

EMISSIONS REDUCTIONS IN HOTELS IN 2030

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ABSTRACT

Detailed simulations of two hotels have been carried out, to determine whether CO₂ emissions can be reduced by 50%. The hotels, one older and converted and the other newer and purpose-built, were chosen to represent the most common UK hotel types.

The effects were studied of interventions expected to be available in 2030 including fabric improvements, HVAC changes, lighting and appliance improvements and renewable energy generation. The main finding was that it is technically feasible to reduce emissions by 50% without compromising guest comfort. Ranking of the interventions was problematical for several reasons including interdependence and the impacts on boiler sizing of large reductions in the heating load.

INTRODUCTION

The reality of climate change is now widely accepted, along with the likelihood that the cause is carbon dioxide emissions due to human activity. The primary need is for reductions in carbon dioxide emissions connected with fossil fuel combustion. Following the RCEP report (2000), the UK government put into law a 60% reduction in emissions by 2050 and has since increased the figure to 80%.



Figure 1. Newer hotel

It is estimated that buildings account for 47% of UK carbon dioxide emissions (Carbon Trust 2005). As a result, a great deal of attention has been directed at this sector, and the UK government has pledged to make all new buildings carbon-neutral: residential by

2016 and the remainder by 2019. However, in the period during which drastic emissions reductions will need to be made, the great majority of buildings will be ones that exist now.

The TARBASE (Technology Assessment for Radically Improving the Built Asset baSE) project was conceived to study ways in which emissions from existing buildings can be reduced. It has looked at a wide spectrum of both domestic and non-domestic buildings with a view to identifying ways of achieving cuts in emissions of at least 50%. The types of intervention considered included changes in building fabric and HVAC, improved efficiency of lighting and appliances and renewable energy generation.

The present work addresses hotels. They were selected because, among non-domestic buildings, they belong to one of the highest emitting sectors (BRE 2002b). Reasons for the high emissions are likely to include the desire of hotel management to ensure guest comfort and the expectations of guests for a luxury experience with none of the pressures for energy-efficient behaviour that they might experience elsewhere. The area is therefore a challenging one in which to address emission reductions, and in recognition of the constraints on hotels a principle was adopted that interventions should not compromise guest comfort: almost all of the proposed measures will be invisible to guests.

The approach adopted has been to design and to study the behaviour of exemplars: models of non-existent but representative buildings. The building is first modelled as accurately as possible for the year 2005. It is then modelled for the year 2030, using an appropriate climate, with a range of emission-reducing interventions deemed to have been carried out in the intervening period. In some cases this requires assumptions about the technologies that will be available then.

It is important to note that the present work deals with technical feasibility. Economics is not specifically considered, although cost-effectiveness (by current standards) has had an impact on the inclusion and ordering of some interventions.

SIMULATION

Hotel selection

Project resources allowed for two hotel variants to be studied. They were selected by analysing data on hotels in the UK by broad category and selecting the two most common types. Those selected are broadly representative of 67% of hotels in the UK.

The most common type was a business park (“newer”) hotel, deemed to have been purpose-built in 1986 to the construction standards in force then. This means that it has loft insulation, double glazing and some wall insulation. It has 126 bedrooms and, since it caters to the business community in particular, it also has conference facilities. A sketch of the hotel is shown in Fig. 1.

The other (“older”) hotel is a converted city-centre building of pre-1900 construction. It has solid walls and single glazing and contains 88 bedrooms. A sketch is shown in Fig. 2.



Figure 2. Older hotel

The hotels were assumed to offer similar facilities, with each having a bar, restaurant and laundry. Both had en suite guest rooms containing the usual facilities offered in mid-price hotels such as minibars and hairdryers. In addition, the newer hotel had a conference room. Other features common to both hotels were a kitchen and lifts to all floors. Since the hotels are mid-price rather than luxury standard and operating in the UK, it was assumed that there was no mechanical cooling.

Advice was obtained from an engineering consultancy on the expected types of HVAC equipment.

Organization of work

The building simulation was carried out using ESP-r. Timesteps of 1 hour were used and simulations were performed for the whole of a year, either 2005 or 2030.

