.155	7.936

Table 8.2 Linear stepwise regression for 'Willingness to pay more'

8.6 Willingness to pay more -variable dependency to annual income

Although no statistical significance was found between income and *Willingness to pay more*, it was of interest to see the distribution of replies among the income categories. As expected, the lowest income category chose primarily the 'up to 10%' option, as seen in Fig. 8.2. The highest willingness to pay more was found in the category €55000-69999 where 56.0% of the guests were willing to pay more than 10%. While there seemed to be generally increasing willingness to pay more with greater income, it was interesting to note that the highest level of no willingness at all to pay more was found in the highest income category. It would suggest that the wealthier guests are notoriously more demanding in terms of quality and value for money for their holiday experience.

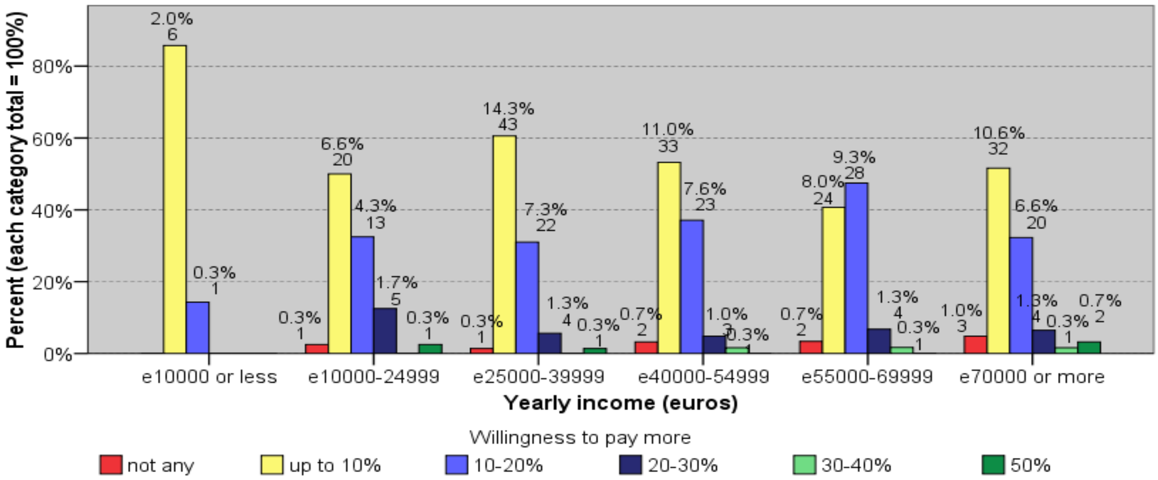


Figure 8.2 Willingness to pay more vs. yearly income in the hotel guest survey

8.7 Discussion on the qualitative questions of the survey questionnaire

The respondents were given several opportunities to write comments in the survey questionnaire. Many valuable insights were shared, some of them already mentioned earlier in the analysis. The guests' comments are briefly discussed below.

Guest preferences concerning using AC at night were asked. Besides ticking the preferred option, an opportunity was given to explain why. A wide range of reasons was reported. While many guests felt that the room simply was not comfortable enough to sleep without the use of AC, other reasons surfaced that almost made it look like some guests were forced to opt for AC. Insects coming from open windows were frequently reported as a problem as well as outdoor noise and reduced safety associated with open windows. Subsequently it appears that providing insect nets on windows would offer the option to sleep with an open window for more guests. Noise is an issue that depends on the location of the hotel or even the rooms within one hotel. There is no universal solution to it especially if it is traffic noise from a nearby street. Efforts should be taken to isolate noise generated in-house from the guestrooms. Examples include placing AC chillers or compressors and housekeeping traffic so that they are not in the direct vicinity of the guestrooms. Natural sounds such as the sea and birds from an open window were welcomed by the guests. As for security, ground floor rooms do have a disadvantage. A different window design can partially eliminate the problem, i.e. windows that have openings at a higher level rather than the typical sliding balcony door windows currently an industry standard. Also, louvered window covers can add security. Comments explaining why an open window was chosen were also worth noting. Some guests reported that the AC unit itself was too noisy to sleep with. While the outcome is desirable, inferior equipment most certainly causes overall guest dissatisfaction. Therefore, it is the premise of this study that technically assisted thermal comfort, when offered, should be of the highest standard. Related to the previous were general health concerns associated with AC. Some guests were concerned about the germs in the AC, although it was not clear whether they were referring to ACs in general or if there was something specific in the room to prompt such a comment. Other reasons for choosing an open window included health issues such as asthma, AC being too cold and drying up one's throat, wishes to reduce room CO_2 levels and even pitching in help for the hotel to reduce energy costs. Hybrid ways were also reported, such as running the AC for a short time before going to bed to cool down the room but then switching it off for the night. Some guests, however, felt that since the AC was included in the price, they may as well use it. This comment raises a question whether there should be a premium for using AC, thus offering a financial incentive to forgo it. Charging an extra fee for AC is practised in some lower category hotels and hotel apartments but not in higher class hotels. The author does not favour direct charges but rather proposes more innovative ways to offer incentives to guests to save energy and water. Such mechanisms are discussed later in the thesis.

The next open question was related to Q18 asking what changes, if any, people anticipated due to climate change in the future in their holiday travel. Less frequent and shorter distance was commonly reported but other comments of interest also surfaced. While the question was initially meant to measure change due to climate change as an ethical driver, some guests took it literally and looked at the changes in temperature and weather patterns and how those would affect their holiday choices. Reasons to that extent included travelling to cooler and more comfortable climates (could mean shorter or longer distance) or earlier/later in the year (spring/fall/winter) when it is cooler. As for Cyprus, choosing a location within the island, such as a mountain retreat instead of a beach resort was also considered. Such a comment is interesting indeed as originally tourism on the island started from mountain tourism and only later sifted to the coastal areas. Some guests were even hoping that due to climate change the UK would become warmer and drier therefore making it more attractive to stay closer to home for holidays. Another aspect that rose from the replies was the mode of transportation. More train, ferry and car holidays were anticipated. Mainland Europe was considered accessible with alternative modes of transportation, other than by air. Some guests were hoping for more efficient airplane technology and greener fuels so as to continue flying for holidays. Some were even ready to pay 'green taxes' on their air travel or aiming for carbon neutrality. Related to the above was added eco-awareness in the destination either by own choices such as not renting a car or by preferring eco-friendly destinations (hotels/countries). Finally, the financial aspect was also noted by some guests. It was suggested that shorter stays abroad would be expected so as to reduce costs. Some guests reported longer holidays in the UK. More camping holidays were also anticipated.

Q21 asking whether willing to visit Cyprus again had also space to explain why. As stated earlier, 96.0% of the guests considered visiting Cyprus again. It is interesting to see not only what makes them consider it but also why the remaining 4.0% would not want to come back. Enjoyable climate, nice scenery, beautiful sea and good beaches were frequently reported as reasons to come again. Also, an overwhelming number of guests reported how they found Cypriot people friendly, hospitable and helpful, tying back to the importance of local people. It was remarkable to see how many guests had made friends in Cyprus and therefore wanted to visit regularly. Also the fact that local people spoke English made communication problem-free for British tourists. Good local food was considered a reason by itself to come again. Some guests appreciated the relative safety in Cyprus making it possible to walk even late at night, although better street lighting was asked for. Some wanted to come back at springtime to see local wild flowers while others found great relief for their hay-fever symptoms. Cyprus was also seen as a convenient base for short trips to the Holy Land. Regarding value for money, holiday prices to Cyprus were still considered reasonable but any rise was expected to tip off the scales.

As for the reasons not to visit Cyprus again, they were mainly related to value for money. Some guests found Cyprus quite expensive, especially compared to the Canary Islands and Spain. Cyprus was said to be a poor value for money with a long flight and high cost for a mediocre experience. Overdevelopment was considered as a turnoff for some guests and others found Cyprus already too hot. Some guests stated that there were many other countries to visit and therefore they might not come back or that they only visited a destination once. While quite a few people thought that there were many places to see and visit within the island, some felt that there was not enough to do. This comment brings up a point that some places within the island are more suitable for young people offering mainly nightlife and as such may not cater for families or older guests. It highlights the importance of careful market segmentation.

Finally, space was provided for the guests to make any further comments they wanted. Wealth of useful comments was indeed received. The most worrying comment made was about the overdevelopment of the island. People were appalled by the endless villa constructions littering the coastal areas with frequent comparisons made to Spain and its touristic 'slums'. People were clearly concerned about the destruction of nature and the fact that small villages were turned into towns thus loosing their original character. One guest put it appropriately by stating that change must be planned. As for the environmental aspects, many commented that for example there was no system in place to recycle. Some were put off by the large number of rental scooters and buggies, 'unsustainable ego aspiration vehicles' as called by one guest, polluting the place in more than one way. Dual-flush toilets were proposed for water conservation. Better public transport options within the island were also requested. While some suggested fuel tax on aviation, others were not willing to pay any green premiums until the USA joined the burden sharing[72]. One guest noted that a hotel could never be truly 'green' because it cannot dictate to its guests how to behave; much the same conclusion as the premise of this thesis. Therefore, bypassing the end-user as much as possible is the way forward for hotels to save energy. Another guest commented that tourism maintained millions of jobs whereas war caused more environmental destruction; another comment that cannot be argued with and also in line with the overall philosophy of this thesis. It was interesting to see that some guests found the political situation in Cyprus depressing, i.e. the division and foreign occupation of the northern part of the island and wowed not to visit Cyprus again until the island was reunited.

8.8 Conclusions and findings

In this chapter the hotel guest survey was analysed in order to provide information for the econometric analysis that follows. The chapter was written in direct response to Objective 4. The hotel guest survey functioned well and was able to answer the primary research question:

How much of an increase in holiday package prices can be passed onto tourists?

The guests' willingness to pay more was derived at 10.71%±9.30%. It is therefore concluded that tourists cannot be relied on for paying a premium for coming to Cyprus. Consequently, it is of vital importance to test the cost-effectiveness of the proposed hotel renovation strategies to identify what can be done with such a small allowable increase in revenue.

Other interesting findings included that although people were concerned about climate change to a more than average degree (3.81 out of 5), they did not foresee significant changes in their holiday travel patterns due to it (2.65 out of 5). 62.8% of the guests had been to Cyprus before and 96.0% were willing to visit Cyprus again, proving the popularity of Cyprus as a holiday destination for first-time and return tourists alike. Therefore, the survey did not quantify any reduction in tourist flows to Cyprus in the future but it was concluded indirectly that the limited willingness to pay more would negatively impact tourist arrivals when the inflation of package holidays would surpass the acceptable threshold. Consequently, incremental reductions in hotel occupancy will be investigated in the econometric model while testing it for sensitivity.

Besides, the survey offered multifaceted insights into the environmental preferences of the guests. Of major importance to hotel renovations, it was discovered that night-time AC use could be reduced by providing insect nets on windows. Also, window designs that would allow partial opening at a higher level for ventilation while maintaining security and louvered window covers should be considered.

[72] The survey was run in 2006 before the USA ratified the Kyoto Protocol.

9 Chapter 9 – Theoretical case studies

9.1 Introduction

This chapter is written in direct response to fulfil Objective 3, i.e. *to evaluate by thermal simulation which energy-efficiency measures implemented in the form of building envelope improvements, thermal comfort criteria adjustments and introduction of renewable energy technology could be cost-effectively employed in existing hotel buildings in order to reduce their space conditioning energy costs at present or in the projected future climates of 2050 and 2090*. Thermal simulation models are constructed for theoretical case study hotels of 3-, 4- and 5-stars and various renovation strategies are tested first for energy-efficiency, later in the chapter for cost-efficiency (and ultimately in Chapter 10 for profitability). Future weather files are developed for use in predicting energy consumption due to climate change. Simulations to estimate the cooling output of solar air-conditioning are performed and solar AC is included in the renovation strategies. End-use energy prices are calculated as a function of crude oil price for use in sensitivity analysis. Package holiday price analysis is done in order to estimate room revenue. Subsequently the investment and SC energy costs are distributed per guest night and it is possible to observe the impacts of thermal renovation on room income.

9.2 Hotel types to be studied

As discussed earlier, 3-, 4- and 5-star hotels represent 71.8% of all hotels and 91.6% of hotel beds in Cyprus (Fig. 3.7). They are also more likely to embark on energy-efficiency upgrades than their lower-class counterparts. Therefore, it is justified to focus on 3-, 4- and 5-star hotels in the detailed analysis. It is noted, however, that from a technical point of view the suggested energy-efficiency improvements can be applied to other hotel and tourist accommodation types as well. Their economic viability, though, would have to be studied case-by-case, as smaller establishments may not have adequate revenue opportunities to finance major capital improvements or equipment upgrades such as solar AC.

A question arose how to best set up the hotel simulation models to serve as archetypes and to provide generalised, widely applicable results. A careful comparison of the requirements[73] for each hotel type indicated that their basic function in essence was the same. Additional amenities and levels of luxury may be present for the higher hotel classes but all three hotel classes are required to have the basic facilities for dining, conference/reception catering, indoor athletics and such. Subsequently, modelling each hotel class separately seemed neither necessary nor optimal. Secondly, purely theoretical hotel models would have lacked the ability to be validated against real, measured data. In order to avoid the above pitfalls, it was decided to slightly modify the case study hotel model and use it as a template for the theoretical analysis. The reasoning behind the slight modification was to eliminate any unique architectural details that may not be present in all hotels. One such a detail was the conservatory type windows in the administration offices. Also, the layout was made more compact and the basement space was not allowed to extend outside the footprint

[73] See Table 3.4 for the summary of requirements for 3-, 4- and 5-star hotels.

of the floors above. Only the main hotel building was included leaving out the bungalows as a unique additional feature of selected hotels only. Subsequently, a new simulation model was prepared using the actual space requirements, orientation and opening sizes of the case study hotel. Three floors of guestrooms were included in the model; one floor for each hotel class of interest. Guestrooms were sized so as to correspond to the minimum requirements set out for each class. The number of guestrooms was taken from the optimisation done in Chapter 3, i.e. 180 rooms for 5-star, 192 rooms for 4-star and 210 rooms for 3-star hotels. Assuming each hotel would utilise three floors to distribute the guestrooms, one 5-star hotel floor would have 60 rooms, 4-star floor 64 and 3-star floor 70 rooms. Subsequently, the guestroom floors in the theoretical model were sized to reflect such requirements.

In order to assure that the hotel models indeed represented realistic sizes, the area ratio for each class was calculated for comparison to industry standards. For a frame of reference, the real case study hotel had a ratio 66.9 m^2/guestroom in the main building as calculated in Chapter 7. The 5-star model yielded a ratio of 69.3, 4-star model 63.1 and 3-star model 57.0 m^2/guestroom. It is noted that the ratio was calculated by dividing the total gross area of the hotel by the number of guestrooms. As discussed before, resort hotels typically have 72, convention hotels 70 and urban business hotels 60 m^2/guestroom (Ransley and Ingram, 2004). It was previously established that the guestrooms in Cypriot hotels were smaller than their international counterparts. However, the estimated sizes of the theoretical hotel models were found to be very reasonable in comparison to the case study hotel and well within international average sizes.

Although the sizes of the common areas were optimised by varying the number of rooms in each hotel class, it is recognised that the intensity of use of the common spaces varies between classes. For example, a 5-star hotel is expected to have much more catering events than a 3-star hotel. Similarly, the gym and spa in 4- and 5-star hotels cater also for outside members, whereas in a 3-star hotel a small gym room is provided for guest use only. In addition, restaurant and bar activity is expected to be higher in higher class hotels. Therefore, while the space requirements may be the same, there are marked differences in their use. Subsequently, a hybrid thermal model was constructed so that scaling up or down the activity level was easy to do and could be adjusted as needed. Namely, the model was run for ‘normal’ (what was defined for 4-star hotels) activity but any scaling could be done on the results since the results were produced per space or room. The scaling factors of the individual heated and/or cooled spaces are shown in Table 9.1. It is noted that some spaces present in the case study hotel that were kept in the theoretical model were not included in the 3-star model. Higher class hotels tend to cater more business related facilities such as seminar and meeting rooms that may not be present in 3-star hotels. Hence they were eliminated from the 3-star results template. Similarly, shops are not required in 3-star hotels[74], so they were not included in the results. It is in this type of extreme flexibility in use that the benefits of the hybrid theoretical model became obvious. It is noted here that the selection of a typical 4-star hotel as a case study and subsequently establishing that it represented an ‘average’ among 3- to 5-star hotels was of great importance as it gave the required confidence to use a calibrated 4-star

[74] As per the requirements set forth on Table 3.4.

hotel model as a template and a scaling block for preparing models of 3- and 5-star hotels.

Space conditioned common areas	Activity fraction			Remarks
	5-star	4-star	3-star	
Restaurant	2	1	0.50	Scaled up for 5-star and down for 3-star hotels.
Seminar room	1	1	0	No seminar room in 3-star hotels.
Hair dressing	1	1	0	No hair dressing saloon in 3-star hotels.
Admin. offices	1	1	1	
Server room	1	1	1	
Gym	1	1	0.25	Scaled down for 3-star hotels.
Meeting room	1	1	0	No meeting room in 3-star hotels.
Chief eng. office	1	1	1	
Kids' club	1	1	1	
Staff restaurant	1	1	1	
Conference centre	1.5	1	0.25	Corresponds to 108 events per year for 5-star, 72 events for 4-star and 18 events (or more but smaller events) for 3-star hotels.
Breakfast cafeteria	1	1	1	
GM office	1	1	1	
Lobby shops	1	1	0	No lobby shops in 3-star hotels.
Lounge	1	1	1	
Bar	2	1	0.25	Scaled up for 5-star and down for 3-star hotels.
Bar kitchen	2	1	0.25	Scaled up for 5-star and down for 3-star hotels.
Reception & lobby	1	1	1	

Table 9.1 Activity fraction coefficients for 3-, 4- and 5-star hotels

As a result, a model capable of providing SC energy consumption for the various spaces of all three categories of hotels in one simulation was created. Total energy consumption could subsequently be calculated for each hotel class by using the activity fractions defined in Table 9.1 before adding up the energy consumption of the individual spaces. Guestroom energy consumption was added to the common areas consumption by first multiplying the consumption of one room by the total number of occupied rooms. Therefore, variance in occupancy was easily incorporated in the results rather than having to rerun the model for different occupancy rates separately. It was assumed that the common areas would have to be space conditioned regardless of occupancy variance within reasonable limits. It was recognised that the internal loads would vary due to occupancy but it was assumed that the SC needs were primarily dictated by the climate.

It is noted that the new layout was checked for neither functionality nor any circulation requirements. It is merely a regrouping of the space volumes as present in the case study hotel. The floor plans and a 3D view of the theoretical hotel can be seen in Figs. 9.1 to 9.4 and larger scale drawings in Appendix IX.

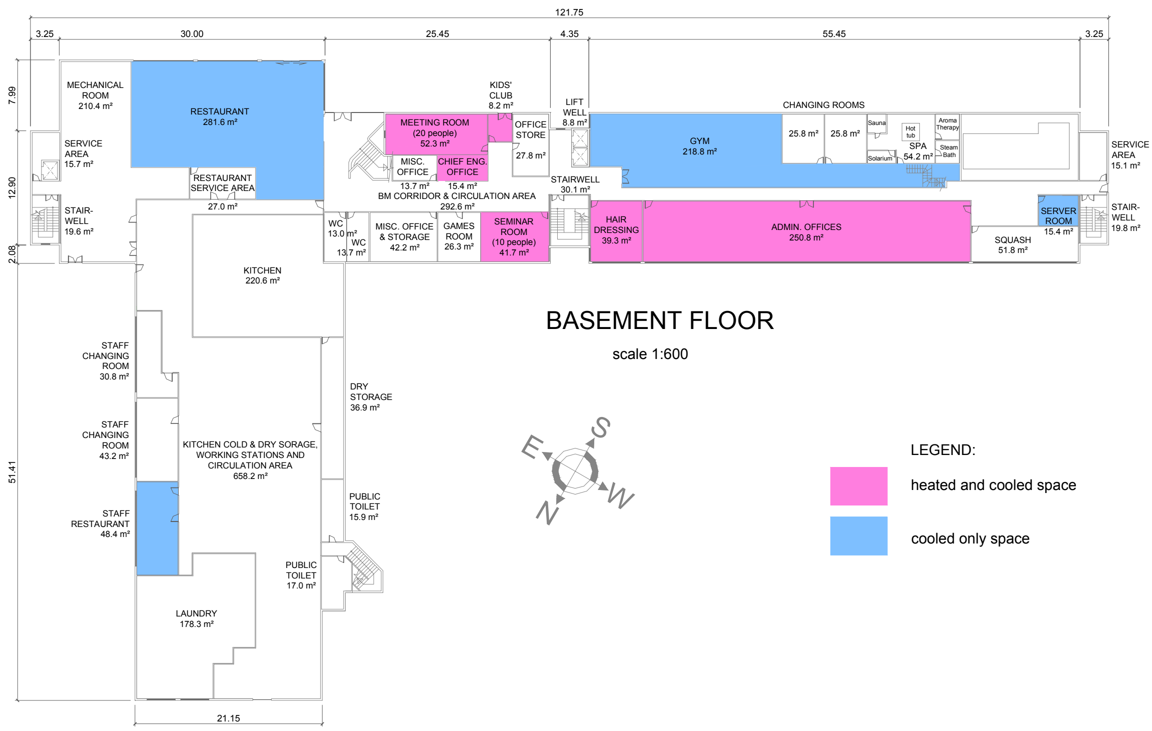


Figure 9.1 Basement floor plan of the theoretical hotel

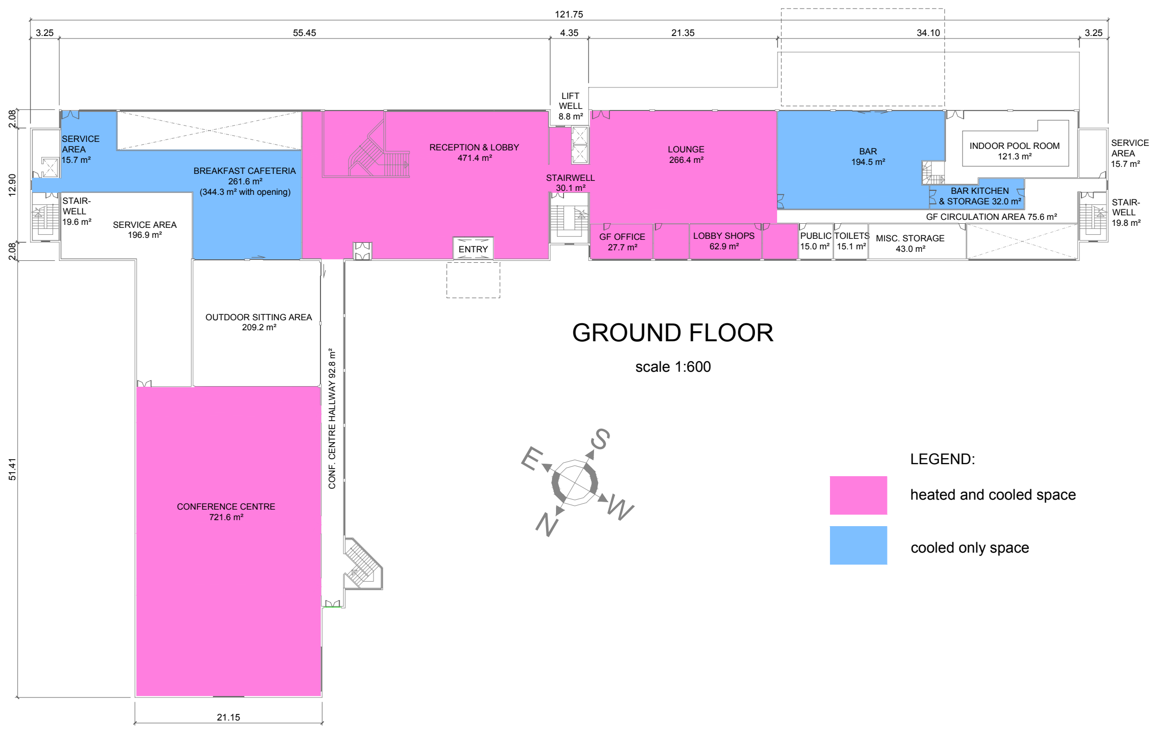


Figure 9.2 Ground floor plan of the theoretical hotel

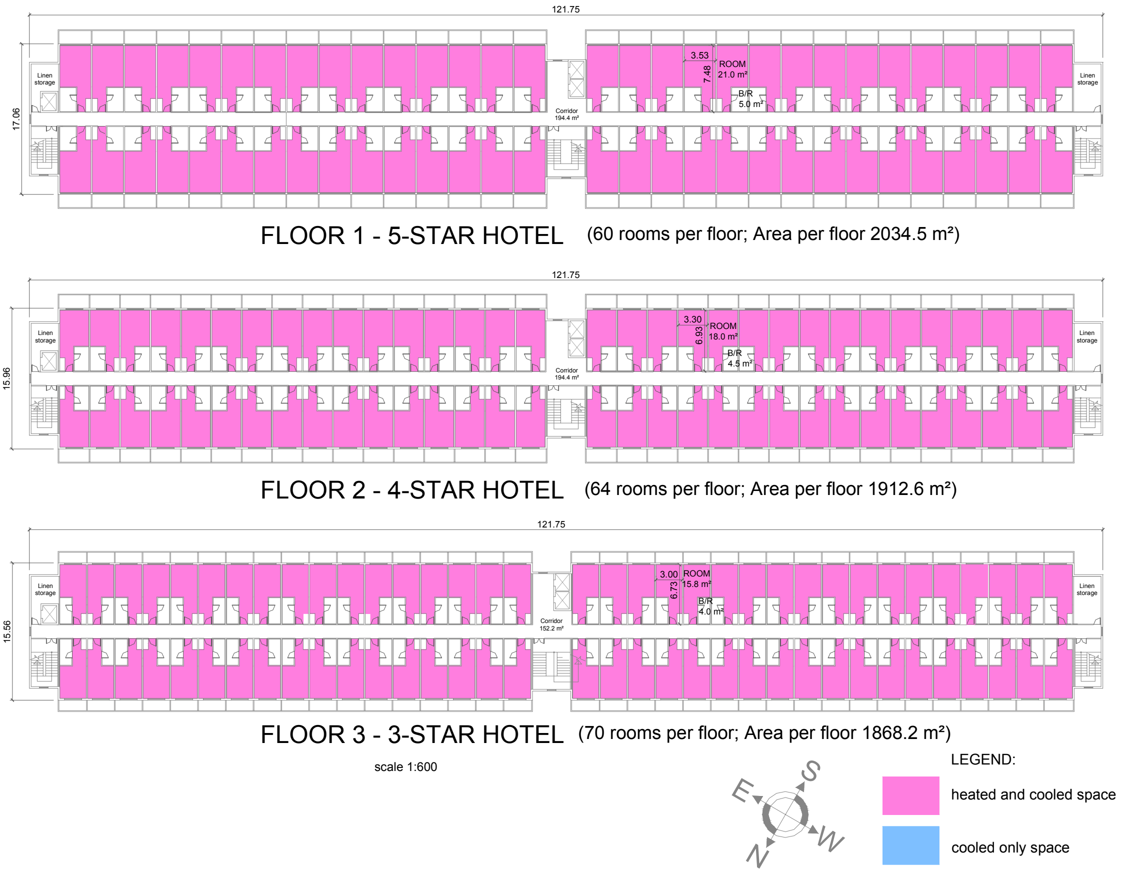


Figure 9.3 Floors 1-3 plan of the theoretical hotel

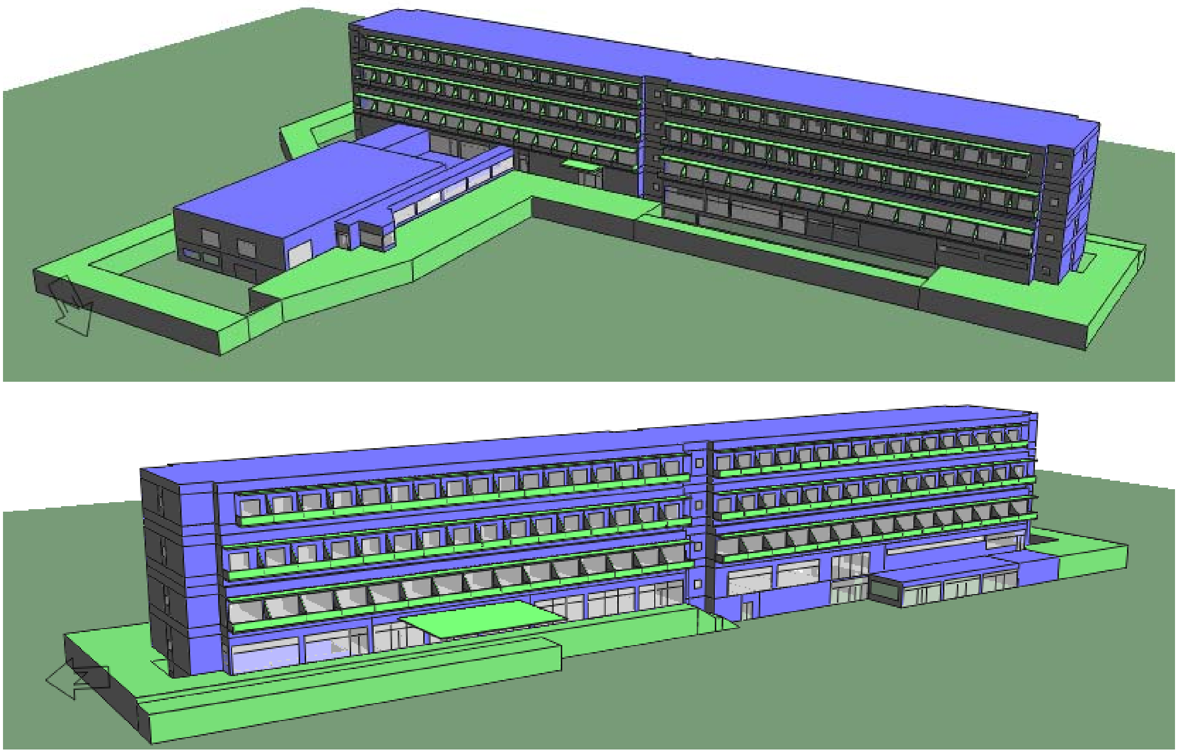


Figure 9.4 3D views of the theoretical hotel model

9.3 Testing the theoretical model

To test the robustness of the newly defined model, a simulation was run with the same usage pattern and internal gains as the case study model. In order to make a proper comparison, the model was modified by removing the guestroom floors of 3- and 5-star hotels and replacing them with 4-star floors, subsequently creating a theoretical version of the case study hotel. Three floors of full occupancy provided the equivalent of the 73.8% occupancy spread over four floors in the case study. Actual weather data for 2007 was used. As a result, the theoretical model was able to capture 91.9% of total electricity consumed (Fig. 9.5). Heating energy consumption was captured at 100% (Fig. 9.6). Although the total electricity and heating energy consumption were a good match, consumption on unit area basis showed some differences. It became obvious that the special architectural features eliminated, more compact layout and the fact that the basement footprint was kept identical to the upper floors (thus minimising exposed surfaces) did have an effect on the spaces in concern. An option to continue calibrating the theoretical case study model to better match the 'real' model by changing some input parameters existed. However, it was decided not to make any changes in the usage schedules for the reason that the original parameters were calibrated against real measured data in a model closely resembling the actual building and found to produce a very close match between the actual and measured energy consumption. Instead, it was decided to alter the infiltration rates so as to partially compensate for the differences in spaces where exposed surfaces were clearly reduced in the theoretical model due to the layout. After numerous rounds of iterations, the values shown in Table 9.2 were derived. It is noted though that some spaces still show a difference from the actual model. However, the variation averages out over the total treated area to an extremely close match at +2.5% for heating and +6.5% for cooling. The match is even closer for the total loads at -0.5% for heating and +4.7% for cooling. In view of the fact that the prime interest in this study was to compare the relative change due to renovation rather than absolute values in energy consumption, the baseline provided by the theoretical model was considered to be acceptable.

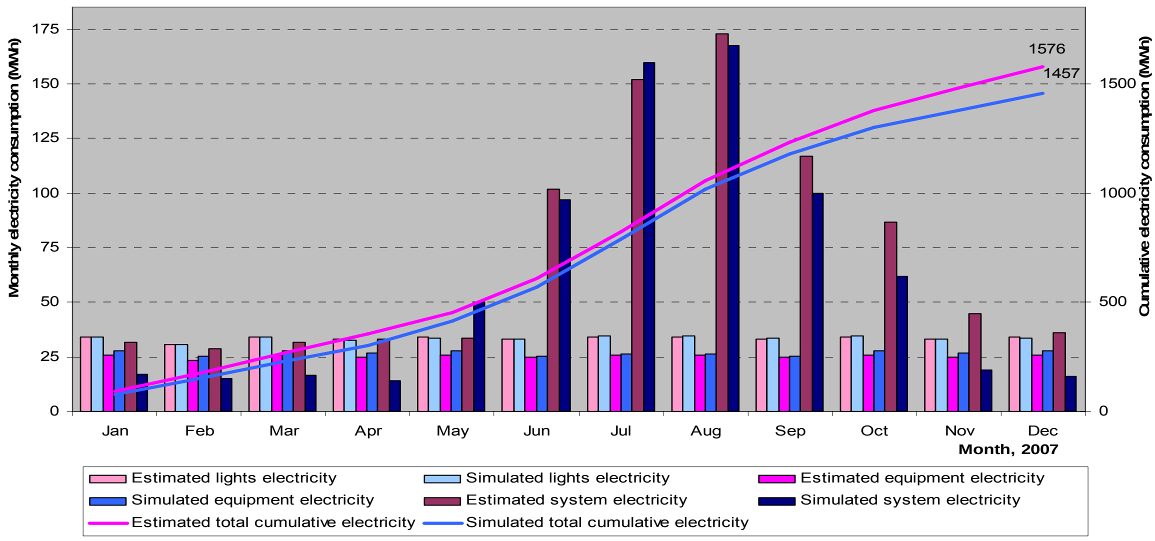


Figure 9.5 Estimated vs. simulated electricity consumption of the theoretical version of the case study hotel

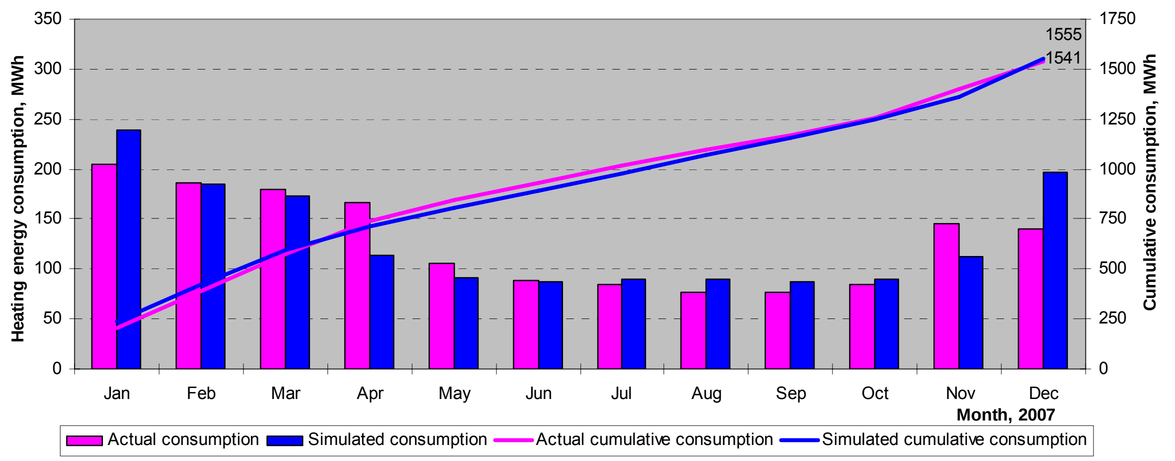


Figure 9.6 Estimated vs. simulated heating energy consumption of the theoretical version of the case study hotel

Heated/cooled space	Area, m²		Theoretical vs. actual hotel model comparison								% difference theor. vs. actual		Infiltration used in theor. model, ach
			Theoretical				Actual						
	Theor.	Actual	Total Heating, MWh	Heating, kWh/m²	Total Cooling, MWh	Cooling, kWh/m²	Total Heating, MWh	Heating, kWh/m²	Total Cooling, MWh	Cooling, kWh/m²	Heating	Cooling	
BM-restaurant	281.6	288.1	0.00	-	25.32	89.9	0.00	-	25.70	89.2		0.8%	0.50
BM-seminar room	41.7	44.1	0.08	1.9	0.29	6.9	0.09	1.9	0.32	7.3	-3.4%	-5.3%	0.90
BM-hair dressing	39.3	41.4	0.71	18.0	5.74	145.8	0.73	17.6	5.67	136.9	2.0%	6.5%	0.50
BM-admin. offices	250.8	288.0	2.72	10.8	24.81	98.9	4.44	15.4	26.56	92.2	-29.7%	7.3%	1.00
BM-server room	15.4	15.3	0.00	-	7.72	500.0	0.00	-	8.25	539.5		-7.3%	0.50
BM-gym	218.8	203.6	0.00	-	84.75	387.4	0.00	-	85.08	418.0		-7.3%	0.50
BM-meeting room	52.3	52.6	0.39	7.4	2.23	42.7	0.39	7.5	2.22	42.3	-0.4%	0.9%	0.50
BM-chief eng. office	15.4	15.6	0.05	3.0	0.97	63.4	0.05	3.1	1.06	67.7	-3.3%	-6.4%	0.55
BM-kids' club	8.2	7.5	0.05	5.9	1.42	172.5	0.05	6.6	1.30	173.6	-10.3%	-0.6%	3.70
BM-staff restaurant	48.4	49.7	0.00	-	8.75	180.8	0.00	-	9.03	181.6		-0.5%	0.50
GF-conf.centre	721.6	714.6	8.14	11.3	51.65	71.6	8.22	11.5	51.46	72.0	-1.9%	-0.6%	0.50
GF-breakfast cafeteria	344.3	335.5	0.00	-	31.57	91.7	0.00	0.0	32.69	97.4		-5.9%	1.00
GF-office	27.7	28.5	0.16	5.7	3.81	137.8	0.19	6.5	3.81	133.5	-11.9%	3.3%	1.20
GF-lobby shops	62.9	62.4	0.33	5.3	8.02	127.5	0.40	6.4	6.20	99.3	-17.8%	28.4%	0.50
GF-bar	206.5	215.2	0.00	-	90.07	436.1	0.00	-	81.69	379.6		14.9%	0.20
GF-bar kitchen	32.0	33.8	0.00	-	6.85	214.3	0.00	-	5.44	161.1		33.0%	1.50
GF-reception, lobby & lounge	737.8	761.8	58.71	79.6	308.28	417.9	57.26	75.2	277.99	364.9	5.9%	14.5%	0.50
Guestroom	18.0	18.3	2.29	127.6	3.06	170.6	2.30	126.0	2.99	163.5	1.3%	4.3%	0.50
Total hotel (138 rooms)	5582.3	5677.9	387.5	196.1	1084.9	194.3	389.3	191.3	1036.6	182.6			
										on unit area basis:	2.5%	6.5%	
										on total basis:	-0.5%	4.7%	

Table 9.2 Comparison of the unit area energy consumption of the actual case study hotel model and its theoretical version

9.4 Design strategies to be modelled

9.4.1 Orientation

The theoretical model was initially drawn to the same orientation as the case study hotel but it was also simulated in three other orientations by rotating the model 90° clockwise for each new orientation. The results of the simulations are shown in Table 9.3. It is seen that Orientation 2 scores the highest boilers and total energy consumption but chillers energy is 1.30% higher in Orientation 4, whereas boilers only 0.41% and total energy only 0.08% higher in Orientation 2. Therefore, since the main focus of this study is on cooling-related electricity consumption, Orientation 4 was selected as the most critical one and used in all subsequent simulations.

Energy (MWh)	Orientation			
	1 (original) 150° east of north	**2** 240° east of north	**3** 30° west of north	**4** 120° west of north
Boilers, MWh	2038.7	2070.9	2055.5	2062.4
Chillers, MWh	353.3	369.4	348.7	374.2
Total, MWh	3502.6	3558.6	3513.7	3555.9

Table 9.3 Comparison of orientations regarding boilers, chillers and total energy consumption

9.4.2 Building envelope upgrade and thermal comfort strategies

Baseline performance was established by using the building elements described in Table 7.5. Building envelope improvements were modelled one at a time to see their impact on energy consumption. At the end they were modelled together and their combined impact was evaluated. The following strategies were studied:

- external wall insulation (10 cm extruded polystyrene with mortar render; U=0.30 W/m^{2}K)[75]
- window replacement (high-performance double-glazed with uPVC frame; U=1.20 W/m^{2}K)
- window replacement (conventional double-glazed with aluminium frame; U=3.00 W/m^{2}K)
- wall insulation and high-performance window replacement combined (U-values as above)
- heating and cooling temperature criteria according to Category II (T_H=20°C and T_C= 26°C from Table 3.5)
- heating and cooling temperature criteria according to Category III (T_H=18°C for guestrooms, T_H=19°C for other spaces and T_C= 27°C for all spaces from Table 3.5)
- ventilation criteria according to Category III (from Tables 3.6-3.7; changes in the individual space ventilation are shown in Table 9.4)
- all combined (external wall insulation, high-performance window replacement, heating/cooling temperature criteria Category III and ventilation criteria Category III)

[75] Roof insulation applied to restaurant and conference centre hallway, U=0.30 W/m^{2}K.

Ventilated space	Ventilation rate, l/s	
	Original	New
Guestroom	25.0	18.5
Reception, lobby & lounge	1000.0	252.0
Bar	2460.0	249.0
Breakfast cafeteria	1500.0	432.0
Restaurant	1100.0	324.0
Conf. centre (day events)	1700.0	560.0
Conf. centre (night events)	8500.0	2800.0
Meeting room	200.0	112.0
Seminar room	100.0	56.0
Administration offices	440.0	240.0

Table 9.4 Ventilation rate comparison of the original and new criteria

Wall insulation thickness was considered carefully and only one thickness was included in the final analysis. It was observed that thicknesses less than 10 cm would still require the same amount of labour in installation whereas the difference in material price would not be significant. On the other hand, insulation thicknesses greater than 10 cm would require extra detailing especially around windows and other openings, thus adding to installation costs. In addition, with 10 cm EPS insulation a U-value of 0.30 W/m^{2}K was achievable, much less than the current building code requirement of 0.85 W/m^{2}K. The regulations are expected to be tightened gradually. Therefore, no major renovation project should be undertaken just to meet the current regulations but rather to optimise the costs and benefits associated with the specific item to be renovated. Therefore, 10 cm was taken as a rational insulation thickness and used in the simulations and cost-benefit analysis. The simulation results indicated that a 17.7% reduction in heating, 0.1% increase in cooling and 6.2% net reduction in SC loads were expected due to external insulation. It is interesting to note that the cooling load did not benefit from wall insulation. Wall insulation reduces the building fabric's ability to expel excess heat at night and highlights the need for controlled ventilation strategies, such as nocturnal or free cooling, rather than relying on uncontrolled infiltration and conductance through walls.

The other strategies were simulated as well and the complete results are shown in Tables 9.7 and 9.8 together with simulations in future climates.

9.5 Baseline energy consumption

In order to fulfil Objective 2, the baseline SC energy consumption of 3-, 4- and 5-star hotels was derived and is shown in Table 9.5. Baselines of total energy and electricity consumption were also defined so as to enable comparison to baseline figures derived from other studies as presented in Chapter 3. It is noted that the total energy and electricity consumption figures were calculated by adding consumption that was not included in the thermal simulation model. Therefore, the energy consumption of items such as kitchen and catering, laundry, outdoor lighting and miscellaneous pumps[76] were added to the energy consumption derived from thermal simulations for a grand total. Downscaling for 3-star and scaling up for 5-star hotels were used according to their typical function pattern. The results are shown in Table 9.6.

SC energy consumption	5-star	4-star	3-star
Heating, kWh/m^2	37.3	39.3	37.1
Heating, kWh/GN	7.4	6.7	6.9
Cooling, kWh/m^2	33.9	34.6	27.4
Cooling, kWh/GN	6.7	5.9	5.1
Total space conditioning, kWh/m^2	71.2	73.9	64.4
Total space conditioning, kWh/GN	14.1	12.5	12.1

Table 9.5 Baseline SC energy consumption of 3-, 4- and 5-star hotels

Energy consumption	5-star	4-star	3-star
Electricity, kWh/m^2	172.6	163.9	114.8
Electricity, kWh/GN	34.1	27.8	21.5
Total energy, kWh/m^2	371.6	346.4	286.7
Total energy, kWh/GN	73.5	58.7	53.7

Table 9.6 Baseline energy consumption of 3-, 4- and 5-star hotels

From comparison to the baseline energy consumption presented in Table 3.1 it can be noted that energy consumption of hotels has indeed increased since the mid-80s that the published baseline figures correspond to. Approximately 30% increase in total energy and 22% in electricity consumption for 5-star, 6% & 54% respectively for 4-star and 49% & 53% for 3-star hotels on guest night basis can be observed. It can subsequently be concluded that the energy consumption of Cypriot hotels has increased over the past 25 years and it may well largely be due to climate change that has already affected cooling needs in particular.

9.6 Future weather scenario development

Central to the objectives of this thesis was to develop a methodology that allows estimation of SC energy costs of Cypriot hotels in future climates. Of particular interest was to observe the effects of climate change and energy prices in hotel operations. 2050s and 2090s were selected as the future time periods for which climate data was desired. The reason why the latter half of the century was selected was to maximise the effects of the weather changes. In preliminary analysis it was noted that changes during the first half of the century were not significant enough compared to recently measured weather data, the reason being that the predictions for the standard IPCC time period of 2010-2039 are already observable.

Once the time periods were fixed a question arouse how to generate weather data for them. Weather morphing techniques were reviewed and considered. In particular, the suitability of a method proposed by Belcher *et. al.* (2005) was studied in detail. The authors outline a weather

[76] Pumps related to HVAC were included in the thermal model but other pumps such as pool, domestic water circulation, sewage, irrigation, etc. pumps were not.

morphing method where present-day observed weather data is combined with results from future climate models to produce weather time series that encapsulate the average weather conditions of future climate scenarios whilst preserving realistic weather sequences. The concept of 'realistic weather sequence' presented some problems as the described morphing technique is designed to amplify temperatures while keeping the weather pattern constant. However, the predictions for Cyprus specifically indicate that heat waves will last longer and that even the seasonal schedules may be shifted. Therefore, using the described morphing method for weather data generation did not appear feasible.

Another way to generate future weather files was to extract data directly from a climate model. As a first attempt, the applicability of the PRUDENCE (Christensen, 2001-2004; Christensen *et al.*, 2005) database was studied. PRUDENCE (*Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects*) looked promising but ultimately failed to provide the necessary data. The online database did not include suitable regional runs for the Eastern Mediterranean and although in theory any regional data should have been available upon request from the webmaster, lack of resources made it impossible to obtain (personal correspondence with the project coordinator). The continuation project ENSEMBLES (van der Linden, 2009) was still in progress at the time when weather data were needed and was therefore not considered further. Instead, GFDL (Geophysical Fluid Dynamics Laboratory, 2010) climate model data available in the public domain was reviewed and data for several scenarios were downloaded. Data download point was selected by coordinates for Larnaca, Cyprus. However, the weather data thus derived turned out to be of limited value as the model did not provide enough detail. The resolution of the grid, 2.5° longitude by 2.0° latitude, was too crude to even capture the island of Cyprus as a land mass, as seen in Fig. 9.7.

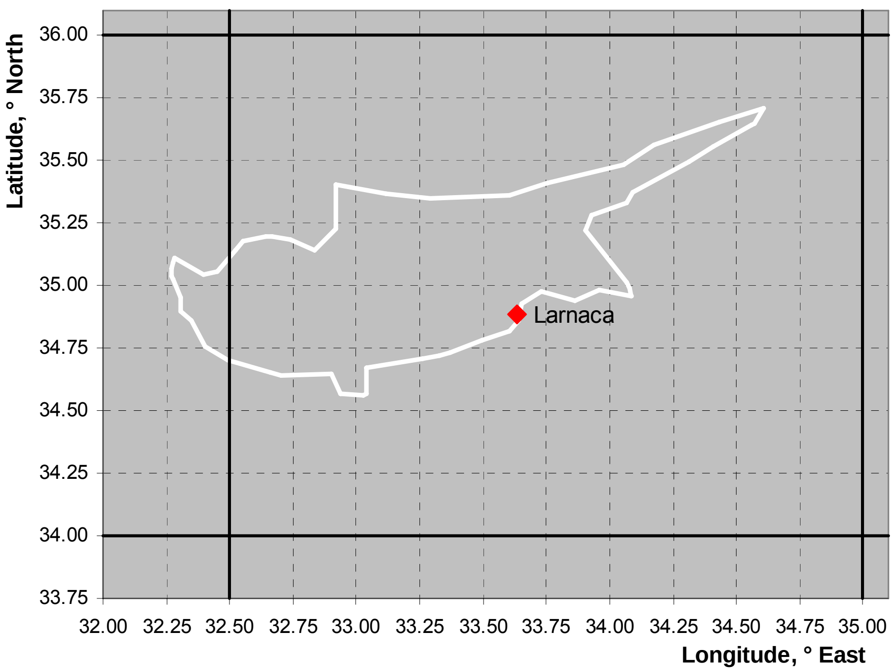


Figure 9.7 Geographical position of the island of Cyprus in relation to the GFDL climate model grid

Therefore, the only option to generate the necessary future weather files was to seek for purpose-run climate model simulations for the island of Cyprus. The Cyprus Institute (2011) actively conducting climate change research in the Eastern Mediterranean area was approached. They agreed to make special customised runs for years 2050 and 2090 using PRECIS (Met Office, 2010) regional climate model.

