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Energy Efficiency and Thermal Comfort in Hospital Buildings: A Review

Anwer A. Gatea[1*], Mohd Faizal Mohideen Batcha[1], Juntakan Taweekun[2]

[1]Center for Energy & Industrial Environment Studies,
Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, Johor, MALAYSIA

[2]Department of Mechanical Engineering, Faculty of Engineering,
Prince of Songkla University, Songkhla, 90110, THAILAND

*Corresponding Author

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Abstract: This paper aims to review the state-of-the-art technologies for the energy efficiency within the hospitals sector. Hospitals are liable for an unstable amount of energy demand and joint emissions, because of their 24/7 nature of operation and hence resulting larger energy consumption than a typical commercial building. Additionally, they need high quality and warranted supplies of electricity. Due to increased energy demand and therefore the depletion of existing fossil fuel-based sources, it is required to use the energy more efficient. Researchers found that hospitals represent close to 6% of total energy consumption within the utility buildings sector. Heating, Ventilation and air-conditioner (HVAC) systems are the most important a part of electricity consumption at hospitals. Apart from effective energy management system, hospitals also require energy efficiency efforts and also incorporation with renewable energy if it's economically feasible. Apart from that, it is necessary to correlate the thermal comfort in hospitals to ensure the well-being of patients as well as optimum productivity of hospital workers. This paper reviews the energy efficiency efforts and their relation to thermal comfort in hospital buildings, to seek further research gaps for further works in this area.

Keywords: Energy efficient, hospital, thermal comfort

1. Introduction

The world's global dependence on energy has been increasing at a terrible rate. In line with the International Energy Agency (IEA), from 1971 to 2014, worldwide energy consumption raised by 92%. Energy contributes to any or all socio-economic development indicators that enhance lifestyles the globe over. However, energy production and consumption are liable for an outsized environmental footprint through GHG emissions (Subramanyam, Paramshivan, Kumar, & Mondal, 2015). The commercial and institutional sector is one in five socio-economic sectors. The sector consumes energy for the most part through building heating and cooling, lighting, water heating, auxiliary operational instrumentation, and auxiliary drive motors. The building sector has contributed to an outsized portion of this increase. In fact, in 2009, the United Nations Environment Program (UNEP) attributed more than 30% of worldwide greenhouse emission emissions and 40% of total energy consumption to the building sector (United Nations Environment Programme, 2009). The international community has taken definitive steps in an effort to curtail these global trends. The biggest economies in the US, the ECU Union, and China have carried out measures that are in particular noteworthy.

The building sector remains one of the biggest energy consumers with over 40% of ultimate energy consumption within the European community (Bellia et al., 2010) and represents clearly a key sector relating to energy savings and decarbonisation opportunities. Indeed, additionally to the energy potency measures, the European Commission

*Corresponding author: mfaizal@uthm.edu.my

(COM/2011/885 Energy Roadmap 2050) has outlined strict semi-permanent goals with 80% decarbonisation by 2050 (Zanni, Righi, Dalla Mora, Peron, & Romagnoni, 2015).

Hospitals and healthcare facilities are among the foremost energy-intensive of all commercial buildings (Singer, 2009) and are accountable for a considerable portion of total commercial energy consumption in China. As in most European and North American countries, hospitals have the highest energy consumption per unit floor area within the buildings sector (Balaras, Dascalaki, & Gaglia, 2007). The continuous use of heating and cooling equipment, so as to maintain satisfactory thermal comfort and indoor air quality levels for the staffs and patients as well as the use of artificial lighting on a continuous basis in several sections and the use of medical devices, result in comparatively higher energy consumption compared with other types of buildings (Santamouris, Dascalaki, Balaras, Argiriou, & Gaglia, 1994).

Saving energy and reducing energy cost includes one of the foremost necessary challenges thought of by the majority of building designers, engineers and decision makers. Hospitals have a special standing in particular because of their twenty-four hours of operation, year round (Azizpour et al., 2011). Additionally, hospitals consume high levels of energy through lighting, air-conditioning systems, medical instrumentation, general workplace instrumentation, lifts, heating and ventilation. Thus, the high-energy costs and soaring electricity consumption at hospitals ought to cause management creating a goal of decreasing the energy cost (Moghimi, Lim, Mat, Zaharim, & Sopian, 2011).