The basic ingredients required for a simulation are:

- a building structure with specified materials for the bounding surfaces (walls, glazing, doors)

- details of the sources of “casual gains”: heat from occupants, appliances and lighting
- air flow rates due to infiltration and ventilation
- climate data, especially outside air temperature.

Heating systems can be represented in a variety of ways. In the present work, set point temperatures were defined for all heated zones and the energy required to achieve the set points was an output from the program. This was then post-processed to produce realistic heating loads by dividing by appropriate seasonal efficiencies. Cooling set points were also defined, but no cooling load was calculated. The assumption was made that adequate cooling would be provided by natural ventilation.

The nature of both the simulation task and the software meant that it was natural to organize the modelling in two parts: physical models, and casual gains & airflow. Physical models were set up of the building structures needed for representing planned interventions. Casual gains and air flow data were then included by the methods described below.

In order to capture the thermal behaviour of the different spaces in the hotels (e.g. kitchens, laundry, conference room, bedrooms, circulation areas) it was necessary to use a relatively large number of zones: 21 in the older hotel and 29 in the newer. Taken with the large number of changes required in the casual gains and air flow data for the different cases being modelled, entering the data became a task requiring significant time and concentration and, consequently, one in which the risk of error was high.

To avoid these difficulties, software was specially written to create the files used by ESP-r for transferring casual gains and air flow data to the simulation engine. The details of the software are described elsewhere (Taylor 2009).

Ventilation heat recovery was modelled by reducing the ventilation air flow rate by the fraction specified for heat recovery, which was 70% in the standard case. There is insufficient space to include a proof of the validity of this approach here, and it will be included in a forthcoming publication.

The main output of the simulations consisted of the annual heating load for each of the zones in the model. This was post-processed to determine consumption of electricity and gas. 100% efficiency was assumed for electric heating, while seasonal efficiencies of 75% and 90% respectively were assumed for the conventional and condensing gas boilers. Carbon dioxide emissions were then obtained by multiplying by Defra (2008) emissions factors. In particular, the long-term marginal factor of 0.43 kg CO₂/kWh for grid electricity was used (Peacock et al 2008). The Defra value of 0.185 kg CO₂/kWh (based on gross CV) was used for natural gas. The difference is more than a factor of two, explaining the major emissions reductions available by switching from electricity to gas.

The other output was the total electricity and gas consumption by different equipment, which was used for calculating the share of the emissions.

Base conditions

The base conditions for both hotels included the use of a 2005 climate for Birmingham (UK) which was taken from the 1995 IWEC weather file.

Building structures used in the modelling work were drawn from CIBSE Guide A (2006). The newer hotel had walls of brick and block construction with an insulated cavity, along with double-glazed windows and a well-insulated roof space. The assumption was made that any “quick wins” such as loft insulation would have been taken already by 2005. The older hotel had solid walls of 220 mm thickness with single-glazed windows and limited roof insulation because the roof is immediately above the top floor.

In order to provide a representative range of results, the newer hotel was assumed to be electrically heated (a common arrangement in such buildings according to the engineering consultancy engaged to provide advice) and the older one to use a conventional gas boiler.

Two electric passenger lifts were used in the newer hotel and one in the older one, while both had a single service lift. Commercial vacuum cleaners were used in both 2005 and 2030.

Modelling was carried out with different levels of occupancy, and it was found that there was a significant effect on the results. Since the aim was to determine the results for average conditions, maximum occupancy was not appropriate and an average was determined using the UK Occupancy Report (2004), with staffing estimated using Lockyer and Scholarios (2004). However, decreasing the occupancy to average with no other changes would also be unrealistic because effective management would reduce costs by closing off certain rooms, using zonal controls to leave them unheated and minimally ventilated. A set of rooms that would be closed off was therefore defined for each hotel, and all the modelling results presented used this arrangement.

Casual gains appropriate to the various types of hotel equipment were included. Catering equipment in the kitchen included gas ovens, electric ovens, fryers, hobs and refrigeration. Professional washing machines in the laundry used hot water from the hotel’s domestic hot water system.