9.6.1 Description of the PRECIS RCM and the customised runs

The PRECIS (*Providing REgional Climates for Impacts Studies*) climate model was developed by the Hadley Centre using their regional climate model as a base (Met Office, 2010). It is a model modified to run on a PC under Linux with a simple user interface so that experiments can easily be set up over any region. Earlier runs using RACMO2 regional climate model (Lenderink, 2007) developed at KNMI in the Netherlands within the framework of the EU ENSEMBLES project (van der Linden, 2009) and PRECIS for the island of Cyprus for the 21st century had indicated that 2-3 months more tropical nights (T_{min}>25°C), 1-2 months more summer days (T_{max}>34°C), 1-2 days longer cold spells (annual count of days with at least 6 consecutive days when T_{min}<10th percentile), 16-46% less rain and approximately one month longer consecutive dry days were to be expected while the daily rainfall intensity was to remain unchanged (Hadjinicolaou *et al.*, 2007). The coastal areas would be particularly prone to increased night-time temperatures, whereas the inland would suffer from higher daytime temperatures. The results were indicative that significant changes in the energy used for thermal comfort would be expected on the island.

The emission scenario SRES A1B (IPCC, 2007) was used for the customised runs. In brief, the A1B scenario represents rapid economic growth with a balanced technological emphasis, meaning that no particular energy source is heavily relied on but rather that similar improvement rates apply to all energy supply and end-use technologies, fossil fuel and renewable alike. In the A1 storyline rapid economic growth is coupled with global population peaking in mid-century and declining thereafter, and rapid introduction of new and more efficient technologies. Major underlying themes such as convergence among regions, capacity building and increased cultural and social interactions with a substantial reduction in regional differences in per-capita income are built into the scenario. Three groups within the A1 family are distinguished by their technological emphasis: fossil-intensive (A1FI), non-fossil energy sources (A1T) or a balance across all sources (A1B).

A question may arise: why this particular emissions scenario and not some other? Without going into details regarding the other scenarios it is noted that the balanced growth within the A1 family is perceived as a reasonable compromise between the fossil-intensive and alternative energy options. As for the A2 scenario based on continuously increasing population, regional economic development and growth, and slower fragmented technological change, it is looking less likely that the current fossil fuel prices can sustain such a trend. B1 scenario on the other hand seems too optimistic in assuming that the world would converge not only towards a declining global population but also towards a service and information economy with reductions in material intensity while introducing clean and resource-efficient technologies. Similarly, B2 scenario assuming an ever-increasing population (albeit at a slower rate than in A2) builds in a tendency towards environmental protection and social equity focused on local and regional levels rather than global. Therefore, the choice made in this study was to place the emissions scenario assumptions somewhere between the 'business as usual' and the 'united sustainable planet' extremes and the A1B scenario seemed to fit in well and is in sync with the overall premise of the thesis.

9.6.2 Output from the PRECIS customised runs

The geographical setup of the customised runs is shown in Fig. 9.8. It is noted that continental coastal areas of Turkey and the Mediterranean coastline of the Arabian Peninsula were included in the model as they influence the climate of Cyprus.

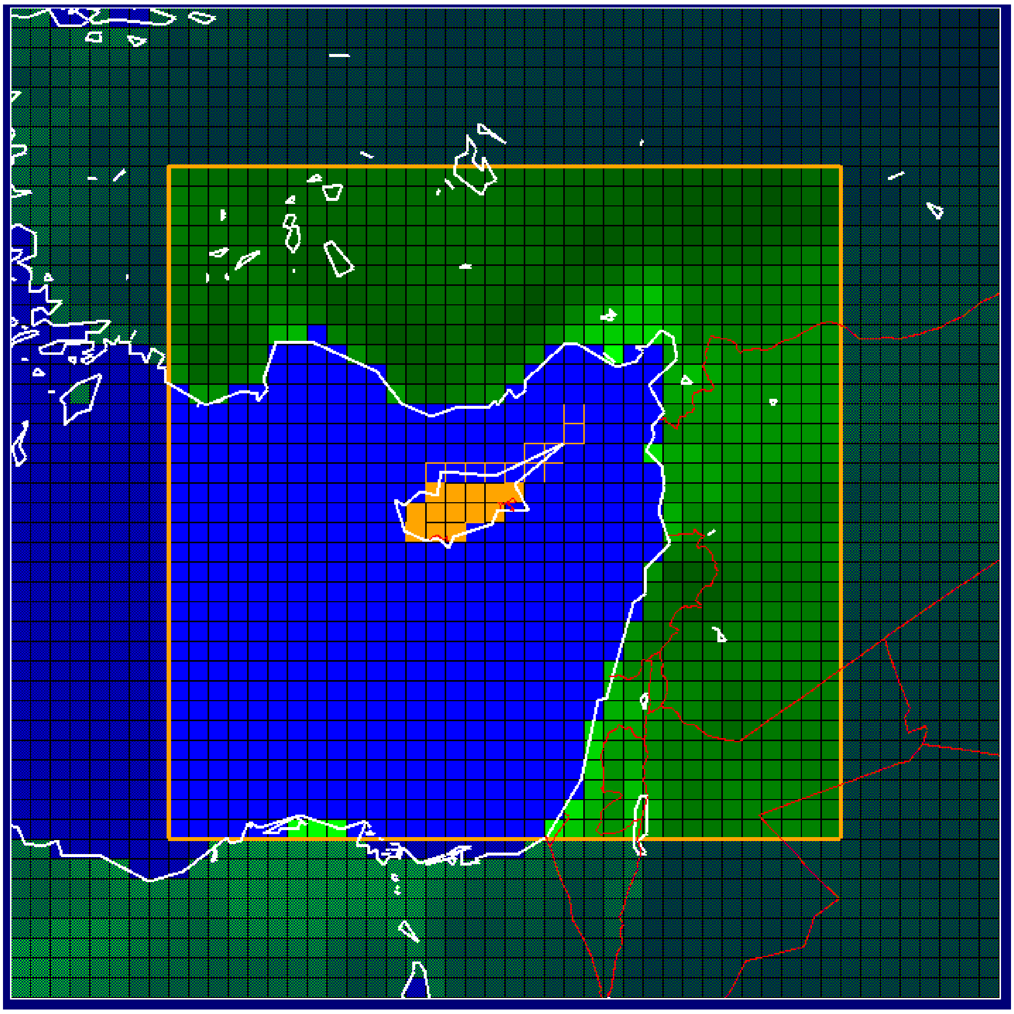


Figure 9.8 Map showing the geographical extents and the grid used for the PRECIS runs

The resolution of the grid used is 25x25 km.

The flowing output was obtained from the PRECIS model runs: Net Down SW[77] Flux, Total Down SW Flux, Total Cloud Fraction, Wind U (at 10 m), Wind V (at 10 m), Temperature (at 1.5 m), Specific Humidity (at 1.5 m), Relative Humidity (at 1.5m), Wind Speed (at 10 m), Total Precipitation and Atmospheric Pressure (at MSL). The output was asked for at hourly intervals for an entire year.

[77] SW stands for shortwave radiation that is the principal portion of the solar spectrum spanning approx. 300-4000 nm in the electromagnetic spectrum (NREL, 2009).

To obtain solar irradiation in a format required for thermal simulations, some data manipulation was necessary. First of all, it was established that *'total down shortwave flux'* was the sum of direct and diffuse solar irradiation incident on a surface, also called global irradiation (NREL, 2009). However, diffuse solar irradiation was not readily available. Therefore, it had to be calculated independently. The same method by Jacovides *et al*. (2006) described earlier for the calibration model diffuse irradiation data generation was used. Subsequently, d*irect horizontal* irradiation became easily obtainable as the difference between global and diffuse irradiation. *Direct normal* irradiation was derived from simple geometrical relationship between the normal and horizontal components.

As seen in Figs. 9.9 to 9.11, the solar irradiation distribution and intensity are not expected to change much in the future. However, large temperature increases are anticipated, as shown in a comparison chart of 1993 baseline, 2050 and 2090 monthly minimum and maximum temperatures in Fig. 9.12. The following observations can be made:

- monthly maximum and minimum temperatures are expected to rise up to 5°C from the 1993 baseline by the end of the 21st century,
- the period with mean maximum temperatures higher than 35°C is getting longer; from approx. one month in 1993 to over 2.5 months in 2090,
- mean minimum temperatures peak at >25°C (tropical nights phenomenon) and
- warmer spring and autumn temperatures are to be anticipated, seen as humps in the curve in March and November, possibly meaning extended cooling season in poorly adapted buildings or shorter heating season depending on the building use.

It is therefore concluded that significant changes in the energy consumption of buildings can be expected during the latter half of the century.

The statistical significance of the climate model findings regarding temperature increase was tested. The non-parametric Wilcoxon 2-sample test (Hadjinicolaou *et al.*, 2011) for the temperature difference was applied between the pairs of the three datasets[78] to quantify their difference and statistical significance (at 95% confidence level, i.e. with an estimated 5% likelihood of the value being below the lower end of the range or above the upper end of the range). The results are as follows:

	Temperature difference, °C	Low	High	P-value
2050 minus 1999	+1.50	+1.26	+1.74	<2.2e-16
2090 minus 1999	+3.12	+2.88	+3.77	<2.2e-16

Subsequently, according to the PRECIS projections T_{max} will increase 1.5°C and 3.1°C by the mid and end of the century compared to the late 1990s. The figures are statistically significant[79] at 95% level and according to the IPCC Working Group I (Solomon *et al.*, 2007) can be characterised

[78] The three datasets compared were 1999, the weather year used in the thermal simulations for 'present' weather conditions, 2050 and 2090 as predicted by the climate model.
[79] The uncertainty estimation was based only on the statistical test for temperature difference of the particular datasets and did not consider other types of uncertainties such as GHG emissions, driving global model, etc.

as ‘extremely likely’. Therefore, one high-confidence probability level estimate was used in this thesis for future weather generation unlike other studies with different aims that have chosen to compare weather predictions with several probabilities using readily available data from the UKCP09 climate projection database (UKCIP, 2012).

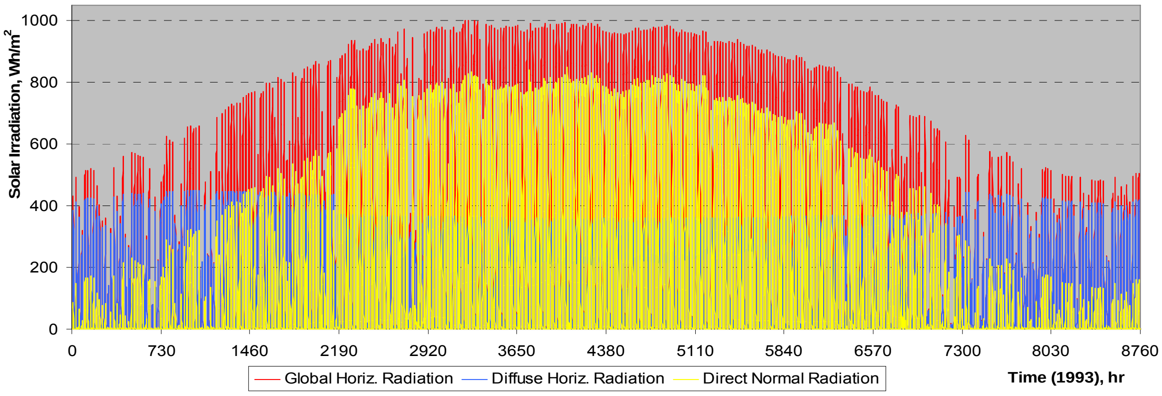


Figure 9.9 Global Horizontal, Diffuse Horizontal and Direct Normal Solar Irradiation for Larnaca, Cyprus for 1993 baseline from the PRECIS climate model

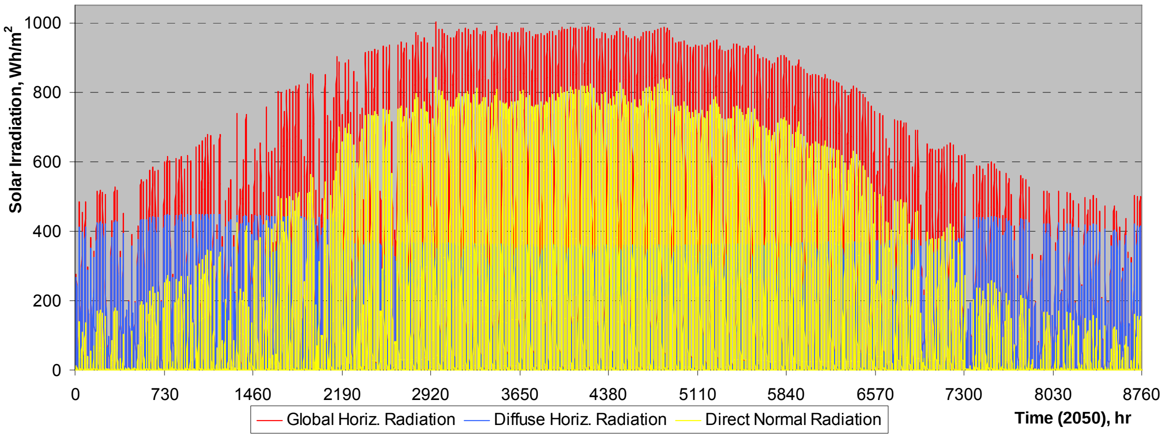


Figure 9.10 Global Horizontal, Diffuse Horizontal and Direct Normal Solar Irradiation for Larnaca, Cyprus for 2050 from the PRECIS climate model

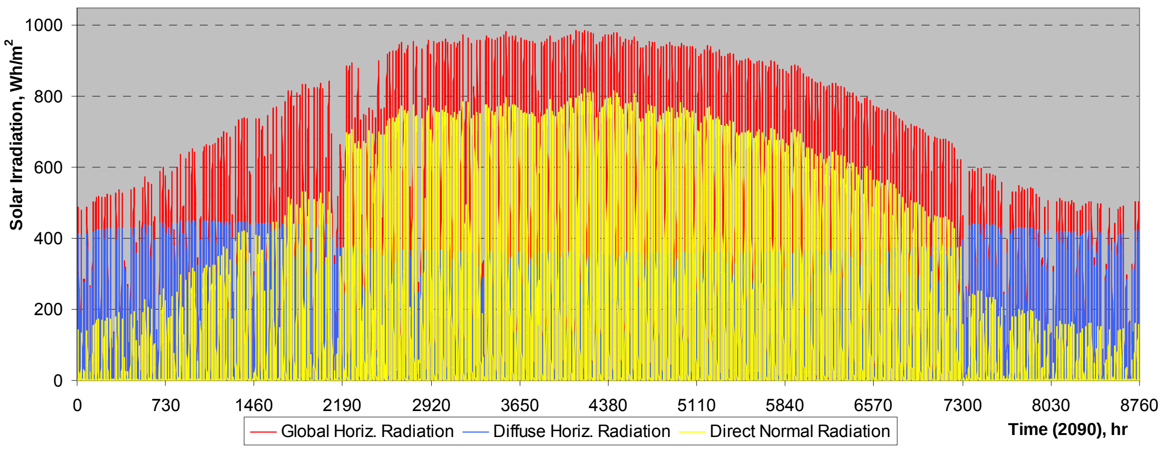


Figure 9.11 Global Horizontal, Diffuse Horizontal and Direct Normal Solar Irradiation for Larnaca, Cyprus for 2090 from the PRECIS climate model

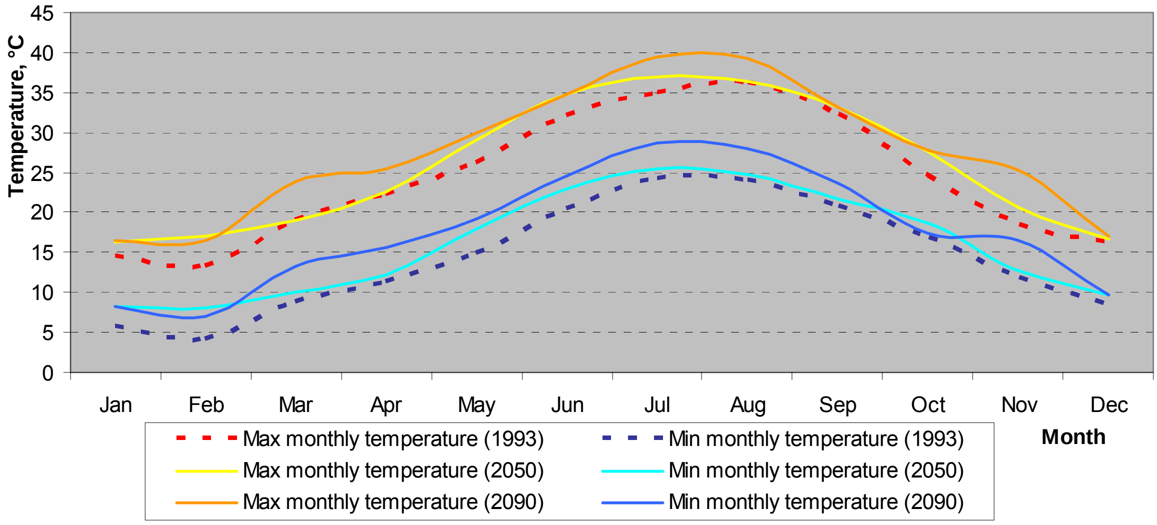


Figure 9.12 Monthly max and min temperatures for Larnaca, Cyprus for 1990, 2050 and 2090 from the PRECIS climate model

9.7 Thermal simulation results with present and future weather data

Thermal simulations of the theoretical hotel models were performed using the future climate files in a similar manner as for the present climate. The previously outlined renovation strategies were compared both to the present baseline and to the future baselines as shown in Tables 9.7 and 9.8.

Energy saving strategy	Present			2050			2090		
	Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total
Baseline, MWh	620.6	1137.2	1757.8	-4.0%	45.2%	27.8%	-18.7%	82.7%	46.9%
External wall insulation*	-17.7%	0.1%	-6.2%	-20.4%	40.8%	19.2%	-32.5%	76.7%	38.1%
HP window replacement	-11.6%	-21.2%	-17.8%	-17.0%	15.0%	3.7%	-30.1%	46.9%	19.7%
Conventional window replacement	-16.7%	-1.7%	-7.0%	-21.2%	40.1%	18.5%	-33.5%	75.2%	36.8%
Wall insulation + HP window replacement	-30.4%	-22.7%	-25.4%	-34.6%	8.7%	-6.6%	-44.8%	38.6%	9.1%
Temperature Category II	-44.9%	-29.1%	-34.7%	-48.7%	16.8%	-6.3%	-54.5%	49.4%	12.7%
Temperature Category III	-68.0%	-45.5%	-53.4%	-70.9%	0.2%	-24.9%	-72.1%	29.4%	-6.5%
Ventilation Category III	-18.3%	-4.1%	-9.1%	-20.9%	36.0%	15.9%	-32.6%	68.7%	32.9%
All combined**	-86.0%	-58.0%	-67.9%	-87.9%	-30.7%	-50.9%	-87.9%	-11.2%	-38.3%

Table 9.7 Heating, cooling and total SC load at present, 2050 and 2090 as a percentage change from the present baseline loads

Energy saving strategy	Present			2050			2090		
	Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total
Baseline, MWh	620.6	1137.2	1757.8	595.8	1651.4	2247.2	504.3	2077.5	2581.8
External wall insulation*	-17.7%	0.1%	-6.2%	-17.1%	-3.0%	-6.8%	-16.9%	-3.3%	-5.9%
HP window replacement	-11.6%	-21.2%	-17.8%	-13.6%	-20.8%	-18.9%	-14.0%	-19.6%	-18.5%
Conventional window replacement	-16.7%	-1.7%	-7.0%	-17.9%	-3.5%	-7.3%	-18.2%	-4.1%	-6.8%
Wall insulation + HP window replacement	-30.4%	-22.7%	-25.4%	-31.9%	-25.2%	-26.9%	-32.1%	-24.2%	-25.7%
Temperature Category II	-44.9%	-29.1%	-34.7%	-46.5%	-19.6%	-26.7%	-44.0%	-18.2%	-23.3%
Temperature Category III	-68.0%	-45.5%	-53.4%	-69.7%	-31.0%	-41.2%	-65.6%	-29.2%	-36.3%
Ventilation Category III	-18.3%	-4.1%	-9.1%	-17.6%	-6.3%	-9.3%	-17.1%	-7.6%	-9.5%
All combined**	-86.0%	-58.0%	-67.9%	-87.4%	-52.3%	-61.6%	-85.2%	-51.4%	-58.0%

Table 9.8 Heating, cooling and total SC loads at present, 2050 and 2090 as a percentage change from the baseline loads

** Roof insulation for the restaurant and conference centre hallway included.*
*** 'All combined' refers to external wall insulation with high-performance windows, temperature Category III and ventilation Category III.*

The following observations can be made from the above tables:

- cooling loads are expected to increase by over 40% by 2050 and over 80% by 2090,
- heating loads would decrease during the same timeframe but not significantly until 2090,
- external wall insulation that causes a marginal increase in cooling loads at present climate would reduce cooling loads in future climates, its main benefit, however, being reduction in heating loads,
- the importance of high-performance windows is emphasised in the future climates as about 20% reduction in cooling loads is possible in all climates compared to the baseline of each climate (Table 9.8),
- conventional window replacement is more efficient than high-performance window replacement in reducing heating loads but its contribution to cooling load reduction remains marginal,
- combined wall insulation and high-performance window replacement reap greater benefits in future climates,
- temperature criteria adjustments become more effective in the future when mean temperatures increase,
- ventilation criteria adjustments increasingly improve energy-efficiency both in heating and cooling as mean temperatures increase, and finally
- by combining all strategies, load reduction up to 87.9% in heating, 11.2% in cooling and 38.3% in total SC is predicted in the 2090 climate when compared to the present baseline.

From the above summary it is important to highlight that the selection of the right type of window replacement is of extreme importance to achieve the best possible energy saving benefits. Disturbance caused to the hotel operation by a window replacement undertaking and the installation costs are equal regardless the type of windows chosen, and the price survey done for this study indicated that the high-performance uPVC-frame windows were actually cheaper than conventional aluminium-frame windows. In any case, the cost-effectiveness of both options is evaluated later in the thesis.

9.8 Solar air-conditioning

It was hypothesised from the beginning of this study that passive and building envelope improvements alone would not be enough to reap significant and cost-effective energy savings but they should be coupled with energy saving technologies utilising renewable energy when possible. As discussed earlier, the most appropriate way to introduce renewable energy into hotel operations is solar heating and cooling. Although solar water heating has a long and successful tradition in Cyprus, there are many obstacles in convincing Cypriot hoteliers to embrace solar cooling. It is generally believed that solar cooling technology is overly expensive and unreliable at best. Therefore, it was of prime interest in this study to carefully evaluate the cost-effectiveness of solar AC within the changing parameters of climate, energy prices and hotel occupancy.

The first decision to make was to select a suitable solar cooling technology to be modelled and simulated. The selection process starts from an audit of the existing building and its HVAC system. Henning and Albers (2004) have mapped out a selection process within a project by IEA called *Task 25: Solar-assisted air-conditioning of buildings*. The same process was used in this study and it is briefly outlined below.

Based on the building audit and the cooling load profile it should be possible to conclude whether installation of a centralised air handling unit is feasible or if already in place, whether able to continue operation after a system upgrade. If centralised air handling is not an option, all-water system must be adopted requiring a chilled water network and a thermally driven chiller producing chilled water at 6-9°C. When centralised air handling is desired, it is of importance to evaluate the air-tightness of the building. Leaky buildings, as often is the case in system upgrades of older buildings, are not suitable for full-air[80] systems and will therefore require a hybrid ‘supply air/chilled water’ system. In such a system supply air provided by a conventional air handling unit is coupled with a chilled water network fed by a thermally driven chiller (water at 6-9°C). It is concluded that most hotels in Cyprus fall in the latter category, as centralised air handling is a system of choice and the building standard does not meet the required air-tightness. However, for the sake of completeness of the subject it is mentioned here that new hotel construction has more solar cooling options to choose from, assuming the building standard supports supply/return air systems. In such cases desiccant cooling systems become optional. Evaporative cooling utilised in desiccant systems is best suited to drier climates but special configurations are available for extremely humid climates also. In hotel applications a hybrid system would most likely be required where the sensible load would be removed by a chilled water system but operating at much higher water

[80] In a full-air system air is supplied and returned via insulated ducting utilising heat recovery when possible.

temperatures of 12-15°C than in cases discussed above. Conventional compression chillers could be utilised in such cases for a chilled ceiling system for example, the obvious benefit being that the required capacity of the chiller would be much less than if the latent loads were to be met as well. Therefore, it is concluded that desiccant cooling systems, although may not be applicable in hotel renovations, can have an important role in the wider context of energy-efficiency improvements in Cyprus and beyond, especially since they rank the highest in the cost-effectiveness scale (Delorme *et al.*, 2004). For further analysis in this study absorption cooling was chosen.

Solar potential was evaluated using a software program SolAC developed within the same Task 25 (Henning and Albers, 2004) by IEA referred to above. The program is capable of estimating solar AC output on an hourly basis in a given climate for a given internal load. Both absorption and adsorption technologies are available for evaluation. It is possible to use custom-made weather files. Therefore, solar potential evaluation in future climates is possible. The program is classified as a *pre-design* tool and as such its performance is limited to a single-zone evaluation. Furthermore, backup energy is available only as auxiliary thermal heat to the chiller either via a gas or oil-fired boiler or an electric heater; no conventional vapour compression chiller is available as a backup. It was concluded from an energy price analysis that thermal heat production from fossil fuel as a backup was not cost-effective in Cyprus. Subsequently, it was decided to use the program for annual energy balance calculations only, i.e. a thermal chiller is chosen for a cooling load, a solar collector field is sized to cover 100% of the thermal input required by the chiller operation, thermal buffer tank is sized to enable the process and the annual cooling energy and heat production are obtained. The output energy is then compared to the SC requirements on the room level after distribution losses have been applied to it. Distribution losses of 20% were assumed due to the poor condition of old HVAC installations with leaky ducting and poor pipe insulation. Solar fraction of cooling and heating could subsequently be determined.

An initial simulation using SolAC was performed using a load file consisting of the baseline heating and cooling loads for one floor, i.e. 64 rooms of a 4-star hotel in present climate. Guestrooms have a uniform load profile so that combining them into a single zone was not of consequence. In order to assist in chiller sizing, total and peak loads of one guestroom were analysed. From Table 9.9 it is observed that the peak of the present baseline of one guestroom floor would be 64x5.7 kW=365 kW. However, a closer look at the load profile indicated that the peak load occurs only for a couple of hours during the entire year, as seen in Fig. 9.13. A frequent peak value of about one third of the absolute peak stood out thus yielding a more reasonable chiller load of about 120 kW. Further, with a solar fraction target of 50%, a 60 kW chiller would appear realistic. Solar chillers, or any chillers for that matter, yield better efficiencies when run at full or close to full load rather than at part load. Therefore, slight under-sizing is preferable. Therefore, the initial simulation was run with a 53 kW absorption chiller available within the program. The load file was prepared from the output obtained from the IES<VE> simulations. WYEC file for the Larnaca airport was used as a weather file to represent the present weather conditions. Solar collector field size was input by trial and error as the program does not size collector fields. Both flat plate and evacuated tube collectors were available for comparison.

Renovation strategy (4-star hotel guestroom)	Present				2050				2090			
	Heating		Cooling		Heating		Cooling		Heating		Cooling	
	kW/m²	Peak load, kW	kW/m²	Peak load, kW	kW/m²	Peak load, kW	kW/m²	Peak load, kW	kW/m²	Peak load, kW	kW/m²	Peak load, kW
Baseline	133.3	6.9	130.3	5.7	125.5	3.7	193.2	3.9	103.7	4.2	244.9	7.6
High performance window replacement	122.6	6.7	92.1	5.4	110.8	3.6	148.0	3.4	91.8	4.1	190.9	7.0
Wall insulation and HP window replacement	93.7	6.5	87.7	5.4	83.3	3.5	132.5	3.3	68.6	4.0	170.5	6.8
All combined	18.3	3.4	46.0	3.0	13.9	1.2	87.5	2.8	13.8	1.5	115.0	6.0

Table 9.9 Heating and cooling total annual and peak loads of one guestroom of a 4-star hotel before and after implementing renovation strategies at present, 2050 and 2090

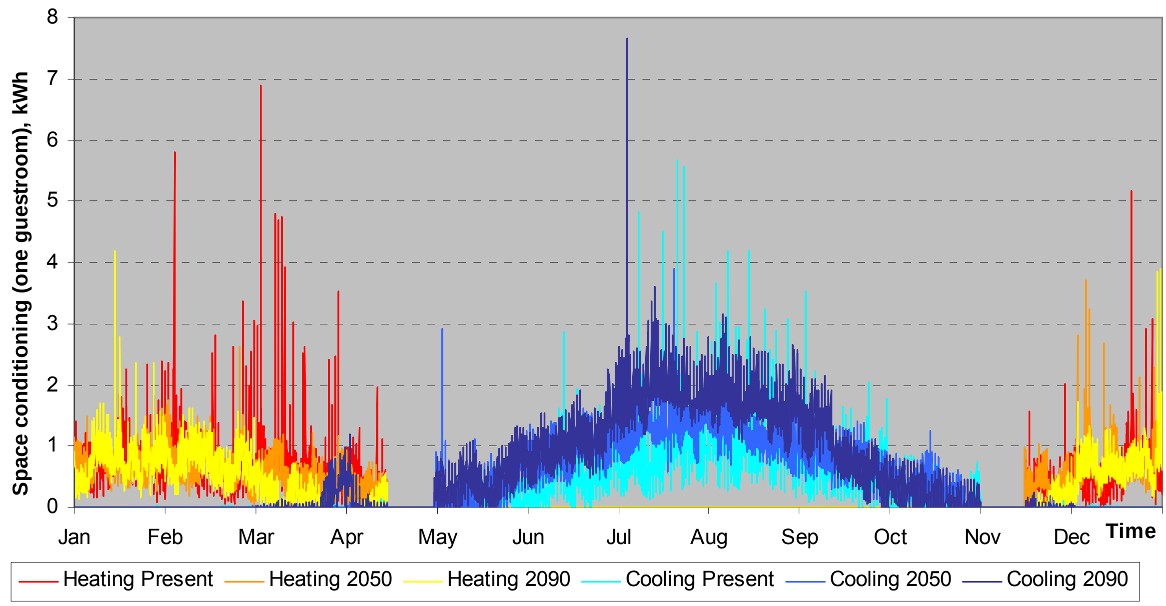


Figure 9.13 Comparison of heating and cooling load profiles for one guestroom of a 4-star hotel in baseline condition at present, 2050 and 2090

The purpose of the above simulation iterations was to find the optimal solar collector field size to power the chosen chiller. Two parameters were compared after each simulation to measure the performance of the system, namely solar heat utilisation that was calculated as a ratio of the cooling output and the required heat input of the chiller, and the specific collector yield as a measure of the available solar irradiation converted into usable heat energy by the collector. The target was to maximise both. It was noted that by trying oversized collector fields both the utilisation and specific yield were reduced. Under-sizing on the other hand would improve collector yield as there would be less stagnation of water within the collectors but there would simply not be enough input energy to power the chiller. The results of the optimisation are shown in Fig. 9.14. It is observed that the optimum size of the collector field is 185 m^2 FPC or 150 m^2 ETC. In both cases solar heat utilisation is over 97%. Due to the inherent differences between the collector types, the ETC has a higher specific yield. Selection between the collector types would subsequently depend on the price, available space or any specific requirements regarding water temperatures produced by the collector.

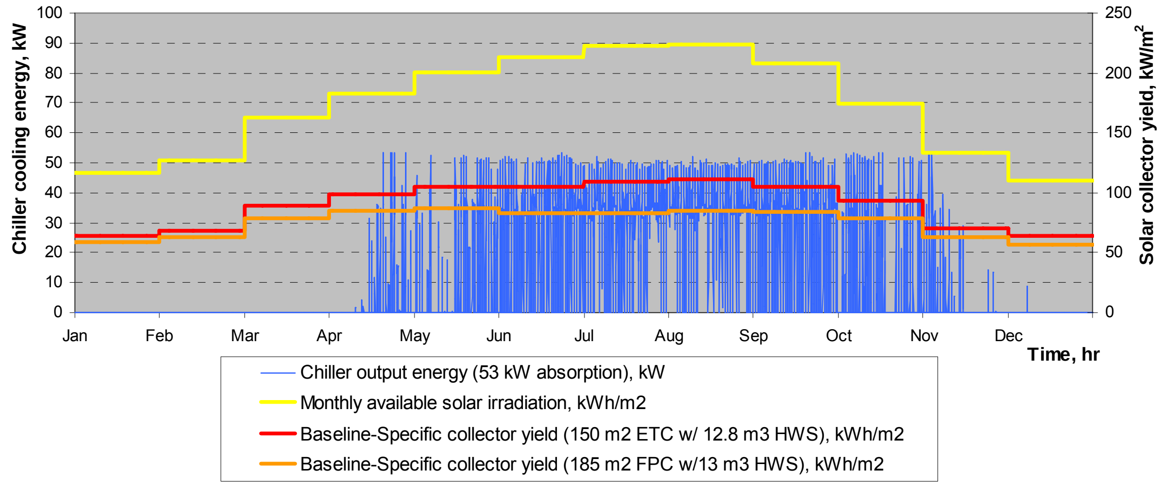


Figure 9.14 Solar potential and the optimised collector field size for a 53 kW absorption chiller serving 64 guestrooms of a 4-star hotel in baseline condition at present climate

FPC stands for flat plate collector, ETC for evacuated tube collector and HWS for hot water storage.

Furthermore, the above system with a 53 kW absorption chiller and a solar collector field of 185 m^2 FPC would yield an average COP for cooling of 0.59, solar fraction (SF) for cooling of 51.8% and 31.3% for heating. By choosing the option with 150 m^2 ETC, COP is increased to 0.61, SF for cooling to 52.6% and 28.4% for heating. In both options a storage tank for hot water of about 13 m^3 would be required as per the minimum sizing by the program. Unfortunately no option is available for chilled water storage that could improve the efficiencies further. It is noted that the solar fractions were calculated by dividing the available solar heat or coolth by the annual heating and cooling demand on the room level but the demand was not matched on hourly basis.

Next, the impacts of future climates were evaluated on solar potential and system sizing. As discussed earlier and as can be seen from Table 9.9, cooling loads are due to increase by 88% between present and 2090[81]. Solar cooling is best introduced after other measures to reduce building loads have been taken. Subsequently, the system should be sized for the demand that remains after other renovation strategies have been implemented. Further simulations were performed to identify how the absorption chiller output would change between the renovation strategies and in future climates. 4-star hotel only was analysed to avoid unnecessary redundancy. At the utilised level of detail, i.e. annual energy balance, it was not necessary to repeat the analysis for all hotel types since the guestroom load profiles are similar. Figs. 9.15-9.17 were produced to illustrate the system minimum requirements.

[81] Calculated for the baseline.

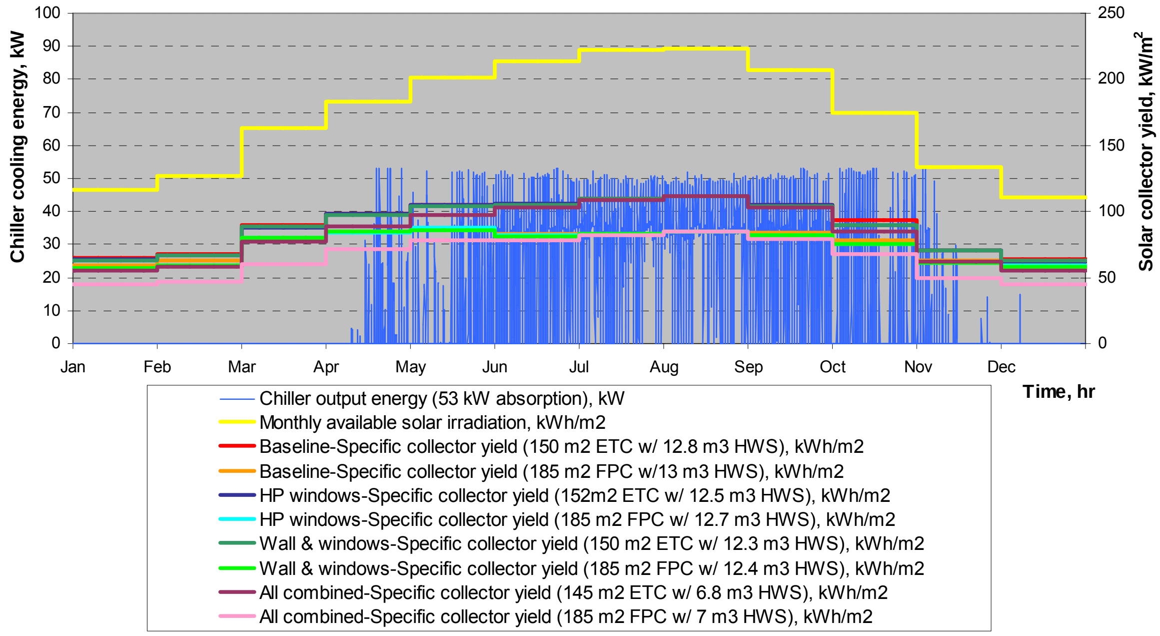


Figure 9.15 Solar potential and optimised collector field size for a 53 kW absorption chiller serving 64 rooms of a 4-star hotel in baseline and renovated conditions at present climate

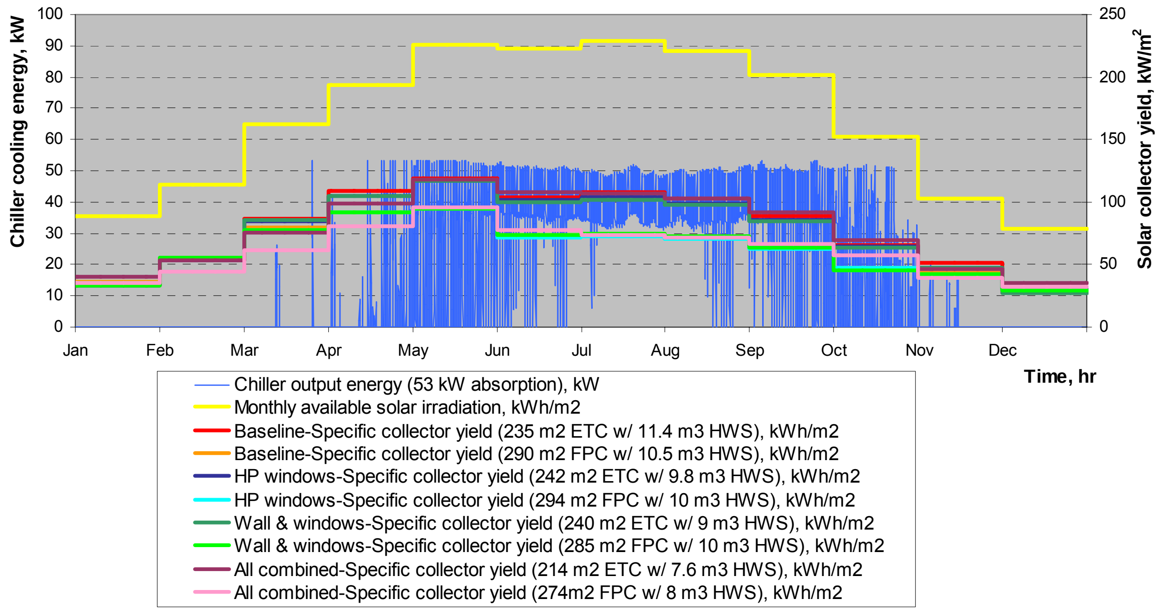


Figure 9.16 Solar potential and optimised collector field size for a 53 kW absorption chiller serving 64 rooms of a 4-star hotel in baseline and renovated conditions in 2050 climate

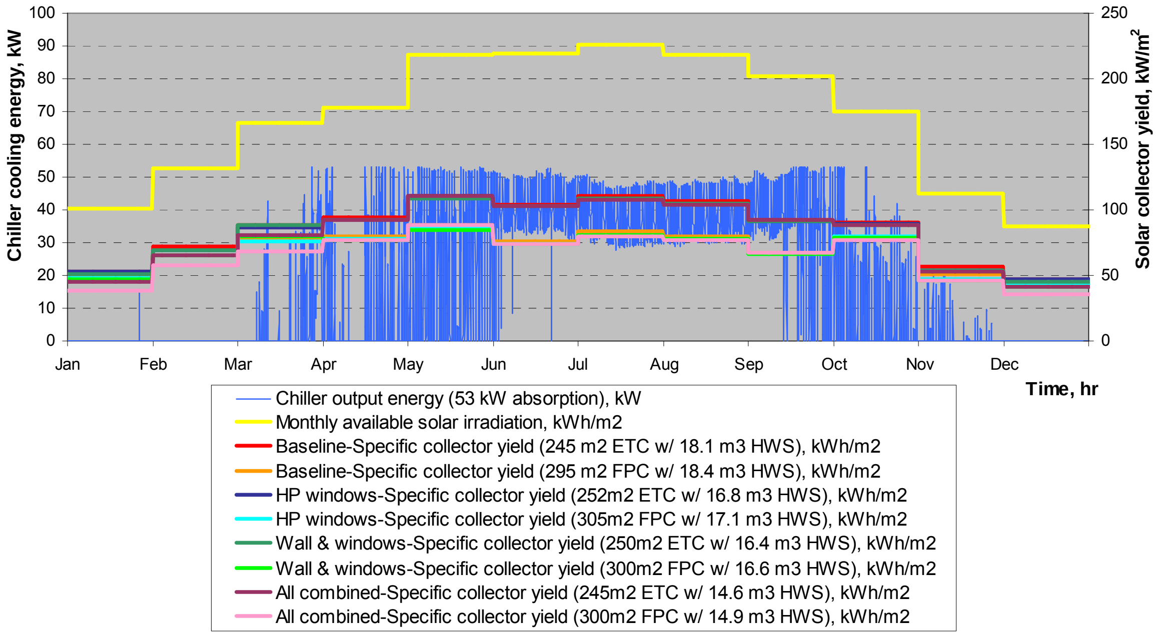


Figure 9.17 Solar potential and optimised collector field size for a 53 kW absorption chiller serving 64 rooms of a 4-star hotel in baseline and renovated conditions in 2090 climate

Renovation strategy	Chiller output, kWh/a		Chiller COP		Solar Fraction			
					Cooling		Heating	
	ETC	FPC	ETC	FPC	ETC	FPC	ETC	FPC
Present								
Baseline	98429	96903	0.61	0.59	52.6%	51.8%	28.4%	31.3%
High-performance window replacement	100039	98023	0.62	0.60	75.6%	74.1%	30.8%	33.9%
Wall insulation and HP window replacement	97590	96458	0.61	0.60	77.5%	76.6%	40.0%	44.2%
All combined	85514	85026	0.62	0.62	129.5%	128.7%	173.5%	177.8%
2050								
Baseline	142738	140675	0.64	0.64	51.4%	50.7%	36.8%	42.5%
High-performance window replacement	142365	139836	0.63	0.63	67.0%	65.8%	41.9%	48.6%
Wall insulation and HP window replacement	140824	137704	0.64	0.64	74.0%	72.3%	54.7%	62.1%
All combined	122572	122035	0.64	0.64	97.6%	97.1%	290.0%	311.0%
2090								
Baseline	148272	146892	0.60	0.61	42.1%	41.8%	54.4%	59.6%
High-performance window replacement	151106	148072	0.61	0.61	55.1%	54.0%	62.0%	67.6%
Wall insulation and HP window replacement	150371	147671	0.61	0.62	61.4%	60.3%	81.7%	88.7%
All combined	140987	138663	0.62	0.62	85.3%	83.9%	371.3%	391.0%

Table 9.10 Summary of chiller output and solar fraction achieved by a 53 kW absorption chiller serving 64 rooms of a 4-star hotel before and after implementing thermal renovation strategies at present, 2050 and 2090

The figures are organised so as to show the specific collector yield for a minimum size collector field, FPC or ETC, that would produce enough heat with the minimum size of thermal storage to run the absorption chiller. Further optimisation was done by adjusting the collector field and storage tank sizes slightly. The system sizing for the renovation strategies was compared. The figures are meant for visual impact rather than for extracting values as the solar collector yield lines are in many cases overlapping in the given scale. But the important data is given in the legend, i.e. the system sizes. The following observations can be made from Figs 9.15-9.17 and Table 9.10:

- the difference between collector yield is notable for FPC and ETC in summer but reduced in winter thus emphasising the importance of the right selection of the collector type for a specific purpose, i.e. if wintertime solar heat production is of prime importance, ETC may not be of added value,
- it is important to optimise the chiller size in regards to the building load; both the chiller output and the specific collector yield go down when the system is oversized as seen in particular for the ‘all combined’ renovation strategy at present climate where the chiller produces the highest solar fraction but the lowest overall output,
- the chiller output plots themselves reveal an interesting fact, namely that in 2050 and 2090 the chiller runs much more efficiently since it does not cycle between zero and full output, but rather at the upper third of its capacity; thus the over 50% increase in total output,
- comparing the available solar irradiation within the three climates it can be concluded that while the maximum seems to be available in July for all climates, some peculiarity is expected in June 2050 where the output drops below that of May,
- the specific collector yield drops sharply in summer 2050 and to a lesser degree in 2090 due to a known phenomenon where collector efficiency is reduced due to high ambient temperatures,
- maximum solar collector yield can be observed in May when the irradiation is high but temperatures still relatively mild,
- the impact of first implementing the renovation strategies is clearly illustrated in Table 9.10 where is observed that the solar fraction of cooling is doubled from the baseline condition to ‘all combined’ renovation strategy,
- ‘all combined’ strategy would yield overcapacity in cooling at present or the system could serve more than 64 rooms, and heating demand in all climates would be met in excess, and finally
- it is observed that the thermal storage volume needs are reduced with the implementation of the other renovation strategies.

Related to what was pointed out above regarding the chiller running more efficiently in future climates, it was observed that the cooling loads in the future climates would be rather more spread out than as increased peaks. As a matter of fact, in 2050 the peak cooling loads of guestrooms are some 30-40% less than at present while the total loads go up by as much as 50-90% as shown in Table 9.9. In 2090 the peak cooling loads do increase but not nearly as much percentagewise as the total loads.

The collector field size was compared to the kilowatts of cooling provided. It appeared that 2.7-5.8 m^2 of solar collector for a kilowatt is warranted. The figure is in par with the rules of thumb by authors such as Hirsch (no date) suggesting 2.3-6.3 m^2/kW cooling capacity and Balaras *et al.* (2007) finding a ratio of 2-5 to be typical for absorption and adsorption chiller installations.

In conclusion, the potential for solar thermal cooling was quantified and it was illustrated how the solar fraction achievable with the same system is greatly improved when the building is first renovated with thermal strategies. The analysis was done for 64 rooms, i.e. one floor of a 4-star hotel. The system module is easily multiplied, i.e. a 106 kW chiller would serve two floors, etc. What remains is to evaluate the economic feasibility of such installations which is done later in the thesis.

9.9 Economic analysis

In order to evaluate the cost-effectiveness of the proposed renovation strategies, economic analysis was performed. It was of special interest to see how cost-effectiveness may be influenced by external drivers such as fossil fuel prices and the climate. In addition, the effects of social factors evaluated earlier in Chapter 8 and possible changes in tourist flows leading to reduced hotel occupancy rates were also included in the analysis.

It is emphasised that even though the renovations and external drivers investigated are presumably taking place in the future, the method of analysis adopted in this thesis is not meant to evaluate future investments in the traditional sense where many other factors, such as inflation, labour costs and availability, policies, directives or building codes regulating the type of works and installations in concern would have to be incorporated into the analysis. Nor is any forecasting done. Instead, the method adopted herewith analyses impacts of future climates with present costs and the present value of money. The purpose of the analysis is to illustrate how climate change may influence the economic feasibility or the technical performance of the proposed works or installations. It is emphasised that the stand point in this thesis is to look into the future but analyse it as if it were happening at present. The same thought process is carried through when analysing fuel prices and their impact on cost-effectiveness. Similarly, hotel occupancy rates are reduced incrementally without an attempt to forecast at what oil price reduction might happen. It is therefore reemphasised that the aim is not to predict **when** for example the oil price would hit a certain ceiling nor when the temperatures predicted by the climate model would actually happen or the hotel occupancies fall, but rather **how** they would impact the economic feasibility of the studied strategies **whenever** they happen and in **whatever** combination.