2. Literature Review and Contributions

Several strategies dedicated to reducing carbon dioxide emissions are developed by governments worldwide since the signing of Kyoto Protocol (Communities, 2009). To meet the worldwide energy consumption demand, it's better to look towards renewable power generation (Reddy & Reddy, 2019). In this sense, specific programs wide have promoted the employment of renewable energies at final stages of consumption moreover as the reduction of carbon dioxide emissions each in energy production processes and in actions involving the development of energy efficiency (Murray, Pahl, & Burek, 2008). Kapoor and Kumar (Kappor & Kumar, 2011) specified HVAC systems to point out the highest energy consumption rates in hospitals, followed by lightning systems (30–65% and 30–40%, respectively). Balaras et al. have noted that thermal comfort as a parameter of indoor air quality in operation rooms affects the operating conditions, well-being, safety and health of the medical personnel who add these environments. They have indicated that the desirable indoor air temperature is 20–24 °C according to international standards, but use of lower or higher temperature is agreeable when patient comfort and/or medical conditions require those situation and the recommended levels of indoor relative humidity are 30–60% (Balaras et al., 2007).

Fasiuddin and Budaiwi (Fasiuddin & Budaiwi, 2011) found that energy savings up to 30% might be obtained whereas maintaining an acceptable level of thermal comfort once HVAC systems were properly chosen and operated. Vakiloroaya et al. (Vakiloroava, Su, & Ha, 2011) discussed the influence of integrated management of shading blinds and natural ventilation on HVAC system performance in terms of energy savings and thermal comfort. Klein (Klein et al., 2012) decrease energy consumption by raising the number of sensors and computational support of the Energy management control Systems (EMCS). Many of case studies can be found within the global literature proving the significant effort performed in the decrease of the energy consumption in the hospitals' sector.

Thirty-three hospitals and clinics in Greece were audited. Based on the energy audit information, varied simulation models were developed so as to evaluate the varied energy efficiency scenarios. Up to twenty per cent, energy efficiency may be achieved by high-efficiency lamps and heating and cooling system maintenance. Cooling loads may be reduced by applying outside shading devices and night ventilation for up to six air changes per hour (Santamouris et al., 1994).

A hospital in Ferrara, Italy was studied by Bizzarri and Morini (Bizzarri & Morini, 2004). The authors studied the effect of fuel cells (FCs) in the reduction of electricity needs and compared the results with the hospital's current conditions. Their analysis showed that FCs can cover up to 86 per cent of hospital electricity needs with annual energy savings of up to 4.925MWh. Moreover, in the same hospital, Bizzarri and Morini (Bizzarri & Morini, 2006) studied the contribution of solar thermal systems and PVs in the reduction of the hospital's energy consumption. Although the use of solar thermal systems can reduce significantly greenhouse gas emissions during the summer period. Renedo (Renedo, Ortiz, Mañana, Silio, & Perez, 2006) studied different cogeneration alternatives for a Spanish hospital building. The authors proved that the scale of the facility and also the control strategy show a strong influence on the system economy, and found that the foremost important parameter is that the electricity produced. additionally, Sanz-Calcedo (García-Sanz-Calcedo, 2014) reported on the analysis of energy efficiency in healthcare buildings to conclude that the potential to scale back the energy consumption of a healthcare building sized 1000 m2 is 10,801 kWh by making a mean investment of €11,601, so saving €2961/year with 3.92 years average payback time.

Another study was performed for the Roturua Hospital (120 beds, primary healthcare) in New Zealand, that used a doublet geothermal heating system from 1977. Steins and Zarrouk (Steins & Zarrouk, 2012) evaluated the performance of the heating system and therefore the impact on the geothermal reservoir. The system, although in-built 1977, is still operating and fulfilling heat demands in an adequate manner. A part of the heated water may be used to partially cover the electricity demand of the hospital.

2.1 Energy Consumption in Buildings

Driven by the rising population, increasing the economy and a look for improved quality of life, energy consumption has raised and the growth rates are expected to continue, fueling the energy demand further. Raised energy consumption can lead to a lot of greenhouse emission (GHG) emission with serious impacts on the atmosphere (Harish & Kumar, 2016).The higher rate of urbanization with increased floor space for both residential and commercial purposes has imposed enormous pressure on the existing sources of energy. Limited availability of energy the present energy resources and highly transient nature of renewable energy sources have enhanced the significance of energy efficiency and conservation in several sectors.

