Automated natural ventilation and lighting strategy for a residential building under extreme hot weather

Automated Natural Ventilation and Lighting Strategy for a Residential Building Under Extreme Hot Weather

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ABSTRACT

Automated control systems, intelligent HVAC and smart lighting can help reduce the energy consumption of the buildings and improve the thermal comfort conditions of the occupants. This study considers a typical detached residential building in the United Kingdom and examines the effect of an automated natural ventilation and lighting strategy on the energy consumption of the building and the thermal comfort of the occupants. For the purpose of this study the windows of two bedrooms of the examined building are modelled with a temperature-based control function and appropriate target illuminance levels have been set to control the lighting. This paper examines the week with the higher external temperature and uses dynamic thermal simulations in order to assess the performance of the building. Simulations are performed with EDSL TAS software using the latest Design Summer Year (DSY) weather files from CIBSE. Results of the simulations show that an automated window opening system can reduce the operative temperatures up to 4°C, improve thermal comfort conditions and reduce lighting gains by 49%.

Keywords: smart windows, smart lights, thermal comfort

1. INTRODUCTION

Recent evidence has shown that overheating risk needs to be taken seriously in the residential sector [1]. Domestic overheating has not always been a problem in the UK but climate change, increased urbanization, construction of high rise apartment blocks and winter energy efficiency measures have all contributed in the amplification of high internal temperatures [1]. Achieving thermal comfort conditions is important in order to ensure the well-being and productivity levels of the occupants as homes that overheat cause significant discomfort and stress to the occupants. This study aims to identify how the application of automated control systems in residential buildings affects the thermal comfort conditions and the energy consumption of the examined building. To achieve its aims, it examines a typical detached residential building in the UK, using the latest weather data sets from Chartered Institution of Building Services Engineers (CIBSE).

2. LITERATURE REVIEW

ICT on smart homes

Smart Homes are becoming a reality with information and communication technologies (ICT) being increasingly present in our homes [2]. A Smart Home is a home that is equipped with highly advanced automatic systems, such that all lightings, heating, security system, appliances and electronic devices can be controlled remotely via smartphone, computer or other through internet or local network [3].

Building occupants may lack the time, knowledge or inclination to create optimally efficient environmental conditions This is where smart building technology can step in, learning and anticipating user preferences, and altering conditions to meet user needs more precisely and flexibly than we ourselves can [4]

Occupant behaviour

Often, there is a significant discrepancy between the designed and the real total energy use in buildings. The reasons of this gap are generally poorly understood and largely have more to do with the role of human behaviour than the building design [5].

It is well documented in the literature that the behaviour of the occupants has a significant impact on the performance of the building. Andersen et al [6] present a number of studies, where it is shown that similar buildings with different usage by the occupants have resulted in big differences in energy consumption.

As occupant behaviours are part of the building system, with implications on building energy use [7], it is important to consider the behaviour of the building's occupants during its design phase. Better assumptions for the behaviour of the occupants will result in better estimates of the building's energy consumption. Implementation of automated control systems in residential buildings, could help to reduce the amount of assumptions made about the behaviour of the occupants during the design phase of building.

Window opening / closing behaviour

Several studies have investigated which parameters affect the decision of the occupants of residential buildings to open or close a window. Reasons for opening and closing the windows can be biological, psychological, social, time and physical environment [8]. Andersen et al [6] report that the window opening mechanism is strongly related to the outdoor temperature.

The Department for Communities and Local Government in their report “Investigation into Overheating in Homes” report findings in the literature which show that windows were closed to control temperature and that the action of closing the windows is mainly driven by the need of keeping warm rather than keeping cool [9]. Andersen et al [6] note that if a window is opened because the occupants feel too warm, it will probably stay open until they start to feel cold. This is also supported by the findings of another study, performed by Raja et al [10] where reasons for closed windows are presented. These reasons mentioned by the people who were interviewed are ``others want them shut,'' ``to prevent draught,'' ``to keep the noise level low,'' or ``interference with blind'' [10].