The bedrooms contained the type of equipment normally available in mid-price hotels: a television, a minibar, hairdryer, shaving socket and trouser press.

In the absence of detailed information on guest behaviour with respect to appliance and mobile equipment use, available data (McAllister and Farrell 2007, MacKay 2008) was supplemented with reasonable assumptions about the use of televisions, hairdryers and kettles and of power sockets for using

laptops and charging mobile equipment. The overall impact was checked at the validation stage (described below) and tested using sensitivity analysis.

Lighting and ventilation levels for 2005 were set to those recommended at the time (CIBSE 1999, 2001), while the most recent recommendations (CIBSE 2006) were used for 2030. Lighting was assumed to be mainly compact fluorescent lamps (CFLs) in 2005. As in the case of loft insulation, it was assumed that the hotel management would be sufficiently aware of the cost benefits to have introduced them before that date. However, incandescent lamps were retained as mood lighting in the restaurant to ensure the guest experience was not compromised.

In order to be realistic, the modelling required both infiltration and ventilation to be modelled. Since both are derived in the present case from external air, the ESP-r “infiltration” function was used because it allows a stated flow rate of external air into the zone of interest. Infiltration was based on data in CIBSE (1999). The values were determined for all zones and then any further variations, such as the reduction resulting from the insulation intervention, were accomplished by multiplying all values by a given factor.

It was assumed that mechanical ventilation was used in both hotels. The ventilation was assumed to be to the standards described in CIBSE (1999) for 2005 and CIBSE (2006) for 2030. Ventilation rates were set so as to achieve recommended air flows when combined with any pre-existing infiltration. In some cases, in the circulation areas for example, this meant that no ventilation was needed because infiltration exceeded the recommended fresh air flow rate.

Occupancy gains were provided by data from CIBSE (2006). Base case energy consumption for appliances and lifts was mainly provided by data from the same source, supplemented by manufacturers’ data where necessary.

Validation

In order to validate the modelling, the base case results were compared with data from a survey of over 50 UK hotels (BRECSU 1993). The survey shows that most hotels surveyed used gas for heating, and the detailed comparisons are therefore made with the older hotel of the present work which used gas.

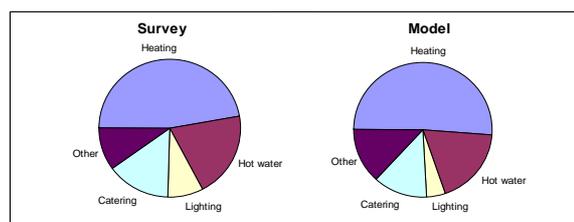


Figure 3. Comparison of proportions of energy use in model with survey

Figure 3 compares the proportions of energy consumed under a range of headings with those in the survey sample.

The main difference is in the lighting, where the modelled value is roughly half of that in the survey. The reason is the use in the model of low-energy compact fluorescent lamps, a type which was little used at the time of the survey (assumed to be the early 1990s). Given the spread in values within the survey, the agreement is good and suggests that the model predictions are in line with measured values.

Interventions

The interventions considered were ventilation heat recovery; wall insulation and triple glazing (considered as a single package); installation of a condensing boiler; efficiency improvements in lighting and equipment; and solar thermal heating of hot water.

However, before any of these interventions was applied, a 2030 climate for Birmingham was imposed. It was done at this stage to provide the appropriate background for the subsequent changes. It was created by Jenkins et al (2008) by applying the algorithm of Belcher et al (2005).

The first of the interventions proper was ventilation heat recovery. Considerable amounts of heat are used for warming cool air that enters buildings, either intentionally as ventilation or unintentionally as infiltration. By transferring heat from exhaust to fresh air, large energy savings can be made. The most effective method is a thermal wheel, which can reliably recover 75% of the available heat, though in the present work a value of 70% has been assumed. Thermal wheels can also help preserve “coolth” in the summer when it is hotter outside than in, and this effect is captured by the present modelling. Allowance was made for the associated energy consumption.