Energy consumption plays an important role because of the lifeline for all activities being meted out in a building. Energy production and consumption data are essential for energy conservation functions. To raised perceive the issues occurring within the energy sector and to propose effective solutions, it is necessary to analyse wherever and once energy is being consumed by the facilities (Parameshwaran, Kalaiselvam, Harikrishnan, & Elayaperumal, 2012). Management and improvement of building energy consumption demand a full understanding of building performance, that ought to foremost determine energy resources and major end-uses of a building. Energy resources in a building typically refer to electricity, gas and district heating supply. The corresponding major end-uses embrace heating, ventilation and air-conditioning (HVAC) system, hot water, lighting, plug-loads, elevators and auxiliary instrumentation. Figure.1 illustrates a representative classification of building energy use adopted in International Standard ISO 12655:2013 (*INTERNATIONAL STANDARD Presentation of measured energy use*, 2013).

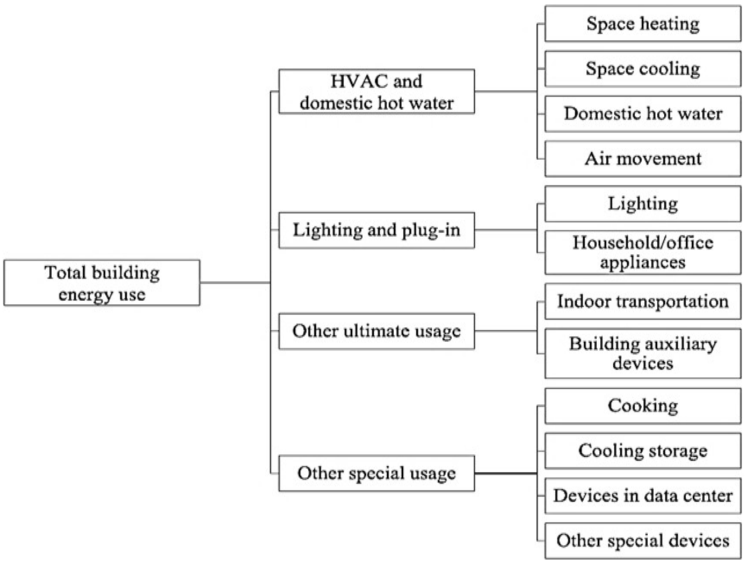

Fig. 1 - The usage of energy in buildings (*INTERNATIONAL STANDARD Presentation of measured energy use*, 2013)

Measurement and observance of energy consumption are important. Chen et al, proposed practical predictions of hospital air-conditioner electricity using the artificial neural network, attributable to its wonderful predictability. The influence variables of hospital air-conditioner electricity are included temperature, relative humidity, the previous 1-hour electricity, the time within the day and a few uncontrolled variables, e.g. the number of surgical operations, the number of persons; and some fix variables. Chen et al. obtained the results that the weekday load model is healthier than whole day model to accumulate the best load prediction of the air-conditioner. Consistent with Chen et al, the results not solely be brought up management the operation of air-conditioner system however conjointly to forecast the hot water production with the heat up system in the hospital (Chen, Shih, & Hu, 2005).

Energy use in buildings for several countries accounting about 41% for U.S (Precci, Oliveira, Altoe, & Correna, 2016), 23% for Spain (Pérez-Lombard, Ortiz, & Pout, 2008), 25% for Japan (*STUDY ON THE ENERGY CONSERVATION PERFORMANCE OF THE AIR-CONDITIONING SYSTEM FOR BUILDING COMBINED A DOUBLE SKIN AND EARTH-TO-AIR HEAT*, 2005), 23% for China (Fridley, Fridley, Zheng, & Zhou, 2008), 39% for the United Kingdom (Pérez-Lombard et al., 2008), 50% for Brazil (Balance, 2014), 47% for Switzerland (Zimmermann, Althaus, & Haas, 2005).U.S and Canada have the heaviest average annual electrical and thermal energy consumption per gross floor space, for typical hospital stock among several countries (Figure 2) (For, Analysis, Of, & Energy, n.d.).

A building usually has multiple zones and there exist heat transfer and balance amongst the zones. Loads in one zone might increase due to the different thermal conditions of neighbouring zones ensuing from occupancy diversity. Many researchers have studied this issue and analyzed occupancy diversity at the building level from the superior management perspective (Oldewurtel, Sturzenegger, & Morari, 2013) with a focus on global controller optimisation, from the occupant classification and segmentation perspective (Gulbinas, Khosrowpour, & Taylor, 2015).