Lisa Gobio-Lamin presented a literature review on domestic ventilation practices [11]. The study discusses window opening behaviour for different dwelling types and for different rooms. It is stated that the preferred temperature in bedrooms is lower than in the living rooms and that bedroom windows are opened for much longer periods than the windows of other rooms. In addition to that findings of the literature review show that some occupants prefer to keep the windows of the main bedroom open during the night even in cold weather conditions.

Acceptable thermal comfort conditions

The adaptive model described in ASHRAE 55-2010 [12] was used to investigate the thermal comfort conditions of the occupants during the examined period.

This model introduces the prevailing mean outdoor temperature (T_{mo}). The (T_{mo}) is calculated as an arithmetic average of the mean outdoor temperatures over no fewer than seven and no more than thirty sequential days, prior to the day in question [13]. Two sets of operative temperature limits – one for 80% acceptability and one for 90% acceptability are defined. For typical applications, the 80% acceptability limits should be used. The 90% acceptability limits are acceptable when a higher standard of thermal comfort is required.

The acceptable operative temperatures for naturally conditioned spaces are determined using the equations (1) to (4) [12].

Upper 80% acceptability limit (°C)

$$0.31*T_{mo} + 21.3 \quad (1)$$

Upper 90% acceptability limit (°C)

$$0.31*T_{mo} + 20.3 \quad (2)$$

Lower 80% acceptability limit (°C)

$$0.31*T_{mo} + 14.3 \quad (3)$$

Lower 90% acceptability limit (°C)

$$0.31*T_{mo} + 15.3 \quad (4)$$

3. METHODOLOGY

EDSL TAS

Thermal simulations of the examined building were performed using EDSL TAS version 9.3.2, a building simulation program developed by Engineering Development Solution Software. TAS is a building modelling and simulation tool, capable of performing dynamic thermal simulations of buildings and accurately predict energy consumption, C02 emissions, operating costs and occupant comfort [14].

The modelling process of a building in EDSL TAS is divided in three parts. The first part is the creation of the 3D model of the building, second part is the assignment of the various building characteristics and the third part is the simulation of the building.

Creation of the building’s 3D model is performed in the TAS 3D Modeler (.t3d). The first step is to import the building’s floor plans to the model and identify the height of the walls, which was set to 3.00 meters for the examined building. The next step is to create the required building elements and the windows of building. Based on the imported drawings the user creates a model of floors, assigns the building elements to the walls and positions the windows. Finally, the user identifies the different zones of the building and assigns a name to them. The zones of the first floor of the examined building can be seen in Figure 2. Upon completion of the modelling of each floor a validation of the model is required in order to check if there are any errors or warnings. The same process is repeated for all the floors of the building.

When the 3D modelling of the building is completed the model is exported to the TAS Building Simulator (.tbd). At this point the user needs to identify the building’s construction materials, its internal conditions and assign a suitable calendar and weather file. A construction should be applied to all the building elements that were created in the 3D Modeler. The U-Values of the constructions applied to the building elements is shown in Table 1. The relevant activities of National Calculation Method (NCM) v5.2.4 were applied to the zones of the examined building. In addition to that a NCM calendar is assigned to the building. Finally, the user assigns to the model a weather file that represents the weather conditions of the location of the building. This study uses the latest at the moment weather data from CIBSE. The weather file used to perform the simulations presented in this paper is the Design Summer Year (DSY) - 2 for London Weather Centre. DSY-2 represents an intense extreme summer, which is chosen as the year with the event which is about the same length as the moderate summer year but has a higher intensity than the moderate summer.

Following the input of the model’s parameters, the building can be simulated using the TAS Building Simulator. Results of the simulation are shown in the TAS Results Viewer (.tsd).

Description of the building

The examined residential building is a two-floor house with a total area of 333 m^2. On the ground floor, the building’s zones consist of a living room, a dining room, hall area, a kitchen with a utility room, two storage areas, a WC and the garage.

On the first floor, the building has four bedrooms and a bathroom. The building is naturally ventilated.