As for the climate, changes are already observed, i.e. what was modelled for 2050 to some degree is already happening, thus shifting the cooling and heating demands towards the mid-century. Oil price in turn could increase very rapidly causing sudden changes in tourist arrivals and thus in hotel occupancy rates. It is therefore concluded that the combinations of the external drivers considered ‘future’ or ‘mid-century’ could take place in a much shorter time span.

9.9.1 Selection of a method

As discussed in Chapter 5, there are many ways to evaluate the economic feasibility of a renovation project targeted for improved energy-efficiency. The analysis chosen here for the theoretical case study hotel models follows the logic presented in Table 5.2. First of all, SPB (simple payback) is calculated for preliminary screening of the renovation alternatives. Secondly, a discount rate is introduced and its effects are observed on DPB (discounted payback). Thirdly, SIR (savings to investment ratios) at the end of the service life of the proposed renovation strategies are compared and finally the projects are ranked according to their LCC (lifecycle costs).

9.9.2 Pricing issues

Pricing information used in the economic analysis was gathered from local businesses offering the said products and services. Unit prices for windows were collected from vendors representing uPVC and aluminium-frame windows. The window prices include installation. Similarly, the price for external wall insulation includes installation and surface treatment with plaster and paint. Value added tax, 15% at the time of writing, is included in the final costs.

Solar AC is priced at indicative prices of the components. Unfortunately there have not been many similar projects yet on the island to guide in total costing. Nevertheless, enough information was available for rough cost estimation.

9.9.3 Economic analysis with current parameters

In order to estimate the building envelope renovation costs, the external wall and opening areas were extracted from the simulation model. All hotels were assumed to have three floors. As defined earlier, the 5-star hotel model had 180, 4-star 192 and 3-star 210 guestrooms in total. With the given number of rooms the public space areas were representative and comparative in each hotel class. It was essential to make the hotel buildings the same size in each class so that the investment costs would be comparable. Subsequently any differences in cost-effectiveness between the classes would be due to their different financial operating structures rather than the investment itself. Therefore, the renovation costs were based on the hotel sizes as outlined above.

The results of the economic analysis using current heating oil and electricity prices taken from Table 9.13 and official occupancy rates for 2010 (CTO, 2011) are shown in Table 9.11. Subsequently, the following input parameters were used:

- electricity price: €0.2153/kWh
- heating costs: €0.1171/kWh (based on calorific value of heating oil of 10.6 kWh/litre (CIBSE, 2004), price of €0.993/litre and boiler efficiency of 80%)
- external wall insulation: €55/m^2
- roof insulation: €50/m^2
- high-performance window replacement, total cost: €378729 for 5-star and €251198 for 4- and €264862 for 3-star hotels

- conventional window replacement, total cost: €620359 for 5-star and €452689 for 4-star and €480634 for 3-star hotels
- external wall maintenance (painting) occurring at every 7 years: €15/m^2
- no window maintenance is expected during their service life
- net bed occupancy rates of 48.0% for 5-star, 51.0% for 4-star and 42.6% for 3-star hotels assumed in the energy consumption and saving calculations

Furthermore, the service life of both the wall and windows was assumed to be 25 years. Both SIR and LCC were calculated at the end of the service life. The initial discount rate used in the analysis was taken as 4% because it represents the magnitude of interest rates paid for savings at local banks at present (personal communication with local banks, July 2011). It is naturally recognised that higher returns for savings are possible when riskier investment options are considered. However, a relatively risk-free savings account interest rate would appear a good starting point for the economic evaluation with a note that the sensitivity of the discount rate was studied as a second step.

The strategy 'All combined' includes external wall insulation with high-performance window replacement together with the thermal comfort strategies described earlier. Costs with this strategy are identical to the strategy 'Wall insulation + high-performance window replacement' but inherently the energy savings are higher. It is assumed that the adjustments in temperature and ventilation control can be done with existing systems and therefore do not require any additional investment. In reality some control equipment upgrades may nonetheless be necessary in order to implement the proposed changes. However, it is beyond the scope of this study to investigate any costs associated with such upgrades.

Renovation strategy	Hotel	Simple Payback, years			Discounted Payback, years (d=4%)			Savings to Investment Ratio			Life-Cycle Cost, €		
		Present	2050	2090	Present	2050	2090	Present	2050	2090	Present	2050	2090
Baseline	5*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2 546 220	3 095 837	3 537 887
	4*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2 293 865	2 784 965	3 153 876
	3*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1 868 814	2 273 658	2 547 790
External wall insulation*	5*	20.1	15.5	16.3	41.5	24.7	26.9	0.54	0.69	0.66	2 662 536	3 172 667	3 623 028
	4*	17.8	14.5	15.1	31.9	22.1	23.7	0.60	0.74	0.71	2 414 157	2 863 385	3 241 574
	3*	24.6	20.0	20.9	105.9	41.1	45.9	0.44	0.54	0.51	2 038 213	2 412 946	2 693 729
High-performance window replacement	5*	13.7	10.5	9.5	20.2	13.9	12.2	1.14	1.48	1.64	2 491 723	2 912 897	3 294 501
	4*	12.9	9.7	8.7	18.6	12.6	10.9	1.21	1.60	1.80	2 241 390	2 633 204	2 952 506
	3*	15.5	11.8	10.5	24.6	16.3	13.9	1.01	1.33	1.49	1 866 482	2 187 444	2 418 034
Conventional window replacement	5*	50.6	40.4	40.1	n/a	n/a	n/a	0.31	0.39	0.39	2 975 121	3 476 225	3 916 760
	4*	54.3	42.3	41.1	n/a	n/a	n/a	0.29	0.37	0.38	2 616 290	3 070 519	3 434 315
	3*	62.9	49.2	47.9	n/a	n/a	n/a	0.25	0.32	0.33	2 230 083	2 601 801	2 871 550
Wall insulation + HP window replacement	5*	14.3	11.1	10.4	21.6	14.9	13.7	0.96	1.24	1.32	2 571 979	2 947 708	3 335 892
	4*	13.8	10.8	10.1	20.4	14.3	13.2	0.94	1.20	1.28	2 326 993	2 671 941	2 998 848
	3*	17.3	13.6	12.7	30.0	19.9	18.0	0.75	0.96	1.03	2 008 606	2 296 265	2 532 288
All combined**	5*	5.0	4.5	4.2	5.7	5.0	4.6	2.72	3.07	3.29	1 461 590	1 794 370	2 097 041
	4*	4.6	4.2	3.9	5.2	4.6	4.4	2.79	3.11	3.30	1 305 360	1 616 637	1 883 483
	3*	5.8	5.2	5.0	6.7	5.9	5.7	2.25	2.50	2.62	1 161 209	1 423 292	1 632 016

Table 9.11 Selected cost-effectiveness indicators for the proposed renovation strategies of 3-, 4- and 5-star hotels at present, 2050 and 2090

** Roof insulation for the restaurant and conference centre hallway included.*
*** 'All' refers to external wall insulation with high-performance windows, temperature Category III and ventilation Category III.*

The following observations can be made from Table 9.11:

- neither external wall insulation nor conventional window replacement can be implemented cost-effectively at present or in future climates (SIR<1 and LCC greater than the baseline),
- high-performance window replacement becomes increasingly more cost-effective in future climates with DPB of 19-25 years at present reduced to 11-16 years in future climates, SIR>1 and LCC below baseline,
- wall insulation combined with high-performance window replacement is not cost-effective at present (SIR<1) but becomes so in future climates albeit with long DPB of 13-18 years, and
- 'all combined' is by far economically the most viable option with less than 7-year DPB and LCC reduced by about one million euro at present and up to 1.4 million euro in the climate of 2090 over the service life of the renovation.

As can be seen, climate change makes all proposed renovation strategies more beneficial in the future, although not necessarily cost-effective. Another interesting observation is that window replacement of a 5-star hotel appears to require more time to be amortised than that of a 4-star hotel. However, when combined with wall insulation, 5-star hotels yield a similar payback to that of 4-star and much shorter than that of 3-star hotels. The reason for the above is that a larger guestroom window (3.4 x 2.4 m^2) was used in 5-star hotel rooms in comparison to the 3- and 4-star rooms (1.95 x 2.15 m^2). Therefore, it is noted that replacing windows is cheaper than renovating wall area, thus improving the cost-effectiveness of the wall and window combination strategy in high glazing ratio applications.

The above analysis utilised a fixed discount rate. However, it is impossible to know future discount rates in advance. Therefore, it was of interest to investigate their influence on the economic feasibility of the proposed renovation strategies.

9.9.4 Influence of the discount rate

The DPB was calculated using different discount rates. The results of the analysis are shown in Table 9.12.

Renovation strategy	Hotel	Discounted Payback DPB in years or discount rate d in %								
		DPB when d=1%, years			DPB when d=10%, years			d when Y=N, %		
		Present	2050	2090	Present	2050	2090	Present	2050	2090
External wall insulation (roof included)	5*	22.5	17.0	17.9	n/a	n/a	n/a	1.76%	4.06%	3.60%
	4*	19.8	15.7	16.5	n/a	n/a	n/a	2.78%	4.72%	4.31%
	3*	28.4	22.4	23.5	n/a	n/a	n/a	0.12%	1.79%	1.44%
High-performance window replacement	5*	14.8	11.2	10.0	65.6	41.0	31.7	5.32%	8.16%	9.40%
	4*	13.9	12.6	9.1	57.3	37.2	21.2	5.89%	9.11%	10.60%
	3*	16.9	16.3	11.1	147.3	41.2	n/a	4.08%	6.88%	8.21%
Conventional window replacement	5*	70.9	52.0	51.6	n/a	n/a	n/a	n/a	n/a	n/a
	4*	78.7	55.3	53.1	n/a	n/a	n/a	n/a	n/a	n/a
	3*	99.7	68.1	65.5	n/a	n/a	n/a	n/a	n/a	n/a
Wall insulation + HP window replacement	5*	15.5	11.8	11.0	76.3	74.3	73.4	4.87%	7.57%	8.35%
	4*	14.9	11.4	10.7	75.8	73.6	72.1	5.22%	7.91%	8.64%
	3*	19.1	14.6	13.6	n/a	79.6	n/a	3.06%	5.39%	6.09%
All combined	5*	5.2	4.6	4.3	7.3	6.2	5.7	19.67%	22.27%	23.92%
	4*	4.8	4.3	4.0	6.6	5.7	5.2	21.36%	23.93%	25.38%
	3*	6.0	5.4	5.1	9.1	7.7	7.2	16.95%	18.99%	19.91%

Table 9.12 Sensitivity of the discount rate on the DPP of the proposed renovation strategies of 3-, 4- and 5-star hotels at present, 2050 and 2090

n/a denotes that the investment would never pay back with the given discount rate or that no discount rate would yield a payback within the service life of the strategy.

The following observations can be made from Table 9.12:

- with discount rates in the order of 10% neither external wall insulation nor conventional window replacement would ever pay back the initial investment costs,
- the discount rate should not be >3% at present, >5% in 2050 nor >6% in 2090 climate in order for the combined wall insulation and window replacement to pay back within its service life, and finally
- the most cost-effective option 'all combined' is the least sensitive to discount rates; discount rates <10% would pay back in <10 years and any discount rate below 17% would result in a payback less than the service life.

It is subsequently concluded that the discount rate is an important parameter in the economic assessment of the proposed renovation strategies, especially the greater the SPB. The strategies with low SPB (<5 years) are not likely to be affected much by the variation of the discount rate in single digits and can sustain cost-effectiveness well into double digits. It is noted that only the DPB was evaluated with varying discount rates. The effects of the discount rate on the SIR and LCC were not evaluated but they are included in the analysis to follow where the variables of fuel prices and hotel occupancy are introduced into the econometric model.

9.10 Sensitivity analysis

The purpose of sensitivity analysis in this study was to see how the hotel energy costs and the economic feasibility of the renovation strategies would be influenced by external drivers such as fuel prices, hotel occupancy rates and a changing climate. At the final level of the analysis room revenue derived from package holidays was introduced into the econometric model in order to study the cost sharing structure of the accommodation and travel components.

9.10.1 Fossil fuel prices and end-use energy costs

It was necessary to factor the effects of fuel prices on end-use energy costs into the econometric model. For electricity the relationship between the price per kWh and fuel oil price was available from the local utility (Electricity Authority of Cyprus, 2011b). Basically, a starting unit price of electricity is set with the price of fuel oil used in the electricity generation of €300 per metric tonne. The final unit price is dictated by the fluctuation of the fuel oil price according to a set relationship. Furthermore, there are two different tariffs that hotels qualify for. Large hotels with load entitlement >500 kVA generally require a tariff with different unit rates for peak and off-peak hours, daily and seasonal. Smaller hotels may have a single-rate tariff and some hotels even qualify for reduced unit rates for the winter when the facility may be closed.

For the purpose of this analysis the single-rate tariff was assumed. It is noted that the thermal simulations done previously did not factor in seasonal variation in occupancy. When calibrating the model, electricity consumption was not matched on month-to-month basis but only to an annual total. Therefore, it was not possible to use a variable-rate tariff in the analysis. Instead, the single-rate tariff was used with a note that it may slightly overestimate the unit price of electricity for larger hotels. A calculation was made for 3-, 4- and 5-star hotels and their average electricity consumption[82] in order to factor in the monthly fixed charges in addition to the average kWh consumed annually. To provide a visual frame of reference, Fig. 9.18 was created to demonstrate the variation in fuel oil and unit electricity prices. The time-frame was selected to run from January 2007 to present to show the year 2008 peak price, the recession and falling oil prices that followed and the fact that ever since the oil prices have been steeply climbing and in fact at present are not far below the August 2008 peak.

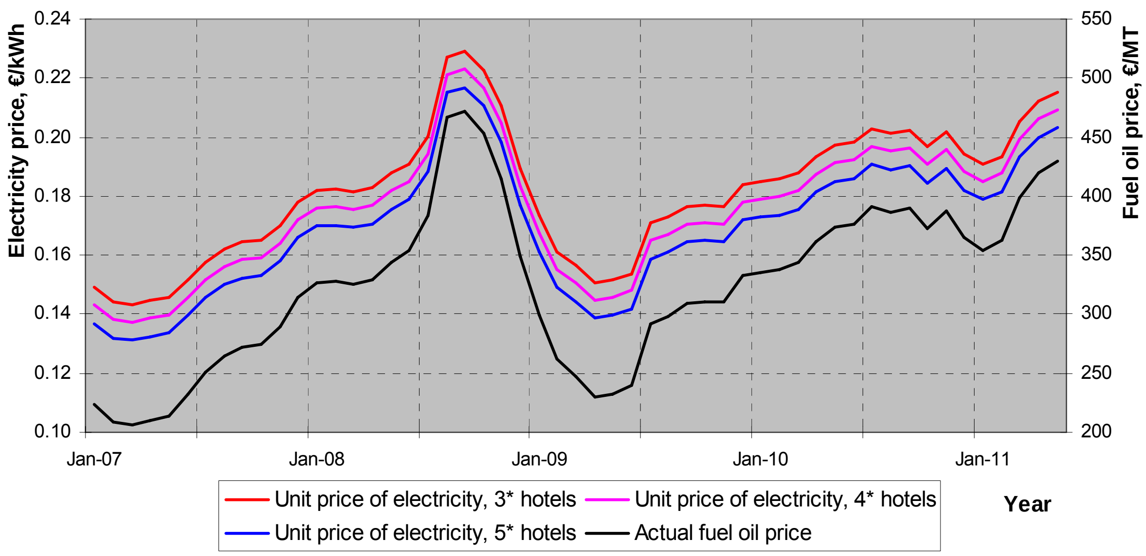


Figure 9.18 The relationship between fuel oil price and electricity unit price of 3-, 4- and 5-star hotels using a single-rate tariff from January 2007 to present

Electricity unit prices include 15% VAT.

[82] As derived from the industry-wide survey in Fig. 7.8.

In order to analyse the impact possible increases in fuel oil price have on the unit price of electricity, Table 9.13 was prepared. The projected price increase in fuel oil is shown as a $20 increment up to $200/barrel. $/barrel price was selected as the reference because it is the price typically quoted by commodity traders and therefore easy to associate with. Conversion to the price in metric tonnes was done to facilitate the calculation of the unit electricity price as shown in the table. In addition, the impact of percentage change in fuel prices is shown on the percentage change of electricity prices. It is noted that for simplicity only one unit price of electricity was chosen for the future price variation analysis, the highest shown in Fig. 9.18.

Projected fuel oil price		Elecricity price	Change in price		Heating oil price
			fuel oil	electricity	
$/barrel	€/MT*	€/kWh	%	%	€/litre
92.07**	429.90	0.2153	-	-	1.01
100.00	466.92	0.2272	8.6%	5.5%	1.10
120.00	560.30	0.2573	30.3%	19.5%	1.32
140.00	653.69	0.2873	52.1%	33.5%	1.54
160.00	747.07	0.3174	73.8%	47.4%	1.76
180.00	840.45	0.3475	95.5%	61.4%	1.98
200.00	933.84	0.3775	117.2%	75.4%	2.20

Table 9.13 Projected oil price and its effect on unit electricity and heating oil prices

* Prices in euro calculated with a dollar-to-euro exchange rate of 1.427 (17-6-2011).
** Actual oil price in June 2011 used in fuel price adjustment calculations (EAC, 2011b).

Similar analysis was necessary for the heating oil price future projections. Unfortunately no published price relationship was available for crude and heating oil in Cyprus. Subsequently an empirical relationship was developed based on crude oil prices by New York Merchandise Exchange (NYMEX) (NYSE.TV, 2011b) and actual heating oil prices in Cyprus for a timeframe from January 2007 to present. Historical records of the heating oil prices in Cyprus were available from the Ministry of Commerce, Industry and Tourism website (www.mcit.gov.cy, 2011). The relationship is shown in Fig. 9.19. It is noted that the crude oil prices originally given in dollars per barrel were converted to euro per litre using the actual historical exchange rates (OANDA, 2011) to reflect the turbulent relationship between the two currencies during the credit crunch of 2008 and the economic recession that followed. It can be seen that the heating oil price has more or less reflected 50-50 split between crude oil and other costs[83]. However, at present the split appears to be changing and the other costs increasing. In June 2011 the fuel oil price seems to have consisted of 40% crude oil and 60% other costs. Therefore, 40-60 split is assumed and subsequently the price of heating oil is taken 2.5 times the price of crude oil. Heating oil prices for the projected oil prices are shown in Table 9.13.

[83] Other costs include refinery, transportation, taxes, duties, etc.

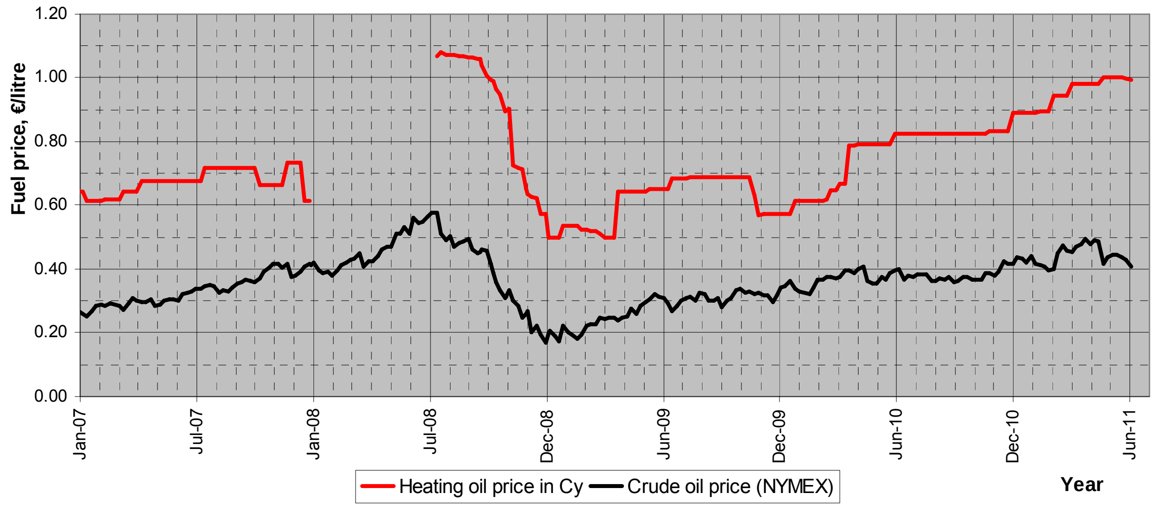


Figure 9.19 Empirical relationship between crude oil and heating oil prices in Cyprus from January 2007 to present

No data was available for the first half of 2008. Heating oil price includes 15% VAT.

9.10.2 Changes in hotel occupancy

As concluded from the guest survey in Chapter 8, not much change in the holiday travel patterns is to be expected due to climate change[84]. But at the same time very little inflation on holiday travel prices would be tolerated either[85]. Consequently, it is prudent to assume that tourist flows would be reduced, should there be a significant price increase in package holidays. Therefore, factoring changes in occupancy into the econometric model seemed sensible in order to evaluate how the feasibility of the renovation strategies might be affected by them. Official occupancy rates for 3-, 4- and 5-star hotels in 2010 were taken as the starting point. Reduction increments of 5, 15 and 25 percentage points were applied to the initial occupancy. What is meant here is that if the initial occupancy rate were 50%, a 5 percentage point decrease would make it 45%, 15 point decrease 35% and so on. Subsequently, the impacts of occupancy could then be analysed within different oil price scenarios as defined earlier for a joint sensitivity analysis. The mechanism how occupancy may affect cost-effectiveness of the renovation strategies is due to the fact that in this thesis the investment costs as well as SC energy costs are distributed over guest nights. If the number of guest nights is reduced, a larger share of investment and energy costs would have to be borne per guest night, thus lowering room income. Similarly, the projected energy savings are realised per guest night. If the number of guest nights goes down due to reduced occupancy, less savings would be realised from the renovation. In other words, the investment was made to renovate the entire building but if the renovated rooms are not used to bring in improved room income (room revenue less investment and SC energy costs), the savings to investment ratio would be lowered.

[84] Score 2.65±1.20 out of 5 as shown in Table 8.1.
[85] 10.71%±9.30% in Table 8.1.

9.10.3 Sensitivity of the economic feasibility of the renovation strategies

Any increase in energy prices would by default make the renovation strategies more feasible and the payback periods shorter. However, reduced occupancy can hinder economic feasibility. Therefore, it was of interest to quantify how exactly the economic feasibility indicators introduced earlier would be influenced by the external drivers of oil price and occupancy levels. The strategies with building envelope and thermal comfort criteria were analysed first followed by complete economic and sensitivity analyses of solar AC.

9.10.3.1 Building envelope and thermal comfort criteria strategies

DPB, SIR and LCC of the renovation strategies that were previously found cost-effective, i.e. high-performance window replacement, wall insulation with HP window replacement and 'all combined' were evaluated in four oil price scenarios with 5%, 15% and 25% occupancy reductions. Tables 9.14 and 9.15 show the results. It is noted that SIR>1 and LCC of the renovated case less than that of the baseline are required for a strategy to be cost-effective. The acceptability of the DBP is subjective. At the very least it has to be less than the service life of the investment but depending on the project requirements, much shorter paybacks are usually expected. In this thesis DBP<10 years is generally considered desirable.

Renovation strategy	Hotel	Discounted Payback, years (d=4%)									Savings to Investment Ratio (d=4%)								
		Present			2050			2090			Present			2050			2090		
Occupancy reduction		-5%	-15%	-25%	-5%	-15%	-25%	-5%	-15%	-25%	-5%	-15%	-25%	-5%	-15%	-25%	-5%	-15%	-25%
Oil price $92.07 per barrel																			
High-performance window replacement	5*	22.3	28.8	41.6	15.3	19.0	25.1	13.3	16.2	20.8	1.07	0.92	0.78	1.39	1.19	1.00	1.54	1.33	1.12
	4*	20.0	23.9	29.8	13.5	15.8	19.0	11.6	13.4	15.9	1.15	1.03	0.91	1.52	1.35	1.19	1.71	1.53	1.35
	3*	27.6	36.8	59.7	17.9	22.5	30.6	15.1	18.6	24.3	0.95	0.82	0.69	1.24	1.07	0.89	1.40	1.21	1.02
Wall insulation + HP window replacement	5*	24.0	31.4	47.1	16.4	20.2	26.8	14.9	18.2	23.5	0.90	0.77	0.65	1.16	1.00	0.84	1.24	1.07	0.91
	4*	22.5	28.1	38.4	15.6	18.7	23.6	14.3	17.0	21.0	0.88	0.78	0.67	1.13	1.00	0.86	1.21	1.07	0.92
	3*	34.5	51.2	n/a	22.2	28.9	42.7	19.3	25.4	35.6	0.70	0.60	0.50	0.90	0.77	0.64	0.96	0.83	0.69
All combined	5*	6.1	6.8	7.9	5.3	6.0	6.8	4.9	5.4	6.1	2.59	2.33	2.06	2.92	2.62	2.33	3.14	2.85	2.56
	4*	5.5	6.2	7.1	4.9	5.5	6.3	4.6	5.1	5.7	2.66	2.39	2.12	2.97	2.67	2.38	3.15	2.87	2.58
	3*	7.2	8.5	10.4	6.4	7.5	9.1	6.0	7.0	8.3	2.11	1.83	1.55	2.35	2.04	1.74	2.47	2.17	1.87
Oil price $120 per barrel																			
High-performance window replacement	5*	16.0	20.4	27.2	11.7	14.2	18.3	10.3	12.4	15.7	1.32	1.14	0.95	1.70	1.46	1.22	1.88	1.62	1.36
	4*	14.1	17.3	21.3	10.5	12.1	14.4	9.1	10.5	12.3	1.40	1.25	1.10	1.86	1.65	1.45	2.08	1.86	1.63
	3*	19.8	25.1	34.7	13.6	16.7	21.8	11.7	14.2	18.0	1.16	1.00	0.84	1.51	1.30	1.09	1.70	1.47	1.23
Wall insulation + HP window replacement	5*	16.7	21.2	28.5	12.2	14.8	19.0	11.3	13.6	17.1	1.13	0.97	0.81	1.44	1.24	1.04	1.53	1.32	1.12
	4*	15.2	19.2	24.7	11.6	13.8	17.0	10.9	12.8	15.5	1.12	0.98	0.84	1.42	1.24	1.07	1.49	1.32	1.14
	3*	22.7	29.8	45.2	16.0	20.1	27.1	14.7	18.2	24.0	0.88	0.76	0.63	1.12	0.96	0.80	1.19	1.02	0.85
All combined	5*	4.7	5.3	6.1	4.2	4.7	5.4	5.0	5.5	6.1	3.25	2.91	2.57	3.64	3.26	2.89	3.88	3.51	3.14
	4*	4.3	4.8	5.5	3.8	4.3	4.9	3.6	4.0	4.5	3.34	3.00	2.66	3.71	3.33	2.96	3.91	3.54	3.18
	3*	5.5	6.5	7.9	4.9	5.8	7.0	4.7	5.5	6.5	2.67	2.31	1.95	2.95	2.56	2.17	3.07	2.69	2.31
Oil price $160 per barrel																			
High-performance window replacement	5*	12.0	14.6	18.0	8.8	10.6	13.4	7.9	9.4	11.7	1.67	1.43	1.20	2.14	1.84	1.53	2.35	2.03	1.70
	4*	11.2	12.9	15.4	8.0	9.2	10.8	7.0	8.0	9.3	1.76	1.57	1.38	2.33	2.07	1.81	2.60	2.32	2.04
	3*	14.4	17.7	23.0	10.2	12.3	15.7	8.9	10.6	13.3	1.45	1.25	1.05	1.90	1.63	1.36	2.12	1.83	1.54
Wall insulation + HP window replacement	5*	12.1	14.8	19.1	9.1	10.9	13.6	8.5	10.1	12.5	1.45	1.24	1.04	1.83	1.58	1.32	1.93	1.67	1.41
	4*	11.4	13.6	16.7	8.6	10.1	12.3	8.2	9.5	11.4	1.43	1.25	1.07	1.80	1.58	1.36	1.89	1.66	1.44
	3*	15.7	19.7	26.7	9.4	14.2	18.5	10.9	13.2	16.9	1.13	0.97	0.80	1.42	1.22	1.01	1.50	1.29	1.08
All combined	5*	3.6	4.1	4.7	3.2	3.6	4.1	4.1	4.5	5.0	4.16	3.72	3.28	4.64	4.15	3.66	4.91	4.43	3.96
	4*	3.3	3.7	4.2	2.9	3.3	3.8	2.8	3.1	3.5	4.29	3.84	3.40	4.74	4.25	3.76	4.95	4.48	4.01
	3*	4.2	4.9	6.0	3.8	4.4	5.3	3.7	4.2	5.0	3.44	2.97	2.50	3.78	3.27	2.77	3.90	3.42	2.93
Oil price $200 per barrel																			
High-performance window replacement	5*	9.5	11.4	14.5	6.4	7.6	9.3	6.4	7.6	9.3	2.02	1.73	1.44	2.58	2.21	1.84	2.83	2.44	2.04
	4*	8.9	10.2	12.1	5.7	6.5	7.5	5.7	6.5	7.5	2.12	1.89	1.66	2.80	2.49	2.17	3.12	2.78	2.44
	3*	11.3	13.7	17.5	7.2	8.5	8.3	7.2	8.5	8.3	1.75	1.50	1.26	2.29	1.96	1.63	2.55	2.20	1.84
Wall insulation + HP window replacement	5*	9.5	11.5	14.5	6.8	8.1	9.9	6.8	8.1	9.9	1.76	1.51	1.26	2.22	1.91	1.60	2.34	2.02	1.70
	4*	8.9	10.6	12.9	6.5	7.6	9.0	6.5	7.6	9.0	1.75	1.53	1.30	2.19	1.92	1.64	2.29	2.01	1.73
	3*	12.0	14.8	19.4	8.6	8.1	12.2	8.6	8.1	12.2	1.39	1.18	0.98	1.73	1.48	1.22	1.82	1.56	1.30
All combined	5*	2.9	3.3	3.8	2.5	2.8	3.1	2.5	2.8	3.1	5.07	4.53	3.98	5.63	5.04	4.44	5.93	5.36	4.78
	4*	2.7	3.0	3.4	2.3	2.6	2.9	2.3	2.6	2.9	5.24	4.69	4.14	5.77	5.17	4.57	6.00	5.43	4.85
	3*	3.4	4.0	4.9	3.0	3.4	4.1	3.0	3.4	4.1	4.20	3.62	3.05	4.61	3.99	3.36	4.73	4.14	3.54

Table 9.14 Cost-effectiveness indicators of the renovation strategies in projected occupancy and oil price scenarios

Renovation strategy	Hotel	Life-Cycle Cost, € (d=4%)								
		Present			2050			2090		
Occupancy reduction		-5%	-15%	-25%	-5%	-15%	-25%	-5%	-15%	-25%
Oil price $92.07 per barrel										
Baseline	5*	2 442 972	2 236 476	2 029 980	2 971 357	2 722 397	2 473 438	3 405 666	3 141 225	2 876 784
	4*	2 196 681	2 002 314	1 807 947	2 668 884	2 436 721	2 204 559	3 031 789	2 787 613	2 543 438
	3*	1 759 509	1 540 900	1 322 290	2 142 117	1 879 036	1 615 954	2 409 253	2 132 181	1 855 108
High-performance window replacement	5*	2 416 267	2 265 355	2 114 443	2 825 129	2 649 592	2 474 055	3 201 800	3 016 397	2 830 994
	4*	2 159 385	1 995 373	1 831 361	2 538 011	2 347 625	2 157 239	2 853 211	2 654 620	2 456 029
	3*	1 773 993	1 589 016	1 404 039	2 078 720	1 861 271	1 643 823	2 304 489	2 077 400	1 850 310
Wall insulation + HP window replacement	5*	2 507 619	2 378 900	2 250 181	2 872 703	2 722 694	2 572 685	3 255 361	3 094 299	2 933 237
	4*	2 260 077	2 126 244	1 992 412	2 594 012	2 438 153	2 282 294	2 916 240	2 751 023	2 585 806
	3*	1 927 770	1 766 099	1 604 428	2 200 796	2 009 859	1 818 921	2 431 606	2 230 240	2 028 874
All combined	5*	1 441 231	1 400 511	1 359 792	1 763 067	1 700 459	1 637 852	2 056 855	1 976 482	1 896 109
	4*	1 281 612	1 234 116	1 186 619	1 582 164	1 513 218	1 444 271	1 841 121	1 756 395	1 671 669
	3*	1 130 831	1 070 076	1 009 321	1 378 395	1 288 602	1 198 809	1 578 028	1 470 050	1 362 072
Oil price $120 per barrel										
Baseline	5*	3 025 295	2 761 713	2 498 131	3 653 279	3 339 665	3 026 051	4 156 655	3 827 037	3 497 418
	4*	2 733 618	2 484 660	2 235 702	3 293 664	3 000 329	2 706 993	3 711 326	3 406 162	3 100 998
	3*	2 199 296	1 919 912	1 640 529	2 652 654	2 320 952	1 989 251	2 958 245	2 612 499	2 266 754
High-performance window replacement	5*	2 904 121	2 710 326	2 516 530	3 387 623	3 165 311	2 943 000	3 824 256	3 592 195	3 360 134
	4*	2 632 024	2 420 882	2 209 739	3 078 272	2 836 658	2 595 044	3 440 131	3 191 016	2 941 900
	3*	2 157 970	1 920 405	1 682 839	2 516 266	2 241 033	1 965 799	2 773 446	2 489 138	2 204 831
Wall insulation + HP window replacement	5*	2 944 846	2 780 361	2 615 877	3 377 367	3 188 182	2 998 998	3 824 293	3 623 525	3 422 756
	4*	2 669 008	2 497 643	2 326 278	3 063 586	2 866 705	2 669 823	3 437 623	3 231 329	3 025 034
	3*	2 264 710	2 057 968	1 851 226	2 586 478	2 345 703	2 104 929	2 852 517	2 601 309	2 350 102
All combined	5*	1 608 937	1 558 433	1 507 928	1 991 905	1 915 646	1 839 388	2 344 085	2 246 444	2 148 802
	4*	1 438 006	1 378 431	1 318 857	1 794 669	1 710 032	1 625 394	2 104 739	2 001 210	1 897 681
	3*	1 255 275	1 179 187	1 103 100	1 548 896	1 438 749	1 328 602	1 788 215	1 656 258	1 524 301
Oil price $160 per barrel										
Baseline	5*	3 835 221	3 493 707	3 152 192	4 606 643	4 204 093	3 801 544	5 212 502	4 792 631	4 372 760
	4*	3 477 937	3 154 590	2 831 242	4 164 766	3 787 435	3 410 103	4 664 501	4 275 030	3 885 560
	3*	2 807 178	2 444 881	2 082 585	3 362 750	2 936 709	2 510 669	3 726 525	3 285 756	2 844 986
High-performance window replacement	5*	3 582 251	3 330 099	3 077 946	4 173 817	3 887 368	3 600 919	4 699 406	4 402 909	4 106 413
	4*	3 286 081	3 010 885	2 735 688	3 830 597	3 518 822	3 207 048	4 262 659	3 943 866	3 625 072
	3*	2 687 508	2 378 383	2 069 258	3 123 863	2 769 368	2 414 874	3 428 905	3 065 591	2 702 277
Wall insulation + HP window replacement	5*	3 554 922	3 341 640	3 128 359	4 084 887	3 841 852	3 598 818	4 626 223	4 370 474	4 114 725
	4*	3 237 427	3 014 909	2 792 390	3 719 884	3 466 667	3 213 450	4 170 638	3 907 526	3 644 415
	3*	2 731 084	2 462 872	2 194 660	3 123 689	2 814 404	2 505 119	3 442 413	3 122 227	2 802 040
All combined	5*	1 847 005	1 782 906	1 718 807	2 317 903	2 222 420	2 126 938	2 753 467	2 631 455	2 509 442
	4*	1 658 762	1 582 529	1 506 296	2 096 361	1 989 762	1 883 162	2 479 501	2 349 559	2 219 617
	3*	1 430 297	1 333 042	1 235 787	1 790 389	1 651 737	1 513 085	2 086 378	1 920 742	1 755 105
Oil price $200 per barrel										
Baseline	5*	4 645 148	4 225 701	3 806 253	5 560 007	5 068 522	4 577 038	6 268 350	5 758 226	5 248 102
	4*	4 222 255	3 824 519	3 426 783	5 035 868	4 574 541	4 113 213	5 617 676	5 143 899	4 670 121
	3*	3 415 060	2 969 851	2 524 641	4 072 845	3 552 466	3 032 087	4 494 806	3 959 012	3 423 218
High-performance window replacement	5*	4 260 381	3 949 872	3 639 362	4 960 011	4 609 425	4 258 838	5 574 556	5 213 624	4 852 691
	4*	3 940 139	3 600 888	3 261 637	4 582 923	4 200 987	3 819 051	5 085 188	4 696 715	4 308 243
	3*	3 217 045	2 836 361	2 455 676	3 731 461	3 297 704	2 863 948	4 084 364	3 642 043	3 199 722
Wall insulation + HP window replacement	5*	4 164 999	3 902 919	3 640 840	4 792 408	4 495 523	4 198 638	5 428 153	5 117 423	4 806 693
	4*	3 805 847	3 532 175	3 258 503	4 376 181	4 066 629	3 757 077	4 903 653	4 583 724	4 263 795
	3*	3 197 458	2 867 776	2 538 094	3 660 900	3 283 104	2 905 309	4 032 310	3 643 144	3 253 979
All combined	5*	2 085 074	2 007 380	1 929 686	2 643 902	2 529 195	2 414 487	3 162 849	3 016 466	2 870 083
	4*	1 879 519	1 786 627	1 693 736	2 398 053	2 269 492	2 140 930	2 854 263	2 697 908	2 541 554
	3*	1 605 318	1 486 896	1 368 474	2 031 882	1 864 725	1 697 568	2 384 542	2 185 226	1 985 909

Table 9.15 Life-Cycle Cost of the renovation strategies in projected occupancy and oil price scenarios

The following observations can be made from Tables 9.14 and 9.15:

- with the current oil price in present climate no strategy employing building envelope improvements only would have DBP<10 years, in some scenarios DBP even exceeds the service life, whereas when thermal comfort criteria modifications are included, i.e. the ‘all combined’ strategy, DPB falls between 5-10 years,

- with the current oil price the HP window replacement would be cost-effective (SIR>1) but would lose it due to occupancy reduction,
- with the current oil price the wall and window strategy would not be cost-effective but it would gain cost-effectiveness from $120/barrel oil price onwards (3-star hotel from $160/barrel onwards), and
- 3-star hotels are the most vulnerable to losing cost-effectiveness due to occupancy reduction.

It is interesting to observe from the above that although reduced occupancy appears to lower the lifecycle costs, the renovation strategies lose their competitive advantage as it happens and in some cases no longer remain cost-effective as their SIR falls below one. Therefore, it is concluded that reduced occupancy is a serious threat to the economic feasibility of the proposed renovation strategies. Further, it is imperative to combine the building envelope improvements with revised thermal comfort criteria in order to obtain cost-effectiveness within acceptable payback.

9.10.3.2 Strategies utilising solar AC

As discussed earlier, the right time to introduce solar AC is after measures have been taken to minimise the building loads. It was on purpose that solar AC was separated from the above cost-effectiveness analysis of building envelope improvements and thermal comfort strategies. The reason for evaluating the cost-effectiveness of solar AC by itself and as the last rather than the first option was of course to emphasise the correct sequence to its implementation but also the fact that a system equal in size would yield higher solar fraction for a renovated condition than for the baseline, as discussed earlier and shown in Table 9.10. Or that a system could simply be sized smaller to reduce initial investment costs. But perhaps the most important reason is that a hotel planning for energy-efficiency improvements most likely would not have the required funds available to implement all measures at once, i.e. building envelope improvements and system upgrades. Therefore, the technically correct sequence would also be a financially sensible way to introduce energy-efficiency measures when a project is divided into phases to be implemented over a number of years. As already concluded, wall insulation alone is of little value, whereas high-performance window replacement could be implemented alone as the first measure. Wall insulation could follow after a few years when the funds become available and perhaps when the façade is due to be renovated in any case. Similarly, solar AC could be introduced at a later stage after the other investments have been at least partially amortised.

To facilitate the economic feasibility analysis, the prices of the components required in solar AC systems were taken as follows:

- 53 kW absorption chiller: €30000
- 106 kW absorption chiller: €46250
- flat plate collectors: €200 per m^2 installed
- evacuated tube collectors: €300 per m^2 installed
- thermal storage: €1500 per m^3 in a large storage tank
- cooling tower: €100 per kW of cooling

Besides the above components in the necessary quantities, a project would also require piping, pumps and a control system. Engineering and installation costs would also need to be added. It is noted that the cheapest possible solar collector prices are quoted above. For the ETC it means Chinese-made that are less than half price of their European-made counterpart. FPCs quoted are made locally and are of 'fair' quality. It is important to recognise that the quality and longevity of solar collectors is of importance for the efficient long-term operation of the entire system. Another issue to consider is the proper pipe insulation. Stagnation water in the solar collectors can reach temperatures well above the normal operating temperatures of the system of 80-85°C, thus requiring special lagging for the outlet piping. The difference in price in this case could be as much as four times between the standard and special product for high temperatures. Keeping quality issues in mind the economic feasibility analysis that follows incorporates a yearly maintenance expense of 2% of the initial project cost. With such a budget some faulty collector units can be replaced in addition to the regular maintenance required by the system itself. Subsequently a 25-year service life for the entire system was assumed and used in the analysis.

For obvious reasons it was not possible to accurately estimate the total project costs but a rough total costing was made to enable the economic feasibility study. It was therefore decided to evaluate the project with four options as follows:

Present

- Option 1: 53 kW absorption chiller with 150 m^2 ETC and a 13 m^3 hot water storage

  Total cost: €166750
- Option 2: 53 kW absorption chiller with 185 m^2 FPC and a 13 m^3 hot water storage

  Total cost: €157550
- Option 3: 106 kW absorption chiller with 300 m^2 ETC and a 26 m^3 hot water storage

  Total cost: €264800
- Option 4: 106 kW absorption chiller with 370 m^2 ETC and a 26 m^3 hot water storage

  Total cost: €246400

2050

- Option 1: 53 kW absorption chiller with 242 m^2 ETC and a 10 m^3 hot water storage

  Total cost: €193300
- Option 2: 53 kW absorption chiller with 294 m^2 FPC and a 10.5 m^3 hot water storage

  Total cost: €178300
- Option 3: 106 kW absorption chiller with 484 m^2 ETC and a 20 m^3 hot water storage

  Total cost: €317900
- Option 4: 106 kW absorption chiller with 588 m^2 ETC and a 21 m^3 hot water storage

  Total cost: €287900

2090

- Option 1: 53 kW absorption chiller with 250 m^2 ETC and a 18 m^3 hot water storage

  Total cost: €209900
- Option 2: 53 kW absorption chiller with 300 m^2 FPC and a 18 m^3 hot water storage

  Total cost: €192650
- Option 3: 106 kW absorption chiller with 500 m^2 ETC and a 36 m^3 hot water storage

  Total cost: €351050
- Option 4: 106 kW absorption chiller with 600 m^2 ETC and a 36 m^3 hot water storage

  Total cost: €316550

Options 1 and 2 feature ETC and FPC respectively sized according to the optimised results presented earlier in Figs. 9.15-9.17. As there was slight variation between the system size requirements between the renovation strategies, the largest component sizes were selected to cover the needs of all strategies. In options 3 and 4 the chiller capacity was doubled with the obvious implications to double the sizes of the collector field and water storage also. However, the total cost benefitted from the economies of scale as the chiller itself would not double in price and the auxiliary items would remain more or less the same. Options 3 and 4 were included to observe the changes in the economic feasibility when taking advantage of a smaller unit cooling price made possible by a larger system. An even larger system option could have been included, i.e. triple or quadruple of the initial 53 kW system but it is argued that most hotels would not have the space available required to host solar collector fields and hot water storage of such magnitudes.

The solar AC project options were analysed in the same manner as the building envelope and thermal comfort criteria strategies earlier, i.e. their DPB, SIR and LCC were established and the impact of oil price was observed. The results of the analysis are shown in Table 9.16. It is noted that the objective was to observe the difference in cost-effectiveness of the four solar AC options due to changes in SC loads resulting from the implementation of the other thermal renovation strategies and to select the most efficient one for further analysis. The analysis did not take into account the additional investments required to implement the building envelope improvements. Such analysis is done in Chapter 10.

