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Would High Level of Insulation in Buildings Improve Energy Savings ?

Sherna Salim, Amin Al-Habaibeh* and Ahmad Lotfi
Innovative and Sustainable Built Environment Technologies Research Group (iSBET)
Nottingham Trent University, UK

sherna.salim2017@my.ntu.ac.uk; *Amin.Al-Habaibeh@ntu.ac.uk; Ahmad.Lotfi@ntu.ac.uk
*Corresponding Author

Abstract
The UK government is committed to reduce 80% of its carbon footprint by the year 2050. With today's increase in oil prices and the significant growth in energy demand, energy savings in heating and cooling of buildings is becoming an important area to address to reduce energy consumption. This paper reviews literature on energy consumption patterns and investigates the energy consumption in residential buildings based on people's consumption behaviour. Infrared thermography has been used to identify areas in the building where heat is significantly lost. The case studies presented in this paper show that no matter how insulated a building is, significant heat can be lost due to the opening of windows by occupants. This is to improve the ventilation and temperature's comfort level. It can be concluded that proper energy efficient ventilation is necessary to improve the energy efficiency. And the occupant's behaviour plays an important role in controlling the energy savings regardless of the level of insulation of the building.

1. Introduction

Although there is progress on UK's clean energy policy, so far the issue of fuel poverty has not been dealt with effectively. According to Dr Joanne Wade, the CEO of the Association of Conservation of Energy, "The Energy Company Obligation alone will not solve the problem of fuel poverty. To close the investment gap, the Government needs to take robust action to ensure that Minimum Energy Efficiency Standards for the Private Rented Sector are enforced, strengthened, and complemented by strong incentives for action in other housing sectors" [1]. UK has to invest in a nationwide upgrade in energy efficiency of the UK housing stock in order to meet the country's 2050 climate commitments [2]. Such a retrofit might increase the relative impact of the occupant's behaviour on energy use, thereby defining success more and more as the way a building is being used by its occupants [3]. Recent years has seen a rapid increase in urbanisation, a substantial rise from 30% in 1050 to 55% in 2018 [4]. In fact, by 2050, 68% of the world population is projected to live in urban areas [4]. The UK government has committed to reduce 80% of its carbon footprint by the year 2050 [5]. The UK is currently on track with the carbon reduction targets within the second and third budgets (2013 – 2022). But more challenging measures are required in addition to the existing progress, to reach the fourth budget target (2023 – 2027) [6]. Policies such as feed-in-tariffs (FIT) or renewable portfolio standards support the attainment of these tariffs [7]. The effectiveness of this approach is questionable since they rely on the conventional building energy management systems (BEMS). It was found that smart BEMS produce better results when combined with policy measures than conventional BEMS [8]. Although commercial buildings have the high energy consumption, it does not vary significantly with changes in occupancy levels. Consumption patterns depend highly on the way the building is managed [9]. In 2017, the total CO_2 emissions in the UK, from the residential sector was 17% of the overall CO_2 emissions. This was after a drop of 4.3% from the previous year [10]. In contrast, there has been an increase of 3% in CO_2 emissions in 2018, when compared to 2017 [11]. In the past decade the energy used in residential space heating, which accounts for 69% of the total energy consumption, in the UK has only dropped from 1187.55 Petajoule (PJ) to 1107.41 PJ [13]. These numbers make domestic energy use a prominent target for greenhouse gas reduction. There has been a steady increase in the number of households in the UK, since 1991, contributed by factors such as increase in birth rate, net immigration and the long-term trend of single adult households [14]. According to Mintel statistics, the number of households has reached 27.2 million in 2017 and it is projected outreach 32.1 million by 2034 [14]. This means an increase in overall energy consumption. There has been an increasing evaluation of energy use in buildings in the past 15 years, and it has been widely acclaimed that there is a considerable gap between the predicted and actual energy consumption in buildings. Extensive research has been done using energy simulation tools analysing climatic data and properties of buildings, but the impact of occupant behaviour in energy performance analysis has hugely been overlooked. Nevertheless, several studies have been undertaken to analyse post occupancy energy use such as [15, 16, 17, 18]. However, occupant behaviour is one of the most overlooked parameter during energy efficiency design of buildings [17].

In his paper, the occupants' behaviour will be examined with significant focus on windows the relationship between people's behaviour.