The reduction of hospital energy consumptions may be obtained at different building levels, such as ward/roomand a complete hospital building (Čongradac, Prebiračević, Jorgovanović, & Stanišić, 2012). This will be done by controlling heating and cooling in mere one area or thermal zone (e.g. by adopting sensors that regulate the radiator valves), and by reducing the complete building energy consumption (e.g. by adopting a chiller water temperature management counting on the ambient temperature).

Thermal comfort in a building has a higher priority than energy efficiency in building. Fortunately, when energy efficiency is implemented well in a building, the thermal comfort would be improved as well. Many authors have considered the intense energy consumption issue of the building sector by considering thermal consumption [36–38] and thus, different solutions highlighting bioclimatic architecture strategies (Manzano-Agugliaro, Montoya, Sabio-Ortega, & García-Cruz, 2015) are proposed with great success. Bioclimatic architectural systems have demonstrated that they'll effectively contribute to the reduction of energy consumption whereas considering potential construction solutions at each passive and active levels. The application of energy savings and energy efficiency directives will increase, particularly in European countries, thermal demand is becoming electric demand because of the intensive use of electrical heat pumps. So, the analysis of power consumption in buildings is becoming far more relevant today than within the past, once it was several orders less than thermal demand. Moreover, monitoring will provide advanced visualization and data analysis tools to realize energy savings and peak power optimization [40 - 41].

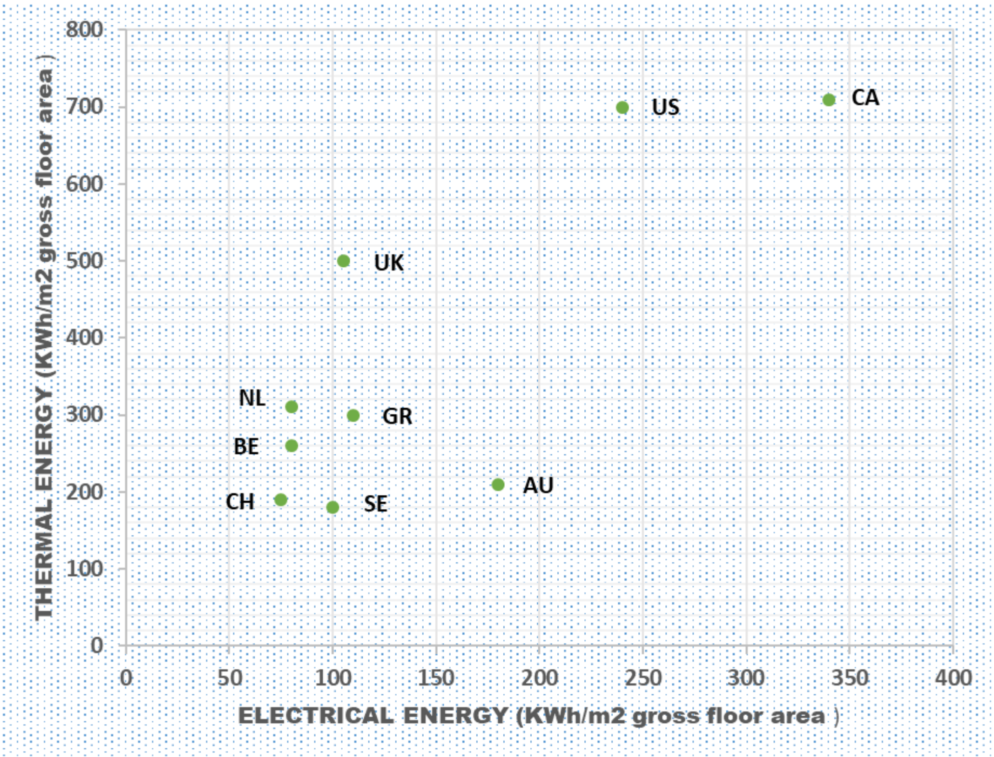

Fig. 2 - Average annual electric and thermal energy consumption per gross floor area, for typical hospital stock in various countries. (For et al., n.d.)