Renovation strategy	Option	Discount rate d when Y=N, %			Discounted Payback, years (d=4%)			Savings to Investment Ratio (d=4%)			Life-Cycle Cost, € (d=4%)		
		Present	2050	2090	Present	2050	2090	Present	2050	2090	Present	2050	2090
Oil price $92.07 per barrel													
Baseline	1	7.77%	12.33%	14.20%	14.6	9.3	8.1	1.09	1.55	1.75	866 740	992 724	1 032 768
	2	8.94%	14.06%	15.81%	12.8	8.2	7.2	1.21	1.74	1.93	854 665	980 650	1 020 693
	3	10.64%	16.03%	18.27%	10.8	7.1	6.2	1.38	1.96	2.21	1 643 299	1 895 267	1 975 355
	4	12.24%	18.41%	20.55%	9.4	6.1	5.5	1.54	2.22	2.47	1 619 150	1 871 118	1 951 206
High-performance window replacement	1	7.92%	12.19%	14.26%	14.3	9.5	8.0	1.11	1.54	1.76	765 555	853 470	880 819
	2	9.05%	13.94%	15.73%	12.7	8.2	7.3	1.22	1.73	1.92	753 481	841 396	868 744
	3	10.82%	15.86%	18.35%	10.7	7.2	6.2	1.39	1.94	2.22	1 440 929	1 616 759	1 671 457
	4	12.37%	18.26%	20.45%	9.3	6.2	5.5	1.56	2.21	2.46	1 416 780	1 592 610	1 647 308
Wall insulation + HP window replacement	1	7.66%	12.03%	14.17%	14.6	9.6	8.1	1.08	1.52	1.75	664 957	738 379	769 573
	2	8.87%	13.56%	15.63%	12.9	8.5	7.3	1.20	1.68	1.91	652 882	726 305	757 499
	3	10.52%	15.67%	18.24%	10.9	7.3	6.2	1.36	1.92	2.20	1 239 732	1 386 577	1 448 965
	4	12.15%	17.80%	20.33%	9.5	6.4	5.5	1.53	2.15	2.44	1 215 583	1 362 428	1 424 816
All combined	1	7.75%	12.55%	15.33%	14.8	9.2	7.5	1.09	1.58	1.88	377 170	448 671	501 268
	2	8.55%	13.96%	16.69%	13.4	8.2	6.8	1.17	1.73	2.03	365 095	436 597	489 194
	3	10.62%	16.29%	19.65%	10.8	7.0	5.7	1.37	1.98	2.37	664 158	807 161	912 355
	4	11.77%	18.28%	21.64%	9.8	6.2	5.2	1.49	2.21	2.59	640 009	783 012	888 206
Oil price $120 per barrel													
Baseline	1	10.66%	15.93%	18.25%	10.8	7.2	6.2	1.38	1.94	2.21	1 048 710	1 196 634	1 236 062
	2	12.08%	18.08%	20.26%	9.5	6.3	5.6	1.53	2.19	2.44	1 036 635	1 184 560	1 223 988
	3	14.04%	20.37%	23.22%	8.2	5.5	4.8	1.74	2.45	2.78	2 007 239	2 303 088	2 381 943
	4	15.99%	23.37%	26.09%	7.1	4.8	4.2	1.95	2.80	3.11	1 983 090	2 278 939	2 357 794
High-performance window replacement	1	10.81%	15.78%	18.33%	10.7	7.2	6.2	1.39	1.93	2.21	922 657	1 024 229	1 049 234
	2	12.19%	17.96%	20.17%	9.5	6.3	5.6	1.54	2.17	2.43	910 583	1 012 155	1 037 160
	3	14.22%	20.19%	23.31%	8.1	5.6	4.8	1.76	2.43	2.79	1 755 133	1 958 277	2 008 287
	4	16.12%	23.22%	25.98%	7.1	4.8	4.3	1.97	2.78	3.10	1 730 984	1 934 128	1 984 139
Wall insulation + HP window replacement	1	10.52%	15.58%	18.22%	11.0	7.3	6.2	1.36	1.91	2.20	790 066	875 121	906 498
	2	11.97%	17.49%	20.04%	9.6	6.5	5.6	1.51	2.12	2.41	777 992	863 047	894 424
	3	13.87%	19.95%	23.18%	8.3	5.6	4.8	1.72	2.40	2.77	1 489 951	1 660 061	1 722 816
	4	15.86%	22.63%	25.81%	7.2	4.9	4.3	1.94	2.71	3.08	1 465 803	1 635 912	1 698 667
All combined	1	10.66%	16.27%	19.71%	10.8	7.0	5.7	1.38	1.98	2.37	417 431	500 973	563 947
	2	11.60%	18.00%	21.41%	9.9	6.3	5.2	1.48	2.18	2.57	405 357	488 899	551 873
	3	14.04%	20.79%	25.01%	8.2	5.4	4.4	1.74	2.50	2.99	744 682	911 766	1 037 713
	4	15.42%	23.27%	27.53%	7.4	4.8	4.0	1.89	2.78	3.28	720 533	887 617	1 013 565
Oil price $160 per barrel													
Baseline	1	14.36%	20.69%	23.65%	8.0	5.4	4.7	1.77	2.49	2.83	1 296 673	1 476 621	1 517 085
	2	16.11%	23.43%	26.21%	7.1	4.7	4.2	1.96	2.80	3.13	1 284 599	1 464 546	1 505 011
	3	18.47%	26.22%	29.89%	6.1	4.2	3.7	2.23	3.13	3.56	2 503 165	2 863 061	2 943 990
	4	20.92%	30.08%	33.60%	5.4	3.6	3.2	2.51	3.59	4.00	2 479 016	2 838 912	2 919 841
High-performance window replacement	1	14.52%	20.52%	23.75%	7.9	5.5	4.7	1.79	2.47	2.84	1 136 172	1 258 099	1 281 496
	2	16.22%	23.30%	26.11%	7.0	4.8	4.2	1.98	2.79	3.12	1 124 097	1 246 024	1 269 422
	3	18.67%	26.01%	30.01%	6.1	4.2	3.6	2.25	3.11	3.58	2 182 163	2 426 017	2 472 811
	4	21.06%	29.91%	33.46%	5.3	3.7	3.2	2.53	3.57	3.99	2 158 014	2 401 868	2 448 662
Wall insulation + HP window replacement	1	14.17%	20.27%	23.61%	8.1	5.5	4.7	1.75	2.44	2.82	960 578	1 062 905	1 095 889
	2	15.95%	22.70%	25.93%	7.2	4.9	4.3	1.95	2.72	3.10	948 503	1 050 831	1 083 814
	3	18.24%	25.70%	29.84%	6.2	4.3	3.7	2.20	3.07	3.56	1 830 975	2 035 630	2 101 596
	4	20.73%	29.15%	33.25%	5.4	3.8	3.3	2.49	3.48	3.96	1 806 826	2 011 481	2 077 448
All combined	1	14.37%	21.18%	25.56%	8.0	5.3	4.3	1.77	2.54	3.05	472 959	574 181	651 989
	2	15.52%	23.36%	27.73%	7.4	4.8	4.0	1.90	2.80	3.31	460 885	562 106	639 915
	3	18.49%	26.82%	32.27%	6.1	4.1	3.4	2.23	3.20	3.84	855 738	1 058 180	1 213 798
	4	20.20%	29.99%	35.52%	5.6	3.6	3.0	2.43	3.57	4.23	831 589	1 034 031	1 189 649
Oil price $200 per barrel													
Baseline	1	17.88%	25.33%	28.95%	6.3	4.4	3.8	2.16	3.03	3.45	1 544 637	1 756 607	1 798 108
	2	19.97%	28.68%	32.09%	5.6	3.8	3.4	2.40	3.42	3.82	1 532 562	1 744 533	1 786 034
	3	22.76%	31.99%	36.51%	4.9	3.4	3.0	2.72	3.81	4.35	2 999 092	3 423 034	3 506 036
	4	25.73%	36.74%	41.07%	4.3	2.9	2.6	3.07	4.37	4.89	2 974 943	3 398 885	3 481 887
High-performance window replacement	1	18.06%	25.14%	29.07%	6.3	4.4	3.8	2.18	3.00	3.47	1 349 687	1 491 969	1 513 758
	2	20.10%	28.54%	31.96%	5.6	3.8	3.4	2.42	3.40	3.81	1 337 612	1 479 894	1 501 683
	3	22.98%	31.75%	36.66%	4.8	3.4	2.9	2.75	3.78	4.37	2 609 192	2 893 756	2 937 334
	4	25.89%	36.55%	40.91%	4.3	3.0	2.6	3.09	4.35	4.87	2 585 043	2 869 607	2 913 186
Wall insulation + HP window replacement	1	17.64%	24.84%	28.90%	6.4	4.5	3.8	2.14	2.97	3.45	1 131 089	1 250 690	1 285 279
	2	19.78%	27.80%	31.75%	5.7	4.0	3.4	2.38	3.32	3.78	1 119 015	1 238 615	1 273 205
	3	22.46%	31.38%	36.44%	5.0	3.5	3.0	2.69	3.74	4.34	2 171 998	2 411 198	2 480 377
	4	25.48%	35.62%	40.64%	4.3	3.0	2.6	3.04	4.24	4.84	2 147 849	2 387 049	2 456 228
All combined	1	17.91%	25.79%	31.32%	6.3	4.3	3.5	2.17	3.10	3.73	528 487	647 388	740 031
	2	19.27%	28.62%	33.98%	5.9	3.8	3.2	2.32	3.41	4.05	516 413	635 313	727 957
	3	22.79%	32.79%	39.49%	4.9	3.3	2.7	2.73	3.91	4.70	966 793	1 204 594	1 389 882
	4	24.86%	36.66%	43.49%	4.5	2.9	2.5	2.97	4.37	5.18	942 644	1 180 446	1 365 733

Table 9.16 Economic feasibility of solar AC options 1-4 in four oil price scenarios at present, 2050 and 2090

The following conclusions can be made from Table 9.16:

- IRR discount rates where the DPB would equal to the service life of the equipment are provided so that a rough idea can be formulated of the impact of the discount rate on payback; i.e. the DPB would fall between that given for d=4% and the service life of the equipment if d was taken in-between 4% and the value of d when Y=N,
- options 2 and 4 using FPC yield slightly shorter DBP, higher SIR and lower LCC for all strategies in all climates and oil price scenarios,
- DPB for the baseline at present climate varies from 14.6 to 9.4 years depending on the option; options 3 and 4 with twice the cooling capacity would have DPBs 3-4 years less than the half-size options,
- ‘all combined’ option at present demonstrates slightly increased DPB but the lowest LCC,
- oil price increase from $92.07 to $200 would cut the DPB in less than half for all climates, equipment options and renovation strategies,
- at high oil prices DPB would be in the order of 3-6 years,
- SIR at 1.09-1.54 is obtainable at present climate and current oil price but is increased incrementally for each oil price category and future climate reaching 5.18 at oil price $200/barrel in the 2090 climate, and
- it is clearly demonstrated that LCC of all options are reduced when the option is implemented in connection with the building envelope renovation and thermal comfort adjustment strategies.

It is noted that the double-size options 3 and 4 have a shorter payback, higher SIR and their LCC is less than double of those of the basic options 1 and 2. Therefore, it would be economically more efficient to implement the larger system although the basic system also demonstrated its feasibility. It is subsequently concluded that solar AC installations are economically feasible and as such should be within the investment capabilities of most hotels.

9.10.4 Sensitivity of SC energy costs after energy saving measures

By using the earlier established oil and end-use energy price relationships, it was possible to estimate the SC energy costs in 3-, 4- and 5-star hotels in various fuel price scenarios. Guest night is the unit of revenue production in the hotel industry. Therefore, it was sensible to quantify energy costs per guest night[86] in order to establish their impact on room income. Annual heating and cooling energy costs per guest night for four different oil price categories, namely the present at $92.07/barrel, $120/barrel, $160/barrel and $200/barrel are shown in Tables 9.17-9.18[87]. In addition, the tables factor in incremental reduction in occupancy. It is noted that only the renovation strategies found cost-effective in the economic evaluation were included here, i.e. high-

[86] Guest nights sold annually were established from the official occupancy figures by the CTO (2011) and the number of beds in each hotel class model as stipulated for the theoretical hotel models earlier. Annual energy consumption from the thermal simulation model was then divided by the number of guest nights sold annually to derive the energy costs per guest night.
[87] Due to the large amount of data the table had to be split into two parts showing two oil price categories at a time.

performance windows alone, wall insulation with HP windows and 'all combined', implemented with or without solar AC. The base case was included for a frame of reference. Option 4 was assumed for the solar AC.

Hotel	Occu-pancy rate	Annual space conditioning energy costs, €/guest night															
		Oil price = $92.07 per barrel								Oil price = $120.00 per barrel							
		building envelope/thermal comfort				with solar air-conditioning				building envelope/thermal comfort				with solar air-conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
PRESENT																	
5*	48.0%	€2.58	€2.14	€1.97	€0.84	€2.08	€1.63	€1.47	€0.35	€3.20	€2.66	€2.43	€1.02	€2.56	€2.02	€1.80	€0.40
4*	51.0%	€2.07	€1.78	€1.59	€0.67	€1.61	€1.33	€1.15	€0.24	€2.56	€2.23	€1.97	€0.82	€1.99	€1.66	€1.41	€0.27
3*	42.6%	€1.87	€1.57	€1.41	€0.58	€1.34	€1.08	€0.93	€0.11	€2.29	€1.97	€1.77	€0.71	€1.67	€1.35	€1.15	€0.12
Occupancy reduction 5%																	
5*	43.0%	€2.77	€2.31	€2.13	€0.92	€2.20	€1.74	€1.57	€0.37	€3.43	€2.86	€2.62	€1.11	€2.71	€2.14	€1.91	€0.42
4*	46.0%	€2.19	€1.89	€1.70	€0.72	€1.69	€1.39	€1.20	€0.24	€2.71	€2.36	€2.10	€0.88	€2.09	€1.73	€1.48	€0.27
3*	37.6%	€2.00	€1.68	€1.51	€0.63	€1.40	€1.12	€0.96	€0.09	€2.44	€2.10	€1.89	€0.77	€1.74	€1.40	€1.19	€0.09
Occupancy reduction 15%																	
5*	33.0%	€3.30	€2.79	€2.58	€1.14	€2.57	€2.04	€1.85	€0.43	€4.08	€3.44	€3.18	€1.37	€3.15	€2.50	€2.25	€0.47
4*	36.0%	€2.56	€2.21	€2.00	€0.86	€1.91	€1.57	€1.37	€0.25	€3.15	€2.75	€2.47	€1.05	€2.35	€1.95	€1.67	€0.27
3*	27.6%	€2.39	€2.00	€1.82	€0.76	€1.58	€1.24	€1.07	€0.03	€2.90	€2.50	€2.26	€0.93	€1.95	€1.54	€1.31	€0.01
Occupancy reduction 25%																	
5*	23.0%	€4.30	€3.68	€3.43	€1.55	€3.24	€2.61	€2.38	€0.52	€5.29	€4.53	€4.21	€1.86	€3.95	€3.18	€2.88	€0.57
4*	26.0%	€3.20	€2.78	€2.53	€1.11	€2.30	€1.89	€1.66	€0.27	€3.93	€3.44	€3.12	€1.35	€2.82	€2.32	€2.02	€0.27
3*	17.6%	€3.23	€2.70	€2.47	€1.05	€1.95	€1.51	€1.29	-€0.09	€3.89	€3.36	€3.05	€1.28	€2.40	€1.86	€1.57	-€0.17
2050																	
5*	48.0%	€3.14	€2.57	€2.35	€1.18	€2.41	€1.85	€1.65	€0.46	€3.87	€3.17	€2.89	€1.42	€2.95	€2.25	€2.00	€0.51
4*	51.0%	€2.49	€2.13	€1.90	€0.95	€1.85	€1.49	€1.27	€0.31	€3.08	€2.64	€2.34	€1.15	€2.27	€1.84	€1.55	€0.34
3*	42.6%	€2.23	€1.88	€1.70	€0.84	€1.52	€1.18	€1.01	€0.14	€2.76	€2.34	€2.10	€1.02	€1.88	€1.46	€1.24	€0.14
Occupancy reduction 5%																	
5*	43.0%	€3.37	€2.77	€2.54	€1.28	€2.55	€1.96	€1.75	€0.47	€4.14	€3.41	€3.11	€1.54	€3.11	€2.39	€2.12	€0.52
4*	46.0%	€2.65	€2.27	€2.03	€1.02	€1.94	€1.56	€1.34	€0.31	€3.27	€2.81	€2.49	€1.23	€2.37	€1.91	€1.62	€0.34
3*	37.6%	€2.38	€2.01	€1.82	€0.90	€1.58	€1.22	€1.04	€0.11	€2.95	€2.50	€2.24	€1.09	€1.94	€1.50	€1.27	€0.09
Occupancy reduction 15%																	
5*	33.0%	€4.02	€3.35	€3.09	€1.58	€2.96	€2.30	€2.06	€0.53	€4.93	€4.11	€3.78	€1.90	€3.59	€2.79	€2.48	€0.57
4*	36.0%	€3.09	€2.66	€2.39	€1.22	€2.18	€1.75	€1.51	€0.31	€3.81	€3.28	€2.94	€1.47	€2.66	€2.14	€1.82	€0.33
3*	27.6%	€2.84	€2.42	€2.19	€1.09	€1.75	€1.34	€1.13	€0.01	€3.51	€2.99	€2.69	€1.32	€2.14	€1.63	€1.37	-€0.04
Occupancy reduction 25%																	
5*	23.0%	€5.24	€4.44	€4.12	€2.14	€3.72	€2.93	€2.64	€0.62	€6.41	€5.43	€5.02	€2.56	€4.49	€3.53	€3.16	€0.66
4*	26.0%	€3.87	€3.35	€3.04	€1.57	€2.61	€2.09	€1.82	€0.31	€4.76	€4.12	€3.72	€1.88	€3.17	€2.54	€2.18	€0.30
3*	17.6%	€3.83	€3.27	€2.97	€1.50	€2.13	€1.58	€1.32	-€0.19	€4.72	€4.04	€3.65	€1.81	€2.57	€1.90	€1.57	-€0.32
2090																	
5*	48.0%	€3.59	€2.96	€2.75	€1.49	€2.78	€2.15	€1.94	€0.64	€4.39	€3.61	€3.34	€1.79	€3.36	€2.60	€2.33	€0.71
4*	51.0%	€2.82	€2.42	€2.19	€1.19	€2.11	€1.71	€1.48	€0.44	€3.46	€2.97	€2.68	€1.44	€2.56	€2.07	€1.78	€0.49
3*	42.6%	€2.50	€2.11	€1.93	€1.05	€1.71	€1.33	€1.15	€0.22	€3.07	€2.60	€2.37	€1.26	€2.08	€1.62	€1.39	€0.22
Occupancy reduction 5%																	
5*	43.0%	€3.86	€3.20	€2.98	€1.62	€2.95	€2.30	€2.08	€0.67	€4.71	€3.90	€3.62	€1.94	€3.57	€2.77	€2.49	€0.74
4*	46.0%	€3.01	€2.58	€2.35	€1.28	€2.22	€1.79	€1.56	€0.45	€3.68	€3.17	€2.86	€1.54	€2.68	€2.17	€1.88	€0.49
3*	37.6%	€2.68	€2.27	€2.07	€1.12	€1.79	€1.38	€1.20	€0.19	€3.29	€2.79	€2.54	€1.36	€2.17	€1.67	€1.43	€0.18
Occupancy reduction 15%																	
5*	33.0%	€4.64	€3.89	€3.64	€1.99	€3.46	€2.72	€2.47	€0.75	€5.65	€4.74	€4.42	€2.39	€4.16	€3.26	€2.95	€0.82
4*	36.0%	€3.54	€3.05	€2.79	€1.53	€2.52	€2.04	€1.79	€0.46	€4.32	€3.73	€3.40	€1.84	€3.04	€2.46	€2.13	€0.49
3*	27.6%	€3.23	€2.74	€2.52	€1.37	€2.02	€1.54	€1.32	€0.10	€3.95	€3.37	€3.08	€1.65	€2.43	€1.85	€1.57	€0.04
Occupancy reduction 25%																	
5*	23.0%	€6.09	€5.19	€4.88	€2.68	€4.40	€3.51	€3.21	€0.91	€7.41	€6.31	€5.92	€3.22	€5.27	€4.19	€3.81	€0.97
4*	26.0%	€4.47	€3.87	€3.57	€1.97	€3.07	€2.48	€2.18	€0.49	€5.45	€4.73	€4.34	€2.36	€3.68	€2.96	€2.59	€0.50
3*	17.6%	€4.40	€3.76	€3.47	€1.89	€2.51	€1.88	€1.60	-€0.10	€5.38	€4.60	€4.23	€2.28	€2.99	€2.22	€1.87	-€0.24

Table 9.17 Annual SC energy costs per guest night in projected oil price and occupancy scenarios – Part 1 of 2

Hotel	Occupancy rate	Annual space conditioning energy costs, €/guest night															
		Oil price = $160.00 per barrel								Oil price = $200.00 per barrel							
		building envelope/thermal comfort				with solar air-conditioning				building envelope/thermal comfort				with solar air-conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
PRESENT																	
5*	48.0%	€4.07	€3.38	€3.08	€1.27	€3.24	€2.55	€2.26	€0.47	€4.93	€4.10	€3.72	€1.52	€3.92	€3.08	€2.72	€0.54
4*	51.0%	€3.26	€2.84	€2.50	€1.02	€2.53	€2.11	€1.78	€0.32	€3.96	€3.46	€3.04	€1.23	€3.07	€2.56	€2.15	€0.37
3*	42.6%	€2.93	€2.53	€2.25	€0.90	€2.13	€1.72	€1.47	€0.13	€3.57	€3.08	€2.74	€1.08	€2.59	€2.10	€1.78	€0.14
Occupancy reduction 5%																	
5*	43.0%	€4.54	€3.77	€3.44	€1.42	€3.42	€2.70	€2.40	€0.49	€5.26	€4.40	€4.01	€1.65	€4.14	€3.27	€2.89	€0.56
4*	46.0%	€3.61	€3.15	€2.78	€1.14	€2.65	€2.20	€1.87	€0.32	€4.19	€3.66	€3.23	€1.32	€3.21	€2.67	€2.25	€0.36
3*	37.6%	€3.32	€2.86	€2.55	€1.01	€2.22	€1.78	€1.51	€0.09	€3.79	€3.28	€2.92	€1.16	€2.69	€2.17	€1.83	€0.09
Occupancy reduction 15%																	
5*	33.0%	€5.16	€4.36	€4.00	€1.70	€3.96	€3.15	€2.82	€0.54	€6.24	€5.27	€4.83	€2.03	€4.77	€3.80	€3.38	€0.62
4*	36.0%	€4.00	€3.50	€3.12	€1.31	€2.97	€2.46	€2.10	€0.31	€4.85	€4.25	€3.78	€1.57	€3.59	€2.98	€2.53	€0.35
3*	27.6%	€3.70	€3.20	€2.87	€1.16	€2.47	€1.96	€1.65	-€0.03	€4.49	€3.89	€3.48	€1.39	€2.99	€2.38	€1.99	-€0.06
Occupancy reduction 25%																	
5*	23.0%	€6.68	€5.72	€5.29	€2.31	€4.96	€3.99	€3.59	€0.64	€8.06	€6.91	€6.38	€2.75	€5.96	€4.79	€4.29	€0.72
4*	26.0%	€4.97	€4.36	€3.93	€1.68	€3.55	€2.93	€2.52	€0.30	€6.02	€5.29	€4.75	€2.00	€4.27	€3.53	€3.02	€0.32
3*	17.6%	€4.94	€4.28	€3.87	€1.59	€3.01	€2.34	€1.96	-€0.27	€5.99	€5.20	€4.68	€1.91	€3.63	€2.83	€2.35	-€0.37
2050																	
5*	48.0%	€4.88	€4.00	€3.63	€1.76	€3.70	€2.83	€2.49	€0.59	€5.89	€4.83	€4.38	€2.10	€4.46	€3.40	€2.98	€0.67
4*	51.0%	€3.90	€3.34	€2.95	€1.43	€2.86	€2.31	€1.94	€0.39	€4.72	€4.05	€3.56	€1.71	€3.45	€2.79	€2.33	€0.45
3*	42.6%	€3.50	€2.98	€2.66	€1.27	€2.37	€1.85	€1.56	€0.14	€4.25	€3.61	€3.22	€1.52	€2.86	€2.23	€1.88	€0.14
Occupancy reduction 5%																	
5*	43.0%	€5.22	€4.30	€3.91	€1.91	€3.91	€2.99	€2.64	€0.60	€6.30	€5.19	€4.72	€2.28	€4.70	€3.60	€3.16	€0.68
4*	46.0%	€4.13	€3.55	€3.14	€1.53	€2.98	€2.41	€2.03	€0.38	€5.00	€4.30	€3.80	€1.83	€3.60	€2.90	€2.43	€0.43
3*	37.6%	€3.73	€3.18	€2.84	€1.36	€2.45	€1.89	€1.59	€0.08	€4.52	€3.85	€3.44	€1.63	€2.95	€2.29	€1.91	€0.06
Occupancy reduction 15%																	
5*	33.0%	€6.21	€5.18	€4.74	€2.35	€4.49	€3.48	€3.08	€0.65	€7.48	€6.25	€5.71	€2.80	€5.39	€4.17	€3.68	€0.72
4*	36.0%	€4.80	€4.15	€3.70	€1.82	€3.33	€2.68	€2.27	€0.36	€5.80	€5.01	€4.46	€2.18	€4.01	€3.23	€2.72	€0.39
3*	27.6%	€4.44	€3.79	€3.40	€1.64	€2.69	€2.04	€1.70	-€0.11	€5.37	€4.59	€4.11	€1.97	€3.23	€2.46	€2.04	-€0.17
Occupancy reduction 25%																	
5*	23.0%	€8.05	€6.82	€6.29	€3.17	€5.60	€4.38	€3.91	€0.72	€9.69	€8.22	€7.56	€3.78	€6.70	€5.24	€4.65	€0.79
4*	26.0%	€5.99	€5.19	€4.67	€2.34	€3.95	€3.17	€2.70	€0.31	€7.23	€6.27	€5.63	€2.79	€4.74	€3.80	€3.22	€0.31
3*	17.6%	€5.96	€5.10	€4.60	€2.25	€3.21	€2.37	€1.94	-€0.49	€7.19	€6.17	€5.55	€2.69	€3.84	€2.83	€2.30	-€0.66
2090																	
5*	48.0%	€5.50	€4.54	€4.19	€2.22	€4.19	€3.23	€2.89	€0.83	€6.62	€5.46	€5.03	€2.65	€5.02	€3.86	€3.44	€0.95
4*	51.0%	€4.35	€3.74	€3.36	€1.78	€3.19	€2.58	€2.21	€0.56	€5.24	€4.50	€4.04	€2.13	€3.83	€3.09	€2.64	€0.63
3*	42.6%	€3.87	€3.28	€2.98	€1.57	€2.60	€2.02	€1.72	€0.23	€4.67	€3.96	€3.59	€1.88	€3.12	€2.42	€2.06	€0.24
Occupancy reduction 5%																	
5*	43.0%	€5.91	€4.89	€4.53	€2.41	€4.44	€3.43	€3.08	€0.86	€7.10	€5.89	€5.44	€2.87	€5.31	€4.10	€3.66	€0.97
4*	46.0%	€4.63	€3.98	€3.59	€1.91	€3.35	€2.70	€2.32	€0.55	€5.58	€4.80	€4.32	€2.29	€4.01	€3.24	€2.77	€0.62
3*	37.6%	€4.14	€3.51	€3.20	€1.69	€2.70	€2.08	€1.77	€0.17	€4.99	€4.24	€3.85	€2.02	€3.24	€2.49	€2.11	€0.16
Occupancy reduction 15%																	
5*	33.0%	€7.07	€5.94	€5.52	€2.96	€5.16	€4.04	€3.63	€0.94	€8.50	€7.14	€6.63	€3.52	€6.17	€4.81	€4.32	€1.05
4*	36.0%	€5.42	€4.68	€4.26	€2.28	€3.78	€3.05	€2.63	€0.54	€6.53	€5.64	€5.11	€2.72	€4.52	€3.64	€3.13	€0.60
3*	27.6%	€4.97	€4.24	€3.87	€2.05	€3.01	€2.29	€1.93	-€0.02	€5.99	€5.11	€4.66	€2.45	€3.60	€2.73	€2.29	-€0.08
Occupancy reduction 25%																	
5*	23.0%	€9.26	€7.90	€7.38	€3.98	€6.52	€5.17	€4.67	€1.08	€11.12	€9.48	€8.85	€4.75	€7.77	€6.14	€5.53	€1.20
4*	26.0%	€6.83	€5.93	€5.43	€2.93	€4.55	€3.66	€3.18	€0.53	€8.20	€7.13	€6.52	€3.49	€5.43	€4.36	€3.77	€0.55
3*	17.6%	€6.75	€5.78	€5.31	€2.82	€3.68	€2.72	€2.27	-€0.42	€8.12	€6.96	€6.38	€3.37	€4.37	€3.23	€2.67	-€0.60

Table 9.18 Annual SC energy costs per guest night in projected oil price and occupancy scenarios – Part 2 of 2

The following observations can be made from Tables 9.17-9.18:

- for the base case, SC energy costs are expected to increase €0.56-0.45 per guest night from the present to 2090, but less increase would be expected for the renovation options,
- $40/barrel increase in the oil price corresponds to about €0.87 increase per guest night for the base case, €0.72 for 'window only', €0.65 for 'wall & window' and €0.25 for the 'all combined' strategies thus making the hotel operations after renovations less vulnerable to fuel price increases,
- the 'all combined' strategy would cut the SC energy costs to less than one third of those of the base case,

- solar AC would reduce the SC energy costs by 20-25% for the base case and building envelope upgrades whereas the ‘all combined’ strategy would benefit from SC energy cost savings of 65-70%, and
- at low occupancy levels in some cases negative price can be observed meaning that the solar AC produces surplus heat that can be used for DHW heating.

While reduced occupancy is a negative thing with obvious implications on the overall profitability of hotel operations, it is demonstrated from the above table that in such unfortunate circumstances hotels simply cannot afford to waste on energy costs. For a 3-star hotel at present climate with a 25% reduction in occupancy the difference between having renovated the building, adjusted the thermal comfort criteria and installed solar AC would mean nearly €90000 savings over the base case. The gap widens further in future climates making the savings potential even higher as the benefits of thermal renovations are not linear but far greater in the extreme circumstances as observed from the above tables and can as such provide a welcome buffer against fuel price increases.

9.10.5 Sensitivity of the investment costs

The initial investment costs of the proposed renovation strategies were distributed over guest nights in order to evaluate their impact on income. The high-performance window replacement alone and wall insulation with HP window replacement were included in the final analysis. The above two strategies were evaluated alone and together with solar AC. For a frame of reference the base case for solar AC was included as well, i.e. the investments costs of implementing solar AC without any building envelope improvements. Option 4 was assumed for the solar AC. The investment costs of the strategies were at first instance distributed over one year’s guest nights in order to produce a template for easy subsequent evaluation; for example the value given for one year can easily be divided by ten to see the costs distributed over ten years and so on. The costs were also calculated over the service life, but most importantly over the simple payback. By introducing the SPB into the evaluation it was possible to observe the effects of oil prices. Since the SPB is different for the building envelope improvements and solar AC, the investment costs of the combined cases were distributed over the payback of the building envelope improvements that is the longer one of the two in any case. Large amount of data was generated and only the results for oil price $92.07/barrel are shown in Table 9.19. The rest of the results can be seen in Appendix X.

Hotel	Occupancy rate	Investment costs, €/guest night														
												Oil price, $/barrel $92.07				
		over one year					over service life					over SPB				
		building envelope		with solar AC			building envelope		with solar AC			building envelope		with solar AC		
		Window only	Wall & window	Base Case	Window only	Wall & window	Window only	Wall & window	Base Case	Window only	Wall & window	Window only	Wall & window	Base Case	Window only	Wall & window
PRESENT																
5*	48.0%	€6.00	€8.74	€3.91	€9.91	€12.65	€0.24	€0.35	€0.16	€0.40	€0.51	€0.44	€0.61	€0.51	€1.30	€1.45
4*	51.0%	€3.51	€6.41	€3.45	€6.96	€9.86	€0.14	€0.26	€0.14	€0.28	€0.39	€0.27	€0.46	€0.45	€0.91	€1.13
3*	42.6%	€4.06	€7.21	€3.77	€7.83	€10.99	€0.16	€0.29	€0.15	€0.31	€0.44	€0.26	€0.42	€0.49	€1.02	€1.26
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€4.36	€11.06	€14.12	€0.27	€0.39	€0.17	€0.44	€0.56	€0.46	€0.64	€0.57	€1.45	€1.62
4*	46.0%	€3.90	€7.11	€3.82	€7.72	€10.93	€0.16	€0.28	€0.15	€0.31	€0.44	€0.29	€0.49	€0.50	€1.01	€1.25
3*	37.6%	€4.60	€8.17	€4.27	€8.87	€12.45	€0.18	€0.33	€0.17	€0.35	€0.50	€0.28	€0.44	€0.55	€1.16	€1.43
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€5.68	€14.42	€18.40	€0.35	€0.51	€0.23	€0.58	€0.74	€0.52	€0.72	€0.74	€1.89	€2.11
4*	36.0%	€4.98	€9.08	€4.88	€9.86	€13.96	€0.20	€0.36	€0.20	€0.39	€0.56	€0.33	€0.54	€0.63	€1.29	€1.60
3*	27.6%	€6.26	€11.13	€5.82	€12.08	€16.96	€0.25	€0.45	€0.23	€0.48	€0.68	€0.33	€0.51	€0.75	€1.58	€1.94
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€8.15	€20.68	€26.40	€0.50	€0.73	€0.33	€0.83	€1.06	€0.62	€0.87	€1.06	€2.70	€3.02
4*	26.0%	€6.89	€12.57	€6.76	€13.65	€19.33	€0.28	€0.50	€0.27	€0.55	€0.77	€0.40	€0.65	€0.88	€1.79	€2.22
3*	17.6%	€9.82	€17.46	€9.13	€18.95	€26.59	€0.39	€0.70	€0.37	€0.76	€1.06	€0.43	€0.67	€1.18	€2.48	€3.05
2050																
5*	48.0%	€6.00	€8.74	€4.56	€10.57	€13.31	€0.24	€0.35	€0.18	€0.42	€0.53	€0.57	€0.79	€0.85	€1.96	€2.14
4*	51.0%	€3.51	€6.41	€4.03	€7.54	€10.44	€0.14	€0.26	€0.16	€0.30	€0.42	€0.36	€0.60	€0.75	€1.40	€1.68
3*	42.6%	€4.06	€7.21	€4.41	€8.46	€11.62	€0.16	€0.29	€0.18	€0.34	€0.46	€0.34	€0.53	€0.82	€1.57	€1.87
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€5.10	€11.80	€14.85	€0.27	€0.39	€0.20	€0.47	€0.59	€0.59	€0.82	€0.95	€2.19	€2.39
4*	46.0%	€3.90	€7.11	€4.47	€8.36	€11.57	€0.16	€0.28	€0.18	€0.33	€0.46	€0.38	€0.62	€0.83	€1.55	€1.86
3*	37.6%	€4.60	€8.17	€4.99	€9.59	€13.17	€0.18	€0.33	€0.20	€0.38	€0.53	€0.36	€0.56	€0.93	€1.78	€2.12
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€6.64	€15.37	€19.36	€0.35	€0.51	€0.27	€0.61	€0.77	€0.67	€0.93	€1.24	€2.85	€3.11
4*	36.0%	€4.98	€9.08	€5.71	€10.68	€14.79	€0.20	€0.36	€0.23	€0.43	€0.59	€0.43	€0.70	€1.07	€1.98	€2.38
3*	27.6%	€6.26	€11.13	€6.80	€13.06	€17.94	€0.25	€0.45	€0.27	€0.52	€0.72	€0.43	€0.66	€1.27	€2.42	€2.89
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€9.53	€22.06	€27.77	€0.50	€0.73	€0.38	€0.88	€1.11	€0.80	€1.12	€1.78	€4.09	€4.47
4*	26.0%	€6.89	€12.57	€7.90	€14.79	€20.47	€0.28	€0.50	€0.32	€0.59	€0.82	€0.52	€0.83	€1.48	€2.74	€3.29
3*	17.6%	€9.82	€17.46	€10.67	€20.49	€28.13	€0.39	€0.70	€0.43	€0.82	€1.13	€0.56	€0.86	€1.99	€3.80	€4.53
2090																
5*	48.0%	€6.00	€8.74	€5.02	€11.02	€13.76	€0.24	€0.35	€0.20	€0.44	€0.55	€0.63	€0.84	€1.04	€2.28	€2.55
4*	51.0%	€3.51	€6.41	€4.43	€7.94	€10.84	€0.14	€0.26	€0.18	€0.32	€0.43	€0.41	€0.63	€0.92	€1.64	€2.01
3*	42.6%	€4.06	€7.21	€4.85	€8.90	€12.06	€0.16	€0.29	€0.19	€0.36	€0.48	€0.39	€0.57	€1.01	€1.84	€2.23
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€5.60	€12.31	€15.36	€0.27	€0.39	€0.22	€0.49	€0.61	€0.66	€0.88	€1.16	€2.54	€2.85
4*	46.0%	€3.90	€7.11	€4.91	€8.81	€12.02	€0.16	€0.28	€0.20	€0.35	€0.48	€0.43	€0.66	€1.02	€1.82	€2.23
3*	37.6%	€4.60	€8.17	€5.49	€10.09	€13.66	€0.18	€0.33	€0.22	€0.40	€0.55	€0.41	€0.60	€1.14	€2.08	€2.53
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€7.30	€16.03	€20.02	€0.35	€0.51	€0.29	€0.64	€0.80	€0.74	€1.00	€1.51	€3.31	€3.71
4*	36.0%	€4.98	€9.08	€6.27	€11.25	€15.35	€0.20	€0.36	€0.25	€0.45	€0.61	€0.49	€0.75	€1.30	€2.32	€2.84
3*	27.6%	€6.26	€11.13	€7.48	€13.74	€18.61	€0.25	€0.45	€0.30	€0.55	€0.74	€0.48	€0.71	€1.55	€2.84	€3.45
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€10.47	€23.01	€28.72	€0.50	€0.73	€0.42	€0.92	€1.15	€0.90	€1.21	€2.17	€4.75	€5.32
4*	26.0%	€6.89	€12.57	€8.69	€15.58	€21.26	€0.28	€0.50	€0.35	€0.62	€0.85	€0.59	€0.90	€1.80	€3.22	€3.94
3*	17.6%	€9.82	€17.46	€11.73	€21.55	€29.19	€0.39	€0.70	€0.47	€0.86	€1.17	€0.64	€0.93	€2.43	€4.45	€5.41

Table 9.19 Investment costs per guest night in projected occupancy and oil price scenarios[88]

SPB was chosen as the period of interest for several reasons. First of all, it is easy to calculate and typically available at the early stages of project evaluation. Secondly, it does not require the guesswork with future discount rates and finally, the purpose of the above analysis was to provide a rough magnitude of the cost implication on guest night basis rather than any exact figures. For more accurate figures the one year template value can be divided by the DPB calculated earlier for various discount rates. It is noted that what are referred to as investment 'costs' here are also the 'savings' due to the implemented renovation strategy since by definition the costs equal to savings over the simple payback period. So, in essence by maintaining room rates, the energy savings can

[88] Parts 2 to 4 can be seen in Appendix X.

finance the project. Of course the actual project costs would be somewhat higher as the above cost allocation does not factor in any capital or borrowing costs nor the time value of money but the point made is that with minimal room rate adjustments even large renovation projects can be financed. It may seem overwhelming for a hotelier to embark on a project costing half a million euro but when understood that in essence efforts in the order of less than €1/GN are required to finance the project, the outlook may seem completely different. It is believed that such small costs as around €1/GN could easily be passed onto the guest without much adverse effects.

The following conclusions can be made from Table 9.19 and the complete data in Appendix X:

- the investment costs over the service life of the renovation project are minimal, even with heavily reduced occupancies reaching beyond €1/GN on a few occasions only,
- as the oil price increases, the unit 'savings' increase also due to the fact that the initial investment is distributed over a shorter payback period,
- as the occupancy rate is reduced, the costs are distributed over fewer units, thus increasing the costs per guest night, and
- in the future climates the savings potential increases on the guest-night-basis subsequently making it easier to finance renovation projects by the savings they yield.

9.10.6 Estimating the hotel share from a package holiday price

Since hotels in Cyprus rely primarily on revenue from package holidays, it was necessary to investigate the share they get and how it may be affected by the external influences of fuel prices and occupancy rates.

For the purpose of this study a breakdown of costs of a typical holiday package from the UK to Cyprus is presented. A web-based survey was performed to derive the average cost of such holiday packages. Online brochures for 2011 of ten large tour operators, including the two largest operators with a 58% combined market share, were studied for package holidays to Cyprus. All offers to 3-, 4- and 5-star hotels on bed and breakfast basis were recorded for the peak season, i.e. the latter half of July and early August. Package prices were recorded for 7- and 14-day holidays. 70 offers were included for 3-star, 132 for 4-star and 108 for 5-star hotels in the price analysis. The average prices were then calculated for the three hotel classes. It is noted that half-board and all-inclusive packages were not included so as to keep the dataset uniform.

Further analysis was carried out in order to estimate the travel and accommodation components. From a package holiday costing example by Travel and Tourism Publishing (2007), operating costs of a charter plane were derived at €0.032[89] per available seat kilometre. The example assumes that a Boeing 737 with 168 seats is flown from London to the Greek island of Corfu with 90% load factor, i.e. 90% of the seats occupied. Comparison of the cost per available seat kilometre (CASK) to those of charter and low-cost airlines that are around €0.038 for airlines such as Monarch and Air2000, €0.055 for Ryanair (Horder, 2003) and €0.0575 for Norwegian

[89] Exchange rate of €1=£0.9019 (4-7-2011) assumed in currency conversion.

(norwegian.com, 2011), the figure looked reasonable. The CASK of €0.032 was extrapolated to the distance from London to Cyprus (6600 km vs. 4061 km to Corfu) yielding a total cost per seat of €211. However, the actual price could be slightly lower because only the time-based operating costs, such as fuel go up, frequency-based costs such as take-off and landing fees, ground handling, maintenance etc. remaining equal. Fuel costs account typically for some 27% of the total operating costs of airplanes (ICAO Secretariat, 2007a; norwegian.com, 2011) but perhaps for a tour operator's vertically integrated charter plane it may be assumed that the share would be as high as 50% since the administration, sales and marketing, etc. costs would be significantly reduced. The above assumption results in a price per seat of €173. Such a price appears to be in line with the last minute offers occasionally available when charter planes try to sell their remaining seats as a travel-only option. It may well be though that the remaining seats are sold below actual costs, therefore not reflecting the true per-seat cost. In view of the above and for simplicity, a cost per seat of €200 is assumed in the calculations that follow.

Before deriving the share taken by the accommodation, other expenses had to be factored in. A package holiday price typically also includes ground transfers between the airport and the chosen accommodation. It is assumed here that a €15 fee per person applies. Finally, the tour operator must cover its own overhead and administration costs, commission to agents selling its products, destination staff, taxes, duties, etc. Typically a 20% mark-up is added to the package price to cover expenses and to yield a profit (Travel and Tourism Publishing, 2007). The total price can now be broken down as shown in Table 9.20.

Holiday package component	5-star hotels		4-star hotels		3-star hotels	
	7 days B&B	14 days B&B	7 days B&B	14 days B&B	7 days B&B	14 days B&B
Airfare	€200	€200	€200	€200	€200	€200
Hotel accommodation	€728	€1397	€448	€824	€338	€578
Ground transfers	€15	€15	€15	€15	€15	€15
Operator's mark-up	€188	€323	€133	€207	€111	€159
TOTAL	€1131	€1935	€796	€1246	€664	€952

Table 9.20 Derived package holiday price breakdown for 3-, 4- and 5-star hotels for 7 and 14 days on bed and breakfast basis

Having now established the transportation and accommodation components, changes in fuel price and occupancy could be factored in. The analysis was carried out on per-guest-night basis. The average daily rates were derived from the above table as follows: €101.20 for 5-star, €60.57 for 4-star and €43.64 for 3-star on bed and breakfast basis. Room income was calculated by deducting SC energy costs (Tables 9.17-9.18) and investment costs (Table 9.19 and Appendix X) from the room rates. For sensitivity analysis it was noted that an increase in oil price was assumed to have a direct impact on the airfare fuel component that was taken as 50% of the total airfare. As hypothesised, the accommodation component was to absorb any increases in the travel component. For the first round of analysis the total price of the holiday package and the other components were assumed to stay unchanged. It is recognised that the ground transport also has an inherent fuel cost but the increase per passenger was found to be negligible for the fairly short distances of 80-150 km roundtrip indicated. A second round of analysis was performed with an assumption that the holiday package price was increased by 10.71%, the mean increase the surveyed guests were willing to pay for holidays in Cyprus. It was further assumed that the increase applied to the accommodation component and the tour operator's mark-up only, other components remaining as before but any subsequent oil price increase was absorbed by the accommodation as before. Complete analysis results are shown in Appendix X and highlights in Figs 9.20 to 9.23.

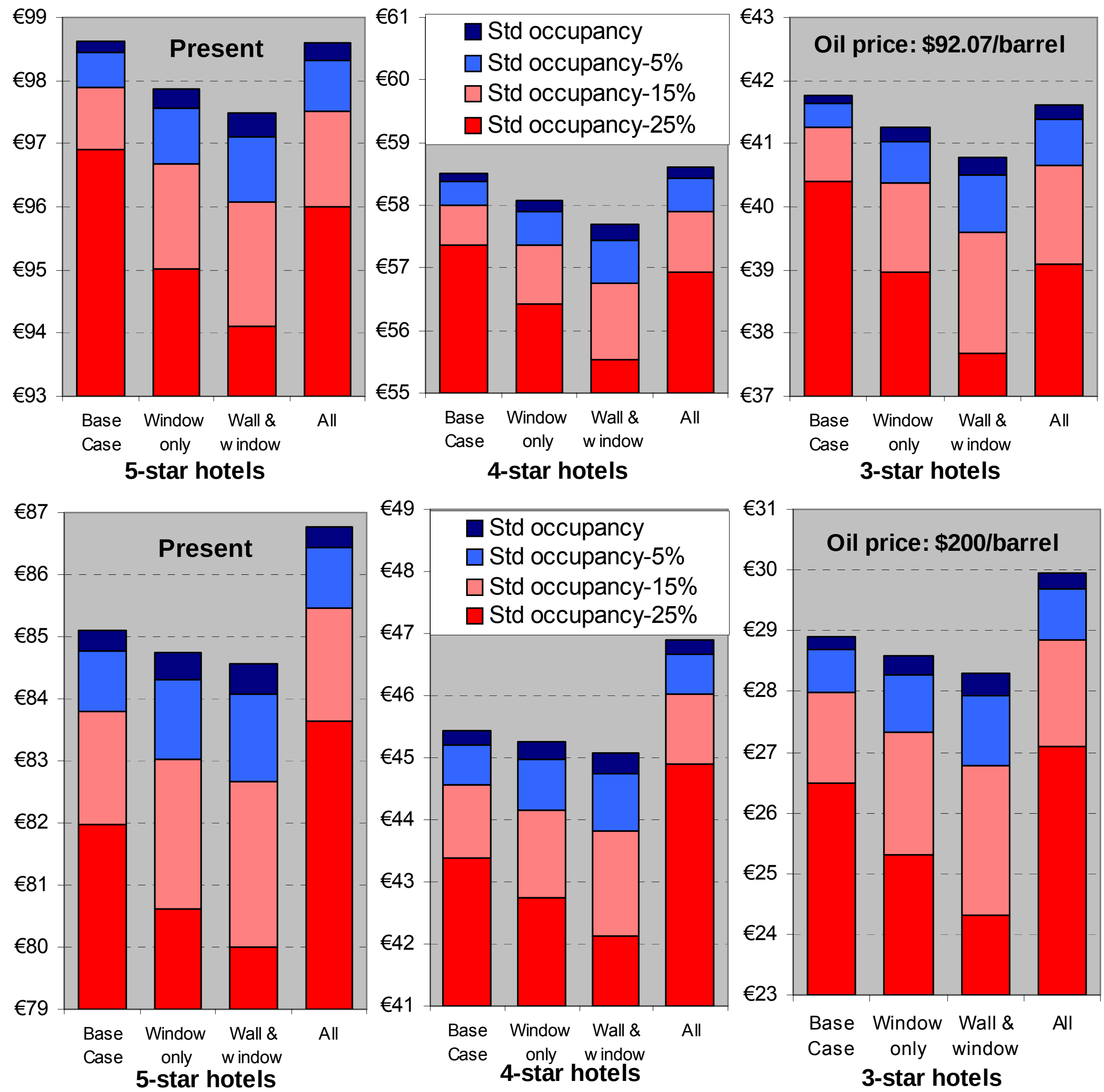


Figure 9.20 Room income per guest night as influenced by occupancy and oil price in present climate (without solar AC)

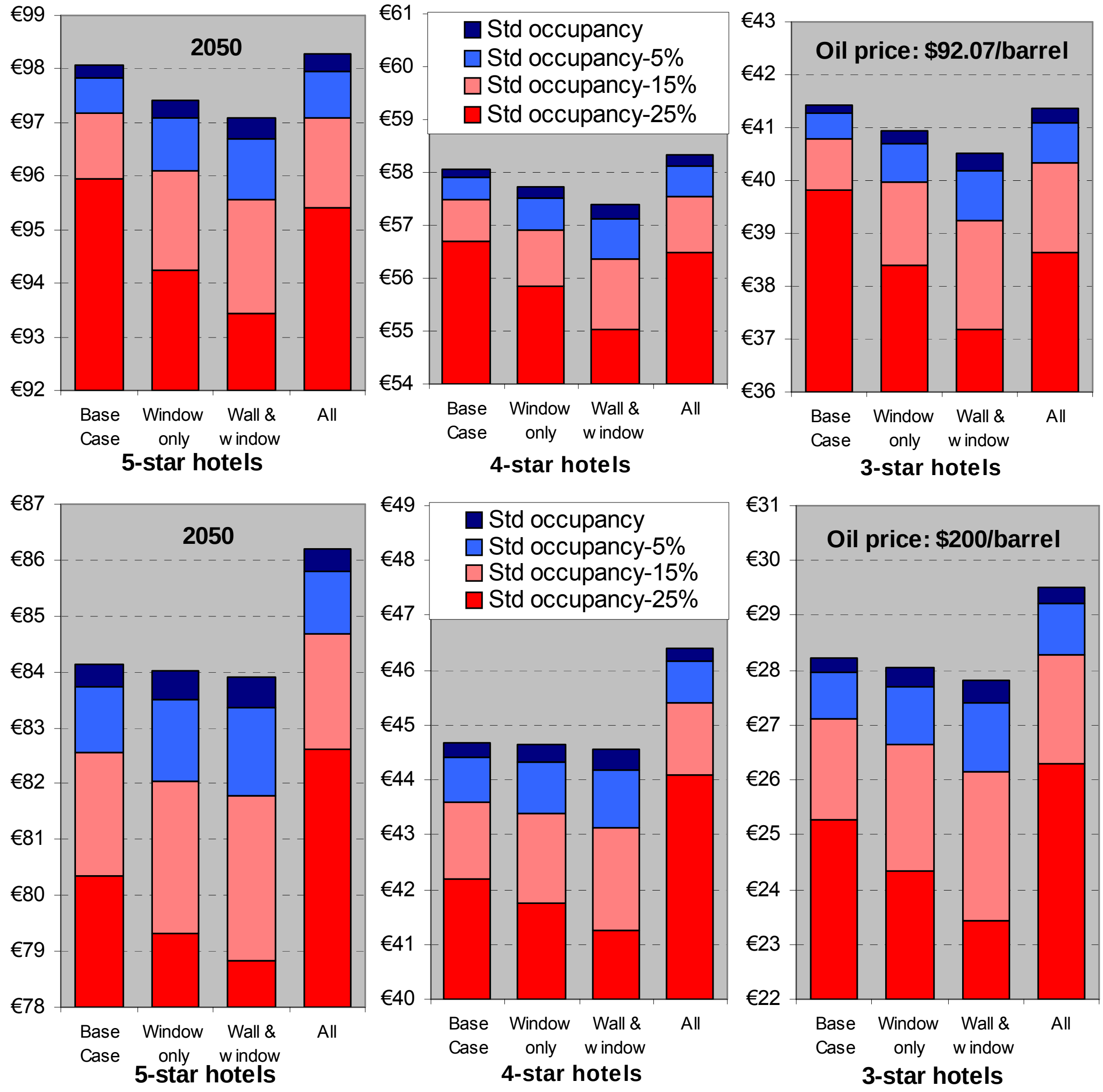


Figure 9.21 Room income per guest night as influenced by occupancy and oil price in 2050 climate (without solar AC)

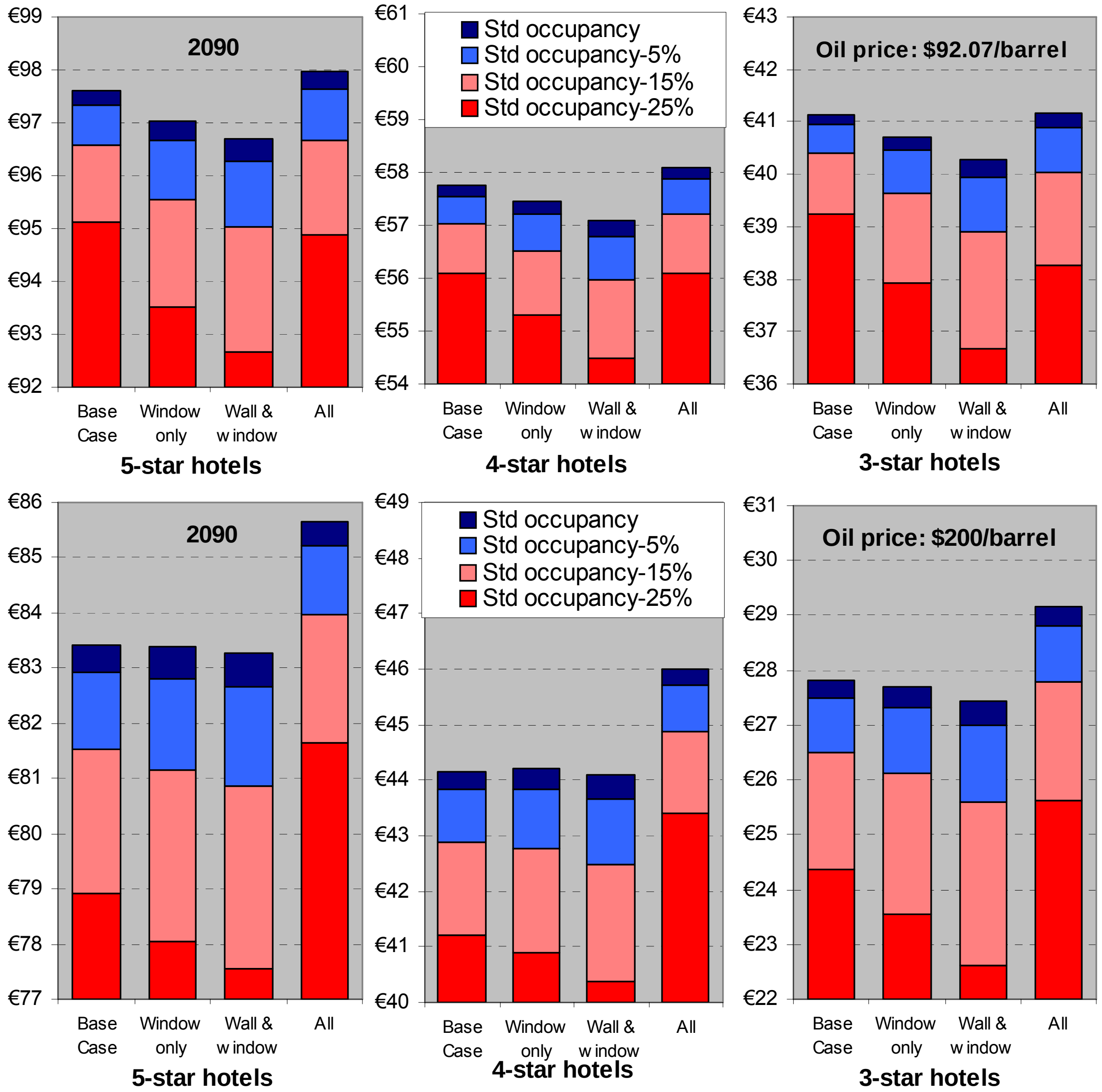


Figure 9.22 Room income per guest night as influenced by occupancy and oil price in 2090 climate (without solar AC)

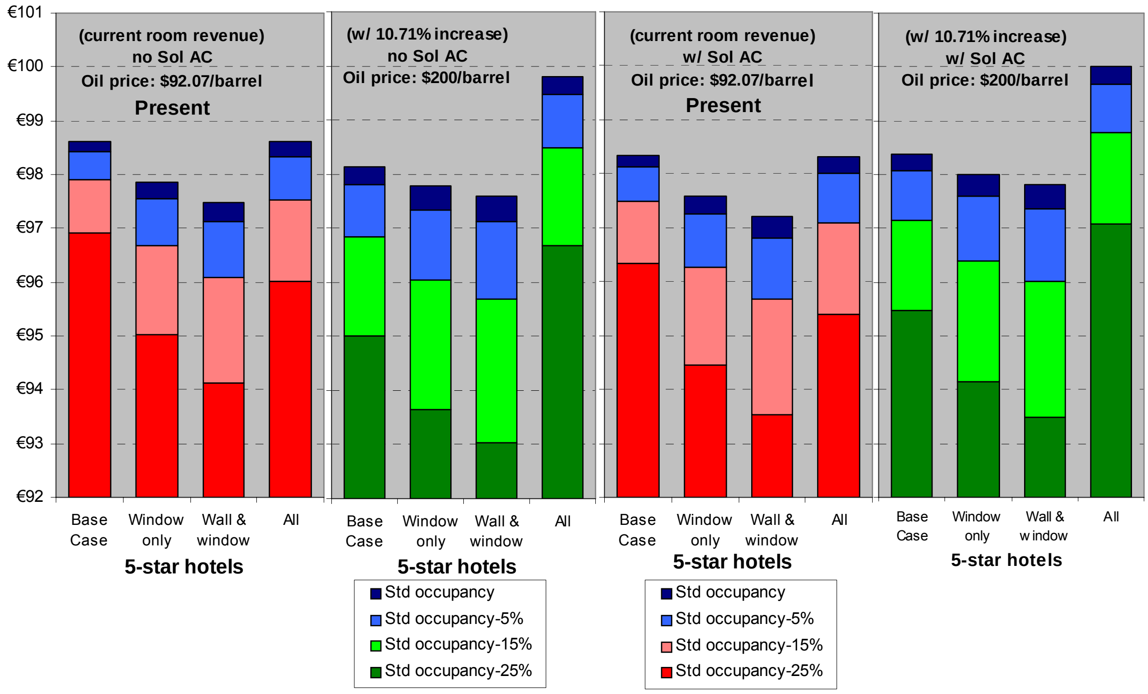


Figure 9.23 Room income per guest night with current room rates and 10.71% increase in package holiday price - comparison in two oil price categories in present climate as influenced by occupancy

The following conclusions can be made from Figs 9.20 to 9.22:

- the renovated cases are more vulnerable to occupancy reduction than the base case,
- at current oil price the 'all combined' strategy can maintain room income and slightly increase it in future climates but at $200/barrel it would greatly increase income (up to over €2 per guest night),
- at $200/barrel in future climates there is very little reduction in room income due to renovation investment, i.e. the energy savings would finance the investment,
- 3-star hotels would suffer the most from occupancy reduction and oil price increases; their room income would be reduced by 42% from the present base case to the base case in 2090 with the highest oil price and occupancy reduction, whereas 4-star hotels would suffer 30% and 5-star hotels 20% decrease in room income for the same external changes,

and from Fig. 9.23[90]:

- a 10.71% increase would actually increase the room income per guest night by €13.03 for 5-star, €8.68 for 4-star and €6.87 for 3-star hotels for the present base case,
- with the increase 5-star hotels could maintain the current base case (before increase) room income to $160/barrel oil price and 25% occupancy reduction by thermal renovation and all the way to $200/barrel and 5% occupancy reduction with the 'all combined' strategy,

[90] Complete results presented in Appendix X.