2. **Methodology**

In this paper two approaches have been utilised. The first one is to monitor windows open/close status over significant period of time during warm and clod seasons. The other approach is infrared thermography surveys to look at the status of buildings in cold weather and to develop qualitative and quantitative understanding of people's behaviour. In the first part of the study, Nottingham Trent University (NTU), with collaboration from Nottingham City Homes (NCH), have conducted a study to analyse energy efficiency in social housing. This paper focuses on 17 residential buildings based in Nottingham with a diverse construction design, constructed over a period ranging from 1902 to 2012. Houses were equipped with Wireless Sensor networks (WSN) to record opening and closing of windows, in addition to other temperature and energy variables. The experiment was conducted from May 2012 to March 2014. Moreover, to better understand and evaluate occupant behaviour with respect to thermal comfort, a survey was done in different areas of Nottingham in the United Kingdom, during the night, in winter with environmental temperature between 3°C and 5°C. By using infrared technology, areas of heat-loss in the building can be specified accurately, with the temperature values. Thermal images of buildings were taken on two cold winter nights and were studied based on their temperature range and the building features. The images collected were of buildings built in different decades, with different types of insulations.

3. Results

3.1 Longitudinal study of windows status

Figure 1 presents the windows status (open/closed) in 17 of the monitored buildings. Figure -a shows the bedroom window status of the houses, when the outside ambient temperature is 5°C or less. It has been found that 70% of the houses open their windows at least once even when the outside ambient temperature is less than or equal to 5°C. Figure 1-b shows the frequency of opening the bedroom window in each house. Even at a temperature of 5°C or below, 43% of the houses keep the windows open more than 5% of the time, of which 29% keep it open more than 30% of the time.

The highest frequency of opening windows is by house 11, which opens the bedroom window 59% of the time, when outside ambient temperature is 5°C or below. House 11 has good insulation. House 3 is also well insulated and the occupants keep the bedroom window open 37.8% of the time at low temperatures.

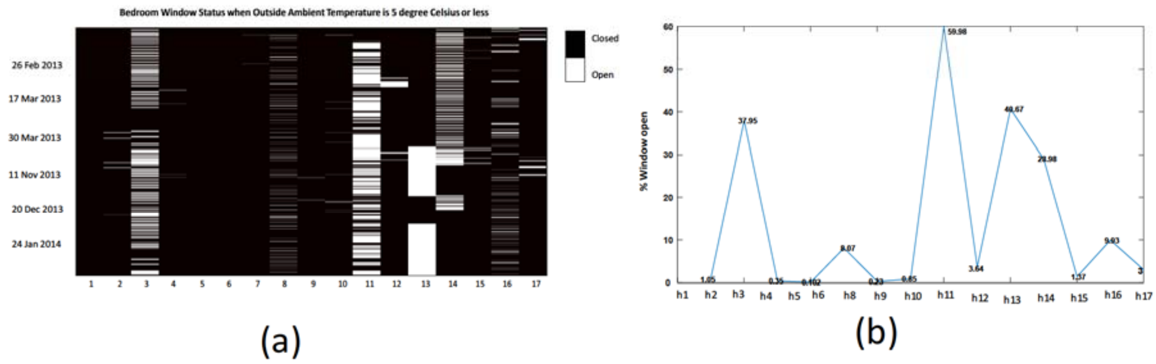

Figure 1: Window opening frequency

3.2 Infrared Survey

For this part, infrared thermography survey was done in Nottingham city to examine the open windows in cold weather.

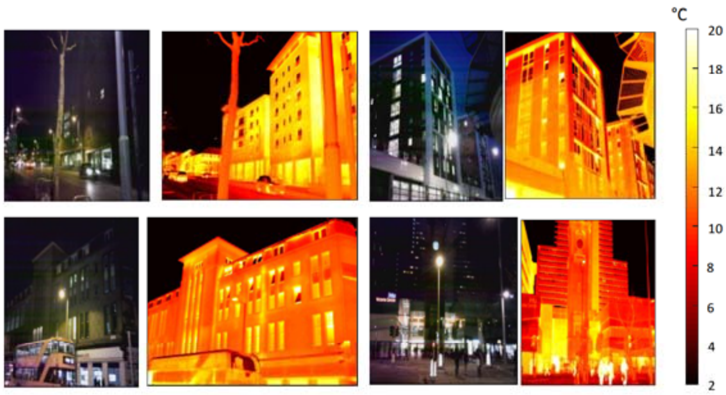

Figure 2:Thermal images of buildings in Nottingham City

Thermal images of buildings in Nottingham city centre are examined including offices, multi-story student accommodation buildings and residential houses. Figure 2 presents examples of surveyed buildings.