Fong et al. (Fong, Hanby, Greenough, Lin, & Cheng, 2015) performed an experimental study using three completely different ventilation systems with six different exhaust configurations to investigate the impact of those systems on the indoor thermal environment and energy consumption. Their results show that significant enhancements in thermal comfort and energy consumption were achieved once the exhaust opening was set at the ceiling level (rear-middle-level). Heidarinejad et al. (Heidarinejad, Fathollahzadeh, & Pasdarshahri, 2015) looked into the influence of return opening heights on thermal comfort, energy savings and indoor air quality in a very room served by an underfloor air distribution (UFAD) system. They found that decrease the height of the return opening to 1.3 m higher than floor level will help improve energy savings by up to 15.3% for the identical level of thermal comfort. According to Nicol and Humphreys (Nicol & Humphreys, 2002), the connection between indoor comfort temperature and out of doors temperature for heated and cooled buildings is a lot of complex and less stable compared to it under a free running mode. Adaptive relations can offer necessary scientific data for determinant the dynamic temperature settings for the cooling system within the summer which can lead to energy saving potential, because the energy usage of the mechanical system is linked with the temperature settings (Yun, Kong, & Kim, 2012).

2.2 Energy Efficiency

There is no generally accepted definition for energy efficiency. According to (European Parliment and the Council of the European Union, 2003) : Energy efficiency is defined as a way of managing and restricting the increase in energy consumption. Energy consumption in the building is effective if it provides more services for the same energy inputs or the same services for lower energy inputs. Energy efficiency as another means to decrease energy and electricity usage that indirectly contributes to the mitigation of GHGs emission. Efforts on rising the energy efficiency of the existing buildings were mainly targeted on the technology and instrumentation efficiency levels from both powers provide and demand sides. At technology efficiency level, efforts are made to introduce renewable power generating technologies to buildings, as well as solar systems (Wu, Tazvinga, & Xia, 2015), wind systems .From the energy provide side. At the same time, several energy efficiency technologies are developed and reported from the demand side. These technologies embrace the development of insulation materials (Hurtado, Rouilly, Vandenbossche, & Raynaud, 2016), energy-efficient equipment. At the instrumentation level, the maintenance of envelope system, ventilation and air-con (HVAC) systems and lighting systems was additionally studied (B. Wang, Wu, & Xia, 2017). The energy efficiency of Health Centres was ascertained to be improvable by an acceptable management of buildings' operational parameters, which could be achieved via specific actions just like the following: controlling the operational hours of heating/cooling equipment, guaranteeing water tightness of the building (Shohet, 2003), controlling the employment of artificial lighting, avoiding needless use of electrical stoves and similar devices (mainly used once heat is inconsistently distributed by customary heating units), avoiding further energy waste caused by stand-by modus in electrical types of equipment, etc.

Thermal comfort ought to be achieved through an efficient use of energy. Since facilities are expected to satisfy comfort needs throughout the entire year, auxiliary energy consumption ought to be reduced and acclimation equipment ought to, therefore, be operated to fulfil the wants that might not be overcome by natural procedures (McCormick & Shepley, 2003). Many authors are concerned in researchers concerning the efficient use of energy and therefore the potential energy savings within the hospital sector, on the premise of theory and practical case studies and from each technical and regulatory points of view. Recent and comprehensive literature reviews on hospitals energy efficiency and energy saving potentials on their HVAC systems (Teke & Timur, 2014), also taking into consideration thermal comfort with respect to the results on patients' healing method and the staff's levels of productivity(Khodakarami & Nasrollahi, 2012), are obtainable in the literature. Energy savings measures regard the envelope (e.g. isolation for reducing leakages (Short, Lomas, Giridharan, & Fair, 2012), thermal insulation, etc.) and also the heating (e.g. heat exchangers), cooling (e.g. air-cooled chillers with centrifugal compressors), ventilation (e.g. advanced ventilation ways (Kim & Augenbroe, 2013)).

3. Building Energy Systems

Building energy systems (BES) can be defined as those, which are responsible for the consumption of energy in buildings. These are often any physical equipment or machinery or is a process or a mix of them.

3.1 HVAC Systems

Heating, ventilation and air-con (HVAC) systems are the foremost energy intense building services representing roughly half the ultimate energy use within the building sector and between one-tenth and one-fifth of the energy consumption in developed countries (Perez-Lombard, Ortiz, & Maestre, 2011). Ventilation is a process of supply fresh air and removing heat and air pollution inside the building to provide acceptable indoor air quality (IAQ) (Wahab, Ismail, Abdullah, Rahmat, & Salam, 2018). HVAC systems play a vital role in assuring occupant comfort and are among the biggest energy consumers in buildings. If temperature and humidity levels in the building are too high or too low, occupants will fall into an uncomfortable zone and feel dissatisfied with the environment, a condition that reduces their productivity (Rasli et al., 2019). Almost 50% of the energy demand in commercial buildings is employed to support indoor thermal comfort conditions (Enteria & Mizutani, 2011). Moreover, as most of the people spend quite 90% of their time inside, the development of energy efficient in HVAC systems will play a key role in reducing energy consumption and greenhouse gas emissions.