- 4-star hotels would be able to maintain the current base case (before increase) room income to $120/barrel oil price and 25% occupancy reduction or to $160/barrel oil price with unchanged occupation by thermal renovation,
- 3-star hotels would be able to maintain the current base case (before increase) room income to $120/barrel oil price and 25% occupancy reduction by thermal renovation,
- with the increase 3-star hotels' room income would be reduced by 25% from the present base case to the base case of 2090 with the highest oil price and occupancy reduction, 4-star hotels by 15% and 5-star hotels by 7% for the same external changes, and
- at current oil prices solar AC would lower room income but at high oil prices it would increase it.

It is beyond the scope of this study to guess how much, if any, room income loss could be absorbed by the hotels. But it is fair to assume that any reduction in present income would be undesirable especially when the income loss were due to increases in energy prices. Higher energy prices would be felt in the entire hotel operation from laundry to food preparation, dishwashing, housekeeping, maintenance, garden irrigation, etc. The price of water itself is intimately related to electricity prices due to desalination being an important source of potable water in Cyprus (Naukkarinen, 2006). Therefore, any reduction in room income at the time when the hotels' all other running expenses were going up would certainly be unwelcome. That's why thermal renovation was introduced as a means to guard against external factors such as energy price increases and climate change. But it is recognised that there is a limit to how much change can be absorbed. It is noted that no measures can maintain current income. However, with 10.71% increase in holiday package prices current base case room income could be maintained as explained above. Subsequently, it can be concluded that 5-star hotels are quite resilient against fuel price increases and occupancy reduction and thus can protect themselves with thermal renovation. The case is still quite good for 4-star hotels but not so for 3-star hotels whose income would start to erode at $160/barrel oil price even with thermal renovation and 10.71% increase in package holiday prices.

It is noted that even if income erosion could be prevented by energy saving measures in absolute terms, the overall profit margins of the hotels would suffer due to other running expenses or income generation indirectly affected by higher fuel prices and lower occupancy. Therefore, it is essential that all measures possible are taken to minimise the impacts caused by increasing energy prices.

9.11 Conclusions

In this chapter the theoretical hotel models were defined and a thermal simulation model was produced representing 3-, 4- and 5-star hotels. The model was calibrated against the real case study hotel and a good match between the real and the theoretical models was found. The model was then simulated in four orientations to establish the most severe orientation that was subsequently used in all succeeding simulations. Objective 2 was fulfilled by deriving the baseline SC energy consumption for 3-, 4- and 5-star hotels.

Future weather data for 2050 and 2090 representing the impacts of climate change in mid and end of the century were taken from purpose-made regional climate model runs. Thermal simulations with present and future weather data followed to predict energy savings due to thermal renovation of the building envelope, changes in thermal comfort criteria and introduction of renewable energy via solar AC.

The economic feasibility of the identified renovation strategies was evaluated and the impact of the external drivers on end-use energy prices and hotel occupancy were studied in the said three climates. End-use energy prices were calculated as a function of crude oil price and were used in the sensitivity analysis. The income generating potential of 3-, 4- and 5-star hotels was evaluated by first conducting a package holiday brochure price analysis in order to derive the average room rates and to establish room income.

It was found from the room rate analysis that no renovation strategy could maintain income into the $120/barrel oil price. However, a 10.71% increase in package holiday prices would give leverage against income erosion and would maintain it into the $120/barrel for 3-star, $160/barrel for 4-star and $200/barrel range for 5-star hotels.

The work undertaken in this chapter was to fulfil Objective 3, i.e. to identify cost-effective thermal renovation measures to reduce hotels' SC energy costs. All this work was in preparation to develop the concept of profitable hotel renovation further in Chapter 10.

10 Chapter 10 – Findings

10.1 Introduction

Various renovation strategies including building envelope improvements, thermal comfort criteria adjustments and system upgrades with renewable energy were introduced and their cost-effectiveness was analysed in the previous chapter. The purpose of this chapter is to expand on the individual strategies and see how they could be used as a guide by hotels planning thermal renovation as a means to maximise their room income generation. Furthermore, in this chapter the findings from the previous chapters are summarised, ranked and prioritised and they are discussed in a wider context and their predicted energy saving potential is extrapolated to the entire hotel building stock of Cyprus. The renovation strategies are tested by the newly developed indicator for their profitability in terms of income generation. The hypothesis that *a minimum of 20% savings in space conditioning energy costs can be realised by cost-effective thermal renovation of hotel buildings in Cyprus* is tested. Subsequently, this chapter addresses the Objectives 5 and 6, namely by developing and testing a new cost-efficiency indicator (Objective 5) and by extrapolating the predicted energy savings to the entire hotel building stock of Cyprus (Objective 6).

10.2 Renovation strategies and their cost-effectiveness

The following energy saving strategies were analysed in the previous chapter: external wall insulation, high-performance window replacement, conventional window replacement, external wall insulation together with high-performance window replacement and ‘all combined’ meaning that the external wall insulation and high-performance window replacement were accompanied by adjustments in thermal comfort criteria in regards to temperature settings and ventilation air volumes. The analysis indicated that neither external wall insulation alone nor conventional window replacement could be implemented cost-effectively in any scenarios studied. High-performance window replacement either alone or together with wall insulation in turn demonstrated cost-effectiveness but its feasibility was vulnerable to reductions in occupancy rates. The ‘all combined’ strategy was economically the most viable as it offered the greatest savings in SC energy costs. Finally, solar AC was introduced as a ‘wild card’ strategy to be implemented after other measures to reduce building loads had been taken and it offered promising cost-effectiveness. The strategies are summarised in Tables 10.1-10.3. The tables are organised so that ‘Y’ for yes is given if a strategy is economically efficient and ‘N’ for no if not. ‘YY’ denotes ‘exceptional efficiency’ and is defined as follow: for the DPB ‘Y’ if the DPB is less than the service life, ‘YY’ if less than 10 years, for the SIR ‘Y’ if the SIR>1, ‘YY’ if SIR>2, and for the LCC: ‘Y’ if the LCC is less than that of the reference baseline, ‘YY’ if less than half of the reference baseline. In addition, ranking of the strategies based on their lifecycle costs is given in Table 10.2. Ranking is not given for the solar AC implemented after the building envelope improvements and thermal comfort criteria adjustments as the ranking order does not change from that shown in Table 10.2.

Renovation strategy	Hotel	Discounted Payback, years (d=4%)												Savings to Investment Ratio (d=4%)											
		Present				2050				2090				Present				2050				2090			
Occupancy reduction		0%	-5%	-15%	-25%	0%	-5%	-15%	-25%	0%	-5%	-15%	-25%	0%	-5%	-15%	-25%	0%	-5%	-15%	-25%	0%	-5%	-15%	-25%
Oil price $92.07 per barrel																									
High-performance window replacement	5*	Y	Y	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	Y	Y	Y
	4*	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
	3*	Y	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	Y	Y	Y	Y
Wall insulation + HP window replacement	5*	Y	Y	N	N	Y	Y	Y	N	Y	Y	Y	Y	N	N	N	N	Y	Y	N	N	Y	Y	Y	N
	4*	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	Y	Y	N	N	Y	Y	Y	N
	3*	N	N	N	N	Y	Y	N	N	Y	Y	N	N	N	N	N	N	N	N	N	N	Y	N	N	N
All combined	5*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
	4*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
	3*	YY	YY	YY	Y	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	Y	Y	YY	YY	YY	Y	YY	YY	YY	Y
Oil price $120 per barrel																									
High-performance window replacement	5*	Y	Y	Y	N	Y	Y	Y	Y	YY	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	YY	Y	Y	Y
	4*	Y	Y	Y	Y	YY	Y	Y	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YY	YY	Y	Y
	3*	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Wall insulation + HP window replacement	5*	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
	4*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
	3*	Y	Y	N	N	Y	Y	Y	N	Y	Y	Y	Y	N	N	N	N	Y	Y	N	N	Y	Y	Y	N
All combined	5*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
	4*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
	3*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	Y	YY	YY	YY	YY	YY	YY	YY	YY
Oil price $160 per barrel																									
High-performance window replacement	5*	YY	Y	Y	Y	YY	YY	Y	Y	YY	YY	YY	Y	Y	Y	Y	Y	YY	YY	Y	Y	YY	YY	YY	Y
	4*	YY	Y	Y	Y	YY	YY	YY	Y	YY	YY	YY	YY	Y	Y	Y	Y	YY	YY	YY	Y	YY	YY	YY	YY
	3*	Y	Y	Y	Y	YY	Y	Y	Y	YY	YY	Y	Y	Y	Y	Y	Y	YY	Y	Y	Y	YY	YY	Y	Y
Wall insulation + HP window replacement	5*	YY	Y	Y	Y	YY	YY	Y	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YY	Y	Y	Y
	4*	YY	Y	Y	Y	YY	YY	Y	Y	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	YY	Y	Y	Y
	3*	Y	Y	Y	N	Y	YY	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
All combined	5*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
	4*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
	3*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
Oil price $200 per barrel																									
High-performance window replacement	5*	YY	YY	Y	Y	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	Y	Y	YY	YY	YY	Y	YY	YY	YY	YY
	4*	YY	YY	Y	Y	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	Y	Y	YY	YY	YY	YY	YY	YY	YY	YY
	3*	Y	Y	Y	Y	YY	YY	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	YY	YY	Y	Y	YY	YY	YY	Y
Wall insulation + HP window replacement	5*	YY	YY	Y	Y	YY	YY	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	YY	YY	Y	Y	YY	YY	YY	Y
	4*	YY	YY	Y	Y	YY	YY	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	YY	YY	Y	Y	YY	YY	YY	Y
	3*	Y	Y	Y	Y	YY	YY	YY	Y	YY	YY	YY	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
All combined	5*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
	4*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY
	3*	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY	YY

Table 10.1 Summary of thermal renovation strategies of 3-, 4- and 5-star hotels – building envelope improvements and thermal comfort criteria adjustments – Part 1 of 2

Renovation strategy	Hotel	Life-Cycle Cost, € (d=4%)																															
		Present								2050								2090															
Occupancy reduction		0%		-5%		-15%		-25%		0%		-5%		-15%		-25%		0%		-5%		-15%		-25%									
Oil price $92.07 per barrel			Rank		Rank		Rank		Rank		Rank		Rank		Rank		Rank		Rank		Rank		Rank		Rank								
High-performance window replacement	5*	Y	2	Y	2	N	-	N	-	Y	2	Y	2	Y	2	N	-	Y	2	Y	2	Y	2	Y	2								
	4*	Y	2	Y	2	Y	2	N	-	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2								
	3*	Y	2	N	-	N	-	N	-	Y	2	Y	2	Y	2	N	-	Y	2	Y	2	Y	2	Y	2								
Wall insulation + HP window replacement	5*	N	-	N	-	N	-	N	-	Y	3	Y	3	N	-	N	-	Y	3	Y	3	Y	3	N	-								
	4*	N	-	N	-	N	-	N	-	Y	3	Y	3	N	-	N	-	Y	3	Y	3	Y	3	N	-								
	3*	N	-	N	-	N	-	N	-	N	-	N	-	N	-	N	-	Y	3	N	-	N	-	N	-								
All combined	5*	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								
	4*	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								
	3*	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								
Oil price $120 per barrel																																	
High-performance window replacement	5*	Y	2	Y	2	Y	2	N	-	Y	3	Y	3	Y	2	Y	2	Y	3	Y	2	Y	2	Y	2								
	4*	Y	2	Y	2	Y	2	Y	2	Y	3	Y	3	Y	2	Y	2	Y	3	Y	3	Y	2	Y	2								
	3*	Y	2	Y	2	N	-	N	-	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2								
Wall insulation + HP window replacement	5*	Y	3	Y	3	N	-	N	-	Y	2	Y	2	Y	3	Y	3	Y	2	Y	3	Y	3	Y	3								
	4*	Y	3	Y	3	N	-	N	-	Y	2	Y	2	Y	3	Y	3	Y	2	Y	2	Y	3	Y	3								
	3*	N	-	N	-	N	-	N	-	Y	3	Y	3	N	-	N	-	Y	3	Y	3	Y	3	N	-								
All combined	5*	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								
	4*	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								
	3*	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								
Oil price $160 per barrel																																	
High-performance window replacement	5*	Y	3	Y	3	Y	2	Y	2	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	2								
	4*	Y	3	Y	3	Y	2	Y	2	Y	3	Y	3	Y	3	Y	2	Y	3	Y	3	Y	3	Y	2								
	3*	Y	2	Y	2	Y	2	Y	2	Y	3	Y	3	Y	2	Y	2	Y	3	Y	2	Y	2	Y	2								
Wall insulation + HP window replacement	5*	Y	2	Y	2	Y	3	Y	3	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	3								
	4*	Y	2	Y	2	Y	3	Y	3	Y	2	Y	2	Y	2	Y	3	Y	2	Y	2	Y	2	Y	3								
	3*	Y	3	Y	3	N	-	N	-	Y	2	Y	2	Y	3	Y	3	Y	2	Y	3	Y	3	Y	3								
All combined	5*	YY	1	YY	1	Y	1	Y	1	YY	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								
	4*	YY	1	YY	1	Y	1	Y	1	YY	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								
	3*	YY	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								
Oil price $200 per barrel																																	
High-performance window replacement	5*	Y	3	Y	3	Y	3	Y	2	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3								
	4*	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3	Y	3								
	3*	Y	3	Y	3	Y	2	Y	2	Y	3	Y	3	Y	3	Y	2	Y	3	Y	3	Y	2	Y	2								
Wall insulation + HP window replacement	5*	Y	2	Y	2	Y	2	Y	3	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2								
	4*	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2	Y	2								
	3*	Y	2	Y	2	Y	3	N	-	Y	2	Y	2	Y	2	Y	3	Y	2	Y	2	Y	3	Y	3								
All combined	5*	YY	1	YY	1	YY	1	Y	1	YY	1	YY	1	YY	1	Y	1	YY	1	Y	1	Y	1	Y	1								
	4*	YY	1	YY	1	YY	1	YY	1	YY	1	YY	1	YY	1	Y	1	Y	1	Y	1	Y	1	Y	1								
	3*	YY	1	YY	1	Y	1	Y	1	YY	1	YY	1	Y	1	Y	1	Y	1	Y	1	Y	1	Y	1								

Table 10.2 Summary of thermal renovation strategies of 3-, 4- and 5-star hotels – building envelope improvements and thermal comfort criteria adjustments – Part 2 of 2

Renovation strategy	Hotel	Discounted Payback, years (d=4%)			Savings to Investment Ratio (d=4%)			Life Cycle Cost, € (d=4%)											
		Present	2050	2090	Present	2050	2090	Present				2050				2090			
Occupancy reduction		0%	0%	0%	0%	0%	0%	0%	-5%	-15%	-25%	0%	-5%	-15%	-25%	0%	-5%	-15%	-25%
Oil price $92.07 per barrel																			
Solar AC w/ baseline	5*	YY	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ HP window replacement	5*	Y	YY	YY	Y	Y	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	Y	YY	YY	Y	Y	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	Y	YY	YY	Y	Y	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ wall insulation + HP window replacement	5*	Y	Y	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	Y	Y	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ all combined	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Oil price $120 per barrel																			
Solar AC w/ baseline	5*	YY	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ HP window replacement	5*	Y	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	Y	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ wall insulation + HP window replacement	5*	Y	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	Y	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	Y	YY	YY	Y	Y	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ all combined	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	YY	Y	Y	YY	YY
Oil price $160 per barrel																			
Solar AC w/ baseline	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ HP window replacement	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ wall insulation + HP window replacement	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	Y	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ all combined	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YY
	3*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	YY	YY	YY	YY	YY	YY	YY
Oil price $200 per barrel																			
Solar AC w/ baseline	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ HP window replacement	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ wall insulation + HP window replacement	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	3*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar AC w/ all combined	5*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	4*	YY	YY	YY	YY	YY	YY	Y	Y	Y	Y	Y	Y	YY	YY	Y	YY	YY	YY
	3*	YY	YY	YY	YY	YY	YY	Y	Y	Y	YY	YY	YY	YY	YY	YY	YY	YY	YY

Table 10.3 Summary of thermal renovation strategies of 3-, 4- and 5-star hotels – solar AC implemented after building envelope improvements and thermal comfort criteria adjustments

Note: Comparison made to the same strategy without solar AC.

The following conclusions can be made from Tables 10.1-10.3:

- the proposed strategies without thermal comfort criteria adjustments are not viable at present climate and current oil price with heavily reduced occupancies,
- as observed before, the 'all combined' strategy and higher oil prices improve cost-effectiveness of all combinations, and

- solar AC makes all combinations cost-effective, some demonstrating exceptional efficiency for several combinations as seen in Table 10.3.

It can be concluded from the analysis above and in the previous chapter that thermal renovation is a powerful weapon against the external drivers of climate change, inflation of energy prices and reduced hotel occupancy. It remains to test whether the initial hypothesis was correct in quantifying the potential energy savings.

10.3 Hypothesis testing

The initial hypothesis of the thesis was that thermal renovation can be used to realise a minimum of 20% reduction in SC energy costs of hotels. It was also hypothesised from early on that building envelope improvements alone might not be enough to obtain such savings but that system upgrades introducing renewable energy would be necessary to reach the target. Therefore it was with great interest that the hypothesis was tested and the results are shown in Table 10.4. It can be observed from the table that neither external wall insulation nor high-performance nor conventional window replacement would reach energy cost savings of 20%. 20% reduction in heating costs would be possible in a few circumstances but not in total energy costs. However, in combination wall insulation and high-performance window replacement would be predicted to offer savings well over 20%. When thermal comfort criteria adjustments were included, total energy savings in excess of 60% were predicted, slightly less in the 2090 climate. The inclusion of solar AC would further increase the energy cost savings potential by reducing heating costs by 30%-90%, cooling by 14%-46% and 20%-55% in total. It is observed that solar AC together with building envelope improvements would predict higher savings than solar AC implemented alone. The greatest savings potential would rest with the adjustment of thermal comfort criteria combined with building envelope and systems improvements predicting savings in excess of 100% in heating, i.e. producing surplus heat that can be used for DHW heating, 64%-76% savings in cooling and up to 94% in total. The importance of thermal comfort criteria adjustments cannot therefore be overemphasised as they are a no-cost way to save substantial amounts of SC energy. It is noted that current energy prices were used in the analysis. Any increase in energy prices would improve the savings potential further.

Renovation strategy	Hotel	Change in heating and cooling costs due to energy saving strategy, % from the baseline								
		Present			2050			2090		
		Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total
With building envelope and thermal comfort criteria:										
External wall insulation	5*	-16.3%	0.4%	-5.3%	-15.8%	-1.9%	-5.6%	-15.6%	-2.0%	-4.7%
	4*	-20.7%	0.1%	-7.9%	-20.1%	-2.8%	-8.0%	-20.0%	-2.9%	-6.8%
	3*	-17.0%	0.5%	-7.0%	-16.6%	-2.3%	-7.1%	-16.3%	-2.6%	-6.1%
High-performance window replacement	5*	-14.9%	-18.1%	-17.0%	-16.9%	-18.6%	-18.1%	-17.4%	-17.6%	-17.6%
	4*	-7.5%	-16.8%	-13.2%	-9.6%	-16.6%	-14.5%	-9.9%	-15.6%	-14.3%
	3*	-7.3%	-19.5%	-14.3%	-9.7%	-18.4%	-15.4%	-10.0%	-17.4%	-15.5%
Conventional window replacement	5*	-20.5%	-0.8%	-7.5%	-21.7%	-2.7%	-7.8%	-21.9%	-3.1%	-6.8%
	4*	-13.2%	-1.0%	-5.7%	-14.4%	-2.3%	-6.0%	-14.8%	-2.8%	-5.5%
	3*	-13.3%	-1.2%	-6.4%	-14.7%	-2.7%	-6.7%	-14.9%	-3.2%	-6.2%
External wall insulation + HP window replacement	5*	-33.0%	-19.0%	-23.7%	-34.4%	-21.7%	-25.1%	-34.7%	-20.7%	-23.5%
	4*	-29.8%	-18.1%	-22.6%	-31.3%	-20.7%	-23.9%	-31.6%	-19.8%	-22.4%
	3*	-25.9%	-20.4%	-22.8%	-27.7%	-21.9%	-23.9%	-27.8%	-21.1%	-22.8%
All combined	5*	-90.3%	-55.5%	-67.3%	-91.5%	-51.7%	-62.4%	-89.3%	-50.9%	-58.5%
	4*	-85.6%	-55.7%	-67.2%	-87.2%	-50.8%	-61.8%	-85.2%	-49.9%	-57.8%
	3*	-83.8%	-56.4%	-68.1%	-85.4%	-50.6%	-62.3%	-82.9%	-49.7%	-58.1%
Thermal comfort criteria adjustments only	5*	-78.9%	-43.4%	-55.4%	-79.7%	-35.4%	-47.2%	-75.6%	-35.2%	-43.2%
	4*	-76.0%	-44.3%	-56.5%	-77.2%	-35.3%	-48.0%	-73.1%	-35.0%	-43.6%
	3*	-76.2%	-43.2%	-57.3%	-77.1%	-34.1%	-48.5%	-72.9%	-33.7%	-43.6%
With solar air-conditioning:										
Baseline	5*	-30.5%	-14.0%	-19.6%	-59.0%	-16.8%	-28.1%	-70.9%	-14.1%	-25.4%
	4*	-29.8%	-16.7%	-21.7%	-40.1%	-19.6%	-25.8%	-55.9%	-16.4%	-25.3%
	3*	-33.0%	-22.0%	-26.7%	-44.4%	-25.2%	-31.6%	-61.4%	-21.1%	-31.3%
High-performance window replacement	5*	-44.9%	-32.6%	-36.8%	-58.4%	-34.9%	-41.2%	-74.3%	-31.6%	-40.1%
	4*	-36.8%	-34.2%	-35.2%	-50.4%	-35.6%	-40.1%	-66.0%	-31.9%	-39.6%
	3*	-39.8%	-42.3%	-41.2%	-54.8%	-42.8%	-46.8%	-71.6%	-38.2%	-46.7%
External wall insulation + HP window replacement	5*	-62.6%	-33.2%	-43.2%	-74.4%	-37.8%	-47.6%	-90.9%	-34.7%	-45.8%
	4*	-58.8%	-35.1%	-44.2%	-70.7%	-39.4%	-48.9%	-86.9%	-36.0%	-47.5%
	3*	-57.9%	-42.9%	-49.3%	-71.3%	-46.1%	-54.5%	-88.7%	-42.0%	-53.8%
All combined	5*	-121.8%	-68.0%	-86.3%	-138.5%	-66.0%	-85.4%	-155.7%	-64.1%	-82.2%
	4*	-116.4%	-70.6%	-88.2%	-133.5%	-67.5%	-87.5%	-150.7%	-65.2%	-84.4%
	3*	-117.9%	-76.0%	-93.9%	-136.5%	-72.1%	-93.7%	-154.9%	-69.4%	-91.1%

Table 10.4 Summary of hypothesis testing showing the percentage of SC energy savings due to implementation of various energy saving strategies

Option 4 with 106 kW cooling capacity assumed for the solar AC.
Current end-use energy prices assumed in the calculations.

10.4 Ranking of the energy-efficiency strategies

It is now possible to rank the energy saving strategies by their cost saving potential and investment costs. A brief summary is presented below.

10.4.1 High cost – high efficiency measures

Solar AC would qualify as a high cost - high efficiency measure as it has been demonstrated both in the economic analysis and the cost saving analysis above to offer high return for the investment. As pointed out in several contexts earlier, solar AC is best to be introduced only after first implementing other measures to minimise the building loads. If it is therefore implemented together with building envelope improvements, the combination of measures would be the highest cost and highest efficiency measure.

10.4.2 High cost – low efficiency measures

Wall insulation alone and conventional window replacement are both measures that did not qualify by the economic feasibility analysis. While they do offer some heating energy cost savings as seen in Table 10.4, they are simply not cost-effective and as such high cost – low efficiency measures and not recommended in any hotel renovations.

10.4.3 Low cost – high efficiency measures

One strategy not discussed yet in this thesis, namely applying the proposed thermal comfort criteria adjustments alone without any building envelope improvements was included in the analysis presented in Table 10.4. It is noted that the strategy yielded over 70% savings in heating, 34%-44% in cooling and 43%-57% in total SC energy costs. Adjustments in temperature settings and ventilation flow rates can be made at no cost. Yet as shown, large energy savings potential is predicted. Therefore the strategy would actually be no cost – high efficiency measure.

10.4.4 Low cost – low efficiency measures

None of the proposed energy-efficiency strategies qualify as low-cost. Low-cost measures would typically include measures such as weather stripping. The impact of weather stripping was indeed analysed in Chapter 7[91] and it was concluded that about 0.5% savings in heating costs would be predicted whereas cooling costs would slightly increase. The costs were not estimated but should not be more that a few hundred euro if executed by in-house staff during a low season.

10.5 Space Conditioning Profitability

It was the ultimate goal of this thesis to define a unique cost-efficiency indicator introduced in Chapter 6 called *Space Conditioning Profitability* (SCP). As explained before, SCP is a measure of how profitable a renovation strategy would be in regards to room income generation. Other research was identified where an economic indicator system was developed for the hotel industry aiming at forecasting the industry's growth and turning points based on variables such as stock exchange index, wages and salaries, consumer confidence, GDP, hotel failure liabilities and many others (Choi, 2003). However, the objective in this study was to define an indicator that can be used as a decision-making tool when choosing thermal renovation alternatives, not a forecasting tool. But before further discussion on the developed indicator, it is necessary to briefly introduce how hotel operations are evaluated in economic terms in general. The terminology is defined according to deRoos and Rushmore (2003). First of all, hotel's *Net Income* equals to its *Departmental Income* less its *Undistributed Operating Expenses* and *Fixed Charges*. *Departmental Income* is further defined as *Total Revenues* less *Departmental Expenses*. *Total Revenues* of hotels include revenue from guestrooms, food & beverage sales, guest telephone use, etc. The *Departmental Expenses* include the direct expenses of rooms, food & beverage, telephone and 'other'. *Undistributed Operating Expenses* in turn include administrative & general, marketing, franchise fees, property operation & maintenance and energy costs. And finally, *Fixed Charges* include property taxes, insurance, management fees and a capital expenditure reserve, typically 4% in magnitude. In this study the interest is on *room income* that can be defined as room revenue

[91] Discussed in detail in Section 7.2.3.6.

less direct expenses, undistributed operating expenses and fixed charges. However, the only type of expense of interest in this study is SC energy costs, i.e. the portion of energy costs that is used for heating and cooling, hence the name of the indicator: Space Conditioning Profitability. Therefore, when referring to room income in this study, the following is implied:

Room Income = Room Revenue – SC Energy Costs – Investment Costs

Investment costs would include the costs of implementing an energy saving measure and it is assumed in the analysis that the costs are distributed over five years. Five years was chosen as a period because typically hotels are reluctant to make investments beyond that. It is noted that the actual payback periods of the measures may be longer but the analysis is done with a fixed 5-year period. Naturally, if a longer period were assumed, room income would increase as a smaller portion of investment costs would be deducted per guest night, albeit over a longer time period.

For the SCP analysis the SC energy costs of the entire hotel are distributed over the annually sold guest nights. Therefore, the SC energy costs per guest night do not reflect only the energy consumed in the guestrooms but also in the common areas. It is further assumed that the common areas have a fixed SC energy consumption regardless of occupancy. It is noted that internal gains would vary due to occupancy but the positive and negative components of displacement energy are expected to balance out annually when heating and cooling energies are combined. Occupancy as a sensitivity variable has, however, a profound impact on the profitability analysis via dictating the number of annual guest nights and the way SC energy costs are distributed. Decrease in occupancy could subsequently result in higher SC energy costs per guest night. Increase in end-use energy prices, another sensitivity variable, would by default increase the SC energy costs per guest night. Climate progression in the context of this study in turn means increased cooling needs but decreased heating needs in future climates. Therefore, the SCP analysis gives an opportunity to see how the sensitivity variables affect the annual balance of SC energy costs in combination. As illustrated in Fig. 10.1, the objective of SCP analysis is to identify the window of opportunity where energy savings per guest night would exceed the investment costs incurred and therefore would have the ability to increase room income as a direct result of the energy-efficiency improvement; in other words where:

SC Energy Costs (after ren.) + Investment Costs < SC Energy Costs (before ren.)

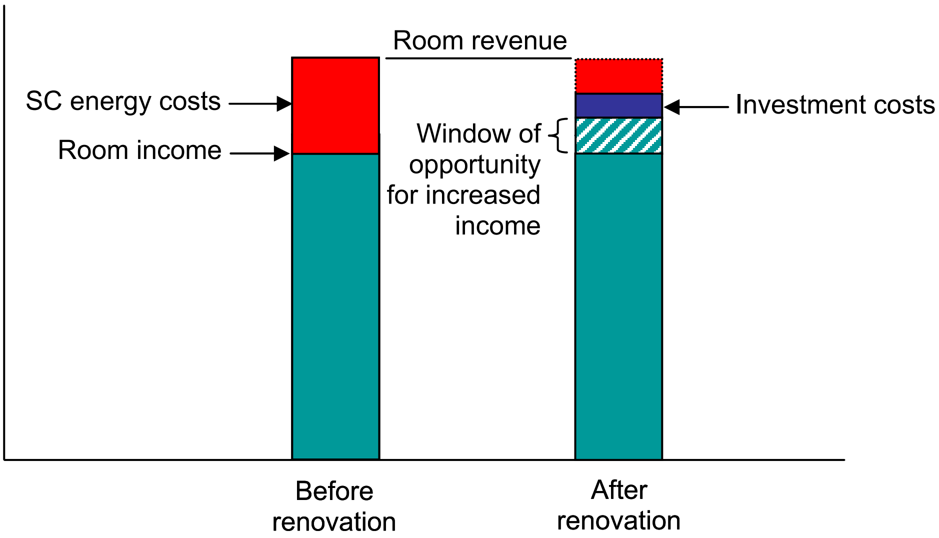


Figure 10.1 Relationship between hotel room revenue and income and the influence of thermal renovation on it

Regarding the exact mechanism how the SCP indicator works, all renovation strategies in all combinations of climate, oil prices and occupancy are compared to the baseline[92] and their income ratio is calculated. In other words, the room income is calculated for each combination by subtracting the SC energy and investment costs from the room revenue. Income per guest night of each combination is subsequently divided by that of the base case. If the ratio is greater than one, the strategy in the given external circumstances is considered profitable as it would generate more income than the baseline condition. However, if it is less than one, the strategy would not be able to prevent income erosion. It is to be noted that space conditioning profitability assessment is independent of the cost-effectiveness of the strategies evaluated in the previous chapter. A renovation measure can be cost-effective but not profitable in a sense that it would increase room income. Actually three levels of efficiency exist and were evaluated in this thesis, i.e. technical efficiency measuring if and how much energy can be saved due to a renovation strategy, cost-benefit analysis assessing if the savings can be achieved cost-effectively and finally if such a measure could increase room income in hotels. In the analysis room revenues were taken from the room rates generated from standard package holidays, as defined earlier. As a second step a price increase of 10.71% was applied to the package holiday price and its impact on room revenue and thus on space conditioning profitability was observed.

Tables 10.5-10.8 were prepared to show the SCP for the proposed renovation strategies including solar AC in all climates, oil prices and occupancies. Solar AC was investigated so that it accompanied each building envelope improvement and thermal comfort adjustment strategy for a convenient way to identify where it was the most profitable. Option 4 was selected for the analysis as the most cost-effective solar AC option. All values >1 are highlighted in blue in the tables. It is noted that in some cases a value 1.00 is highlighted while in other cases not due to rounding of the values to two decimal places.

[92] Baseline condition refers to existing construction standards, present climate, current oil price and occupancy.

Hotel	Occupancy rate	Space Conditioning Profitability with standard revenue from package holidays															
		Oil price = $92.07 per barrel								Oil price = $120.00 per barrel							
		building envelope/thermal comfort				with solar air-conditioning				building envelope/thermal comfort				with solar air-conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
PRESENT																	
5*	48.0%	1.00	0.99	0.99	1.00	1.00	0.99	0.99	1.00	0.96	0.96	0.95	0.97	0.96	0.96	0.95	0.97
4*	51.0%	1.00	0.99	0.99	1.00	1.00	0.99	0.98	1.00	0.94	0.94	0.93	0.95	0.94	0.93	0.93	0.95
3*	42.6%	1.00	0.99	0.98	1.00	0.99	0.98	0.97	0.99	0.92	0.91	0.90	0.92	0.92	0.91	0.90	0.92
Occupancy reduction 5%																	
5*	43.0%	1.00	0.99	0.98	1.00	1.00	0.99	0.98	0.99	0.96	0.95	0.95	0.97	0.96	0.95	0.95	0.96
4*	46.0%	1.00	0.99	0.98	1.00	0.99	0.99	0.98	0.99	0.94	0.93	0.93	0.95	0.94	0.93	0.92	0.94
3*	37.6%	1.00	0.98	0.97	0.99	0.99	0.98	0.96	0.98	0.92	0.90	0.89	0.92	0.91	0.90	0.89	0.91
Occupancy reduction 15%																	
5*	33.0%	0.99	0.98	0.97	0.99	0.99	0.98	0.97	0.98	0.96	0.94	0.94	0.96	0.95	0.94	0.94	0.95
4*	36.0%	0.99	0.98	0.97	0.99	0.99	0.97	0.96	0.98	0.93	0.92	0.91	0.94	0.93	0.92	0.91	0.93
3*	27.6%	0.99	0.97	0.95	0.97	0.98	0.96	0.94	0.96	0.91	0.89	0.87	0.90	0.90	0.88	0.86	0.89
Occupancy reduction 25%																	
5*	23.0%	0.98	0.96	0.95	0.97	0.98	0.96	0.95	0.97	0.94	0.93	0.92	0.94	0.94	0.92	0.91	0.94
4*	26.0%	0.98	0.96	0.95	0.97	0.97	0.96	0.94	0.96	0.92	0.90	0.89	0.92	0.91	0.90	0.89	0.92
3*	17.6%	0.97	0.93	0.90	0.94	0.95	0.92	0.89	0.92	0.88	0.85	0.82	0.86	0.87	0.84	0.81	0.85
2050																	
5*	48.0%	0.99	0.99	0.98	1.00	0.99	0.99	0.98	0.99	0.96	0.95	0.95	0.96	0.96	0.95	0.95	0.96
4*	51.0%	0.99	0.99	0.98	1.00	0.99	0.98	0.98	0.99	0.93	0.93	0.92	0.94	0.93	0.93	0.92	0.94
3*	42.6%	0.99	0.98	0.97	0.99	0.99	0.98	0.96	0.99	0.91	0.90	0.89	0.92	0.91	0.90	0.89	0.92
Occupancy reduction 5%																	
5*	43.0%	0.99	0.98	0.98	0.99	0.99	0.98	0.98	0.99	0.95	0.95	0.95	0.96	0.95	0.95	0.95	0.96
4*	46.0%	0.99	0.98	0.98	0.99	0.99	0.98	0.97	0.99	0.93	0.92	0.92	0.94	0.93	0.92	0.92	0.94
3*	37.6%	0.99	0.97	0.96	0.98	0.98	0.97	0.96	0.98	0.91	0.89	0.88	0.91	0.91	0.89	0.88	0.91
Occupancy reduction 15%																	
5*	33.0%	0.99	0.97	0.97	0.98	0.98	0.97	0.97	0.98	0.95	0.94	0.93	0.95	0.95	0.94	0.93	0.95
4*	36.0%	0.98	0.97	0.96	0.98	0.98	0.97	0.96	0.98	0.92	0.91	0.90	0.93	0.92	0.91	0.90	0.93
3*	27.6%	0.98	0.96	0.94	0.97	0.97	0.95	0.93	0.96	0.89	0.87	0.86	0.89	0.89	0.87	0.86	0.89
Occupancy reduction 25%																	
5*	23.0%	0.97	0.96	0.95	0.97	0.97	0.95	0.94	0.96	0.93	0.92	0.91	0.93	0.93	0.92	0.91	0.93
4*	26.0%	0.97	0.95	0.94	0.97	0.96	0.95	0.93	0.96	0.90	0.89	0.88	0.91	0.90	0.89	0.88	0.91
3*	17.6%	0.95	0.92	0.89	0.93	0.94	0.91	0.88	0.91	0.86	0.83	0.80	0.85	0.86	0.83	0.80	0.85
2090																	
5*	48.0%	0.99	0.98	0.98	0.99	0.99	0.98	0.98	0.99	0.95	0.95	0.95	0.96	0.95	0.95	0.95	0.96
4*	51.0%	0.99	0.98	0.98	0.99	0.98	0.98	0.97	0.99	0.93	0.92	0.92	0.94	0.93	0.92	0.92	0.94
3*	42.6%	0.98	0.97	0.96	0.99	0.98	0.97	0.96	0.98	0.90	0.89	0.88	0.91	0.90	0.89	0.88	0.91
Occupancy reduction 5%																	
5*	43.0%	0.99	0.98	0.98	0.99	0.98	0.98	0.97	0.99	0.95	0.94	0.94	0.96	0.95	0.94	0.94	0.96
4*	46.0%	0.98	0.98	0.97	0.99	0.98	0.97	0.97	0.99	0.92	0.92	0.91	0.94	0.92	0.92	0.91	0.94
3*	37.6%	0.98	0.97	0.96	0.98	0.98	0.96	0.95	0.97	0.90	0.89	0.88	0.90	0.90	0.89	0.88	0.91
Occupancy reduction 15%																	
5*	33.0%	0.98	0.97	0.96	0.98	0.98	0.97	0.96	0.98	0.94	0.93	0.93	0.95	0.94	0.93	0.93	0.95
4*	36.0%	0.97	0.97	0.96	0.98	0.97	0.96	0.95	0.97	0.91	0.91	0.90	0.92	0.91	0.91	0.90	0.93
3*	27.6%	0.97	0.95	0.93	0.96	0.96	0.94	0.92	0.95	0.88	0.87	0.85	0.88	0.88	0.87	0.85	0.89
Occupancy reduction 25%																	
5*	23.0%	0.96	0.95	0.94	0.96	0.96	0.94	0.94	0.96	0.92	0.91	0.90	0.93	0.92	0.91	0.90	0.93
4*	26.0%	0.96	0.95	0.93	0.96	0.95	0.94	0.93	0.95	0.89	0.88	0.87	0.90	0.89	0.88	0.87	0.90
3*	17.6%	0.94	0.91	0.88	0.92	0.93	0.90	0.87	0.91	0.85	0.82	0.79	0.84	0.85	0.82	0.79	0.84

Table 10.5 Space Conditioning Profitability of 3-, 4- and 5-star hotels with standard revenue from package holidays, Part 1 of 2

Hotel	Occupancy rate	Space Conditioning Profitability with standard revenue from package holidays															
		Oil price = $160.00 per barrel								Oil price = $200.00 per barrel							
		building envelope/thermal comfort				with solar air-conditioning				building envelope/thermal comfort				with solar air-conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
PRESENT																	
5*	48.0%	0.91	0.91	0.91	0.92	0.91	0.91	0.91	0.92	0.86	0.86	0.86	0.88	0.87	0.86	0.86	0.88
4*	51.0%	0.86	0.85	0.85	0.88	0.86	0.86	0.85	0.88	0.78	0.77	0.77	0.80	0.78	0.78	0.77	0.80
3*	42.6%	0.81	0.80	0.79	0.82	0.81	0.80	0.79	0.82	0.69	0.68	0.68	0.72	0.70	0.69	0.68	0.72
Occupancy reduction 5%																	
5*	43.0%	0.91	0.90	0.90	0.92	0.91	0.91	0.90	0.92	0.86	0.85	0.85	0.88	0.86	0.86	0.86	0.88
4*	46.0%	0.85	0.85	0.84	0.87	0.86	0.85	0.85	0.87	0.77	0.77	0.76	0.80	0.78	0.77	0.77	0.80
3*	37.6%	0.80	0.79	0.78	0.81	0.80	0.79	0.78	0.81	0.69	0.68	0.67	0.71	0.69	0.68	0.67	0.72
Occupancy reduction 15%																	
5*	33.0%	0.90	0.89	0.89	0.91	0.90	0.89	0.89	0.91	0.85	0.84	0.84	0.87	0.85	0.85	0.84	0.87
4*	36.0%	0.85	0.84	0.83	0.86	0.85	0.84	0.83	0.86	0.76	0.75	0.75	0.79	0.77	0.76	0.75	0.79
3*	27.6%	0.79	0.77	0.75	0.80	0.79	0.77	0.76	0.80	0.67	0.65	0.64	0.69	0.68	0.66	0.65	0.70
Occupancy reduction 25%																	
5*	23.0%	0.89	0.87	0.86	0.89	0.89	0.87	0.87	0.89	0.83	0.82	0.81	0.85	0.84	0.82	0.82	0.85
4*	26.0%	0.83	0.82	0.80	0.84	0.83	0.82	0.81	0.84	0.74	0.73	0.72	0.77	0.75	0.74	0.73	0.77
3*	17.6%	0.76	0.73	0.70	0.75	0.76	0.73	0.70	0.76	0.63	0.61	0.58	0.65	0.65	0.62	0.59	0.66
2050																	
5*	48.0%	0.91	0.90	0.90	0.92	0.91	0.90	0.90	0.92	0.85	0.85	0.85	0.87	0.86	0.86	0.86	0.88
4*	51.0%	0.85	0.85	0.84	0.87	0.85	0.85	0.85	0.87	0.76	0.76	0.76	0.79	0.77	0.77	0.77	0.80
3*	42.6%	0.79	0.79	0.78	0.81	0.80	0.79	0.78	0.82	0.68	0.67	0.67	0.71	0.69	0.68	0.68	0.72
Occupancy reduction 5%																	
5*	43.0%	0.90	0.90	0.90	0.92	0.91	0.90	0.90	0.92	0.85	0.85	0.85	0.87	0.86	0.85	0.85	0.88
4*	46.0%	0.84	0.84	0.84	0.86	0.85	0.85	0.84	0.87	0.76	0.76	0.76	0.79	0.77	0.77	0.76	0.80
3*	37.6%	0.79	0.78	0.77	0.80	0.79	0.79	0.78	0.81	0.67	0.66	0.66	0.70	0.68	0.68	0.67	0.71
Occupancy reduction 15%																	
5*	33.0%	0.89	0.88	0.88	0.91	0.90	0.89	0.88	0.91	0.84	0.83	0.83	0.86	0.84	0.84	0.84	0.87
4*	36.0%	0.83	0.83	0.82	0.85	0.84	0.83	0.83	0.86	0.75	0.74	0.74	0.78	0.76	0.75	0.75	0.79
3*	27.6%	0.77	0.76	0.74	0.78	0.78	0.77	0.75	0.79	0.65	0.64	0.63	0.68	0.67	0.66	0.64	0.70
Occupancy reduction 25%																	
5*	23.0%	0.87	0.86	0.85	0.89	0.88	0.87	0.86	0.89	0.81	0.80	0.80	0.84	0.83	0.82	0.81	0.85
4*	26.0%	0.81	0.80	0.79	0.83	0.82	0.81	0.80	0.84	0.72	0.71	0.71	0.75	0.74	0.73	0.72	0.77
3*	17.6%	0.73	0.71	0.68	0.74	0.75	0.72	0.70	0.75	0.61	0.58	0.56	0.63	0.63	0.61	0.59	0.66
2090																	
5*	48.0%	0.90	0.90	0.89	0.91	0.90	0.90	0.90	0.92	0.85	0.85	0.84	0.87	0.85	0.85	0.85	0.88
4*	51.0%	0.84	0.84	0.84	0.86	0.85	0.84	0.84	0.87	0.75	0.76	0.75	0.79	0.76	0.76	0.76	0.80
3*	42.6%	0.78	0.78	0.77	0.80	0.79	0.79	0.78	0.81	0.67	0.66	0.66	0.70	0.68	0.68	0.67	0.71
Occupancy reduction 5%																	
5*	43.0%	0.90	0.89	0.89	0.91	0.90	0.90	0.89	0.92	0.84	0.84	0.84	0.86	0.85	0.85	0.84	0.87
4*	46.0%	0.84	0.83	0.83	0.86	0.84	0.84	0.83	0.86	0.75	0.75	0.75	0.78	0.76	0.76	0.76	0.79
3*	37.6%	0.78	0.77	0.76	0.80	0.79	0.78	0.77	0.81	0.66	0.65	0.65	0.69	0.67	0.67	0.66	0.71
Occupancy reduction 15%																	
5*	33.0%	0.88	0.88	0.87	0.90	0.89	0.88	0.88	0.90	0.83	0.82	0.82	0.85	0.84	0.83	0.83	0.86
4*	36.0%	0.82	0.82	0.81	0.85	0.83	0.82	0.82	0.85	0.73	0.73	0.73	0.77	0.75	0.74	0.74	0.78
3*	27.6%	0.76	0.75	0.73	0.77	0.77	0.76	0.74	0.79	0.63	0.63	0.61	0.67	0.66	0.65	0.63	0.69
Occupancy reduction 25%																	
5*	23.0%	0.86	0.85	0.84	0.88	0.87	0.86	0.85	0.89	0.80	0.79	0.79	0.83	0.81	0.80	0.80	0.84
4*	26.0%	0.80	0.79	0.78	0.82	0.81	0.80	0.79	0.83	0.70	0.70	0.69	0.74	0.72	0.72	0.71	0.76
3*	17.6%	0.71	0.69	0.67	0.73	0.73	0.71	0.68	0.75	0.58	0.56	0.54	0.61	0.62	0.60	0.57	0.65