Building fabric U-Values	Construction	U-Value
	External Wall	0.24 W/m^{2}K
	Partition Wall	0.73 W/m^{2}K
	Roof	0.13 W/m^{2}K
	Windows	2.30 W/m^{2}K

Table 1. Building fabric U-Values

The front elevation of the building model as it was created in EDSL TAS in shown in Figure 2.

Fig 1. Front elevation of building

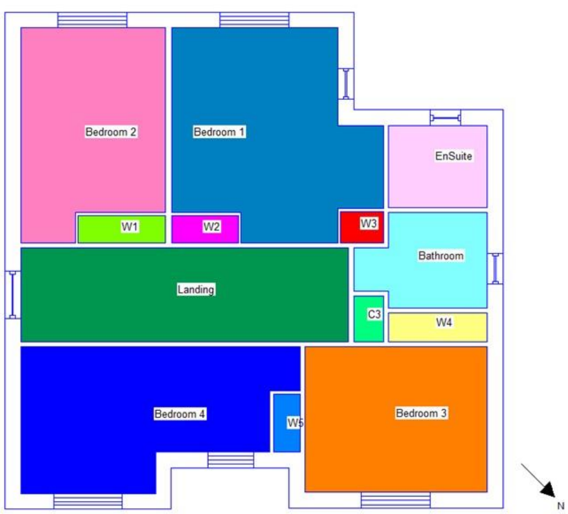

Fig 2. Zoning of first floor

Examined scenarios

In order to investigate the effect of automated controls on the thermal comfort conditions and energy consumption this paper examines two scenarios. The first scenario represents a manual operation of the windows and the lights and the second scenario represents an automated operation.

The examined period is the week of the year which includes the day with the highest external temperature. The day with the highest external temperature is the 222nd day of the year, so this paper examined the week commencing on the 218th day of the year and ending on the 224th day of the year.

This paper presents results for rooms Bedroom 2 which is south facing and Bedroom 3 which is north facing. The bedrooms are considered to be occupied 24 hours a day. Based on the findings of the literature review, the windows of the bedroom are considered fully opened at all times for the manual control scenario.

Finding of the literature review suggest that switching on the light in early morning often means that it stays on throughout the day [10]. The manual control of the lights is based on a similar norm. The occupants will turn the lights of each zone on when the illuminance levels are lower than the target illuminance and they will leave them on until the end of the day. The start of the day is modelled to be at 06:00 and the end of the day at 22:00.

The automated opening and closing of the windows is controlled by a function. This function simulates natural ventilation with external temperature cut-off. The aperture is modelled to begin to open when the resultant temperature in the adjacent zone exceeds 21°C and to be fully open when the resultant reaches 23°C. If the external temperature exceeds the internal temperature the aperture will begin to close. In order to examine the effect of automated control on the lighting loads, a function that controls the lighting of the zones of the building was modelled. This function models a photocell control of the lighting. Acceptable illuminance levels are maintained at all hours during the occupancy schedule. Target illuminance was set at 100lux. As illuminance increases, lighting gain will decrease. When examining the automated lighting control, a parasitic power of 0.57 W/m^2 is added to the total lighting gain. This is the amount of energy used by the photocell sensor.

4. RESULTS AND DISCUSSION

Thermal comfort

Figures 3 and 4 presented below show the operative temperature of bedrooms 2 and 3 respectively. Operative temperature of the manual control scenario is shown with the blue line and operative temperature of the automated control scenario is shown with the green line. The vertical axis shows the temperature in (°C) and the horizontal axis represents the time. The purple horizontal lines show the 80% acceptability limit and the yellow lines represent the 90% acceptability limit. The acceptability limits for each day were calculated by the mean outdoor temperature of the previous seven days.

As it can be observed from the graphs the greater differences in operative temperature between the two scenarios occur during the daytime. This is due to the fact that in the automated control scenario the windows close when the external temperature is higher than the internal temperature. As a result, lower operative temperatures are achieved, and thermal comfort conditions are improved.