Research studies that deals with accomplishing sensible thermal comfort and improved indoor environmental conditions attributed to the improved energy savings of HVAC systems were performed, in recent years (Engdahl & Johansson, 2004). Using advanced intelligent logical management mechanisms into the integrated building management systems would change the modern HVAC systems to perform higher than the traditional systems. The advantage of using these controllers for HVAC systems in buildings was in an elaborate way discussed by Ahmed et al. (Ahmed, Majid, Novia, & Rahman, 2007) and Karunakaran et al. (Karunakaran, Iniyan, & Goic, 2010). Additional information pertaining to the development of building energy regulations for HVAC systems together with its scope and requirements may be obtained from (Karunakaran et al., 2010).

Korolija et al. (Korolija, Marjanovic-Halburd, Zhang, & Hanby, 2011) investigated the link between building heating and cooling load and subsequent energy usage with different Heating, ventilation and air-con systems. Their results indicated that the building energy performance can't be evaluated only based on building heating and cooling demand because of its dependency on HVAC thermal characteristics. Huang et al. (Huang, Zaheeruddin, & Cho, 2006) developed and evaluated five energy internal control functions programmed according to the building behaviour and enforced for a variable air volume HVAC system. Their simulation results incontestable that energy saving of 17% can be achieved when the system is operated with these control functions.

3.2 Lighting Systems

The modern hospitals demand additional energy for providing the most effective possible healthcare facilities and standards. The HVAC system constitutes associate degree energy consumption of around 40 % whereas lighting constitutes the second largest energy consumer, after the HVAC system (Patil & Kamath, 2018). Lighting systems consume around 30%–40% of the electricity employed in commercial buildings. This usually amounts to concerning one-third of a building's electricity bill (Ullah, 1996). Buildings' design options (i.e. their size and number of windows) have been found to have an effect on the length of your time the lighting is on in hospital environments. Occupant behaviour is another crucial issue which will cause deviations in energy use in such buildings (Nisiforou, Poullis, & Charalambides, 2012). Previous studies have shown that plenty of energy is wasted due to occupants' behaviour, i.e. leaving lights on unnecessarily, notably in unoccupied spaces (Masoso & Grobler, 2010). Such behaviour usually happens in shared environments (or temporarily owned spaces) as a result of the occupants typically don't feel directly responsible for switch off the lights (Tetlow, Beaman, Elmualim, & Couling, 2014). In multifunction and various habitant environment like hospital treatment rooms, lighting system style plays a significant role. Lighting should be appropriate for three different classes of people: it ought to think about the comfort of the patients, the vital visual requirements for hospital staff, the comfort and visual want of the visitors.

To promote energy savings on lighting use, aside from the use of a lot of energy efficient luminaries such as LEDs (Magno, Polonelli, Benini, & Popovici, 2015), various lighting control strategies are designed and implemented in office buildings. Examples of such strategies embrace daylight-linked automatic lighting control, dimming control and occupancy-based lighting control. Linking a light system with occupancy sensors may be a cost-efficient and easy solution for reducing lighting energy use. Their implementation has been demonstrated successfully during the number of studies, wherever the energy used for lighting has been reduced by between 20% and 60%, depending on the configuration, type of space and kind of occupancy sensor used (Galasiu, Newsham, Suvagau, & Sander, 2007).

4. Conclusions

Forecasting the energy use of a hospital building is an important however difficult task. There's typically a large gap between a building's usually and observed energy demand. The major issue for energy and comfort management in hospital automation is to balance the conflict between the users' comfort and therefore the total energy consumption. The ambient temperature and time of day are the most dominant factors determinant the thermal comfort of the occupants in hospital. Various energy conservation methods are simulated and expected energy consumption is compared with a typical energy efficient building. Combining the building envelope, lighting and HVAC energy conservation measures leads to an annual reduction in energy consumption by 20% when in comparison with the ASHRAE baseline case. This review is important for each future research and development of self-managing mechanism supported hospital occupancy, designation and building operation, to improve the knowledge of how to design hospitals and systems to reconcile several conflicting factors for the people occupying these hospitals.

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