Table 10.6 Space Conditioning Profitability of 3-, 4- and 5-star hotels with standard revenue from package holidays, Part 2 of 2

Hotel	Occu-pancy rate	Space Conditioning Profitability with a 10.71% package holiday price increase															
		Oil price = $92.07 per barrel								Oil price = $120.00 per barrel							
		building envelope/thermal comfort				with solar air-conditioning				building envelope/thermal comfort				with solar air-conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
PRESENT																	
5*	48.0%	1.13	1.12	1.12	1.13	1.13	1.12	1.12	1.13	1.10	1.09	1.09	1.10	1.10	1.09	1.09	1.10
4*	51.0%	1.15	1.14	1.13	1.15	1.14	1.14	1.13	1.15	1.09	1.08	1.08	1.10	1.09	1.08	1.08	1.10
3*	42.6%	1.16	1.15	1.14	1.16	1.16	1.15	1.13	1.15	1.09	1.07	1.06	1.09	1.08	1.07	1.06	1.08
Occupancy reduction 5%																	
5*	43.0%	1.13	1.12	1.12	1.13	1.13	1.12	1.11	1.13	1.09	1.09	1.08	1.10	1.09	1.08	1.08	1.10
4*	46.0%	1.15	1.14	1.13	1.15	1.14	1.13	1.13	1.14	1.09	1.08	1.07	1.09	1.09	1.08	1.07	1.09
3*	37.6%	1.16	1.15	1.13	1.15	1.16	1.14	1.13	1.15	1.08	1.07	1.06	1.08	1.08	1.06	1.05	1.08
Occupancy reduction 15%																	
5*	33.0%	1.12	1.11	1.11	1.12	1.12	1.11	1.10	1.12	1.09	1.08	1.07	1.09	1.09	1.07	1.07	1.09
4*	36.0%	1.14	1.13	1.12	1.14	1.13	1.12	1.11	1.13	1.08	1.07	1.06	1.09	1.08	1.07	1.06	1.08
3*	27.6%	1.15	1.13	1.11	1.14	1.14	1.12	1.10	1.13	1.07	1.05	1.03	1.06	1.07	1.05	1.03	1.06
Occupancy reduction 25%																	
5*	23.0%	1.11	1.10	1.09	1.11	1.11	1.09	1.08	1.10	1.08	1.06	1.05	1.07	1.07	1.05	1.05	1.07
4*	26.0%	1.13	1.11	1.10	1.12	1.12	1.10	1.09	1.11	1.07	1.05	1.04	1.07	1.06	1.05	1.03	1.06
3*	17.6%	1.13	1.10	1.07	1.10	1.12	1.08	1.05	1.08	1.05	1.01	0.98	1.03	1.04	1.00	0.98	1.02
2050																	
5*	48.0%	1.13	1.12	1.12	1.13	1.12	1.12	1.11	1.13	1.09	1.08	1.08	1.10	1.09	1.08	1.08	1.10
4*	51.0%	1.14	1.14	1.13	1.15	1.14	1.13	1.13	1.14	1.08	1.08	1.07	1.09	1.08	1.08	1.07	1.09
3*	42.6%	1.16	1.14	1.13	1.15	1.15	1.14	1.13	1.15	1.07	1.06	1.06	1.08	1.07	1.06	1.05	1.08
Occupancy reduction 5%																	
5*	43.0%	1.12	1.12	1.11	1.13	1.12	1.11	1.11	1.12	1.09	1.08	1.08	1.09	1.09	1.08	1.08	1.09
4*	46.0%	1.14	1.13	1.12	1.14	1.14	1.13	1.12	1.14	1.08	1.07	1.07	1.09	1.08	1.07	1.07	1.09
3*	37.6%	1.15	1.14	1.13	1.15	1.15	1.13	1.12	1.14	1.07	1.06	1.05	1.07	1.07	1.06	1.05	1.07
Occupancy reduction 15%																	
5*	33.0%	1.12	1.11	1.10	1.12	1.11	1.10	1.10	1.11	1.08	1.07	1.06	1.08	1.08	1.07	1.06	1.08
4*	36.0%	1.13	1.12	1.11	1.13	1.13	1.12	1.11	1.13	1.07	1.06	1.05	1.08	1.07	1.06	1.05	1.08
3*	27.6%	1.14	1.12	1.10	1.13	1.13	1.11	1.10	1.12	1.06	1.04	1.02	1.06	1.06	1.04	1.02	1.06
Occupancy reduction 25%																	
5*	23.0%	1.11	1.09	1.08	1.10	1.10	1.08	1.08	1.10	1.06	1.05	1.04	1.07	1.06	1.05	1.04	1.07
4*	26.0%	1.12	1.10	1.09	1.11	1.11	1.10	1.08	1.11	1.05	1.04	1.03	1.06	1.05	1.04	1.03	1.06
3*	17.6%	1.12	1.08	1.05	1.09	1.11	1.07	1.04	1.08	1.03	0.996	0.97	1.01	1.03	1.00	0.97	1.01
2090																	
5*	48.0%	1.12	1.12	1.11	1.13	1.12	1.11	1.11	1.12	1.08	1.08	1.08	1.09	1.08	1.08	1.08	1.09
4*	51.0%	1.14	1.13	1.12	1.14	1.13	1.13	1.12	1.14	1.08	1.07	1.07	1.09	1.08	1.07	1.07	1.09
3*	42.6%	1.15	1.14	1.13	1.15	1.14	1.13	1.12	1.15	1.07	1.06	1.05	1.08	1.07	1.06	1.05	1.08
Occupancy reduction 5%																	
5*	43.0%	1.12	1.11	1.11	1.12	1.12	1.11	1.11	1.12	1.08	1.08	1.07	1.09	1.08	1.08	1.07	1.09
4*	46.0%	1.13	1.13	1.12	1.14	1.13	1.12	1.12	1.13	1.07	1.07	1.06	1.08	1.07	1.07	1.06	1.08
3*	37.6%	1.15	1.13	1.12	1.14	1.14	1.13	1.12	1.14	1.06	1.05	1.04	1.07	1.06	1.05	1.04	1.07
Occupancy reduction 15%																	
5*	33.0%	1.11	1.10	1.10	1.11	1.11	1.10	1.09	1.11	1.07	1.06	1.06	1.08	1.07	1.06	1.06	1.08
4*	36.0%	1.12	1.11	1.10	1.13	1.12	1.11	1.10	1.12	1.06	1.05	1.05	1.07	1.06	1.05	1.05	1.07
3*	27.6%	1.13	1.11	1.10	1.12	1.13	1.11	1.09	1.12	1.05	1.03	1.01	1.05	1.05	1.03	1.01	1.05
Occupancy reduction 25%																	
5*	23.0%	1.10	1.08	1.07	1.09	1.09	1.08	1.07	1.09	1.05	1.04	1.03	1.06	1.05	1.04	1.03	1.06
4*	26.0%	1.11	1.09	1.08	1.11	1.10	1.09	1.07	1.10	1.04	1.03	1.02	1.05	1.04	1.03	1.02	1.05
3*	17.6%	1.10	1.07	1.04	1.08	1.09	1.06	1.03	1.07	1.01	0.98	0.96	1.00	1.01	0.98	0.96	1.01

Table 10.7 Space Conditioning Profitability of 3-, 4- and 5-star hotels assuming a 10.71% price increase in the package holidays, Part 1 of 2

Hotel	Occupancy rate	Space Conditioning Profitability with a 10.71% package holiday price increase															
		Oil price = $160.00 per barrel								Oil price = $200.00 per barrel							
		building envelope/thermal comfort				with solar air-conditioning				building envelope/thermal comfort				with solar air-conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
PRESENT																	
5*	48.0%	1.05	1.04	1.04	1.06	1.05	1.04	1.04	1.06	1.00	0.99	0.99	1.01	1.00	0.99	0.99	1.01
4*	51.0%	1.01	1.00	1.00	1.02	1.01	1.00	1.00	1.02	0.93	0.92	0.92	0.95	0.93	0.93	0.92	0.95
3*	42.6%	0.97	0.96	0.95	0.98	0.97	0.96	0.95	0.99	0.86	0.85	0.84	0.88	0.86	0.85	0.85	0.89
Occupancy reduction 5%																	
5*	43.0%	1.04	1.04	1.03	1.05	1.04	1.04	1.03	1.05	0.99	0.99	0.98	1.01	0.99	0.99	0.99	1.01
4*	46.0%	1.00	1.00	0.99	1.02	1.01	1.00	0.99	1.02	0.92	0.92	0.91	0.95	0.92	0.92	0.92	0.95
3*	37.6%	0.96	0.95	0.94	0.98	0.97	0.96	0.95	0.98	0.85	0.84	0.83	0.88	0.86	0.85	0.84	0.88
Occupancy reduction 15%																	
5*	33.0%	1.03	1.03	1.02	1.04	1.04	1.03	1.02	1.04	0.98	0.97	0.97	1.00	0.99	0.98	0.97	1.00
4*	36.0%	1.00	0.99	0.98	1.01	1.00	0.99	0.98	1.01	0.91	0.90	0.90	0.94	0.91	0.91	0.90	0.94
3*	27.6%	0.95	0.93	0.92	0.96	0.95	0.94	0.92	0.96	0.83	0.82	0.81	0.86	0.84	0.83	0.81	0.86
Occupancy reduction 25%																	
5*	23.0%	1.02	1.00	1.00	1.03	1.02	1.00	1.00	1.03	0.96	0.95	0.94	0.98	0.97	0.95	0.95	0.98
4*	26.0%	0.98	0.97	0.95	0.99	0.98	0.97	0.95	0.99	0.89	0.88	0.87	0.92	0.90	0.89	0.88	0.92
3*	17.6%	0.92	0.89	0.86	0.92	0.93	0.89	0.87	0.92	0.80	0.77	0.75	0.81	0.81	0.78	0.76	0.82
2050																	
5*	48.0%	1.04	1.03	1.03	1.05	1.04	1.04	1.03	1.05	0.99	0.98	0.98	1.01	0.99	0.99	0.99	1.01
4*	51.0%	1.00	0.99	0.99	1.02	1.00	1.00	0.99	1.02	0.91	0.91	0.91	0.94	0.92	0.92	0.92	0.95
3*	42.6%	0.96	0.95	0.94	0.98	0.96	0.96	0.95	0.98	0.84	0.84	0.83	0.87	0.85	0.85	0.84	0.88
Occupancy reduction 5%																	
5*	43.0%	1.03	1.03	1.03	1.05	1.04	1.03	1.03	1.05	0.98	0.98	0.98	1.00	0.99	0.98	0.98	1.01
4*	46.0%	0.99	0.99	0.99	1.01	1.00	0.99	0.99	1.02	0.91	0.91	0.90	0.94	0.92	0.91	0.91	0.95
3*	37.6%	0.95	0.94	0.93	0.97	0.96	0.95	0.94	0.98	0.83	0.83	0.82	0.86	0.85	0.84	0.83	0.88
Occupancy reduction 15%																	
5*	33.0%	1.02	1.02	1.01	1.04	1.03	1.02	1.02	1.04	0.97	0.96	0.96	0.99	0.98	0.97	0.97	1.00
4*	36.0%	0.98	0.98	0.97	1.00	0.99	0.98	0.97	1.01	0.89	0.89	0.89	0.92	0.90	0.90	0.90	0.94
3*	27.6%	0.93	0.92	0.91	0.95	0.94	0.93	0.91	0.96	0.81	0.80	0.79	0.84	0.83	0.82	0.81	0.86
Occupancy reduction 25%																	
5*	23.0%	1.01	0.99	0.99	1.02	1.01	1.00	0.99	1.02	0.95	0.94	0.93	0.97	0.96	0.95	0.94	0.98
4*	26.0%	0.96	0.95	0.94	0.98	0.97	0.96	0.95	0.99	0.87	0.86	0.85	0.90	0.88	0.88	0.87	0.92
3*	17.6%	0.90	0.87	0.85	0.90	0.91	0.89	0.86	0.92	0.77	0.75	0.73	0.79	0.80	0.78	0.75	0.82
2090																	
5*	48.0%	1.03	1.03	1.03	1.05	1.03	1.03	1.03	1.05	0.98	0.98	0.98	1.00	0.98	0.98	0.98	1.01
4*	51.0%	0.99	0.99	0.98	1.01	0.99	0.99	0.99	1.02	0.90	0.90	0.90	0.935	0.91	0.91	0.91	0.95
3*	42.6%	0.95	0.94	0.94	0.97	0.96	0.95	0.94	0.98	0.83	0.83	0.82	0.862	0.84	0.84	0.83	0.88
Occupancy reduction 5%																	
5*	43.0%	1.03	1.02	1.02	1.04	1.03	1.03	1.02	1.05	0.97	0.97	0.97	0.996	0.98	0.98	0.98	1.00
4*	46.0%	0.98	0.98	0.98	1.01	0.99	0.99	0.98	1.01	0.90	0.90	0.89	0.93	0.91	0.91	0.90	0.94
3*	37.6%	0.94	0.93	0.93	0.96	0.95	0.94	0.93	0.97	0.82	0.82	0.81	0.85	0.84	0.83	0.83	0.87
Occupancy reduction 15%																	
5*	33.0%	1.02	1.01	1.01	1.03	1.02	1.01	1.01	1.04	0.96	0.96	0.95	0.98	0.97	0.96	0.96	0.99
4*	36.0%	0.97	0.97	0.96	0.99	0.98	0.97	0.97	1.00	0.88	0.88	0.87	0.92	0.89	0.89	0.89	0.93
3*	27.6%	0.92	0.91	0.90	0.94	0.93	0.92	0.91	0.95	0.80	0.79	0.78	0.83	0.82	0.81	0.80	0.85
Occupancy reduction 25%																	
5*	23.0%	0.99	0.98	0.98	1.01	1.00	0.99	0.98	1.02	0.93	0.92	0.92	0.96	0.95	0.94	0.93	0.97
4*	26.0%	0.95	0.94	0.93	0.97	0.96	0.95	0.94	0.98	0.85	0.85	0.84	0.89	0.87	0.87	0.86	0.91
3*	17.6%	0.88	0.86	0.83	0.89	0.90	0.87	0.85	0.91	0.75	0.73	0.71	0.78	0.78	0.76	0.74	0.82

Table 10.8 Space Conditioning Profitability of 3-, 4- and 5-star hotels assuming a 10.71% price increase in package holidays, Part 2 of 2

The following conclusions can be made from Tables 10.5-10.8:

- at present climate, current oil price and occupancy no renovation strategy would be profitable, with or without solar AC, except the 'all combined' strategy for 4-star hotels,
- an increase in room rates would be a must to implement thermal renovation profitably,
- a 10.71% increase in package holiday prices would make almost all strategy combinations profitable all the way through $120 oil price, and

- 3-star hotels would not sustain any profitability into the \$160/barrel range whereas 5-star hotels could implement the ‘all combined’ strategy with or without solar AC profitably even in the \$200/barrel oil price range but not with any reduction in occupancy.

In order to visually illustrate how the various renovation strategies rank in income generation, Fig. 10.2 was prepared. All of the shown options would be profitable but some would generate higher room income than others. The actual monetary value of the contribution of each strategy was used so as to see which strategy would yield the highest income, i.e. after applying a 10.71% increase in the package holiday price the gab between the old baseline room income and the new increased baseline was filled with the contribution of each strategy. It is noted with interest that while for 5- and 3-star hotels the greatest income would be generated by simply applying the increase on the baseline, 4-star hotels would benefit further by implementing solar AC. Even for the 5-star hotels the difference between the base case with increased room rate and ‘all combined’ strategy would be only 1 cent. It is noted that the benefits of also the other strategies would become obvious after the amortisation period of the investments even if the strategies would not reach the maximum possible room income over the amortisation period.

It is subsequently concluded that the ultimate measure of cost-effectiveness of an energy saving strategy in hotel operations is its space conditioning profitability. It combines the aspects of energy costs savings and income maximisation potential in one convenient and easily understood indicator. As an indicator SCP is uniquely applicable for hotels where the owner and operator pays for the energy consumption and therefore is financially motivated in minimising it. The case is not the same for other commercial rental property such as office or retail space or even residential rental property for that matter, where the SC energy costs are passed directly onto the occupant over and above the leasing costs, leaving little or no reason for the owner to engage in any energy-efficiency improvements. The above analysis was done to fulfil Objective 5, i.e. to develop and test a new economic efficiency indicator.

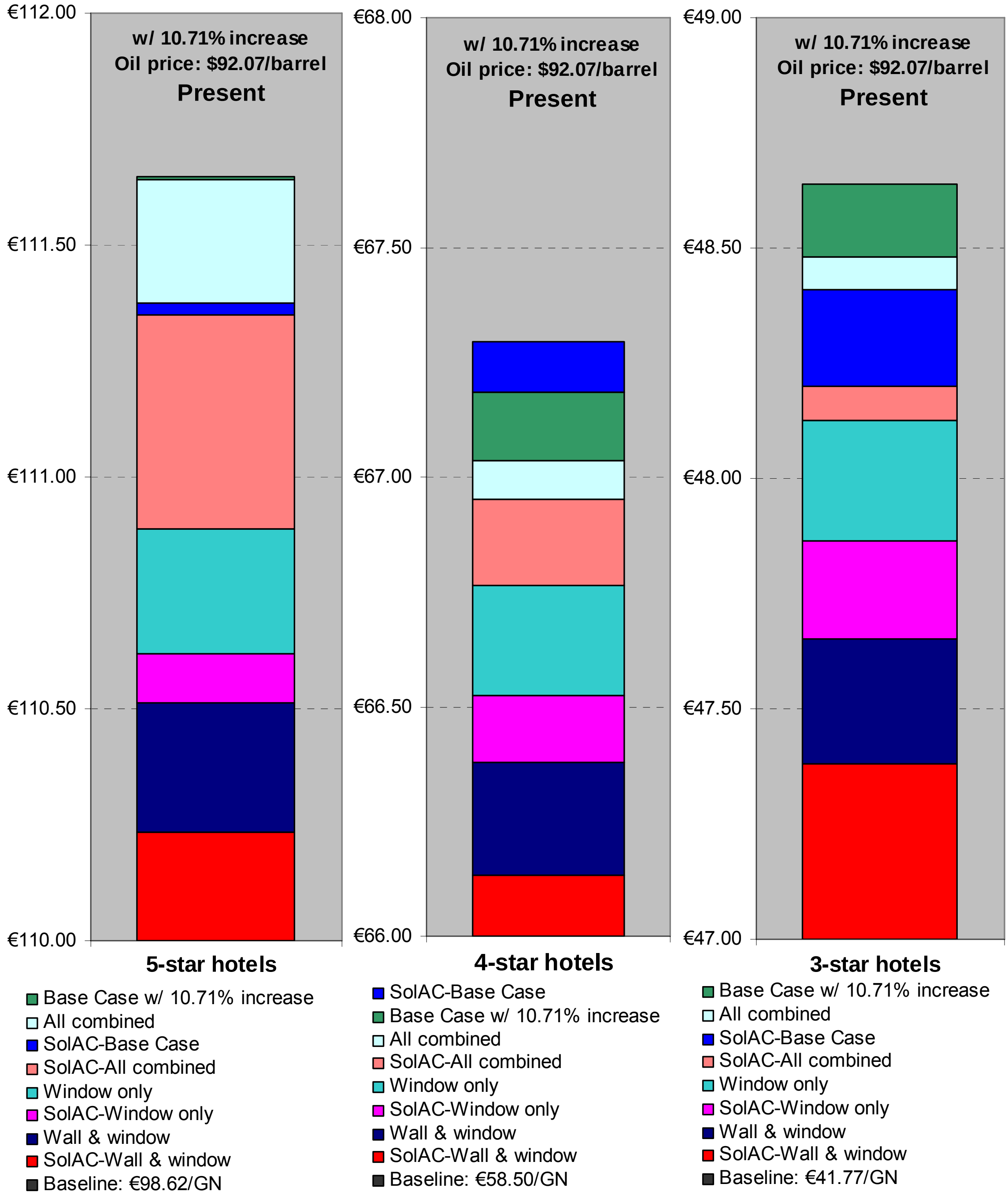


Figure 10.2 Room income as influenced by the renovation strategies

10.6 Extrapolation of the predicted energy and cost savings island-wide

Since Cyprus is a small island economy heavily relying on tourism as a source of livelihood, it was of interest to evaluate the impact thermal renovation of hotels would have island-wide. From the industry-wide dataset (Table 7.8) it was concluded that in 2007 the total electricity consumption of tourist accommodation was 275573 MWh and €35424924 was paid for it. The share of 3-, 4- and 5-star hotels was as follows: 40971.8 MWh for €5296777 by 3-star, 88687.4 MWh for €11319569 by 4-star and 83127.5 MWh for €10541694 by 5-star hotels. By applying the potential savings due to energy-efficiency improvements shown in Table 10.4 the savings can be extrapolated to the entire 3-, 4- and 5-star hotel building stock. It is concluded that by implementing high-performance window replacement in all hotels of the said classes, 38.0 GWh annual energy savings would be possible translating to €8.2 million financial savings with current electricity prices. Similarly, external wall insulation together with high-performance window replacement would yield energy savings of 40.2 GWh and financial saving of €8.7 million and the 'all combined' strategy 118.6 GWh and €25.5 million. Adding solar AC to the 'all combined' strategy would save 150.3 GWh and over €32 million. It is apparent that the island-wide energy saving potential is massive. To put it all in context, 4.3-17.2 MW of power generation could be retired or used for other purposes or new developments.

Similarly, heating costs were evaluated. Annual savings due to high-performance window replacement would amount to 5.3 GWh corresponding to 569 tonne oil equivalent and over €630000. Predicted savings due to external wall insulation together with high-performance window replacement would yield 17.0 GWh (1816 toe) and over €2 million and due to 'all combined' strategy 49.9 GWh (5327 toe) and €5.9 million. With solar AC the 'all combined' strategy could save 68.5 GWh (7305 toe) and over €8 million. Detailed analysis results are shown in Table 10.9.

Renovation strategy	**Hotel**	**Savings due to energy-efficiency strategy**								
		Electricity			**Heating**			**Total**		
		GWh	**Million €**	**toe**	**GWh**	**Million €**	**toe**	**GWh**	**Million €**	**toe**
With building envelope upgrade and thermal comfort criteria adjustments:										
High-performance window replacement	5*	15.04	3.24	3 808	2.04	0.24	217	17.08	3.48	4 025
	4*	14.93	3.21	3 780	2.01	0.24	215	16.94	3.45	3 994
	3*	7.99	1.72	2 022	1.28	0.15	137	9.27	1.87	2 159
External wall insulation + HP window replacement	5*	15.75	3.39	3 988	4.50	0.54	480	20.26	3.93	4 468
	4*	16.07	3.46	4 068	8.01	0.95	854	24.08	4.41	4 922
	3*	8.37	1.80	2 120	4.52	0.54	482	12.89	2.34	2 602
All combined	5*	46.14	9.93	11 681	12.34	1.47	1 316	58.48	11.40	12 997
	4*	49.38	10.63	12 501	22.97	2.73	2 450	72.35	13.36	14 950
	3*	23.10	4.97	5 847	14.63	1.74	1 561	37.73	6.71	7 408
Thermal comfort criteria adjustments only	5*	36.06	7.76	9 128	10.79	1.28	1 151	46.85	9.04	10 279
	4*	39.27	8.45	9 942	20.41	2.43	2 176	59.68	10.88	12 118
	3*	17.70	3.81	4 480	13.31	1.58	1 420	31.01	5.39	5 899
With solar air-conditioning:										
Baseline	5*	11.64	2.50	2 946	4.17	0.50	444	15.80	3.00	3 390
	4*	14.81	3.19	3 749	8.00	0.95	854	22.81	4.14	4 602
	3*	9.02	1.94	2 283	5.76	0.68	614	14.78	2.63	2 897
High-performance window replacement	5*	27.11	5.84	6 862	6.14	0.73	655	33.25	6.57	7 517
	4*	30.29	6.52	7 667	9.89	1.18	1 054	40.18	7.70	8 722
	3*	17.34	3.73	4 390	6.94	0.83	741	24.29	4.56	5 131
External wall insulation + HP window replacement	5*	27.60	5.94	6 987	8.56	1.02	912	36.15	6.96	7 899
	4*	31.14	6.70	7 884	15.79	1.88	1 684	46.94	8.58	9 568
	3*	17.56	3.78	4 444	10.11	1.20	1 078	27.67	4.98	5 523
All combined	5*	56.53	12.17	14 311	16.65	1.98	1 776	73.19	14.15	16 087
	4*	62.60	13.48	15 848	31.25	3.71	3 333	93.86	17.19	19 181
	3*	31.15	6.71	7 886	20.59	2.45	2 196	51.74	9.15	10 082

Table 10.9 Predicted energy and cost savings extrapolated to the entire stock of 3-, 4- and 5-star hotels in Cyprus

As seen, the savings potential adds up and would reduce GHG emissions at the same rate. It is outside the scope of this thesis to quantify the environmental impacts and GHG savings but as stated early on, economic and environmental benefits are mutually supportive and by addressing the economic side, the environmental side is bound to benefit as well.

10.7 Thermal renovations of hotels and national energy saving targets

It was of interest to evaluate the contribution thermal renovation of hotels would make towards Cyprus' national energy saving quota of 185000 toe by 2016 (European Commission, 2011c). It is subsequently noted that the total energy saving potential of 45349 toe, as derived from Table 10.9, represents 24.5% of the energy saving target.

Similarly, the application of solar AC on a mass scale would replace either 35.5 or 76.3 GWh of fossil fuel based electricity generation with renewable energy, depending on whether it is implemented alone or with building energy upgrades. The figures represent 0.7% and 1.5% of the total of 5204.9 GWh generated on the island in 2010. As such, up to one quarter of the island's intermediate target of 6% renewable energy could be met.

It is concluded that thermal renovation of hotels on a mass scale in Cyprus could yield significant savings in energy, operating costs and in GHG emissions, as the industry is large enough to make a sizable contribution towards the EU targets. Furthermore, it was demonstrated that hotel renovation can be implemented without eroding the profit margins of hotels. Therefore, it is the recommendation of this study that policies to encourage or even to mandate hotel renovation would be implemented as a priority in meeting the national energy saving targets.

10.8 Conclusions

In this chapter the energy saving strategies analysed in Chapter 9 were looked at closer and their cost-effectiveness was summarised. Also their costs saving potential was evaluated making it possible to rank the measures as high cost – high efficiency, high cost – low efficiency, low cost – high efficiency and low cost – low efficiency measures. A unique economic indicator *Space Conditioning Profitability* was then introduced and the previously found cost-effective strategies were tested with the new indicator. It was concluded that not all strategies that were cost-effective by the conventional economic indicators were profitable to the hotel operations in a sense that they would not erode the hotels' room income during their amortisation period. Therefore, the new indicator offers a useful way to prioritise strategies according to their profitability. Hopefully such screening would lower the threshold and make it easier for hotels to embark on energy-efficiency improvements. Subsequently, developing and testing the indicator fulfilled Objective 5.

The hypothesis was tested and it revealed that the combination of wall and window replacement was predicted to yield energy cost savings in excess of 20%. Piecemeal renovation such as wall insulation alone or conventional double-glazing should be avoided as they would be beneficial in heating only but not in cooling. It was shown that with the combination of solar AC, building envelope improvements and adjustments in thermal comfort criteria it was possible to predict total energy savings in excess of 80% and generate surplus heat for DHW heating.

Finally, the predicted energy savings were extrapolated to the entire hotel building stock of Cyprus and it was demonstrated that a sizable contribution towards the national energy saving targets of Cyprus could be met by policies encouraging thermal renovation of hotels on a mass scale. The extrapolation was done in order to fulfil Objective 6 of this thesis.

11 Chapter 11 – Conclusions and recommendations

11.1 Introduction

The purpose of this chapter is to summarise the final conclusions and recommendations. Furthermore, an action plan for the Cypriot hotel industry to upgrade the hotel building stock is presented. In addition, the original contribution to knowledge gained from the thesis is assessed and the limitations of the study are discussed. Finally, closing thoughts and reflections on the study as a whole and its relevance from a local and global perspective are offered.

11.2 The main conclusions of the thesis

The main conclusions of the thesis are briefly discussed below in two categories; first by what arose from the execution of the main aim of thesis and secondly what was established on general level and from the detailed analyses carried out according to the study objectives.

11.2.1 Conclusions regarding the thesis aim

The main aim of the thesis was:

to develop a methodology for evaluating the impacts of climate change and rising fossil fuel prices on space conditioning energy costs of hotels in Cyprus and to propose cost-effective thermal renovation strategies to combat such impacts.

The main conclusions concerning the development of the methodology are discussed below.

Regarding the thermal simulation part of the methodology it was concluded that it was not of extreme consequence to match the exact detailing of the building. Over 90% match in annual energy consumption was possible with a simplified model. However, it is important to get the opening sizes, any possible shading and exposed wall areas as close to the real as possible.

Secondly, it was concluded that weather files were important as some typical meteorological years provided with thermal simulation packages may already be outdated and although they may still be useful in estimating annual totals, they may miss out peak loads or extended heat wave periods. Further, it was important that the simulator program allowed the input of user-specified weather files, especially since the intention was to evaluate energy consumption in future climates.

As for the economic analysis, it was demonstrated that simply calculating payback periods was not enough since the lifecycle costs would vary significantly for different options with similar payback periods. Furthermore, the SIR was an important indicator when lifecycle costs were going down due to reduced occupancy, the realised savings per guest night being reduced as well while the investment stayed the same.

Finally, it was discovered that the cost-effectiveness of a renovation strategy did not necessarily mean that the renovation would be profitable for the hotel. Subsequently an indicator was developed that enabled the evaluation of the potential energy cost savings in connection with the income generated by guestrooms. The indicator should be used and any improvements proposed and implemented should be profitable for the hotel operation. The evaluation is simple and does not in any way add complication into the analysis. In this thesis room rates had to be estimated from tour operators' package holiday prices in order to derive an average room rate for hotels of different class. However, in a consultation situation a hotel client can simply provide the average room rates or rates that would be desirable to achieve for use in the profitability analysis. Furthermore, it is outside the duties of the energy consultant to estimate how much room rate increase would be achievable but the hotel management should be able to provide such figures based on its own market research. Alternatively, the energy consultant could derive the room rates that would be required for a certain measure to be profitable for the hotel management to assess if such increases in room rates were feasible within their marketing plan.

It is subsequently concluded that the methodology developed in this thesis is applicable and replicable to any hotel operation evaluation. In addition, it provides a new measure of profitability currently not used in techno-economic feasibility studies done for hotels considering energy-efficiency improvements. It is argued that any measure that can generate more income for a hotel or at least prevent income erosion would be welcomed by the hotel management. Therefore, SCP analysis has the potential of becoming an important defining factor whether an energy-efficiency improvement is approved and implemented or not.

The steps of the methodology are summarised below in a checklist format for quick reference.

Methodology to assess the cost-effectiveness and profitability of hotel energy-efficiency improvements in present and future climates, increasing fuel prices and changes in hotel occupancy

1. Energy audit and monitoring of internal environmental parameters in key areas
2. Thermal simulation model calibrated against monitored data
3. Future climate projections
4. Simulation of renovation strategies
5. Identification of energy-efficient strategies
6. Economic evaluation
7. Identification of cost-effective strategies
8. Sensitivity analysis with climate, energy prices and hotel occupancy
9. Space Conditioning Profitability analysis
10. Selection of profitable strategies

11.2.2 General conclusions

Regarding the theoretical framework of the thesis, it was concluded from the literature review that the high fossil fuel prices were due to an imbalance in supply and demand rather than due to artificial inflation. Subsequently, rising fuel prices would make a small island nation like Cyprus that entirely depends on exported oil, vulnerable in regards to energy supply while at the same time increasing the hazards of overheating and heat stress. It was therefore confirmed that the collective impacts of climate change and rising fuel prices exacerbated the hazards caused by each one separately. By adding the tourism industry into the equation, a unique set of additional risks and challenges emerged. Resource allocation in a small island nation that hosts annually over 2.5 times its own population as tourists becomes a major issue. But when a nation so heavily depends on tourism as an income and employment generator, there are no easy answers. As a result, it was concluded that in the case of Cyprus, climate change, rising fuel prices and tourism were closely linked. Subsequently, the selection of climate change and depletion of fossil fuels as the external drivers for hotel energy-efficiency on the island of Cyprus was fully justified as a basis for the theoretical framework.

Another important conclusion was made from the hotel guest survey, namely that although climate change was not to be expected to have a significant impact on the future holiday travel of the participating tourists, they were not willing to pay much more for holidaying in Cyprus (mean increase +10.71%). This finding is of major importance as it was argued in this thesis that the leverage on hotel room rates dictates the profitability of the proposed energy-efficiency improvements; no renovation strategies were profitable without an increase in room rates.

As for the profitability analysis and the new indicator *Space Conditioning Profitability* developed in this thesis, it is concluded that the new indicator is a valuable tool in prioritising hotel renovations and can be adopted in real-life techno-economic studies of hotel energy-efficiency improvement projects. It is argued that the use of profitability analysis would lower the barriers for project implementation and third-party financing.

It is further concluded that the extrapolated energy saving potential of the proposed hotel thermal renovation is significant and could play a major role in Cyprus' efforts to meet its EU energy saving targets. The main findings regarding energy saving potential of the proposed thermal renovation strategies are concluded as follows:

- Over 20% savings in SC energy costs are predicted with thermal renovation of the hotel building envelope (external wall insulation with high-performance windows).
- Over 60% savings in SC energy costs are predicted if in addition adjustments in thermal comfort criteria are included.
- Over 80% savings in SC energy costs are predicted if solar AC is incorporated with building envelope upgrade and thermal comfort criteria adjustments.
- Over 50% savings in SC energy costs are predicted due to thermal comfort criteria adjustments alone.
- Nearly one quarter of Cyprus' national energy saving quota could be met by mass-scale thermal renovation of 3-, 4- and 5-star hotels
- With a minimal increase in room rates (10.71%) hotels could maintain or even increase room income by implementing strategic thermal renovation, subsequently improving profitability of the hotel operations even during the amortisation period of the investments.

11.3 The main recommendations of the thesis

The main recommendations of this thesis are as follows:

- Thermal renovation of hotels should be encouraged or even mandated as a policy tool in order for Cyprus to meet its national energy saving and renewable energy targets.
- Future climate analysis should be incorporated in the technical evaluation of hotel renovation.
- Techno-economic studies evaluating hotel energy efficiency improvements should include profitability analysis utilising Space Conditioning or Total Energy Profitability indicators and profitable strategies should be given priority in implementation and financing.
- Hotels should embrace environmental management and energy efficiency as their core values in order to improve their financial bottom-line and to appeal to niche markets of environmentally conscious tourists.

11.4 Action plan for the Cypriot hotel industry

Encouraged by the massive energy saving potential extrapolated for the entire hotel building stock of Cyprus in the previous chapter and to fulfil Objective 6, an action plan for the hotel industry providing recommendations for thermal renovation was developed. It can be summarised as follows: Prepare-Repair-Declare-Take Care, inspired by the modus operandi of Total Quality Management: Plan-Do-Check-Act discussed earlier. The following paragraphs explain what is meant by the slogan.

11.4.1 Preparing for the renovation project

It has by now been demonstrated that thermal renovation is not only advisable but essential if hotels want to remain profitable in the near and more distant future. As with any capital intensive projects, many obstacles have to be overcome before thermal renovation can go ahead. Depending on the management structure of a hotel, approvals for such projects may have to be sought at several levels and large amounts of capital must be raised. Securing financing may in particular be difficult at the present environment where the world is still recovering from a global credit crisis. Also as discussed earlier, it is complicated for a hotel to plan long term since the agreements with tour operators, for example, are done only for one year at a time making it difficult to predict occupancy and revenue streams any further. Therefore, it takes vision and perseverance to convince all stakeholders to agree and approve a renovation project. It is, however, important that the efforts to prepare the mindset of the stakeholders and to raise capital start the earliest.

In parallel it is essential to conduct a techno-economic feasibility study that considers the particulars of the individual hotel, identifies the most profitable renovation options and prioritises them so that they can be implemented in phases. It is a mistake to execute a presumed energy saving strategy without carefully studying its impact in the given circumstances. It is noted with regret that many Cypriot hotels have gone ahead and replaced single-glazed windows with conventional double-glazed aluminium-frame windows thinking that they would achieve significant energy savings. But as concluded earlier in the analysis, conventional window replacement brings minimal energy savings and in no circumstances can be cost-effective, let alone profitable.

With financing, advantage can be taken of several government incentives schemes that apply to energy-efficiency improvements and introduction of renewable energy sources. In order to qualify, the installed cost of the proposed improvements needs to be compared to that of their conventional counterparts since the grant amount is calculated as a percentage of the difference. Therefore, it is essential to have a detailed techno-economic study and usually it is the consultant who is in the best position to fill out an application for a grant. The following incentives schemes applicable to the type of renovation strategies proposed earlier are currently available for hotels to apply (Republic of Cyprus, 2011):

1. grant for energy-efficiency improvements covering 30% of the purchase price difference with a maximum amount of €50000 and
2. grant for introducing renewable energy covering 35% of the purchase price difference with a maximum amount of €75000.

Grant 1 is vague in regards what it covers but it appears that any measure, material or system that produces at least 10% energy savings compared to its conventional counterpart would qualify. It is, however, not clear how the grant amount would be calculated for added insulation for example when the conventional alternative would be no insulation at zero cost or for high performance windows that are not necessarily more expensive than the conventional ones.

Grant 2 covers all forms of renewable energy and has a subcategory for solar-thermal applications aimed at space heating and cooling. The same 10%-rule applies as explained above. There is also a subcategory for solar-thermal DHW production that is covered by 30%. In addition, there are grants available for photovoltaics, small-scale wind power generation, geothermal heat pumps, biomass boilers, etc. that could be applicable in some hotels although not explicitly studied in this thesis. It is possible for a hotel to apply for multiple grants but there is a maximum total amount of €200000 for a 3-year period that any one hotel can get.

11.4.2 Repairing or renovating

The implementation of a renovation project can follow quickly once all the preparatory work outlined above has been done. It is best to execute the renovation during a low season or if possible, to close the hotel for the duration of the project. Window replacement and façade work would require setting up scaffolding and cranes, so the disturbance to the hotel operation would probably be too much. Hotels under the same management or ownership can easily share resources and sister hotels can serve the guests that would otherwise stay in the hotel under renovation. During the low season occupancy would not be an issue. Even neighbouring hotels can make such arrangements assuming they schedule their renovation projects not to coincide.

11.4.3 Declaring a new image

Energy-efficiency improvements should ideally be implemented as part of a greater ‘green master plan' that addresses other environmental aspects related to hotel operations. Seeking to qualify for eco-labels is highly recommended. With a visible eco-label like the EU flower a hotel could completely reinvent its image and target a different market segment, one that would be willing to pay a premium for it. Green credentials of the accommodation as a selection criterion for holiday destination scored relatively high at 3.53 in the guest survey. In addition, the guests staying at one of the hotels that had already implemented some sustainable features, such as serving locally grown food and conserving the surrounding nature, seemingly appreciated the efforts taken. Therefore, having a green image is of significance although as discussed in Chapter 3, hotels are reluctant to implement environmental features unless they can be associated with increased revenue or profit.

One way to change the image of the hotel is to specialise in something that would immediately connect with a niche market. Typical examples of such specialisation are golf or spa resorts, although neither one a particularly sustainable example in a drought-stricken country like Cyprus. But the concept is worthy and if it can be connected to environmental or sustainable ideals, it would be a way to differentiate the holiday product. A grant scheme is available for investments that aim at enriching the tourism product, co-financed by the EU's European Regional Development Fund (CTO, 2010). Within the same scheme there is also a provision for comprehensive upgrading and modernisation of existing tourism accommodation. Conventional refurbishment does not qualify under the scheme but upgrading that would result in a higher class or at least in a substantial diversification of the operational features would qualify. Therefore, the scheme would appear appropriate for 3-star hotels trying to upgrade to 4-star status while also improving energy-efficiency. Such upgrades would be doubly beneficial as they would enable an immediate increase in room rates thus improving cost-effectiveness as well as space conditioning profitability of the renovation. The grant scheme covers 10%-35% of the investment costs of the above two types of improvements depending on the overall project costs and the geographical location of the hotel[93].

11.4.4 Taking care of the renewed hotel and image

What happens after a successful renovation and image reinvention determines the long term impacts of the undertaking. 'Taking care' may sound like a cliché but it is essential for continued energy savings that the new systems are kept in proper working order. With mechanical systems like solar AC it means regular maintenance, with building envelope improvements normal good housekeeping standards suffice. It is observed that sometimes when an energy-efficiency measure has been applied, it is taken for granted that the 'work is done' as the initial investment was made. It is subsequently assumed that the savings are guaranteed from there on. However, energy-efficient lighting still wastes energy if left on unnecessarily, same with solar AC even if the driving energy were free and in unlimited supply. Therefore, it is important to follow along the usage chain and make sure that the necessary optimisations are made at every level. For AC it would mean sensors that switch the AC off when the balcony doors are open, or an intelligent system that lowers the AC to a standby setting when the rooms are unoccupied. For lighting, occupancy and

[93] The scheme is currently closed for applications but is expected to reopen again in 2012.

daylight sensors would be recommended. In any case, careful monitoring of energy consumption should be done after such a renovation and if adequate sub-metering devices were not in place, they should be installed as part of the renovation project. This would be continued commissioning in practise as discussed earlier in the context of the soft landings framework.

As for adjustments in thermal comfort criteria, post-occupancy evaluation would be an ideal way to study how the changes were received by the building users. Guests are bound to complain if their thermal comfort needs are not met. Proactively, they can be encouraged to fill out a short questionnaire left in the guestrooms for feedback on the entire renovation project and image revamp. The questionnaire can also be used for disseminating information to the guests what was done and what the goals of the renovation were. Perhaps the environmental benefits, such as CO_2 savings achieved due to the energy-efficient renovation could be published also. It is argued that even discomfort can be tolerated to some degree if the reasons are known to be altruistic. It is, however, important to pass the message in the right way to the guests and engage them in the process to save energy. If a guest is told that he cannot lower the room temperature below 27°C in order not to decrease the profit of the hotel owner, the message would not be received well. If, however, the guest is explained the environmental impacts of increasing the cooling temperature settings, he may appreciate the effort and be willing to accept a lower level of comfort. It is, however, maintained that guest satisfaction is a delicate matter and balancing between energy saving and the thermal comfort needs of guests takes tact and perhaps some trial and error.

The caretaking does not end at the hotel facility. If a hotel truly wants to portray a green image, the actions must extend outside the hotel building itself. Caring about the surrounding environment and participating in communal activities promoting various sustainable agendas would be a way to send a strong message across that the interest in the environmental issues is genuine. It is emphasised that being ‘green’ is more than just hanging a sign that says so. The problem of ‘green washing’ has been noted regarding buildings across the board, hotels being no exception. As discussed earlier, even prestigious green building certifications can be obtained by design intentions without meeting them in practise; the same thing to a large extent with eco-labels and environmental certifications. That in turn opens the door for marketing ploys aimed at attracting good-natured, concerned tourists by false claims that a hotel is environmentally friendly. As a result even the savviest guests have difficulty knowing how much really is done to save resources or how ‘green’ a hotel is. In a critical article Pizam (2009) asked the very question: ‘Green hotels: A fad, ploy or fact of life?’ and concluded that there most certainly were elements of fad and ploy in many unscrupulous ‘green’ hotels but that with the spiralling energy costs and the accelerated resource depletion, hotels, like most other businesses will have no other choice but to become ’real green’. It is also the premise of this study that altruism will cease to be the defining factor in embracing environmental agendas and energy saving as it will simply make no business sense not to do so. But what is advocated as part of the hotels’ image revamp is to enjoy the financial benefits that have been realised due to the environmental plan and to give something back to the local community as an example in true environmental leadership. It was discussed in the very beginning of this thesis how hotels have been the beacons of new living and building standards throughout millennia. It is in the environmental stewardship that they could again take a leading role.

11.4.5 Summary of the Action Plan

The following is a summary of the Action Plan in a checklist format:

PREPARE - A techno-economic study

- Should be conducted as outlined in the methodology described in this thesis.
- Should investigate the feasibility of thermal comfort criteria adjustments.
- Should produce a list of profitable renovation options.
- If profitability is not possible with the proposed measures, more comprehensive renovation should be considered aiming at upgrading the hotel class that allows higher room rates to be charged as a result. This is particularly applicable for 3* hotels seeking for 4* status.
- Opportunities for government or other sponsored funding should be identified.
- Plan for an environmental program should be outlined.

REPAIR – Implementation

- Demand-side reductions with lighting and small power.
- High-performance window replacement; target U=1.2 W/m^2K.
- Externally insulated façade system (when required); target U=0.3 W/m^2K.
- Roof insulation where possible. Priority given to low-rise wings or extensions such as restaurants, conference facilities, indoor pool houses, etc. Target U=0.3 W/m^2K.
- Installation of solar AC.

DECLARE – Eco-label or environmental certification

- Implement an environmental program.
- Provide training for all levels of the staff to learn, embrace and implement the program.
- Establish the means to monitor and measure the performance of the program.
- Once the environmental program is running smoothly and performing as expected, seek for formal recognition by applying for an eco-label like the EU flower.
- Disseminate information about the energy-efficiency improvements done to the guests via info leaflets in the guestrooms, close-circuit TV, etc.
- Employ innovative ways to engage the staff and guests to save energy and water.
- Use the image in marketing, negotiations with tour operators and attracting niche markets.

TAKE CARE – Continued commissioning of the renovated building

- Testing and fine-tuning of the HVAC systems.
- Feedback from staff and guests as a POE survey.
- Engage in communal environmental agendas and activities.