The next intervention was a package of insulation and glazing measures. 100 mm of external wall insulation was applied externally to the newer hotel and 50 mm internally to the older building. Argon-filled triple glazing replaced double glazing in the newer building and single glazing in the older one. An additional consequence of making such changes is a reduction in infiltration. A reduction of 50% was assumed for both cases. No further loft insulation was used. Physical limitations prevented it in the older hotel, while tests showed that further enhancement of the loft insulation in the newer hotel had negligible effect.

A power & lighting intervention consisted of efficiency improvements in lighting, electrical appliances and kitchen catering equipment, both electric and gas-powered. All lighting was assumed to be by LED or an equivalent low-power source. Luminous intensities followed those used in other TARBASE work (Jenkins et al 2008). Tumble dryers

were switched from electric to gas powered to improve emissions performance. Predicted appliance efficiency improvements drew on data from EU projects on energy-using appliances for refrigeration, dishwashers and washing machines (MTP 2008) and catering equipment (Lane 2000). Further catering data came from Deru et al (2003), CEEP (2005) and Fisher (2007). Improvements in lift efficiencies were estimated using CIBSE (2006). No specific data could be obtained for the vacuum cleaners used by the cleaning staff and an overall 10% improvement was assumed.

A switch from electric or conventional gas heating to the use of a gas condensing boiler was made next. To maintain simplicity, a fixed seasonal efficiency of 90% was assumed. Part-load calculations would be needed for a more accurate view, and their use is discussed later.

Finally, water heating using solar thermal collectors was applied. A simple approach based on the BREDEM-12 model (BRE 2002a) was used, with the key parameter being the area of panels available. For the older city centre hotel it was assumed that ¾ of the flat roof space was available for the panels, with the further assumption that each 1 m width of panel required 1.5 m of roof space. For the newer business park hotel in its default north-south orientation, there was very little suitable roof area available. The assumption was made that part of the car park could be used by mounting the panels on a canopy which would also provided sheltered parking.

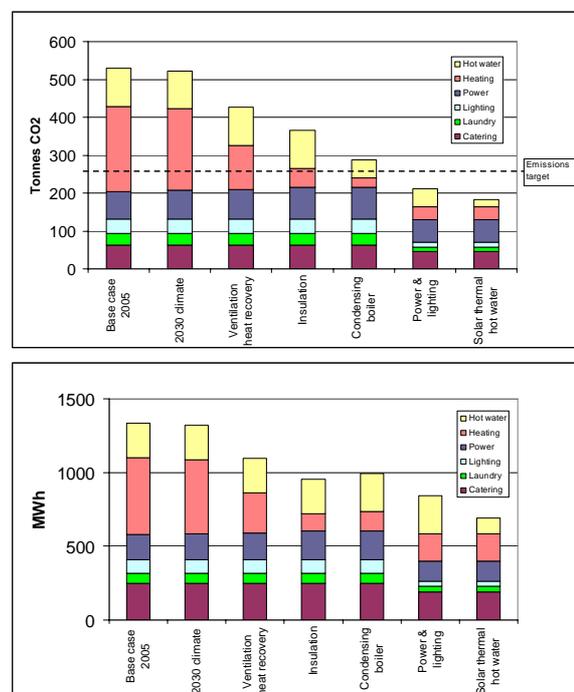


Figure 4. Effect of interventions on newer hotel. (a) annual CO2 emissions. (b) annual energy consumption

RESULTS

Effect of interventions

Figures 4 and 5 show the effect of the interventions on both carbon dioxide emissions and energy consumption of the two hotels.

The effect of the switch to the 2030 climate was fairly small, and masked to some extent by a simultaneous increase in ventilation rates in response to new recommendations in 2006. The effect was to reduce energy use for heating by about 5%, with a corresponding decrease in emissions. Without the change in ventilation, the reduction in heating energy use would have been about 12%. If mechanical cooling had been included, there would have been a corresponding increase in emissions due to the extra cooling required in the warmer climate.

Each of the interventions led to a significant reduction in emissions except for the installation of a condensing boiler in the older hotel. The unit being replaced was a conventional gas boiler, so the improvement was due to a relatively small change in efficiency.

The insulation package consisted of three separate effects: the addition of wall insulation (external in the new hotel, internal in the old), upgrading to Ar-filled triple glazing, and reduction in infiltration as a consequence of these changes. An analysis of the detailed results showed that in both hotels the infiltration reduction provided the biggest benefit.