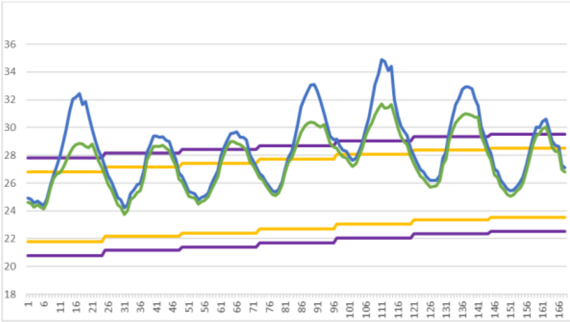

Fig. 3. Comparison of operative temperatures (Bedroom 2)

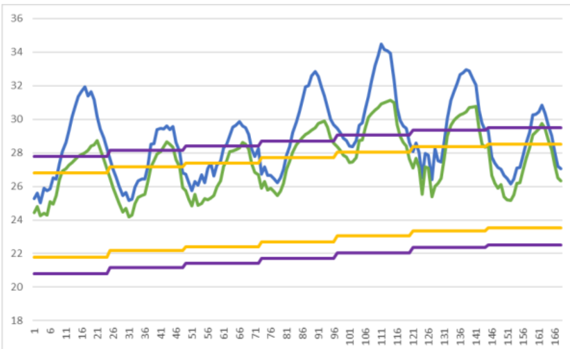

Fig. 4. Comparison of operative temperatures (Bedroom 3)

Lights

Results presented in Figure 5 below show the lighting gains for the two scenarios during the examined period. The blue bars represent the lighting gains for the manual control scenario and the yellow bars for the automated control. A reduction of the lighting gains by 49% is recorded for both bedrooms.

Illuminance levels are investigated hourly and the target illuminance is 100lux. At the start of the day, at 06:00, the illuminance levels are below 100lux and lighting was provided in order to reach the target illuminance. When examining the manual control scenario, the lights remained on until the end of the day at 22:00 On the other hand when examining the automated control scenario, the lights were off all the hours that the target illuminance was achieved through daylight. In the automated control scenario, artificial lighting was required again at 19:00 in order to reach the target illuminance.

Application of automated systems can result in more energy efficient buildings and in more comfortable conditions for the occupants. Furthermore, automated control systems could help to make more accurate estimations about the behaviour of the occupants and thus to reduce the gap between the simulated and the actual performance of the building.

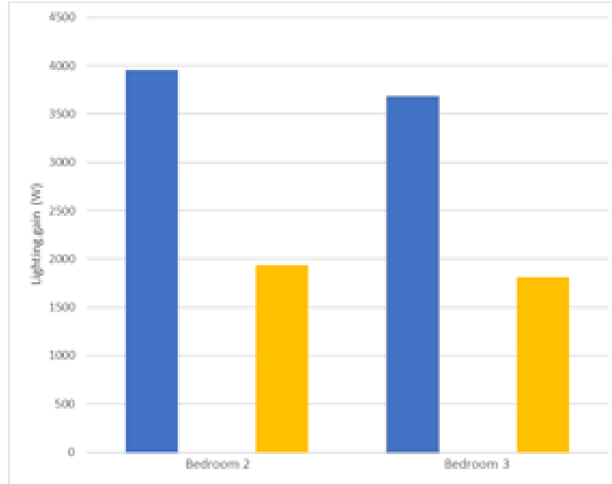

Fig. 5. Lighting gains (W)

5. CONCLUSIONS

This study aimed to identify the effect of automated control systems on thermal comfort and lighting gains. More specifically, it examined a typical detached residential building in the UK using dynamic thermal simulation and the latest weather files from CIBSE and presented the results for a south facing and a north facing bedroom.

Automated control of the opening of the windows resulted in reduced operative temperatures and improved thermal comfort conditions. Operative temperatures of the examined rooms were compared with the 80% and 90% acceptability limits defined in ASHRAE 55-2010. Using automated control systems on the windows resulted in differences of up to 4°C during daytime. Automated control of lighting based on target illuminance levels resulted in a 49% reduction of lighting gains for both rooms.

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