11.5 Energy saving innovations

Energy-efficiency is a journey, not a destination. Therefore as discussed earlier, the process does not end upon completion of a renovation project but monitoring and optimisation must continue in order to make sure that the expected energy savings are indeed continuously realised. This is what continued commissioning advocated by the soft landings framework discussed earlier is all about. However, there are additional ways that energy or water saving can be encouraged. Engaging or even challenging guests to participate in conservation activities for a symbolic reward would be one way of doing it. The concept is based on the idea that rather than charging extra for certain comforts like the AC in the room, one should be rewarded for not using them instead. Implementing such a program would require individual sub-meters to be installed in the rooms for electricity and/or water consumption monitoring, depending on which one was targeted. Such a program could be tried out by fitting just a few rooms with metering devices and selecting for those rooms guests that are willing to participate. The challenge would be for the guests to save energy and/or water and based on the total savings at the end of their stay, to reward them accordingly. The reward could be free drinks or ice cream or something along those lines as a symbolic gesture for the guests' effort and participation. Such a trial would be a great way to raise guest awareness on energy and water conservation and a means for the hotel to monitor savings achieved over a period of time. If the savings were substantial, the program could be extended for more rooms or even for the entire hotel and it could become part of the hotel's new brand or image. It is argued that such an approach would in no way compromise guest comfort. Cooling could still be opted for as required but most certainly lights, AC and TVs would be turned off when not in the room, shorter showers taken, etc. So, in essence such a program would teach mindfulness more than anything else and would utilise the guests to optimise energy use, rather than relying on technologies to do the optimisation. Crowne Plaza Copenhagen Towers, a carbon neutral hotel, has adopted an opposite concept; they have chosen to reward their guests for not **saving** energy but **generating** it, by connecting the exercise bikes at the gym to an electric generator. Any guest who generates 10 Wh of electricity can claim a free meal at the hotel restaurant (Harris, 2011).

There is a place for technology to be relied on in conserving energy and as discussed earlier, invisible and intelligent controls should be installed wherever applicable but doing so in no way prevents engaging guests in innovative and captivating ways to do their part.

11.6 Original contribution to knowledge

The original contribution of this research lies in the methodology that systematically evaluates the cost-effectiveness of hotel renovation under the combined influence of three variables, namely the climate, energy prices and hotel occupancy. The impacts of hotel occupancy in future climates on hotel energy consumption have been studied by others. Similarly, many studies have investigated individual or combined renovation measures to reduce hotel energy consumption with or without a sensitivity analysis in terms of energy prices. But no existing research was identified investigating energy-efficient renovation of hotels or any other building type with the said three variables simultaneously. Furthermore, the unique cost-efficiency indicator Space Conditioning

Profitability developed to measure the impact of thermal renovation on hotels' room income generation potential is believed to radically change the way how techno-economic studies aiming at evaluating and ranking hotel energy-efficiency improvements would be conducted and hopefully increase the uptake of implementation and encourage third-party financing for such projects. In this study the indicator was used only in space conditioning but the same concept can be extended to include all energy consumption. *Total Energy Profitability* indicator could be used when other energy saving measures such as lighting, small power, control systems, etc. were included in the studied strategies. Although the methodology was tested in the Cypriot context, there is no reason why it could not be used in any other country, provided that there is a way to estimate the end-use energy prices as a function of oil prices or at least that the electricity and heating oil prices can be estimated in a logical manner, i.e. in a way that the prices could coexist. Such estimation is perceived difficult if electricity generation includes multiple sources such as coal or oil based, hydro power, nuclear and wind, for example, in varying combination. In this thesis hotel room rates were assumed to be dictated by agreements with tour operators but it is not a prerequisite for the methodology. Any pricing structure can be used for the room rates and the profitability analysis of the energy saving strategies can be carried out as outlined.

This study contributed to knowledge in other respects as well. Suggestions were made how to prioritise nationwide energy saving building renovation in a cost-effective manner. Hotels catering for foreign tourism are in a unique position to finance their energy-efficiency improvements by foreign capital. What is meant here is not by taking a loan from a foreign bank but rather that foreign tourists pay for energy-efficient hotel renovations by spending their holidays in Cypriot hotels. As discussed earlier, the mechanism of profitable renovation finances the investments made and increases or at least maintains room income at the same time. No other building type has the opportunity to benefit from such a mechanism as the renovation of residential, commercial and public buildings would have to be financed by funds available within the country and interdependencies within a limited pool of financial resources exist. An example of such an interdependency would be the public sector heavily investing on upgrading its building stock. Subsequently there would be less public funds available for grants targeted for residential building upgrades that consecutively would affect the amount of disposable income the residents have to spend on other things, provided they had to self-finance mandatory building energy-efficiency measures. That in turn would be felt by the retail and services sector resulting in less profit and capital for the energy-efficiency improvements and building upgrades of the commercial sector. Therefore, a finding of this study is to target hotel buildings as a priority within the legally binding energy saving obligations Cyprus has as an EU member state. Policies to that extent could be implemented as a direct result of the findings from this study.

Tourism is a delicate matter to the Cyprus government as it is so fundamental in supporting the local economy. The policy has been to protect the industry rather than to impose any hard conditions on it. However, in the light of the findings of this thesis, mandatory energy-efficiency improvements could be imposed on hotels as they have the ability to implement them without income erosion. A carefully drafted policy could be the right impetus to break the barrier preventing mass implementation of energy-efficiency improvements within the sector.

Finally, the interdependencies between climate change and fossil fuel depletion explored in this thesis have hopefully contributed to an increased understanding of ultimately the survival of tourism-based economies in a wider scale.

11.7 Limitations of the research

The major limitation of this study is that the analysis was based on one case study hotel only. Although great care was taken to select the case study hotel to be typical in its own class and an 'average' among 3-, 4- and 5-star hotels, one could argue that a better approach would have been to study each hotel class separately. However, in view of the limited time and resources to conduct energy audits, monitor energy consumption and environmental parameters for a full year, and to construct and calibrate thermal simulation models, a rational approach was adopted.

Another aspect that may attract criticism is the selection of renovation strategies for detailed analysis. The choice of strategies was entirely intentional as only space conditioning energy saving was evaluated. Subsequently, the rational was to focus on building envelope upgrades and introduction of the most applicable renewable energy technology currently available. Furthermore, the reason to focus on envelope and HVAC system upgrades was the fact established earlier that a large number of hotels in Cyprus were built in the 1980s and early 90s and as such the building façades and the HVAC systems were approaching the end of their natural service life. In addition as discussed earlier, the EU's EPBD targets buildings by envelope improvements and boiler/chiller inspections. Subsequently, it would appear rational to target the building envelope and air-conditioning as a priority especially within the theoretical framework adopted for this thesis predicting increased overheating and heat stress hazards in the future. Conventional boiler and chiller replacements were not studied because the introduction of solar air-conditioning would retire conventional chiller capacity and allow the oldest chillers to be decommissioned first, following the conclusion discussed earlier that most hotels have added cooling capacity over the years establishing a cooling plant that consists of many chillers of different age. It is recognised that further energy saving potential remains in lighting controls and efficient utilisation of natural daylight and to a lesser degree in the catering and small power equipment. But this study does not advocate for example a mass campaign of equipment replacement in hotels as there are wider environmental implications in doing so, such as wastage of natural resources, issues related to safe disposal of electrical equipment classified as hazardous waste, etc. It is believed that equipment replacement should largely follow their natural lifecycle and any equipment that can no longer be used should be replaced by the most energy-efficient model available. The same applies for larger equipment, such as boilers and chillers. It is reemphasised here that this thesis was not assigned to identify a set of measures that would achieve a fixed energy saving target. Instead, a set of strategies were selected that would have to be addressed by Cypriot hotels in any case in the near future and subsequently it was of interest to evaluate how much energy could be saved if such refurbishments were executed in an energy-efficient manner. Consequently, it was of great interest to study the impacts of window and wall upgrades in SC energy use in order to avoid piecemeal renovation that could lock the buildings in sub-optimal performance for decades.

Furthermore, it was fundamental in this thesis to analyse only strategies that would not require behavioural change, as it is argued that predicted energy savings that rely on behavioural change cannot be extrapolated nationwide. This distinction is important as there are other studies (Tarbase, etc.) set out to identify measures what it would take to reach certain carbon saving targets. A different approach was chosen for this study, not as a limitation but rather as a complimentary way to assess energy saving potential with an overriding philosophy to do only what needs to be done but to do it energy-efficiently. Such a philosophy is in broad agreement with what is advocated by the building performance evaluation movement and their slogan: 'Keep it simple and do it well' (Bordass and Leaman, 2011). Furthermore, the originality of this thesis is in the way it analyses cost-efficiency and profitability of energy-efficiency improvements by relating them to room income generation and in the methodology that lends itself to the simultaneous sensitivity analysis on three variables, namely climate, energy prices and hotel occupancy. Simply evaluating renovation strategies and their energy saving potential would not be original even if dozens of strategies were evaluated, as similar work has been done in many existing studies as discussed earlier. It is therefore the premise of this study that not every study should attempt to study everything.

11.8 Needs for further research

This thesis focussed on SC energy consumption of hotels whereas water consumption and conservation were touched only in a passing context. The focus was intentional as it is impossible to go into the required depth with all aspects of the operating parameters of hotels in a single thesis. Therefore, other studies should be conducted where water conservation is analysed in depth. Climate change is predicted to increase water stress in many areas of the world; therefore research into water conservation in the context of tourism is an important subject.

Since this study looked at SC energy saving only, further research should evaluate the energy saving potential of other energy consumption in hotels, such as lighting, small power, catering equipment, etc. Such strategies should be tested with *Total Energy Profitability*, an indicator similar to Space Conditioning Profitability but including all energy consumption.

Another area that lends itself for further research in the domain of building services engineering would be a study on intelligent building management control strategies that could be used to regulate temperatures, optimise ventilation to take advantage of free or nocturnal cooling, control lighting, etc. It would be interesting to see a study that compares different levels of control strategies and estimates the energy savings due to them. Many hotels employ BMS systems but it is not necessarily clear how much energy savings are due to them.

Finally, in the area of guest attitudes it would be useful to investigate if any differences exist due to the nationality of guests in regards to their attitudes about environmental issues related to tourism. Also, educational background as a control variable would be valuable for the analysis since age and income level did not reach significance. Actually, a guest survey conducted as part of a post-occupancy evaluation in renovated hotels would be a natural follow-up to this study and it is suggested in the Action Plan to conduct a POE survey after every major renovation.

11.9 Afterthoughts

The topic of this thesis is timely indeed as at the time of writing (August 2011) the island of Cyprus is still recovering from an accidental explosion that destroyed one of the island's three power plants, instantaneously removing 428 MW (32%) of the total nominal power generating capacity of 1338 MW from the grid. The accident happened during the hottest time of the year with the highest cooling demand and the peak tourist season. While the local households and businesses had to suffer daily power cuts due to power rationing, it was the government's priority to protect the tourism industry. The accident was a regrettable reminder how valuable energy is and especially how difficult life would be without it. While the nation was suffering from power cuts, the sun kept shining and sending free, clean energy to the earth. If only more solar energy could have been harnessed at the time when manmade systems were out of service. The accident in Cyprus happened only four months after a much larger-scale accident in Japan where an earthquake and a tsunami destroyed a nuclear power plant with not only disruptions in power supply and loss of life but a massive environmental catastrophe to be felt by generations to come. Energy security is a serious issue indeed and quite often overlooked at least at the grass root level. There may be concerns about buying fossil fuel from hostile producers but once the fuel is securely procured, it is expected to deliver uninterrupted power and all the modern conveniences that depend on it.

Therefore, energy saving would not only benefit those whose energy bills were reduced as a direct result of it but all consumers within the shared grid. The current power deficit problem in Cyprus is largely due to high cooling demand during business hours; an issue that could be easily addressed by solar cooling that takes off power demand at the hottest time of the day, at peak consumption. Large scale application of solar cooling would subsequently help the national grid to run more efficiently by reducing the difference between peak and average consumption.

So, what is it that is stopping massive energy saving campaigns to go forward? It is speculated that the effects of high oil prices have not been felt enough yet. The 2008 credit crisis and the recession that followed interrupted the trend of rapid increase in fossil fuel prices and perhaps gave false hope that a $145/barrel oil price was only a freak incident. At the same time the recession has made hotel owners and investors wary of financing projects and perhaps renovation projects that would have been given green light in mid-2008 were buried or postponed. But the efforts to fight climate change must continue. The Secretary-General of the UNWTO Mr Rifai sums it up perfectly:

> *In a world looking for new models of economic growth and development, fighting climate change and adopting sustainable management practices is no longer an option, but a condition for survival and success.* (Hotel Energy Solutions, 2011, p.7)

It is therefore important that hotels take preventive action to future-proof themselves before facing a situation where the energy bills are eating up their profits. A strategy to do just that was outlined in this thesis and it is the sincerest wish of the author that many hotels in Cyprus and beyond would implement it and enjoy the benefits thereof for years to come.

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A P P E N D I X I

Definition of buildings according to their pollution class

I Appendix I - Definition of buildings according to their pollution class

The following definitions are taken from BS EN 15251:2007 (British Standards, 2007) in order to assist in understanding what makes a building 'very low-polluting', 'low-polluting' or non-low-polluting'.

Materials that qualify as low-polluting are natural traditional materials, such as stone and glass, which are known to be safe with respect to emissions, and materials that meet the following requirements:

- Emission of total volatile organic compounds (TVOC) is below 0.2 mg/m²h
- Emission of formaldehyde (H_2CO) is below 0.05 mg/m²h
- Emission of ammonia (NH_3) is below 0.03 mg/m²h
- Emission of carcinogenic compounds (IARC) is below 0.005 mg/m²h
- Material is not odorous (dissatisfaction with the odour is below 15%)

The above requirements meet the criteria set for M1 category of materials except in respect to carcinogenic compounds. In M1 category carcinogenic compounds are not allowed to exceed 0.0005 mg/m²h, i.e. a stricter criteria by tenfold (British Standards, 1999, p.71).

A very low-polluting building is one in which all materials are very low-polluting, smoking has never occurred and is not allowed. Very low-polluting materials, such as stone, glass and metals, and other materials must fulfil the following requirements:

- Emission of total volatile organic compounds (TVOC) is below 0.1 mg/m²h
- Emission of formaldehyde is below 0.02 mg/m²h
- Emission of ammonia is below 0.01 mg/m²h
- Emission of carcinogenic compounds (IARC) is below 0.002 mg/m²h
- Material is not odorous (dissatisfaction with the odour is below 10%)

Buildings that do not meet the above criteria of either class are considered non-low-polluting.

A P P E N D I X I I

Sample steady-state calculation of a typical hotel room

II Appendix II - Sample steady state calculations of a typical hotel room

This appendix is provided to illustrate the energy saving potential of upgrading the building envelope (walls and windows) of hotels to current building regulations. To quantify the energy savings, a simplified steady state calculation of one hotel room was performed. It was assumed that the room had dimensions as shown in Fig. A-II.1. Furthermore, it was assumed that heat loss or gain took place through the exterior wall and window only, the other surfaces being adiabatic. This assumption holds true for rooms that have occupied spaces on both sides, on top and below. Using the steady state heat loss rate equation:

$Q=\sum U \cdot A \cdot \Delta T$ where,

U is thermal transmittance in W/m^2K

A is surface area (3.78 m^2 for window, 4.80 m^2 for net exterior wall), and

ΔT is the temperature difference between outdoors and indoors (5.6°C using mean monthly temperature[1] of 27.6°C and indoor temperature of 22°C).

Using the above input data and current construction U-values, the heat gain rate became 176 W. Modifying the U-values to meet the minimum requirements, heat loss rate was reduced to 103 W, i.e. 41% reduction. If infiltration was taken into account with the assumption that it equalled to approximately one air change per hour (CIBSE, 2007, Table 4.10, p.4-10), infiltration heat gain rate could be calculated as follows:

$Q_i=(c_{air} \cdot \rho_{air} \cdot N \cdot V \cdot \Delta T):3600$ s

where, c_{air} is density of air, 1.25 kg/m^3

ρ_{air} is specific heat capacity of air, 1050 J/kgK

N is air change per hour, 1/h, and

V is volume of the room[2], 47.9 m^3

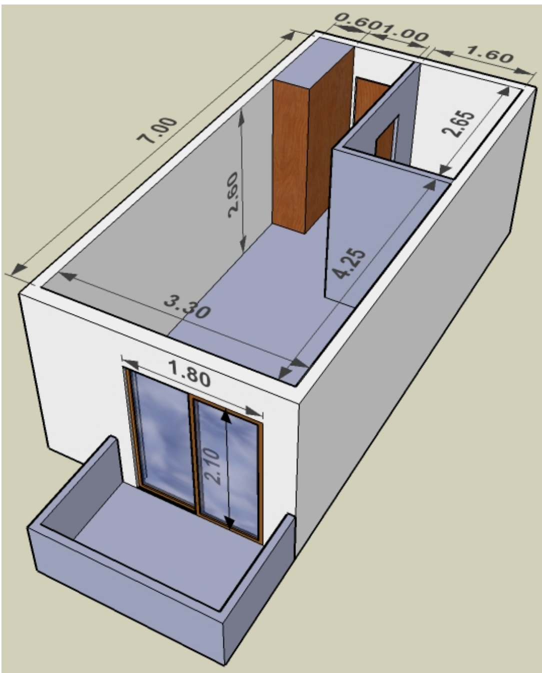

Figure A-II.1 Typical 4-star hotel room schema

[1] Mean monthly temperature of August in Larnaca for observations in 1991-2000 (Meteorological Service of Cyprus, 2005b)
[2] Floor area of the room only since bathrooms are not typically air-conditioned.

Subsequently, infiltration heat gain rate became 98 W. If it was further assumed that air-conditioning was required for 4.5 months per year (June to mid-October) translating into 137 days or 3288 hours, the baseline annual cooling load in a guestroom became:

$L_{cooling}$=3288 h·(176 W+98 W)=901 kWh

Distribution of the load over the floor area of the room (18.4 m^2) yielded a cooling load of 49 kWh/m^2. It is to be noted that any opening of the balcony door would have a tremendous effect on the infiltration heat gain. Therefore, the figure could increase significantly as it is quite common that resort hotel guests go in and out of the balcony several times a day. On the other hand, the air conditioning may be switched off for part of a day whereas 24-hour operation was assumed in the above calculation. It is therefore assumed that the calculated figure represents an average cooling load. It is further noted that the calculated figure represents the guestrooms only. The common areas of hotels, such as the lobby, breakfast room, restaurants and bars have greater cooling loads per unit area owing to their much higher ceiling heights and much greater glazing ratio and internal loads. In addition, the common areas are constantly exposed to outside air due to opening of doors.

Although the above calculation was merely a simplified approximation of heat gain and cooling loads of a typical hotel room, they did provide a clear indication of the magnitude of energy savings that can be achieved by upgrading the building envelope. Therefore, the initial hypothesis of this study stating that minimum of 20% energy savings are possible by energy-efficient renovation of hotel buildings would indeed seem plausible.

APPENDIX VI

Indoor pool evaporation calculations

Calculation of Evaporation Rate from a Swimming Pool

Input parameters for winter:

Ambient temperature, T_a: $T_a := 18$ °C (winter: November-April)

Relative humidity, rH: $rH := 0.60$ %

Pool surface water temperature, T_w: $T_w := 28$ °C

Air velocity on the surface water, V_s: $V_s := 0.127 \frac{m}{s}$

Actual area of pool, A_p: $A_p := 52.2 \cdot m^2$

Area of wet boundary, A_w: $A_w := 70.4 \cdot m^2$
(0.5 m around the pool)

Latent heat of water Y according to ***A Short Course in Cloud Physics***, 3rd Ed., by R.R. Rogers & M.K. Yau (1989), Cubic fit to Table 2.1 (p.16):

$$Y := -0.0000614342 \cdot T_w^{3} + 0.00158927 \cdot T_w^{2} - 2.36418 \cdot T_w + 2500.79$$

$$Y = 2434.5 \ \frac{kJ}{kg}$$

Saturation pressure of water vapour P_{aws} in the ambient air temperature according to ***2009 ASHRAE Handbook of Fundamentals***, Eq. 6 (p.1.2):

$$P_{aws} = \exp(1)^{\frac{-5800.2206}{T_a+273.15} + 1.3914993 - 0.048640239 \cdot (T_a+273.15) + ...}$$

$$\exp(1)^{.... + 4.1764768 \cdot 10^{-5} \cdot (T_a+273.15)^2 - 1.4452093 \times 10^{-8} \cdot (T_a+273.15)^3 + ...}$$

$$\exp(1)^{.... + 6.5459673 \cdot \ln(T_a+273.15)}$$

$$P_{aws} = 2064.3 \ Pa$$

Partial pressure of water vapour P_w in the moist air according to ***2009 ASHRAE Handbook of Fundamentals***, Eq. 24 (p.1.8):

$$P_w := rH \cdot P_{aws} \qquad P_w = 1238.6 \ Pa$$

Dew point temperature of the ambient air T_d according to ***2009 ASHRAE Handbook of Fundamentals***, Eq. 39 (p.1.9)::

$$T_d = 6.54 + 14.526 \cdot \ln\left(\frac{P_w}{1000}\right) + 0.7389 \cdot \ln\left(\frac{P_w}{1000}\right)^2 + 0.09486 \cdot \ln\left(\frac{P_w}{1000}\right)^3 + ...$$

$$.... + 0.4569 \cdot \ln\left(\frac{P_w}{1000}\right)^{0.1984}$$

$$T_d = 10 \ \ °C$$

Saturation pressure of water vapour in the dew point temperature P_a:

$$P_a = \exp(1)^{\frac{-5800.2206}{T_d+273.15}+1.3914993-0.048640239\cdot(T_d+273.15)+....}$$

$$\exp(1)^{....+4.1764768\cdot 10^{-5}\cdot(T_d+273.15)^2-1.4452093\times 10^{-8}\cdot(T_d+273.15)^3+....}$$

$$\exp(1)^{....+6.5459673\cdot\ln(T_d+273.15)}$$

$P_a = 1233.1$

Saturation pressure of water P_{ws} at the water-air interface:

$$P_{ws} = \exp(1)^{\frac{-5800.2206}{T_w+273.15}+1.3914993-0.048640239\cdot(T_w+273.15)+....}$$

$$\exp(1)^{....+4.1764768\cdot 10^{-5}\cdot(T_w+273.15)^2-1.4452093\times 10^{-8}\cdot(T_w+273.15)^3+....}$$

$$\exp(1)^{....+6.5459673\cdot\ln(T_w+273.15)}$$

$P_{ws} = 3782.2069679$

Evaporation rate according to ***2007 ASHRAE Handbook - HVAC Applications***, Eq. 1 (p.4.6):

$$W_e := \frac{(P_{ws} - P_a)\cdot(0.089 + 0.0782\cdot V_s)}{Y}\cdot 3.6\cdot\left(\frac{kg}{hr\cdot m^2}\right)$$

$$W_e = 0.373\frac{kg}{hr\cdot m^2}$$

The above evaporation rate is applicable for pools with activity factor of 1. A typical activity factor for hotel pools is 0.8 (2007 ASHRAE Handbook - HVAC Applications, p.4.6). Subsequently, the evaporation rate becomes:

$$W_{hotel} := 0.8\cdot W_e$$

$$W_{hotel} = 0.298\frac{kg}{hr\cdot m^2}$$

Heat supply required to maintain the pool water temperature:

$$q_p := Y\cdot W_{hotel}\cdot A_p\cdot\left(\frac{kJ}{kg}\right)$$

$$q_p = 10.53\,kW$$

Heat supply required to maintain the pool water temperature assuming 50 cm wet perimeter around the pool:

$$q_w := Y\cdot W_{hotel}\cdot A_w\cdot\left(\frac{kJ}{kg}\right)$$

$$q_w = 14.2\,kW$$

Incidentally, the latent heat gain from evaporation, w_L, equals to the heat supply. Therefore,

$w_L := q_p$ $\quad w_L = 10.5\,kW$ for actual pool surface area

$w_L := q_w$ $\quad w_L = 14.2\,kW$ for pool surface + wetted area around the pool

Input parameters for summer:

Ambient temperature, T_a:	$T_a := 28$ °C	(summer: May-October)
Relative humidity, rH:	$rH := 0.60$ %	
Pool surface water temperature, T_w:	$T_w := 28$ °C	
Air velocity on the surface water, V:	$V_s := 0.127\ \frac{m}{s}$	
Actual area of pool, A_p:	$A_p := 52.2 \cdot m^2$	
Area of wet boundary, A_w: (0.5 m around the pool)	$A_w := 70.4 \cdot m^2$	

Latent heat of water Y according to ***A Short Course in Cloud Physics***, 3rd Ed., by R.R. Rogers & M.K. Yau (1989), Cubic fit to Table 2.1 (p.16):

$$Y := -0.0000614342 \cdot T_w^{3} + 0.00158927 \cdot T_w^{2} - 2.36418 \cdot T_w + 2500.79$$

$$Y = 2434.5 \ \frac{kJ}{kg}$$

Saturation pressure of water vapour P_{aws} in the ambient air temperature according to ***2009 ASHRAE Handbook of Fundamentals***, Eq. 6 (p.1.2):

$$P_{aws} = \exp(1)^{\frac{-5800.2206}{T_a+273.15} + 1.3914993 - 0.048640239 \cdot (T_a+273.15) + \ldots}$$

$$\exp(1)^{\ldots + 4.1764768 \cdot 10^{-5} \cdot (T_a+273.15)^2 - 1.4452093 \times 10^{-8} \cdot (T_a+273.15)^3 + \ldots}$$

$$\exp(1)^{\ldots + 6.5459673 \cdot \ln(T_a+273.15)}$$

$$P_{aws} = 3782.2 \ \text{Pa}$$

Partial pressure of water vapour P_w in the moist air according to ***2009 ASHRAE Handbook of Fundamentals***, Eq. 24 (p.1.8):

$$P_w := rH \cdot P_{aws} \qquad P_w = 2269.3 \ \text{Pa}$$

Dew point temperature of the ambient air T_d according to ***2009 ASHRAE Handbook of Fundamentals***, Eq. 39 (p.1.9)::

$$T_d = 6.54 + 14.526 \cdot \ln\left(\frac{P_w}{1000}\right) + 0.7389 \cdot \ln\left(\frac{P_w}{1000}\right)^2 + 0.09486 \cdot \ln\left(\frac{P_w}{1000}\right)^3 + \ldots$$

$$\ldots + 0.4569 \cdot \ln\left(\frac{P_w}{1000}\right)^{0.1984}$$

$$T_d = 19.4 \ °C$$

Saturation pressure of water vapour in the dew point temperature P_a:

$$P_a = \exp(1)^{\frac{-5800.2206}{T_d+273.15}+1.3914993-0.048640239\cdot(T_d+273.15)+....}$$

$$\exp(1)^{....+4.1764768\cdot10^{-5}\cdot(T_d+273.15)^2-1.4452093\times10^{-8}\cdot(T_d+273.15)^3+....}$$

$$\exp(1)^{....+6.5459673\cdot\ln(T_d+273.15)}$$

$P_a = 2264.5$

Saturation pressure of water P_{ws} at the water-air interface:

$$P_{ws} = \exp(1)^{\frac{-5800.2206}{T_w+273.15}+1.3914993-0.048640239\cdot(T_w+273.15)+....}$$

$$\exp(1)^{....+4.1764768\cdot10^{-5}\cdot(T_w+273.15)^2-1.4452093\times10^{-8}\cdot(T_w+273.15)^3+....}$$

$$\exp(1)^{....+6.5459673\cdot\ln(T_w+273.15)}$$

$P_{ws} = 3782.2069679$

Evaporation rate according to ***2007 ASHRAE Handbook - HVAC Applications***, Eq. 1 (p.4.6):

$$W_e := \frac{(P_{ws} - P_a)\cdot(0.089 + 0.0782\cdot V_s)}{Y}\cdot 3.6\cdot\left(\frac{kg}{hr\cdot m^2}\right)$$

$$W_e = 0.222\frac{kg}{hr\cdot m^2}$$

The above evaporation rate is applicable for pools with activity factor of 1. A typical activity factor for hotel pools is 0.8 (2007 ASHRAE Handbook - HVAC Applications, p.4.6). Subsequently, the evaporation rate becomes:

$$W_{hotel} := 0.8\cdot W_e$$

$$W_{hotel} = 0.178\frac{kg}{hr\cdot m^2}$$

Heat supply required to maintain the pool water temperature:

$$q_p := Y\cdot W_{hotel}\cdot A_p\cdot\left(\frac{kJ}{kg}\right)$$

$$q_p = 6.3\,kW$$

Heat supply required to maintain the pool water temperature assuming 50 cm wet perimeter around the pool:

$$q_w := Y\cdot W_{hotel}\cdot A_w\cdot\left(\frac{kJ}{kg}\right)$$

$$q_w = 8.5\,kW$$

Incidentally, the latent heat gain from evaporation, w_L, equals to the heat supply. Therefore,

$w_L := q_p$ $\quad w_L = 6.3\,kW$ $\quad$ for actual pool surface area

$w_L := q_w$ $\quad w_L = 8.5\,kW$ $\quad$ for pool surface + wetted area around the pool

A P P E N D I X V I I

Hotel energy and water survey questionnaire

Hotel Energy and Water Consumption Survey Questionnaire

OXFORD BROOKES UNIVERSITY

This survey is part of a study undertaken at the Department of Architecture, Oxford Brookes University, UK in order to evaluate the impact of climate change and the rising fuel prices on the operating expenses of hotels in Cyprus. The aim of this survey questionnaire is to map and consolidate the current energy and water consumption figures of Cypriot hotels/hotel apartments and subsequently propose cost-effective renovation strategies that would introduce significant energy savings in the hospitality operations. Your input is vital in collecting a large, representative sample of data. Please take a few moments to answer the questions and do note that the data generated shall be retained and safely stored in accordance with the University's policy of Academic Integrity. Furthermore, the information you give herewith shall be treated confidential and neither the name of your establishment nor any other details that could identify you will be revealed. The collected data shall be analysed statistically and therefore your complete anonymity is guaranteed.

This questionnaire may require input from a technical and from a managerial person separately. Please try to give complete and accurate information to the best of your knowledge. It is especially vital that the energy and water consumption figures as well as the treated area of the establishment are accurately given. Some questions ask for estimates and it is quite appropriate to use your best judgement in answering them. If some questions are not applicable to your establishment, simply mark N/A. Any further comments or explanations are welcome in a space provided at the end of the form. The form has been designed so that you can type the answers directly onto the survey form over the green areas. After typing in the answers, please save the form and send it by email to the following address:

hotelsurvey@cytanet.com.cy

For any further questions, please feel free to call at: 99667821.

Many thanks in advance for your kind cooperation.

Sincerely,

Paula Naukkarinen
PhD Researcher, Oxford Institute for Sustainable Development

GENERAL

1 Name of the hotel/hotel apartments ______

2 Town/village ______

3 Year built ______ if extended or built in phases, give years & details ______

4 Total treated (heated or cooled) area ______ m^2

5 Number of rooms ______

6 Number of beds ______

7 Area of irrigated gardens ______ m^2

8 Star rating or category (mark with 'X')

5*	4*	3*	2*	1*	Cat. A	Cat. B	Other	No rating

9 Yearly operation period (mark with 'X') all year ______ part of year ______ dates of operation ______

10 Average annual occupancy rate ______ %

11 Peak seasons summer peak (dates) ______ winter peak (dates) ______

12 Occupancy rate during peak seasons ______ % ______ %

13 Guest nights sold annually ______

14 Demographics of guests (approx. %)

British	Scandinavian	German	Greek	Russian	French	Swiss	Irish	Israeli	Arabs	Cypriot	Other
%	%	%	%	%	%	%	%	%	%	%	%

15 Facilities

number of restaurants ______ total seating capacity ______ number of food covers served per year ______

number of bars ______

number of swimming pools ______ total area of pools ______ m^2 average depth of pools ______ m

number of heated swimming pools ______ area of heated pools ______ m^2 temp. maintained ______ °C heating season (month-month) ______

number of lifts ______

health club (yes/no) ______

in-house laundry (yes/no) ______

conference room (yes/no) ______ total area of conference rooms ______ m^2

16 Year of the latest renovation ______

17 Brief description of what was renovated ______

18 Planned next renovation (year) ______

19 What to be renovated? ______

20 Max acceptable payback period for investments, such as energy efficiency improvements ______ years Remarks ______

CONSTRUCTION DETAILS

21 Windows & glazing (type 1)

double glazing (yes/no) ______

aluminium frame (yes/no) ______ w/ thermal break (yes/no) ______ remarks or if other material, please specify ______

22 Wall type (type 1) (mark with 'X')

uninsulated perforated clay brick with plaster ______ wall thickness ______ cm

insulated perforated clay brick with plaster ______ total wall thickness ______ cm insulation thickness ______ cm insul. material ______

other type (please give details) ______

23 Roof (type 1) (mark with 'X')

uninsulated concrete slab ______ slab thickness ______ cm

insulated concrete slab ______ slab thickness ______ cm insulation thickness ______ cm insul. material ______

sloping roof with tiles ______ insulated (yes/no) ______ insulation thickness ______ cm insul. material ______

other type (please give details) ______

If an area of the property is built using different materials, please record it below as type 2. Estimated area for which type 2 applies to: ______ % (it is implied that together type 1 & 2 construction make up 100% of area)

24 Windows & glazing (type 2)

double glazing (yes/no) ______

aluminium frame (yes/no) ______ w/ thermal break (yes/no) ______ remarks or if other material, please specify ______

25 Wall type (type 2) (mark with 'X')

uninsulated perforated clay brick with plaster ______ wall thickness ______ cm

insulated perforated clay brick with plaster ______ total wall thickness ______ cm insulation thickness ______ cm insul. material ______

other type (please give details) ______

26 Roof (type 2) (mark with 'X')

uninsulated concrete slab ______ slab thickness ______ cm

insulated concrete slab ______ slab thickness ______ cm insulation thickness ______ cm insul. material ______

sloping roof with tiles ______ insulated (yes/no) ______ insulation thickness ______ cm insul. material ______

other type (please give details) ______

ENERGY CONSUMPTION

27 Air conditioning (yes/no)
- electrical vapour compression chillers (yes/no) — if other type, please specify
- central air handling system (yes/no)
- cooling tower (yes/no) — cooling tower water consumption: m^3/day typ. or avg — m^3/day max — Remarks
- typical thermostat setting for cooling — ℃
- typical cooling season (month-month)

28 Space heating (yes/no)
- boiler with burner (yes/no)
- central air handling system (yes/no)
- central heating (water) with radiators (yes/no)
- electric heating (yes/no) — if yes, please give details if central or individual room radiators
- other type (please give details)
- typical thermostat setting for heating — ℃
- typical heating season (month-month)

29 Fuel used for heating (please specify)

30 Heating fuel consumption in 2007 — unit — please indicate unit according to fuel i.e. tonnes, litres, m^3, etc.

31 If possible, please give figures for previous years — 2006: — 2005: — 2004: — 2003: — 2002:

32 Electricity consumption in 2007 — kWh

33 If possible, please give figures for previous years — 2006: — 2005: — 2004: — 2003: — 2002:

34 If known, please indicate approx. % used by — AC % — lighting % — kitchen % — laundry % — pumps % — gym/spa %
(Mark the remaining at 'other' to add up to 100%) — pool % — conf.cen. % — rooms % — other % — Remarks

35 Load entitlement by EAC (max demand load) — kVA — avg annual load factor — avg annual power factor

36 How frequently max load exceeded annually? ('X') — Never — Sometimes — estimated frequency times/yr — max peak load when exceeding the limit kVA

37 Hot water heating system (yes/no)
- boiler with burner (yes/no)
- electric (yes/no)

38 Fuel used for water heating (please specify)

39 Water heating fuel consumption in 2007 — unit — please indicate unit according to fuel i.e. tonnes, litres, m^3, etc.

40 If possible, please give figures for previous years — 2006: — 2005: — 2004: — 2003: — 2002:

41 Solar hot water (yes/no)

42 Approx. area of solar panels — m^2

43 Percentage of hot water produced by solar — % per annum

WATER CONSUMPTION

44 Total domestic water consumption in 2007 — m^3

45 If possible, please give figures for previous years — 2006: — 2005: — 2004: — 2003: — 2002:

46 Hot water consumption in 2007 — m^3 — hot water temperature ℃

47 If possible, please give figures for previous years — 2006: — 2005: — 2004: — 2003: — 2002:

48 Source of domestic water (mark with 'X') — Water board — Communal water supply — Private borehole — Other, specify

49 Grounds irrigation water consumption in 2007 — m^3

50 If possible, please give figures for previous years — 2006: — 2005: — 2004: — 2003: — 2002:

51 Source of grounds irrigation water — irrigation rate litres/m^2/day for months (summer season)
irrigation rate litres/m^2/day for months (winter season)

52 Connected to municipal sewage system (yes/no)

SOLID WASTE

53 Amount of solid waste produced annually — unit — please indicate unit, either tonnes or m^3, etc.

54 Any recycling programmes in place (yes/no) — if yes, please specify — approx. annual amount — unit

ENERGY/WATER SAVING MEASURES

55 Energy saving light bulbs (yes/no) — if yes, approx. percentage of all lighting %

56 Key card control (yes/no)

57 Occupancy sensors for lights (yes/no)

58 Building Energy Management System (yes/no)

59 Special window shading devices (yes/no) — if yes, please specify

60 Grey water recycling (yes/no)

61 Dual-flush toilets (yes/no) — volume of toilet flush (current) litres/flush

62 Water saving showerheads (yes/no) — flow rate of current installation litres/min

63 Water saving taps (yes/no) — flow rate of current installation litres/min

(61–63: Please give these values even if no water saving fixtures are in place)

64 Waterless urinals (yes/no)

65 Automated water taps (yes/no)

66 Other (please specify)

67 Any further comments

A P P E N D I X V I I I

Hotel guest survey questionnaire

Hotel Guest Survey

OXFORD BROOKES UNIVERSITY

Dear Guest,

This survey is part of a study undertaken at the Department of Architecture, Oxford Brookes University, UK in order to evaluate the impact of climate change and the rising fuel prices on the tourism industry of Cyprus. It will focus in particular on the projected changes in the travelling patterns of tourists like yourself in the future when fuel prices may force the price of air travel as well as the running expenses of hotels to increase. Your input is vital in understanding how to safeguard and continuously improve the holiday experience Cyprus has to offer. Please take a few moments to answer the questions below and do note that the data generated shall be retained and safely stored in accordance with the University's policy of Academic Integrity. Furthermore, the sample size of this survey is large and therefore your complete anonymity is guaranteed. You are under no obligation to participate but your kind contribution would be greatly appreciated! If there is a particular question that you prefer not to answer, please feel free to skip to the next question. This questionnaire has been approved by the University Research Ethics Committee but if you have any concerns about the conduct of this survey, please feel free to contact the Chair of the UREC at Oxford Brookes University (*ethics@brookes.ac.uk*).

Sincerely,

Paula Naukkarinen (*paula.naukkarinen@brookes.ac.uk*)

1. Country of your current residence ____

2. Where did you fly to Cyprus from? (airport, city & country) ____

3. How many people are travelling with you? (including yourself)

   ☐1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 or more

4. Duration of stay _______ days Date of check-out: ____________________

5. Classification of stay

   ☐ accommodation only ☐ bed & breakfast ☐ half board ☐ full board

6. Purpose of your visit

   ☐ holiday ☐ business ☐ conference/convention ☐ other

(If the purpose of your visit is other than holiday, please answer the remaining questions to reflect your incurred expenses during this trip but your general holiday travel patterns)

7. How old are you? ____________________

8. Have you been to Cyprus before?

   ☐ No. This is my first time. ☐ once ☐ twice ☐ 3 times ☐ 4 or more times before

9. Please indicate the total yearly income of your household (if travelling alone, your income only) GB£ sterling equivalent given in parenthesis.

   ☐ less than €10000 (£6800) ☐ €10000-24999 (£6800-16999) ☐ €25000-39999 (£17000-27199)

   ☐ €40000-54999 (£27200-37399) ☐ €55000-69999 (£37400-47599) ☐ €70000 (£47600) or more

10. How much did you pay for your holiday package? (for the whole party/family)

    ____ (please indicate clearly the currency)

11. Roughly, how much money have you spent while in Cyprus? (for the whole party/family)

    ____ (please indicate clearly the currency)

12. How would you quantify your annual budget for holiday travel? (of the total household income)?

    ☐ one month's salary or less ☐ 2 mos. salary ☐ 3 mos. salary ☐ 4 mos. salary or more

13. How often do you travel abroad on holiday?

    ☐ every 5 years or less ☐ every other year ☐ once a year ☐ twice a year or more

over please =>

14. In a scale of 1 to 5, how important are the following factors when selecting a holiday destination?

	not important 1	2	3	4	5 very important
price	☐	☐	☐	☐	☐
climate (warm & sunny)	☐	☐	☐	☐	☐
nature & natural beauty	☐	☐	☐	☐	☐
cultural heritage	☐	☐	☐	☐	☐
food	☐	☐	☐	☐	☐
character of the people	☐	☐	☐	☐	☐
the hotel's 'green' or ecological reputation	☐	☐	☐	☐	☐

15. While on holiday, are you environmentally conscientious to the same degree as at home, i.e. conserving energy and water, recycling, etc.?

much less than at home 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ very much the same

16. During your stay in Cyprus, did you prefer to sleep with the air conditioning on or an open window? (winter guests: please indicate if heating was required at night)

☐ I preferred AC ☐ I preferred an open window ☐ heating on ☐ no heating on

Please explain why ____

17. To what degree are you concerned about climate change?

not at all concerned 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ deeply concerned

18. To what degree do you anticipate your holiday travel patterns changing in the future due to your concern about climate change?

no change 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ significant change

If change anticipated, in what way (less frequent? shorter distance?) ______________________________

____

19. How much more would you be willing to pay for your holiday experience in Cyprus if the package price was to go up due to increases in air travel and hotel running costs? (Have in mind that other tourist destinations would suffer from similar price increases.)

☐ up to 10% ☐ 10-20% ☐ 20-30% ☐ 30-40% ☐ 50% ☐ double or more

20. To what degree has your stay in Cyprus been "good value for money"?

☐ very poor ☐ poor ☐ average ☐ good ☐ very good

21. Would you consider visiting Cyprus again?

☐ yes ☐ no (please explain why) ____

22. Any further comments you would like to make? ____________________________________

____

____

____

Thank you for taking your time to complete this survey. And hope you have had a memorable stay in Cyprus!

A P P E N D I X   X

Economic analysis data

X Appendix X - Economic analysis data

Hotel	Occu-pancy rate	Investment costs, €/guest night														
												Oil price, $/barrel $120.00				
		over one year					over service life					over SPB				
		building envelope		with solar AC			building envelope		with solar AC			building envelope		with solar AC		
		Window only	Wall & window	Base Case	Window only	Wall & window	Window only	Wall & window	Base Case	Window only	Wall & window	Window only	Wall & window	Base Case	Window only	Wall & window
PRESENT																
5*	48.0%	€6.00	€8.74	€3.91	€9.91	€12.65	€0.24	€0.35	€0.16	€0.40	€0.51	€0.54	€0.77	€0.64	€1.64	€1.83
4*	51.0%	€3.51	€6.41	€3.45	€6.96	€9.86	€0.14	€0.26	€0.14	€0.28	€0.39	€0.33	€0.59	€0.57	€1.15	€1.42
3*	42.6%	€4.06	€7.21	€3.77	€7.83	€10.99	€0.16	€0.29	€0.15	€0.31	€0.44	€0.32	€0.53	€0.62	€1.29	€1.59
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€4.36	€11.06	€14.12	€0.27	€0.39	€0.17	€0.44	€0.56	€0.57	€0.80	€0.71	€1.83	€2.04
4*	46.0%	€3.90	€7.11	€3.82	€7.72	€10.93	€0.16	€0.28	€0.15	€0.31	€0.44	€0.35	€0.61	€0.63	€1.27	€1.58
3*	37.6%	€4.60	€8.17	€4.27	€8.87	€12.45	€0.18	€0.33	€0.17	€0.35	€0.50	€0.34	€0.55	€0.70	€1.47	€1.80
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€5.68	€14.42	€18.40	€0.35	€0.51	€0.23	€0.58	€0.74	€0.63	€0.90	€0.93	€2.38	€2.65
4*	36.0%	€4.98	€9.08	€4.88	€9.86	€13.96	€0.20	€0.36	€0.20	€0.39	€0.56	€0.40	€0.68	€0.80	€1.63	€2.01
3*	27.6%	€6.26	€11.13	€5.82	€12.08	€16.96	€0.25	€0.45	€0.23	€0.48	€0.68	€0.40	€0.65	€0.95	€2.00	€2.45
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€8.15	€20.68	€26.40	€0.50	€0.73	€0.33	€0.83	€1.06	€0.76	€1.08	€1.34	€3.42	€3.81
4*	26.0%	€6.89	€12.57	€6.76	€13.65	€19.33	€0.28	€0.50	€0.27	€0.55	€0.77	€0.49	€0.81	€1.11	€2.26	€2.79
3*	17.6%	€9.82	€17.46	€9.13	€18.95	€26.59	€0.39	€0.70	€0.37	€0.76	€1.06	€0.53	€0.84	€1.50	€3.13	€3.84
2050																
5*	48.0%	€6.00	€8.74	€4.56	€10.57	€13.31	€0.24	€0.35	€0.18	€0.42	€0.53	€0.70	€0.98	€1.07	€2.47	€2.68
4*	51.0%	€3.51	€6.41	€4.03	€7.54	€10.44	€0.14	€0.26	€0.16	€0.30	€0.42	€0.44	€0.74	€0.95	€1.76	€2.10
3*	42.6%	€4.06	€7.21	€4.41	€8.46	€11.62	€0.16	€0.29	€0.18	€0.34	€0.46	€0.42	€0.66	€1.04	€1.98	€2.34
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€5.10	€11.80	€14.85	€0.27	€0.39	€0.20	€0.47	€0.59	€0.73	€1.03	€1.20	€2.75	€3.00
4*	46.0%	€3.90	€7.11	€4.47	€8.36	€11.57	€0.16	€0.28	€0.18	€0.33	€0.46	€0.46	€0.78	€1.05	€1.95	€2.33
3*	37.6%	€4.60	€8.17	€4.99	€9.59	€13.17	€0.18	€0.33	€0.20	€0.38	€0.53	€0.45	€0.70	€1.17	€2.24	€2.66
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€6.64	€15.37	€19.36	€0.35	€0.51	€0.27	€0.61	€0.77	€0.82	€1.15	€1.56	€3.59	€3.90
4*	36.0%	€4.98	€9.08	€5.71	€10.68	€14.79	€0.20	€0.36	€0.23	€0.43	€0.59	€0.53	€0.87	€1.34	€2.49	€2.98
3*	27.6%	€6.26	€11.13	€6.80	€13.06	€17.94	€0.25	€0.45	€0.27	€0.52	€0.72	€0.52	€0.82	€1.60	€3.05	€3.62
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€9.53	€22.06	€27.77	€0.50	€0.73	€0.38	€0.88	€1.11	€0.98	€1.39	€2.24	€5.15	€5.60
4*	26.0%	€6.89	€12.57	€7.90	€14.79	€20.47	€0.28	€0.50	€0.32	€0.59	€0.82	€0.64	€1.04	€1.86	€3.45	€4.13
3*	17.6%	€9.82	€17.46	€10.67	€20.49	€28.13	€0.39	€0.70	€0.43	€0.82	€1.13	€0.68	€1.07	€2.51	€4.78	€5.67
2090																
5*	48.0%	€6.00	€8.74	€5.02	€11.02	€13.76	€0.24	€0.35	€0.20	€0.44	€0.55	€0.77	€1.04	€1.31	€2.87	€3.21
4*	51.0%	€3.51	€6.41	€4.43	€7.94	€10.84	€0.14	€0.26	€0.18	€0.32	€0.43	€0.49	€0.78	€1.16	€2.07	€2.53
3*	42.6%	€4.06	€7.21	€4.85	€8.90	€12.06	€0.16	€0.29	€0.19	€0.36	€0.48	€0.47	€0.70	€1.27	€2.32	€2.81
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€5.60	€12.31	€15.36	€0.27	€0.39	€0.22	€0.49	€0.61	€0.81	€1.09	€1.47	€3.21	€3.58
4*	46.0%	€3.90	€7.11	€4.91	€8.81	€12.02	€0.16	€0.28	€0.20	€0.35	€0.48	€0.52	€0.82	€1.28	€2.29	€2.80
3*	37.6%	€4.60	€8.17	€5.49	€10.09	€13.66	€0.18	€0.33	€0.22	€0.40	€0.55	€0.50	€0.75	€1.44	€2.63	€3.18
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€7.30	€16.03	€20.02	€0.35	€0.51	€0.29	€0.64	€0.80	€0.91	€1.23	€1.91	€4.18	€4.66
4*	36.0%	€4.98	€9.08	€6.27	€11.25	€15.35	€0.20	€0.36	€0.25	€0.45	€0.61	€0.59	€0.92	€1.64	€2.93	€3.58
3*	27.6%	€6.26	€11.13	€7.48	€13.74	€18.61	€0.25	€0.45	€0.30	€0.55	€0.74	€0.59	€0.87	€1.96	€3.58	€4.34
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€10.47	€23.01	€28.72	€0.50	€0.73	€0.42	€0.92	€1.15	€1.09	€1.49	€2.74	€5.99	€6.69
4*	26.0%	€6.89	€12.57	€8.69	€15.58	€21.26	€0.28	€0.50	€0.35	€0.62	€0.85	€0.72	€1.10	€2.27	€4.06	€4.95
3*	17.6%	€9.82	€17.46	€11.73	€21.55	€29.19	€0.39	€0.70	€0.47	€0.86	€1.17	€0.78	€1.14	€3.07	€5.61	€6.80

Table A-X.1 Investment costs per guest night in projected occupancy and oil price scenarios – Part 2 of 4

Note: Part 1 of 4 was presented in the main text of the thesis as Table 9.19.