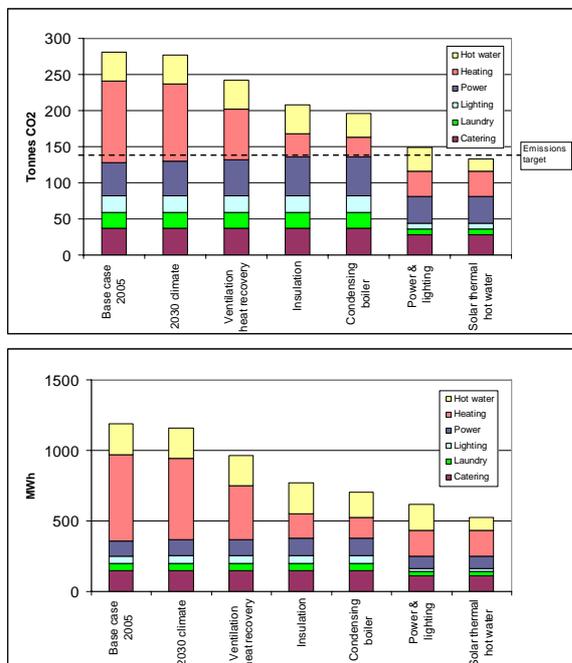


Figure 5. Effect of interventions on older hotel. (a) annual CO₂ emissions. (b) annual energy consumption

Change in intervention order

Overall, emissions reductions of more than 50% were achieved for both hotels, although fewer interventions were needed in the newer electrically-heated one where the switch to gas heating provided a significant emissions saving.

The interventions described were carried out in a specific order which was a compromise taking into account cost, practical advantages and immediate demonstration of benefits. This last point is considered further here. It turned out that in some alternative orderings the full benefit of an intervention was not realized until a subsequent intervention had been applied.

In Fig. 4, the “power & lighting” (P & L) intervention, in which very low energy lighting is installed along with higher efficiency appliances, was made after the switch to a condensing boiler in the electrically heated newer hotel. The corresponding annual emissions reduction was 75.8 tonnes CO₂. However, if the P & L intervention is applied *before* the condensing boiler, the modelling shows that the reduction is lower at 64.2 tonnes CO₂. Since the net result of two interventions must be the same whatever the order, this implies that the “missing” 11.5 tonnes CO₂ must be delivered with the condensing boiler installation.

Sensitivity analysis

Sensitivity analysis was used to check the reliability of the results by highlighting where they depend strongly on input data. Most of the areas selected for investigation were those for which the values used were relatively uncertain. For example, the level assumed for usage of laptop computers and charging of mobile phones and other portable electronic devices in 2030, though based on literature values, is unlikely to be accurate because future trends in such usage are difficult to predict. So in this case, the impact on the results of doubling the assumed usage has been calculated. The results are shown in Fig. 6 along with results for some other input data of interest.

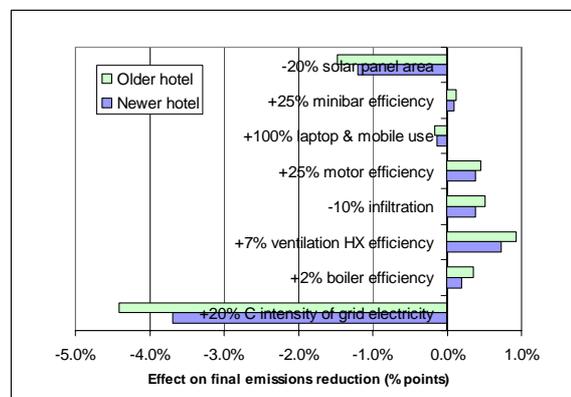


Figure 6. Sensitivity of annual emissions to possible changes in input values

The most significant result is the effect of an increase in grid carbon intensity of 20%, which would represent an increased proportion of coal-powered generation. The change in the emissions reduction for the older hotel is enough to prevent the target of 50% reductions being achieved. Further calculation shows that the increase in carbon intensity that causes the emissions reduction to just fail to reach 50% is 15%.