Hotel	Occupancy rate	Investment costs, €/guest night										Oil price, $/barrel $160.00				
		over one year					over service life					over SPB				
		building envelope		with solar AC			building envelope		with solar AC			building envelope		with solar AC		
		Window only	Wall & window	Base Case	Window only	Wall & window	Window only	Wall & window	Base Case	Window only	Wall & window	Window only	Wall & window	Base Case	Window only	Wall & window
PRESENT																
5*	48.0%	€6.00	€8.74	€3.91	€9.91	€12.65	€0.24	€0.35	€0.16	€0.40	€0.51	€0.69	€0.99	€0.82	€2.11	€2.34
4*	51.0%	€3.51	€6.41	€3.45	€6.96	€9.86	€0.14	€0.26	€0.14	€0.28	€0.39	€0.42	€0.76	€0.73	€1.48	€1.83
3*	42.6%	€4.06	€7.21	€3.77	€7.83	€10.99	€0.16	€0.29	€0.15	€0.31	€0.44	€0.40	€0.67	€0.80	€1.66	€2.03
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€4.36	€11.06	€14.12	€0.27	€0.39	€0.17	€0.44	€0.56	€0.72	€1.03	€0.92	€2.35	€2.61
4*	46.0%	€3.90	€7.11	€3.82	€7.72	€10.93	€0.16	€0.28	€0.15	€0.31	€0.44	€0.44	€0.79	€0.81	€1.64	€2.02
3*	37.6%	€4.60	€8.17	€4.27	€8.87	€12.45	€0.18	€0.33	€0.17	€0.35	€0.50	€0.43	€0.71	€0.90	€1.88	€2.30
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€5.68	€14.42	€18.40	€0.35	€0.51	€0.23	€0.58	€0.74	€0.80	€1.15	€1.20	€3.06	€3.41
4*	36.0%	€4.98	€9.08	€4.88	€9.86	€13.96	€0.20	€0.36	€0.20	€0.39	€0.56	€0.50	€0.88	€1.03	€2.09	€2.59
3*	27.6%	€6.26	€11.13	€5.82	€12.08	€16.96	€0.25	€0.45	€0.23	€0.48	€0.68	€0.50	€0.83	€1.23	€2.57	€3.14
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€8.15	€20.68	€26.40	€0.50	€0.73	€0.33	€0.83	€1.06	€0.96	€1.38	€1.72	€4.39	€4.89
4*	26.0%	€6.89	€12.57	€6.76	€13.65	€19.33	€0.28	€0.50	€0.27	€0.55	€0.77	€0.61	€1.04	€1.43	€2.90	€3.58
3*	17.6%	€9.82	€17.46	€9.13	€18.95	€26.59	€0.39	€0.70	€0.37	€0.76	€1.06	€0.66	€1.07	€1.93	€4.03	€4.92
2050																
5*	48.0%	€6.00	€8.74	€4.56	€10.57	€13.31	€0.24	€0.35	€0.18	€0.42	€0.53	€0.88	€1.25	€1.38	€3.17	€3.43
4*	51.0%	€3.51	€6.41	€4.03	€7.54	€10.44	€0.14	€0.26	€0.16	€0.30	€0.42	€0.55	€0.95	€1.21	€2.26	€2.69
3*	42.6%	€4.06	€7.21	€4.41	€8.46	€11.62	€0.16	€0.29	€0.18	€0.34	€0.46	€0.53	€0.85	€1.33	€2.54	€3.00
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€5.10	€11.80	€14.85	€0.27	€0.39	€0.20	€0.47	€0.59	€0.92	€1.30	€1.53	€3.53	€3.83
4*	46.0%	€3.90	€7.11	€4.47	€8.36	€11.57	€0.16	€0.28	€0.18	€0.33	€0.46	€0.58	€0.99	€1.35	€2.50	€2.98
3*	37.6%	€4.60	€8.17	€4.99	€9.59	€13.17	€0.18	€0.33	€0.20	€0.38	€0.53	€0.56	€0.89	€1.50	€2.87	€3.40
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€6.64	€15.37	€19.36	€0.35	€0.51	€0.27	€0.61	€0.77	€1.03	€1.46	€2.00	€4.61	€4.99
4*	36.0%	€4.98	€9.08	€5.71	€10.68	€14.79	€0.20	€0.36	€0.23	€0.43	€0.59	€0.66	€1.11	€1.72	€3.20	€3.81
3*	27.6%	€6.26	€11.13	€6.80	€13.06	€17.94	€0.25	€0.45	€0.27	€0.52	€0.72	€0.65	€1.04	€2.05	€3.91	€4.63
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€9.53	€22.06	€27.77	€0.50	€0.73	€0.38	€0.88	€1.11	€1.23	€1.76	€2.87	€6.61	€7.16
4*	26.0%	€6.89	€12.57	€7.90	€14.79	€20.47	€0.28	€0.50	€0.32	€0.59	€0.82	€0.80	€1.32	€2.38	€4.43	€5.28
3*	17.6%	€9.82	€17.46	€10.67	€20.49	€28.13	€0.39	€0.70	€0.43	€0.82	€1.13	€0.86	€1.35	€3.21	€6.14	€7.25
2090																
5*	48.0%	€6.00	€8.74	€5.02	€11.02	€13.76	€0.24	€0.35	€0.20	€0.44	€0.55	€0.97	€1.32	€1.69	€3.69	€4.11
4*	51.0%	€3.51	€6.41	€4.43	€7.94	€10.84	€0.14	€0.26	€0.18	€0.32	€0.43	€0.62	€0.99	€1.49	€2.66	€3.24
3*	42.6%	€4.06	€7.21	€4.85	€8.90	€12.06	€0.16	€0.29	€0.19	€0.36	€0.48	€0.59	€0.89	€1.63	€2.98	€3.60
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€5.60	€12.31	€15.36	€0.27	€0.39	€0.22	€0.49	€0.61	€1.01	€1.38	€1.88	€4.12	€4.59
4*	46.0%	€3.90	€7.11	€4.91	€8.81	€12.02	€0.16	€0.28	€0.20	€0.35	€0.48	€0.65	€1.04	€1.65	€2.95	€3.59
3*	37.6%	€4.60	€8.17	€5.49	€10.09	€13.66	€0.18	€0.33	€0.22	€0.40	€0.55	€0.62	€0.94	€1.85	€3.38	€4.08
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€7.30	€16.03	€20.02	€0.35	€0.51	€0.29	€0.64	€0.80	€1.13	€1.55	€2.45	€5.37	€5.98
4*	36.0%	€4.98	€9.08	€6.27	€11.25	€15.35	€0.20	€0.36	€0.25	€0.45	€0.61	€0.74	€1.17	€2.11	€3.77	€4.59
3*	27.6%	€6.26	€11.13	€7.48	€13.74	€18.61	€0.25	€0.45	€0.30	€0.55	€0.74	€0.73	€1.10	€2.52	€4.60	€5.56
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€10.47	€23.01	€28.72	€0.50	€0.73	€0.42	€0.92	€1.15	€1.37	€1.88	€3.52	€7.70	€8.58
4*	26.0%	€6.89	€12.57	€8.69	€15.58	€21.26	€0.28	€0.50	€0.35	€0.62	€0.85	€0.90	€1.39	€2.92	€5.22	€6.35
3*	17.6%	€9.82	€17.46	€11.73	€21.55	€29.19	€0.39	€0.70	€0.47	€0.86	€1.17	€0.97	€1.44	€3.94	€7.22	€8.72

Table A-X.2 Investment costs per guest night in projected occupancy and oil price scenarios – Part 3 of 4

Hotel	Occu-pancy rate	Investment costs, €/guest night														
												Oil price, $/barrel $200.00				
		over one year					over service life					over SPB				
		building envelope		with solar AC			building envelope		with solar AC			building envelope		with solar AC		
		Window only	Wall & window	Base Case	Window only	Wall & window	Window only	Wall & window	Base Case	Window only	Wall & window	Window only	Wall & window	Base Case	Window only	Wall & window
PRESENT																
5*	48.0%	€6.00	€8.74	€3.91	€9.91	€12.65	€0.24	€0.35	€0.16	€0.40	€0.51	€0.83	€1.21	€1.01	€2.57	€2.86
4*	51.0%	€3.51	€6.41	€3.45	€6.96	€9.86	€0.14	€0.26	€0.14	€0.28	€0.39	€0.50	€0.92	€0.89	€1.81	€2.23
3*	42.6%	€4.06	€7.21	€3.77	€7.83	€10.99	€0.16	€0.29	€0.15	€0.31	€0.44	€0.49	€0.82	€0.97	€2.03	€2.48
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€4.36	€11.06	€14.12	€0.27	€0.39	€0.17	€0.44	€0.56	€0.86	€1.26	€1.13	€2.87	€3.19
4*	46.0%	€3.90	€7.11	€3.82	€7.72	€10.93	€0.16	€0.28	€0.15	€0.31	€0.44	€0.53	€0.96	€0.99	€2.00	€2.47
3*	37.6%	€4.60	€8.17	€4.27	€8.87	€12.45	€0.18	€0.33	€0.17	€0.35	€0.50	€0.51	€0.87	€1.10	€2.30	€2.81
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€5.68	€14.42	€18.40	€0.35	€0.51	€0.23	€0.58	€0.74	€0.97	€1.41	€1.47	€3.74	€4.16
4*	36.0%	€4.98	€9.08	€4.88	€9.86	€13.96	€0.20	€0.36	€0.20	€0.39	€0.56	€0.60	€1.07	€1.26	€2.56	€3.16
3*	27.6%	€6.26	€11.13	€5.82	€12.08	€16.96	€0.25	€0.45	€0.23	€0.48	€0.68	€0.60	€1.01	€1.50	€3.14	€3.83
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€8.15	€20.68	€26.40	€0.50	€0.73	€0.33	€0.83	€1.06	€1.16	€1.68	€2.10	€5.37	€5.97
4*	26.0%	€6.89	€12.57	€6.76	€13.65	€19.33	€0.28	€0.50	€0.27	€0.55	€0.77	€0.73	€1.27	€1.75	€3.55	€4.37
3*	17.6%	€9.82	€17.46	€9.13	€18.95	€26.59	€0.39	€0.70	€0.37	€0.76	€1.06	€0.79	€1.31	€2.36	€4.92	€6.01
2050																
5*	48.0%	€6.00	€8.74	€4.56	€10.57	€13.31	€0.24	€0.35	€0.18	€0.42	€0.53	€1.06	€1.52	€1.68	€3.86	€4.18
4*	51.0%	€3.51	€6.41	€4.03	€7.54	€10.44	€0.14	€0.26	€0.16	€0.30	€0.42	€0.67	€1.15	€1.48	€2.76	€3.28
3*	42.6%	€4.06	€7.21	€4.41	€8.46	€11.62	€0.16	€0.29	€0.18	€0.34	€0.46	€0.64	€1.03	€1.62	€3.09	€3.65
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€5.10	€11.80	€14.85	€0.27	€0.39	€0.20	€0.47	€0.59	€1.11	€1.58	€1.87	€4.31	€4.67
4*	46.0%	€3.90	€7.11	€4.47	€8.36	€11.57	€0.16	€0.28	€0.18	€0.33	€0.46	€0.70	€1.20	€1.64	€3.06	€3.63
3*	37.6%	€4.60	€8.17	€4.99	€9.59	€13.17	€0.18	€0.33	€0.20	€0.38	€0.53	€0.67	€1.09	€1.84	€3.51	€4.14
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€6.64	€15.37	€19.36	€0.35	€0.51	€0.27	€0.61	€0.77	€1.24	€1.77	€2.44	€5.62	€6.08
4*	36.0%	€4.98	€9.08	€5.71	€10.68	€14.79	€0.20	€0.36	€0.23	€0.43	€0.59	€0.79	€1.34	€2.10	€3.91	€4.64
3*	27.6%	€6.26	€11.13	€6.80	€13.06	€17.94	€0.25	€0.45	€0.27	€0.52	€0.72	€0.79	€1.26	€2.50	€4.78	€5.63
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€9.53	€22.06	€27.77	€0.50	€0.73	€0.38	€0.88	€1.11	€1.48	€2.13	€3.50	€8.07	€8.72
4*	26.0%	€6.89	€12.57	€7.90	€14.79	€20.47	€0.28	€0.50	€0.32	€0.59	€0.82	€0.96	€1.60	€2.90	€5.41	€6.43
3*	17.6%	€9.82	€17.46	€10.67	€20.49	€28.13	€0.39	€0.70	€0.43	€0.82	€1.13	€1.03	€1.64	€3.92	€7.49	€8.84
2090																
5*	48.0%	€6.00	€8.74	€5.02	€11.02	€13.76	€0.24	€0.35	€0.20	€0.44	€0.55	€1.16	€1.59	€2.06	€4.51	€5.02
4*	51.0%	€3.51	€6.41	€4.43	€7.94	€10.84	€0.14	€0.26	€0.18	€0.32	€0.43	€0.74	€1.20	€1.82	€3.25	€3.95
3*	42.6%	€4.06	€7.21	€4.85	€8.90	€12.06	€0.16	€0.29	€0.19	€0.36	€0.48	€0.71	€1.08	€1.99	€3.64	€4.40
Occupancy reduction 5%																
5*	43.0%	€6.70	€9.76	€5.60	€12.31	€15.36	€0.27	€0.39	€0.22	€0.49	€0.61	€1.22	€1.66	€2.30	€5.03	€5.60
4*	46.0%	€3.90	€7.11	€4.91	€8.81	€12.02	€0.16	€0.28	€0.20	€0.35	€0.48	€0.78	€1.26	€2.02	€3.60	€4.38
3*	37.6%	€4.60	€8.17	€5.49	€10.09	€13.66	€0.18	€0.33	€0.22	€0.40	€0.55	€0.75	€1.14	€2.26	€4.13	€4.98
Occupancy reduction 15%																
5*	33.0%	€8.73	€12.72	€7.30	€16.03	€20.02	€0.35	€0.51	€0.29	€0.64	€0.80	€1.36	€1.87	€3.00	€6.56	€7.30
4*	36.0%	€4.98	€9.08	€6.27	€11.25	€15.35	€0.20	€0.36	€0.25	€0.45	€0.61	€0.89	€1.41	€2.58	€4.60	€5.60
3*	27.6%	€6.26	€11.13	€7.48	€13.74	€18.61	€0.25	€0.45	€0.30	€0.55	€0.74	€0.88	€1.33	€3.07	€5.62	€6.79
Occupancy reduction 25%																
5*	23.0%	€12.53	€18.24	€10.47	€23.01	€28.72	€0.50	€0.73	€0.42	€0.92	€1.15	€1.64	€2.27	€4.30	€9.41	€10.47
4*	26.0%	€6.89	€12.57	€8.69	€15.58	€21.26	€0.28	€0.50	€0.35	€0.62	€0.85	€1.08	€1.68	€3.57	€6.37	€7.75
3*	17.6%	€9.82	€17.46	€11.73	€21.55	€29.19	€0.39	€0.70	€0.47	€0.86	€1.17	€1.16	€1.74	€4.82	€8.82	€10.64

Table A-X.3 Investment costs per guest night in projected occupancy and oil price scenarios – Part 4 of 4

Hotel	Occupancy rate	Room income from package holidays after investment and SC energy costs, €/guest night															
		Oil price = $92.07 per barrel								Oil price = $120.00 per barrel							
		building envelope/thermal comfort				with solar air conditioning				building envelope/thermal comfort				with solar air conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
	PRESENT																
5*	48.0%	€98.62	€97.86	€97.48	€98.61	€98.34	€97.59	€97.20	€98.32	€95.11	€94.45	€94.13	€95.54	€94.97	€94.31	€93.98	€95.38
4*	51.0%	€58.50	€58.08	€57.70	€58.61	€58.27	€57.85	€57.45	€58.36	€55.12	€54.75	€54.43	€55.58	€55.00	€54.63	€54.30	€55.44
3*	42.6%	€41.77	€41.26	€40.78	€41.61	€41.54	€41.00	€40.51	€41.33	€38.46	€37.97	€37.54	€38.60	€38.32	€37.84	€37.40	€38.44
	Occupancy reduction 5%																
5*	43.0%	€98.43	€97.55	€97.12	€98.33	€98.13	€97.25	€96.81	€98.00	€94.88	€94.11	€93.74	€95.25	€94.73	€93.96	€93.57	€95.07
4*	46.0%	€58.37	€57.90	€57.45	€58.42	€58.12	€57.63	€57.18	€58.14	€54.97	€54.54	€54.16	€55.38	€54.83	€54.40	€54.01	€55.22
3*	37.6%	€41.64	€41.05	€40.49	€41.38	€41.39	€40.75	€40.19	€41.06	€38.31	€37.73	€37.23	€38.35	€38.16	€37.58	€37.07	€38.17
	Occupancy reduction 15%																
5*	33.0%	€97.90	€96.67	€96.08	€97.52	€97.50	€96.28	€95.67	€97.10	€94.24	€93.12	€92.59	€94.40	€94.03	€92.93	€92.38	€94.16
4*	36.0%	€58.01	€57.36	€56.76	€57.89	€57.69	€57.02	€56.41	€57.52	€54.53	€53.93	€53.40	€54.82	€54.35	€53.76	€53.21	€54.61
3*	27.6%	€41.25	€40.39	€39.60	€40.65	€40.90	€39.98	€39.18	€40.22	€37.85	€36.99	€36.27	€37.60	€37.64	€36.79	€36.05	€37.35
	Occupancy reduction 25%																
5*	23.0%	€96.90	€95.02	€94.12	€96.01	€96.33	€94.45	€93.54	€95.40	€93.02	€91.28	€90.46	€92.80	€92.73	€90.99	€90.15	€92.46
4*	26.0%	€57.37	€56.41	€55.53	€56.94	€56.92	€55.95	€55.04	€56.44	€53.75	€52.86	€52.05	€53.82	€53.51	€52.63	€51.80	€53.54
3*	17.6%	€40.41	€38.97	€37.68	€39.10	€39.86	€38.34	€37.03	€38.41	€36.86	€35.42	€34.21	€35.98	€36.53	€35.11	€33.87	€35.61
	2050																
5*	48.0%	€98.06	€97.43	€97.10	€98.27	€97.88	€97.24	€96.89	€98.08	€94.45	€93.94	€93.68	€95.14	€94.45	€93.94	€93.66	€95.14
4*	51.0%	€58.08	€57.73	€57.39	€58.33	€57.91	€57.57	€57.21	€58.17	€54.60	€54.34	€54.06	€55.25	€54.60	€54.34	€54.04	€55.25
3*	42.6%	€41.41	€40.95	€40.50	€41.36	€41.24	€40.76	€40.30	€41.18	€37.99	€37.60	€37.21	€38.29	€37.99	€37.60	€37.19	€38.29
	Occupancy reduction 5%																
5*	43.0%	€97.83	€97.09	€96.71	€97.97	€97.63	€96.88	€96.48	€97.76	€94.17	€93.56	€93.25	€94.82	€94.18	€93.56	€93.22	€94.82
4*	46.0%	€57.92	€57.52	€57.12	€58.13	€57.74	€57.34	€56.92	€57.94	€54.41	€54.09	€53.77	€55.03	€54.41	€54.09	€53.74	€55.03
3*	37.6%	€41.26	€40.71	€40.19	€41.10	€41.06	€40.50	€39.96	€40.90	€37.81	€37.33	€36.87	€38.02	€37.81	€37.33	€36.85	€38.03
	Occupancy reduction 15%																
5*	33.0%	€97.18	€96.10	€95.57	€97.08	€96.92	€95.83	€95.27	€96.80	€93.38	€92.45	€91.99	€93.87	€93.39	€92.45	€91.96	€93.87
4*	36.0%	€57.48	€56.91	€56.36	€57.53	€57.25	€56.68	€56.10	€57.30	€53.87	€53.40	€52.93	€54.40	€53.88	€53.40	€52.90	€54.40
3*	27.6%	€40.80	€39.97	€39.23	€40.32	€40.53	€39.69	€38.92	€40.04	€37.24	€36.51	€35.83	€37.20	€37.25	€36.51	€35.80	€37.20
	Occupancy reduction 25%																
5*	23.0%	€95.96	€94.26	€93.44	€95.42	€95.58	€93.86	€93.01	€95.02	€91.90	€90.37	€89.64	€92.10	€91.91	€90.37	€89.60	€92.10
4*	26.0%	€56.70	€55.84	€55.02	€56.49	€56.38	€55.52	€54.66	€56.16	€52.93	€52.18	€51.45	€53.28	€52.93	€52.18	€51.41	€53.28
3*	17.6%	€39.81	€38.41	€37.17	€38.65	€39.38	€37.96	€36.69	€38.21	€36.03	€34.75	€33.61	€35.45	€36.04	€34.75	€33.55	€35.45
	2090																
5*	48.0%	€97.61	€97.04	€96.71	€97.96	€97.42	€96.84	€96.50	€97.81	€93.93	€93.50	€93.22	€94.77	€93.94	€93.51	€93.23	€94.85
4*	51.0%	€57.74	€57.45	€57.10	€58.10	€57.57	€57.27	€56.92	€57.96	€54.22	€54.01	€53.72	€54.96	€54.24	€54.02	€53.73	€55.03
3*	42.6%	€41.14	€40.72	€40.27	€41.15	€40.96	€40.53	€40.08	€41.01	€37.68	€37.34	€36.94	€38.05	€37.70	€37.36	€36.95	€38.12
	Occupancy reduction 5%																
5*	43.0%	€97.34	€96.66	€96.27	€97.63	€97.13	€96.44	€96.05	€97.46	€93.60	€93.07	€92.74	€94.42	€93.62	€93.08	€92.75	€94.50
4*	46.0%	€57.56	€57.21	€56.80	€57.87	€57.37	€57.01	€56.60	€57.72	€54.00	€53.73	€53.39	€54.72	€54.01	€53.75	€53.40	€54.79
3*	37.6%	€40.97	€40.46	€39.93	€40.88	€40.75	€40.24	€39.71	€40.72	€37.47	€37.05	€36.58	€37.76	€37.49	€37.06	€36.59	€37.84
	Occupancy reduction 15%																
5*	33.0%	€96.56	€95.56	€95.02	€96.67	€96.28	€95.27	€94.73	€96.45	€92.66	€91.82	€91.35	€93.38	€92.69	€91.84	€91.36	€93.49
4*	36.0%	€57.03	€56.52	€55.96	€57.23	€56.79	€56.28	€55.71	€57.04	€53.36	€52.95	€52.47	€54.03	€53.38	€52.97	€52.48	€54.12
3*	27.6%	€40.41	€39.65	€38.90	€40.05	€40.13	€39.35	€38.59	€39.82	€36.80	€36.13	€35.44	€36.87	€36.83	€36.16	€35.46	€36.99
	Occupancy reduction 25%																
5*	23.0%	€95.11	€93.50	€92.67	€94.87	€94.70	€93.09	€92.25	€94.55	€90.90	€89.49	€88.75	€91.44	€90.94	€89.52	€88.76	€91.60
4*	26.0%	€56.10	€55.32	€54.48	€56.09	€55.77	€54.98	€54.13	€55.83	€52.23	€51.58	€50.82	€52.80	€52.27	€51.60	€50.84	€52.93
3*	17.6%	€39.24	€37.92	€36.68	€38.26	€38.79	€37.46	€36.21	€37.90	€35.37	€34.19	€33.03	€34.98	€35.42	€34.22	€33.04	€35.16

Table A-X.4 Room income per guest night from package holidays after investment and space conditioning energy costs – Part 1 of 2

Hotel	Occupancy rate	Room income from package holidays after investment and SC energy costs, €/guest night															
		Oil price = $160.00 per barrel								Oil price = $200.00 per barrel							
		building envelope/thermal comfort				with solar air conditioning				building envelope/thermal comfort				with solar air conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
PRESENT																	
5*	48.0%	€90.11	€89.59	€89.35	€91.16	€90.15	€89.64	€89.38	€91.17	€85.11	€84.74	€84.57	€86.77	€85.34	€84.97	€84.78	€86.96
4*	51.0%	€50.28	€50.00	€49.76	€51.24	€50.32	€50.04	€49.79	€51.25	€45.45	€45.25	€45.09	€46.89	€45.65	€45.45	€45.28	€47.06
3*	42.6%	€33.68	€33.28	€32.92	€34.28	€33.73	€33.32	€32.95	€34.29	€28.91	€28.58	€28.29	€29.96	€29.13	€28.81	€28.50	€30.14
Occupancy reduction 5%																	
5*	43.0%	€89.64	€89.06	€88.79	€90.81	€89.88	€89.26	€88.95	€90.86	€84.77	€84.30	€84.08	€86.44	€85.03	€84.56	€84.32	€86.65
4*	46.0%	€49.93	€49.61	€49.34	€50.99	€50.13	€49.80	€49.49	€51.04	€45.21	€44.96	€44.75	€46.67	€45.44	€45.19	€44.97	€46.86
3*	37.6%	€33.30	€32.83	€32.43	€33.96	€33.54	€33.06	€32.61	€34.04	€28.68	€28.28	€27.92	€29.69	€28.93	€28.53	€28.16	€29.90
Occupancy reduction 15%																	
5*	33.0%	€89.02	€88.07	€87.63	€89.93	€89.08	€88.14	€87.68	€89.95	€83.80	€83.02	€82.66	€85.46	€84.13	€83.36	€82.98	€85.74
4*	36.0%	€49.54	€49.05	€48.60	€50.42	€49.59	€49.11	€48.65	€50.44	€44.55	€44.16	€43.81	€46.02	€44.84	€44.45	€44.08	€46.27
3*	27.6%	€32.92	€32.16	€31.52	€33.23	€32.98	€32.24	€31.57	€33.25	€27.98	€27.33	€26.77	€28.86	€28.32	€27.68	€27.09	€29.14
Occupancy reduction 25%																	
5*	23.0%	€87.50	€85.95	€85.23	€88.22	€87.59	€86.05	€85.31	€88.25	€81.97	€80.62	€80.01	€83.63	€82.45	€81.11	€80.46	€84.04
4*	26.0%	€48.57	€47.80	€47.09	€49.35	€48.64	€47.88	€47.16	€49.38	€43.39	€42.74	€42.14	€44.89	€43.78	€43.14	€42.51	€45.22
3*	17.6%	€31.67	€30.37	€29.26	€31.53	€31.77	€30.48	€29.34	€31.57	€26.49	€25.32	€24.30	€27.08	€27.02	€25.86	€24.81	€27.53
2050																	
5*	48.0%	€89.29	€88.98	€88.80	€90.66	€89.56	€89.23	€89.02	€90.92	€84.14	€84.01	€83.91	€86.19	€84.67	€84.52	€84.39	€86.71
4*	51.0%	€49.64	€49.49	€49.31	€50.83	€49.88	€49.72	€49.51	€51.06	€44.69	€44.65	€44.56	€46.41	€45.15	€45.11	€44.98	€46.87
3*	42.6%	€33.11	€32.83	€32.51	€33.90	€33.36	€33.08	€32.73	€34.15	€28.23	€28.05	€27.81	€29.51	€28.73	€28.55	€28.28	€30.02
Occupancy reduction 5%																	
5*	43.0%	€88.96	€88.53	€88.31	€90.31	€89.25	€88.82	€88.56	€90.60	€83.74	€83.51	€83.37	€85.80	€84.32	€84.08	€83.90	€86.38
4*	46.0%	€49.41	€49.21	€48.98	€50.59	€49.67	€49.46	€49.20	€50.84	€44.41	€44.32	€44.19	€46.15	€44.92	€44.83	€44.66	€46.66
3*	37.6%	€32.88	€32.52	€32.14	€33.62	€33.17	€32.80	€32.39	€33.90	€27.95	€27.71	€27.40	€29.21	€28.53	€28.27	€27.93	€29.78
Occupancy reduction 15%																	
5*	33.0%	€87.97	€87.25	€86.89	€89.28	€88.35	€87.62	€87.22	€89.66	€82.55	€82.04	€81.79	€84.69	€83.31	€82.79	€82.48	€85.44
4*	36.0%	€48.74	€48.40	€48.03	€49.90	€49.07	€48.72	€48.31	€50.23	€43.60	€43.40	€43.13	€45.41	€44.25	€44.04	€43.73	€46.06
3*	27.6%	€32.17	€31.57	€30.98	€32.74	€32.56	€31.96	€31.32	€33.13	€27.10	€26.64	€26.14	€28.28	€27.88	€27.40	€26.85	€29.06
Occupancy reduction 25%																	
5*	23.0%	€86.12	€84.84	€84.24	€87.35	€86.67	€85.38	€84.71	€87.90	€80.34	€79.31	€78.83	€82.61	€81.43	€80.39	€79.83	€83.69
4*	26.0%	€47.55	€46.97	€46.35	€48.69	€48.01	€47.42	€46.75	€49.14	€42.18	€41.76	€41.26	€44.10	€43.08	€42.65	€42.09	€45.00
3*	17.6%	€30.66	€29.55	€28.52	€30.87	€31.27	€30.15	€29.05	€31.48	€25.28	€24.35	€23.43	€26.30	€26.50	€25.55	€24.55	€27.51
2090																	
5*	48.0%	€88.67	€88.44	€88.24	€90.21	€88.98	€88.74	€88.54	€90.59	€83.42	€83.38	€83.26	€85.64	€84.02	€83.97	€83.84	€86.34
4*	51.0%	€49.19	€49.10	€48.90	€50.48	€49.46	€49.37	€49.16	€50.82	€44.16	€44.20	€44.08	€45.99	€44.69	€44.72	€44.60	€46.61
3*	42.6%	€32.75	€32.52	€32.19	€33.60	€33.04	€32.82	€32.48	€33.97	€27.81	€27.70	€27.44	€29.15	€28.39	€28.28	€28.01	€29.82
Occupancy reduction 5%																	
5*	43.0%	€88.27	€87.94	€87.69	€89.82	€88.61	€88.28	€88.02	€90.25	€82.94	€82.81	€82.65	€85.21	€83.61	€83.47	€83.30	€85.99
4*	46.0%	€48.91	€48.78	€48.53	€50.21	€49.21	€49.08	€48.82	€50.58	€43.83	€43.83	€43.66	€45.70	€44.42	€44.41	€44.23	€46.38
3*	37.6%	€32.48	€32.18	€31.78	€33.29	€32.81	€32.51	€32.11	€33.71	€27.48	€27.32	€26.99	€28.82	€28.14	€27.97	€27.63	€29.58
Occupancy reduction 15%																	
5*	33.0%	€87.10	€86.49	€86.11	€88.68	€87.55	€86.93	€86.54	€89.24	€81.54	€81.15	€80.87	€83.97	€82.41	€82.02	€81.72	€84.98
4*	36.0%	€48.12	€47.86	€47.47	€49.45	€48.51	€48.24	€47.84	€49.93	€42.88	€42.77	€42.47	€44.87	€43.63	€43.51	€43.20	€45.74
3*	27.6%	€31.64	€31.12	€30.52	€32.34	€32.10	€31.58	€30.96	€32.91	€26.49	€26.12	€25.59	€27.80	€27.38	€27.00	€26.46	€28.84
Occupancy reduction 25%																	
5*	23.0%	€84.91	€83.77	€83.14	€86.54	€85.56	€84.41	€83.76	€87.35	€78.92	€78.05	€77.54	€81.64	€80.18	€79.30	€78.76	€83.09
4*	26.0%	€46.72	€46.24	€45.60	€48.10	€47.25	€46.76	€46.11	€48.77	€41.20	€40.90	€40.37	€43.40	€42.24	€41.93	€41.38	€44.60
3*	17.6%	€29.86	€28.87	€27.82	€30.30	€30.59	€29.58	€28.51	€31.20	€24.35	€23.55	€22.61	€25.61	€25.76	€24.94	€23.97	€27.24

Table A-X.5 Room income per guest night from package holidays after investment and space conditioning energy costs – Part 2 of 2

Hotel	Occupancy rate	Room income from package holidays with 10.71% price increase after investment and SC energy costs, €/guest night															
		Oil price = $92.07 per barrel								Oil price = $120.00 per barrel							
		building envelope/thermal comfort				with solar air conditioning				building envelope/thermal comfort				with solar air conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
	PRESENT																
5*	48.0%	€111.65	€110.89	€110.51	€111.64	€111.37	€110.62	€110.23	€111.35	€108.14	€107.48	€107.16	€108.58	€108.00	€107.35	€107.02	€108.41
4*	51.0%	€67.18	€66.76	€66.38	€67.29	€66.95	€66.53	€66.13	€67.04	€63.80	€63.43	€63.11	€64.26	€63.68	€63.31	€62.98	€64.12
3*	42.6%	€48.64	€48.13	€47.65	€48.48	€48.41	€47.87	€47.38	€48.20	€45.33	€44.84	€44.41	€45.46	€45.19	€44.70	€44.27	€45.31
	Occupancy reduction 5%																
5*	43.0%	€111.47	€110.58	€110.15	€111.36	€111.16	€110.28	€109.84	€111.04	€107.92	€107.14	€106.77	€108.28	€107.76	€106.99	€106.61	€108.10
4*	46.0%	€67.05	€66.58	€66.13	€67.10	€66.80	€66.31	€65.86	€66.82	€63.65	€63.22	€62.84	€64.06	€63.51	€63.08	€62.69	€63.90
3*	37.6%	€48.51	€47.91	€47.36	€48.25	€48.25	€47.62	€47.06	€47.93	€45.18	€44.60	€44.10	€45.22	€45.02	€44.45	€43.94	€45.04
	Occupancy reduction 15%																
5*	33.0%	€110.93	€109.70	€109.11	€110.55	€110.53	€109.31	€108.70	€110.13	€107.27	€106.15	€105.63	€107.43	€107.06	€105.96	€105.41	€107.19
4*	36.0%	€66.69	€66.04	€65.44	€66.57	€66.37	€65.70	€65.09	€66.20	€63.21	€62.61	€62.08	€63.50	€63.03	€62.44	€61.89	€63.29
3*	27.6%	€48.12	€47.25	€46.46	€47.52	€47.77	€46.85	€46.05	€47.08	€44.71	€43.86	€43.13	€44.46	€44.50	€43.66	€42.92	€44.22
	Occupancy reduction 25%																
5*	23.0%	€109.93	€108.05	€107.15	€109.04	€109.36	€107.49	€106.57	€108.43	€106.05	€104.31	€103.49	€105.83	€105.76	€104.03	€103.18	€105.50
4*	26.0%	€66.05	€65.09	€64.21	€65.62	€65.60	€64.63	€63.72	€65.12	€62.43	€61.54	€60.73	€62.50	€62.19	€61.31	€60.48	€62.22
3*	17.6%	€47.28	€45.84	€44.55	€45.96	€46.73	€45.21	€43.90	€45.28	€43.73	€42.29	€41.08	€42.85	€43.40	€41.97	€40.74	€42.47
	2050																
5*	48.0%	€111.09	€110.46	€110.13	€111.30	€110.91	€110.27	€109.93	€111.11	€107.48	€106.98	€106.71	€108.17	€107.48	€106.98	€106.69	€108.17
4*	51.0%	€66.76	€66.41	€66.07	€67.01	€66.59	€66.25	€65.89	€66.85	€63.28	€63.02	€62.74	€63.93	€63.28	€63.02	€62.72	€63.93
3*	42.6%	€48.28	€47.81	€47.37	€48.22	€48.10	€47.63	€47.17	€48.04	€44.86	€44.47	€44.08	€45.16	€44.86	€44.46	€44.05	€45.16
	Occupancy reduction 5%																
5*	43.0%	€110.87	€110.12	€109.74	€111.00	€110.66	€109.91	€109.51	€110.79	€107.20	€106.59	€106.28	€107.85	€107.21	€106.59	€106.25	€107.85
4*	46.0%	€66.60	€66.20	€65.80	€66.81	€66.42	€66.02	€65.60	€66.62	€63.09	€62.77	€62.45	€63.71	€63.09	€62.77	€62.42	€63.71
3*	37.6%	€48.13	€47.57	€47.06	€47.97	€47.93	€47.37	€46.83	€47.76	€44.67	€44.20	€43.74	€44.89	€44.68	€44.20	€43.71	€44.89
	Occupancy reduction 15%																
5*	33.0%	€110.21	€109.13	€108.60	€110.11	€109.95	€108.86	€108.30	€109.84	€106.41	€105.48	€105.02	€106.90	€106.42	€105.48	€104.99	€106.90
4*	36.0%	€66.16	€65.59	€65.04	€66.21	€65.93	€65.36	€64.78	€65.98	€62.55	€62.08	€61.61	€63.08	€62.56	€62.08	€61.58	€63.08
3*	27.6%	€47.66	€46.84	€46.10	€47.19	€47.39	€46.56	€45.79	€46.91	€44.11	€43.38	€42.70	€44.07	€44.11	€43.38	€42.66	€44.07
	Occupancy reduction 25%																
5*	23.0%	€108.99	€107.29	€106.47	€108.45	€108.61	€106.89	€106.04	€108.06	€104.93	€103.41	€102.68	€105.13	€104.94	€103.40	€102.63	€105.13
4*	26.0%	€65.38	€64.52	€63.70	€65.17	€65.06	€64.20	€63.34	€64.84	€61.61	€60.86	€60.13	€61.96	€61.61	€60.86	€60.09	€61.96
3*	17.6%	€46.67	€45.27	€44.04	€45.51	€46.25	€44.83	€43.56	€45.07	€42.90	€41.62	€40.47	€42.32	€42.91	€41.62	€40.42	€42.32
	2090																
5*	48.0%	€110.64	€110.07	€109.74	€110.99	€110.45	€109.88	€109.54	€110.84	€106.96	€106.53	€106.25	€107.81	€106.98	€106.54	€106.26	€107.88
4*	51.0%	€66.42	€66.13	€65.78	€66.78	€66.25	€65.95	€65.60	€66.64	€62.90	€62.69	€62.40	€63.64	€62.92	€62.70	€62.41	€63.71
3*	42.6%	€48.01	€47.59	€47.14	€48.02	€47.82	€47.40	€46.94	€47.87	€44.55	€44.21	€43.81	€44.91	€44.57	€44.22	€43.82	€44.98
	Occupancy reduction 5%																
5*	43.0%	€110.37	€109.69	€109.31	€110.66	€110.16	€109.47	€109.08	€110.49	€106.63	€106.10	€105.77	€107.45	€106.66	€106.12	€105.78	€107.53
4*	46.0%	€66.24	€65.89	€65.48	€66.55	€66.05	€65.69	€65.28	€66.40	€62.68	€62.41	€62.07	€63.40	€62.69	€62.43	€62.08	€63.47
3*	37.6%	€47.83	€47.32	€46.80	€47.75	€47.62	€47.11	€46.58	€47.58	€44.33	€43.91	€43.44	€44.63	€44.35	€43.93	€43.45	€44.71
	Occupancy reduction 15%																
5*	33.0%	€109.60	€108.59	€108.05	€109.70	€109.31	€108.31	€107.76	€109.48	€105.69	€104.85	€104.38	€106.41	€105.72	€104.87	€104.39	€106.52
4*	36.0%	€65.71	€65.20	€64.64	€65.91	€65.47	€64.96	€64.39	€65.72	€62.04	€61.63	€61.15	€62.71	€62.06	€61.65	€61.16	€62.80
3*	27.6%	€47.28	€46.51	€45.76	€46.91	€46.99	€46.22	€45.46	€46.69	€43.67	€43.00	€42.31	€43.74	€43.69	€43.02	€42.32	€43.85
	Occupancy reduction 25%																
5*	23.0%	€108.14	€106.53	€105.70	€107.90	€107.74	€106.12	€105.28	€107.58	€103.94	€102.52	€101.78	€104.48	€103.97	€102.55	€101.79	€104.63
4*	26.0%	€64.78	€64.00	€63.16	€64.77	€64.45	€63.66	€62.81	€64.51	€60.91	€60.26	€59.50	€61.48	€60.95	€60.28	€59.52	€61.61
3*	17.6%	€46.11	€44.78	€43.54	€45.13	€45.65	€44.32	€43.07	€44.77	€42.24	€41.05	€39.89	€41.85	€42.28	€41.09	€39.91	€42.03

Table A-X.6 Room income per guest night from package holidays with a 10.71% price increase after investment and space conditioning energy costs – Part 1 of 2

Hotel	Occupancy rate	Room income from package holidays with 10.71% price increase after investment and SC energy costs, €/guest night															
		Oil price = $160.00 per barrel								Oil price = $200.00 per barrel							
		building envelope/thermal comfort				with solar air conditioning				building envelope/thermal comfort				with solar air conditioning			
		Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All	Base Case	Window only	Wall & window	All
PRESENT																	
5*	48.0%	€103.14	€102.63	€102.38	€104.19	€103.18	€102.67	€102.42	€104.21	€98.14	€97.77	€97.60	€99.80	€98.37	€98.00	€97.82	€100.00
4*	51.0%	€58.96	€58.68	€58.44	€59.92	€59.00	€58.72	€58.47	€59.93	€54.13	€53.93	€53.77	€55.57	€54.33	€54.13	€53.96	€55.74
3*	42.6%	€40.55	€40.14	€39.78	€41.14	€40.59	€40.19	€39.82	€41.16	€35.78	€35.45	€35.16	€36.82	€36.00	€35.68	€35.37	€37.01
Occupancy reduction 5%																	
5*	43.0%	€102.67	€102.09	€101.82	€103.84	€102.91	€102.29	€101.98	€103.89	€97.81	€97.33	€97.11	€99.47	€98.06	€97.59	€97.35	€99.68
4*	46.0%	€58.61	€58.29	€58.02	€59.67	€58.81	€58.48	€58.17	€59.72	€53.89	€53.64	€53.43	€55.35	€54.12	€53.87	€53.65	€55.54
3*	37.6%	€40.16	€39.70	€39.29	€40.83	€40.41	€39.92	€39.48	€40.90	€35.55	€35.15	€34.79	€36.55	€35.80	€35.40	€35.02	€36.77
Occupancy reduction 15%																	
5*	33.0%	€102.05	€101.10	€100.66	€102.96	€102.11	€101.17	€100.71	€102.98	€96.83	€96.05	€95.69	€98.49	€97.16	€96.39	€96.01	€98.77
4*	36.0%	€58.22	€57.73	€57.28	€59.10	€58.27	€57.79	€57.33	€59.12	€53.23	€52.84	€52.49	€54.70	€53.52	€53.13	€52.76	€54.95
3*	27.6%	€39.78	€39.03	€38.38	€40.09	€39.85	€39.10	€38.44	€40.12	€34.85	€34.20	€33.63	€35.72	€35.19	€34.55	€33.96	€36.01
Occupancy reduction 25%																	
5*	23.0%	€100.53	€98.98	€98.26	€101.25	€100.62	€99.08	€98.34	€101.28	€95.01	€93.66	€93.04	€96.67	€95.48	€94.14	€93.50	€97.07
4*	26.0%	€57.25	€56.48	€55.77	€58.03	€57.32	€56.56	€55.84	€58.06	€52.07	€51.42	€50.82	€53.57	€52.46	€51.82	€51.19	€53.90
3*	17.6%	€38.54	€37.24	€36.12	€38.40	€38.64	€37.35	€36.21	€38.44	€33.35	€32.18	€31.17	€33.95	€33.88	€32.73	€31.68	€34.40
2050																	
5*	48.0%	€102.33	€102.01	€101.83	€103.70	€102.59	€102.27	€102.06	€103.96	€97.18	€97.04	€96.94	€99.22	€97.70	€97.56	€97.42	€99.74
4*	51.0%	€58.32	€58.17	€57.99	€59.51	€58.56	€58.40	€58.19	€59.74	€53.37	€53.33	€53.24	€55.09	€53.83	€53.79	€53.66	€55.55
3*	42.6%	€39.98	€39.69	€39.38	€40.77	€40.23	€39.94	€39.60	€41.02	€35.10	€34.92	€34.68	€36.38	€35.60	€35.42	€35.14	€36.88
Occupancy reduction 5%																	
5*	43.0%	€101.99	€101.57	€101.34	€103.34	€102.28	€101.85	€101.59	€103.63	€96.77	€96.54	€96.40	€98.83	€97.35	€97.11	€96.94	€99.41
4*	46.0%	€58.09	€57.89	€57.66	€59.27	€58.35	€58.14	€57.88	€59.52	€53.09	€53.00	€52.87	€54.83	€53.60	€53.51	€53.34	€55.34
3*	37.6%	€39.75	€39.39	€39.01	€40.49	€40.04	€39.67	€39.25	€40.77	€34.82	€34.57	€34.27	€36.08	€35.39	€35.14	€34.80	€36.65
Occupancy reduction 15%																	
5*	33.0%	€101.00	€100.28	€99.92	€102.31	€101.38	€100.65	€100.25	€102.69	€95.59	€95.08	€94.82	€97.72	€96.35	€95.83	€95.51	€98.48
4*	36.0%	€57.42	€57.08	€56.71	€58.58	€57.75	€57.40	€56.99	€58.91	€52.28	€52.08	€51.81	€54.09	€52.93	€52.72	€52.41	€54.74
3*	27.6%	€39.04	€38.44	€37.85	€39.61	€39.43	€38.82	€38.19	€40.00	€33.97	€33.50	€33.00	€35.15	€34.75	€34.27	€33.72	€35.93
Occupancy reduction 25%																	
5*	23.0%	€99.15	€97.88	€97.27	€100.39	€99.70	€98.41	€97.74	€100.93	€93.37	€92.34	€91.86	€95.64	€94.46	€93.42	€92.86	€96.72
4*	26.0%	€56.23	€55.65	€55.03	€57.37	€56.69	€56.10	€55.43	€57.82	€50.86	€50.44	€49.94	€52.78	€51.76	€51.33	€50.77	€53.68
3*	17.6%	€37.52	€36.42	€35.39	€37.74	€38.14	€37.02	€35.92	€38.35	€32.15	€31.21	€30.30	€33.17	€33.37	€32.42	€31.42	€34.38
2090																	
5*	48.0%	€101.70	€101.47	€101.27	€103.24	€102.01	€101.77	€101.57	€103.62	€96.45	€96.41	€96.29	€98.67	€97.05	€97.01	€96.88	€99.37
4*	51.0%	€57.87	€57.78	€57.58	€59.16	€58.14	€58.05	€57.84	€59.50	€52.84	€52.88	€52.76	€54.67	€53.37	€53.40	€53.28	€55.29
3*	42.6%	€39.61	€39.39	€39.06	€40.47	€39.91	€39.68	€39.35	€40.84	€34.67	€34.57	€34.31	€36.02	€35.26	€35.15	€34.88	€36.69
Occupancy reduction 5%																	
5*	43.0%	€101.30	€100.97	€100.73	€102.85	€101.65	€101.31	€101.06	€103.28	€95.97	€95.84	€95.68	€98.25	€96.64	€96.51	€96.33	€99.02
4*	46.0%	€57.59	€57.46	€57.21	€58.89	€57.89	€57.76	€57.50	€59.26	€52.51	€52.51	€52.34	€54.38	€53.10	€53.09	€52.91	€55.06
3*	37.6%	€39.34	€39.05	€38.65	€40.16	€39.68	€39.38	€38.98	€40.58	€34.35	€34.18	€33.86	€35.69	€35.01	€34.83	€34.50	€36.45
Occupancy reduction 15%																	
5*	33.0%	€100.13	€99.52	€99.14	€101.71	€100.58	€99.96	€99.57	€102.27	€94.57	€94.18	€93.90	€97.00	€95.44	€95.05	€94.75	€98.01
4*	36.0%	€56.80	€56.54	€56.15	€58.13	€57.19	€56.92	€56.52	€58.61	€51.56	€51.45	€51.15	€53.55	€52.31	€52.19	€51.88	€54.42
3*	27.6%	€38.51	€37.99	€37.39	€39.20	€38.97	€38.45	€37.83	€39.78	€33.35	€32.98	€32.46	€34.67	€34.25	€33.87	€33.33	€35.70
Occupancy reduction 25%																	
5*	23.0%	€97.94	€96.80	€96.17	€99.57	€98.59	€97.44	€96.79	€100.38	€91.95	€91.09	€90.57	€94.67	€93.21	€92.33	€91.79	€96.12
4*	26.0%	€55.40	€54.92	€54.28	€56.78	€55.93	€55.44	€54.79	€57.45	€49.88	€49.58	€49.05	€52.08	€50.92	€50.61	€50.06	€53.28
3*	17.6%	€36.73	€35.73	€34.68	€37.17	€37.46	€36.45	€35.37	€38.07	€31.22	€30.42	€29.47	€32.48	€32.63	€31.81	€30.84	€34.11

Table A-X.7 Room income per guest night from package holidays with a 10.71% price increase after investment and space conditioning energy costs – Part 2 of 2