The effect of different grid carbon intensities is shown in Fig. 7 for the whole set of interventions for the newer hotel. A point that comes out clearly is that the sensitivity to carbon intensity decreases with the number of interventions.

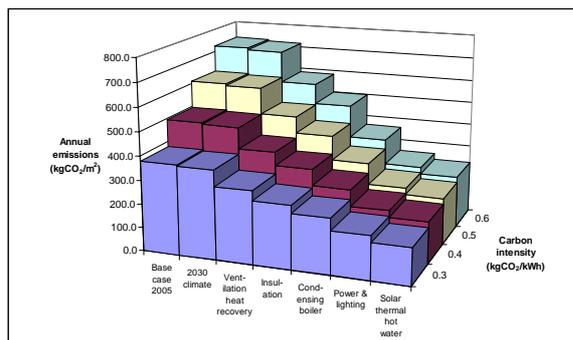


Figure 7. Effect of carbon intensity of grid electricity on emissions from newer hotel

Remaining emissions contributions

The proportions of remaining emissions after all interventions have been applied to the two hotels are shown in Fig. 8. Electricity is responsible for around half of the remaining emissions (slightly less for the older hotel and slightly more for the newer one).

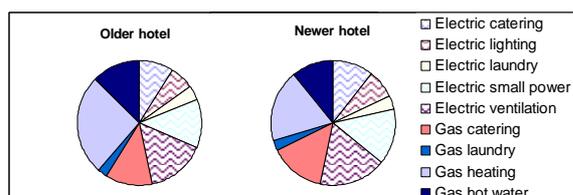


Figure 8. Contributions to remaining emissions

DISCUSSION

Effect of interventions

The decrease in heating energy consumption resulting from the change to a 2030 climate was smaller than might have been expected because of the simultaneous increase in ventilation rates. If the ventilation was left unchanged, the heating energy reduction was consistent with the decrease in degree days between 2005 and 2030.

The combined effect of all of the interventions was greater in the newer hotel than the older. The 50% reduction target was achieved comfortably, without the need for the power & lighting or solar thermal interventions. The main reason for this was that

initially the hotel was electrically heated, so a major emissions reduction was achieved by simply switching to a gas condensing boiler.

By contrast, the older hotel only just achieved a 50% reduction in emissions. Since it was already heated by gas, the emissions improvement from switching to a condensing boiler was relatively small. The limited roof area also reduced the scope for the solar thermal intervention.

The main contributor to the overall effect of the insulation package was not the improved wall insulation or glazing but the reduced infiltration. This finding should be considered as indicative rather than conclusive since it relies on estimates of both the infiltration in the building and its reduction due to the insulation and glazing changes. In reality, the level of infiltration in different buildings is likely to vary widely, but the finding does indicate the importance of reducing infiltration.

Other renewable technologies than solar thermal could feasibly be used in the hotels to reduce emissions further. In particular, since about half of the remaining emissions come from electricity usage as shown in Fig. 8, renewable electricity generation by solar photovoltaic or wind generation could be considered for suitable sites where space permitted.

Reliability of results

The sensitivity analysis presented in Figs. 6 and 7 suggests that the most important threat to the 50% reduction target would be an increase in the carbon intensity of grid electricity. The likely figure in 2030 is difficult to predict. Current trends suggest an increase due to greater use of coal generation. However, the planned increase in renewables, to which the UK government is committed, suggests the carbon intensity could go down in the longer term.

The reduction in the sensitivity of the results to the carbon intensity shown by the changing “front-to-back” slope in Fig. 7 is a simple consequence of the reduction in the use of grid electricity. Further reductions in both emissions and sensitivity would come from the adoption of additional renewable generation technologies as described earlier.

Another way of assessing the reliability of the results is to consider the practicality of the measures considered. The issue here is not economics, which is not addressed in this paper, but feasibility in the context of a hotel. Most of the interventions proposed are fairly mainstream, with examples already implemented in a wide range of buildings. Importantly, none would inconvenience guests, and most would be invisible.

An intervention that would not be invisible is solar thermal water heating in the newer hotel. Given the unsuitable orientation of the roof, the surface selected for installation of the panels was a new roof over the car park. This would have the benefit of providing shelter and would therefore potentially be seen as an

enhancement to guests' comfort, besides the potential selling point that use of renewable generation equipment might present in the future when awareness of its value becomes more widespread. In any case, the newer hotel still achieves close to a 60% emissions reduction without the solar thermal intervention.

Interdependence of interventions

The primary aim of the present work is to determine whether a halving of emissions is technically possible. The implied assumption is that all desired interventions are carried out in one operation, so that the question of ordering does not arise. In reality, however, this would not be the case. It takes time to complete major projects, and budgets are unlikely to cover the full set of proposed interventions. The issue that then needs to be addressed is the order in which the interventions should be carried out.

Subject to reasonable restrictions (e.g. that the timescales for any works are short), there are two main options for the guiding principle: at any stage in the process, the next intervention should provide either the maximum emissions reduction or the best value (maximum emissions reduction per unit cost). In principle, the latter approach could be represented in an emissions abatement curve (e.g. Toke and Taylor 2007) for the building in question.

However, this assumes that the effect of each intervention is independent of the stage at which it is implemented. In reality this is not the case. It is clear, for example, that an intervention that changes the emissions per unit heat demand, such as a change in the efficiency of a boiler, will have different effects on emissions depending upon whether it is implemented before or after an intervention that reduces the heating load, such as insulation.

But there are further effects. The clearest example uncovered in the present work is shown by the differences in emissions reduction attributable to the power & lighting (P & L) and the condensing boiler interventions when they were implemented in different orders. The P & L intervention is more effective when applied after the condensing boiler is fitted. The reason is straightforward. The improvement in electrical equipment efficiency due to the intervention reduces the casual gain. So during the winter period, the equipment contributes less to the heating of the building, and the heating system needs to do more as a result. When the heating is by electricity, this means that nothing has changed since electricity is still doing the heating. The P & L intervention only provides a benefit in the summer when the heating is not working. But when heating is by gas, part of the heating load is transferred from (effectively) electric to gas heating, resulting in a noticeable emissions reduction.

Another implication of carrying out interventions over an extended period relates to the details of heating equipment operation. The above discussion

and related arguments suggest that changing the heating system to one based on a condensing boiler should happen early. However, the other interventions will have a significant impact on the heating energy requirement, as shown in Figs. 3(b) and 4(b). This means that a boiler that is correctly sized for the initial stages will be significantly oversized later in the process, with impacts on efficiency (since it will be operating on part load all the time) and total costs. On the other hand, delaying the installation until near the end (as in the reported modelling) means delaying readily available emissions reductions.

The main implication of the above discussion is that the interactions of interventions, emissions and economics are complex and probably situation-specific. It may be that a consultancy service is required to deal with individual cases.

Future work

Economics plays no real role in the work described, the aim of which has been to investigate the technical feasibility of emissions reductions in hotels. A future task might be to assess the economics of the measures described. However, the discussion of order dependence suggests that this might not be straightforward. In particular, it appears that a simple emissions abatement curve may not be possible.

However, a more sophisticated approach may allow such a curve to be generated, perhaps by working with average emissions reductions, or by modelling the approaches in sufficient detail to capture the order dependence. In any case, an injection of economics is still needed for budgeting and deciding on the measures that would be included in a package. This might allow the definition of generic protocols for emissions reduction measures, but the above discussion implies that significant individual tailoring might be needed.

Further modelling with explicit consideration of the part-load performance would help to resolve the issue of when the boiler should be fitted.

CONCLUSIONS

- 50% reductions in carbon dioxide emissions from hotels are technically feasible
- However, an increase in the carbon intensity of the electricity grid of 15% would prevent the achievement of the target in the older hotel
- The main contributor to the emissions reduction of the insulation package was the infiltration reduction associated with the installation of the wall insulation and triple glazing
- Interactions between the different interventions mean that any package of measures must be carefully planned
- Further emissions reductions are possible using renewable energy technologies.

Acknowledgments

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REFERENCES

- BRE 2002a. BREDEM-12 Model Description: 2001 Update. BR 438. Building Research Establishment 2002.
- Belcher, S.E., Hacker, J.N. and Powell, D.S. 2005. Constructing design weather data for future climates, *Building Services Engineering Research and Technology* 26 (1) 49-61.
- BRE 2002b. Carbon dioxide emissions from non-domestic buildings: 2000 and beyond. BR 442, Building Research Establishment 2002.
- BRECSU 1993. Energy Efficiency in Hotels – A Guide for Owners and Managers. Energy Consumption Guide 36, BRECSU.
- CEEP 2005. Developing Statewide Commercial Foodservice Appliance Rebates, California Energy Efficiency Program, February 23, 2005.
- Carbon Trust 2005. Reducing the carbon footprint for non-domestic buildings: a priority for the Carbon Trust. Presentation by David Vincent, Carbon Trust Technology Director. September 14, 2005.
- CIBSE 1999. Guide A: Environmental Design, Chartered Institution of Building Services Engineers, London, October 1999.
- CIBSE 2001. Guide B2: Ventilation and Air Conditioning, Chartered Institution of Building Services Engineers, London, 2001.
- CIBSE 2006. Guide A: Environmental Design, Chartered Institution of Building Services Engineers, London, January 2006.
- Defra 2008. Guidelines to Defra's Greenhouse Gas Conversion Factors for Company Reporting. <http://www.defra.gov.uk/environment/business/envrp/conversion-factors.htm> (Accessed Jan 2009)
- Deru, M., Torcellini, P., Bottom, K. and Ault, R. 2003. Analysis of NREL Cold-Drink Vending Machines for Energy Savings. National Renewable Energy Laboratory Golden, Colorado, USA, June 2003. <http://www.nrel.gov/docs/fy03osti/34008.pdf> (Accessed Jan 2009).
- Fisher, D. 2007. Is There Energy Star Light in your Kitchen? *Hotel F&B* September/October 2007. <http://www.hotelfandb.com/biol/sept-oct2007-energy-star-equipment.asp> (Accessed Jan 2009)
- Jenkins, D., Liu, Y. and Peacock, A.D. 2008. Climatic and internal factors affecting future UK office heating and cooling energy consumptions. *Energy and Buildings* 40, 874-881.
- Lane, K. 2000. Labelling domestic ovens (Save study 4.1031/D/97-047). 2nd International Conference on Energy Efficiency in Household Appliances and Lighting, Naples, Italy, 27-29 September, 2000.
- Lockyer, C. and Scholarios, D. 2004. *International Journal of Contemporary Hospitality Management* 16, 125-135.
- MacKay, D.J.C. 2008. Sustainable Energy – without the hot air. UIT Cambridge, 2008. www.withouthotair.com (Accessed Jan 2009)
- McAllister, J.A. and Farrell A.E. 2007. Electricity consumption by battery-powered consumer electronics: A household-level survey. *Energy* 32, 1177-1184.
- MTP 2008. Framework Directive for the Eco-design of Energy Using Products (EuP). Market Transformation Programme. <http://www.mtprog.com/cms/eup/> (Accessed Jan 2009)
- Peacock, A., Banfill, P.F., Turan, S., Jenkins, D., Ahadzi, M., Bowles, G., Kane, D., Newborough, M., Eames, P.C., Singh, H., Jackson, T. and Berry, A. 2008. Reducing CO2 emissions through refurbishment of non-domestic UK buildings, Improving Energy Efficiency in Commercial Buildings (IEECB) Conference, 10 - 11 April 2008.
- RCEP 2000. Energy – The Changing Climate, Royal Commission on Environmental Pollution, June 2000.
- Taylor, S.C. 2009. More efficient ESP-r modelling by automatic generation of input files. *Building Simulation 2009*, Glasgow.
- Toke, D. and Taylor, S.C. 2007. Demand Reduction in the UK – Some Selected Measures and Policy Mechanisms, *Energy Policy* 35, 2131-2140.
- UK Occupancy Survey 2004. UK Occupancy Survey for Serviced Accommodation: Summary Report 2004. British Tourist Authority, Northern Ireland Tourist Board, VisitScotland and Wales Tourist Board.