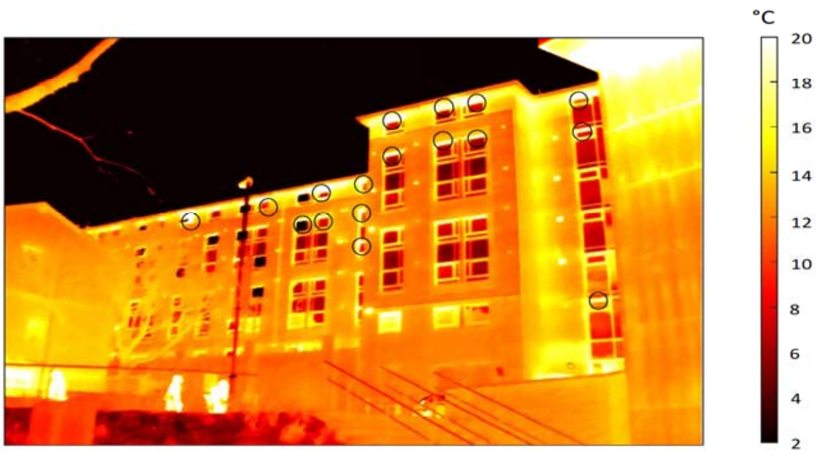

Figure 3: Infrared images of students accommodation

Figure 3 presents a student accommodation. Two windows on the top floor are wide open and 14 other windows can be seen partially open, making a total of 16 windows open, out of 45 observed windows, which makes the total number of opened windows are about 35.5%

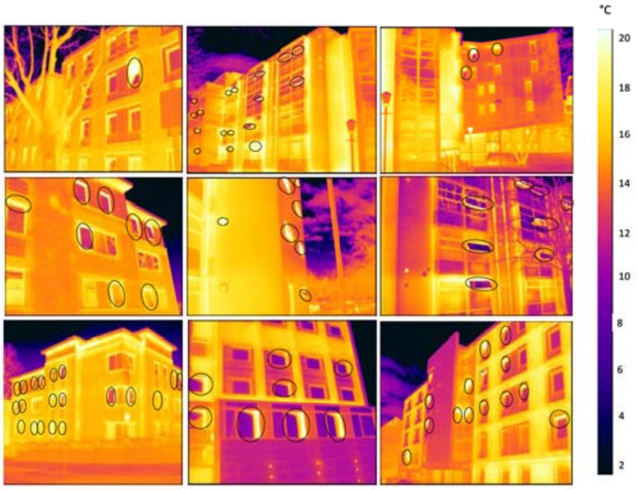

Figure 4: Infrared images of students accommodation buildings

Figure 4 presents more examples of new student accommodation buildings. Although the ambient temperature outside is about 3°C, many of the windows are found open. In the nine buildings shown in Figure 4, out of 152 windows seen, 75 are found open. This implies that even when the temperature outside is cold, 49.3% of the windows are found open in buildings that are well insulated.

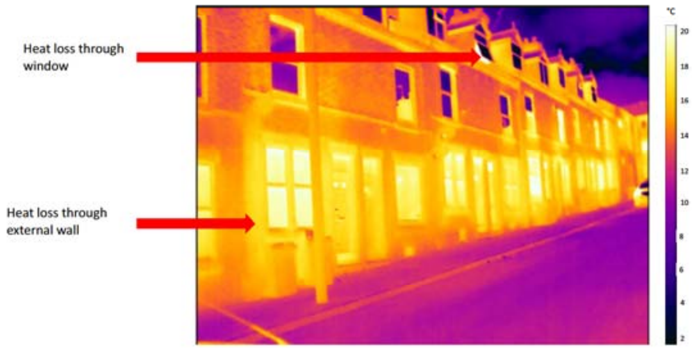

Figure 5: Infrared images of old terraced houses

Figure 5 shows poorly insulated Victorian terrace houses built in the late 19th century. There is heat-loss through windows due to absence of double glazing and through external walls due to absence of insulation. Despite these heat losses the upper floor window can be seen to be wide open.

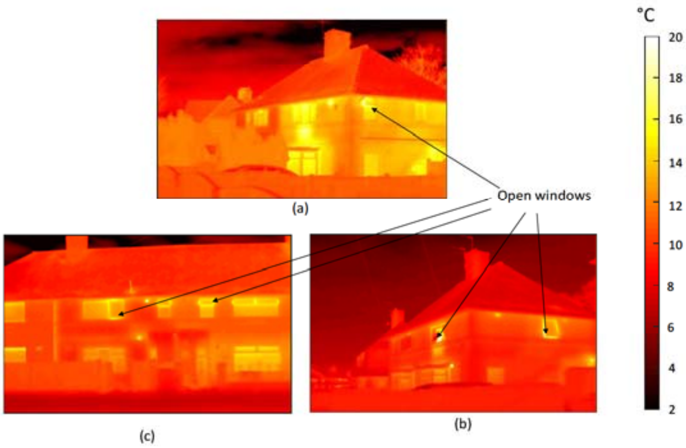

Figure 6: Infrared images of semidetached houses

Figure 6 shows Gregorian houses built in the early 20th century, taken when outside ambient temperature is about 5°C. House (a) has a very poor insulation and single glazed windows, with heat losses through walls. House (b) has wall insulation and double-glazed windows and (c) shows two houses, one with external insulation and one without external wall insulation. Windows can be seen open in the houses, regardless of the insulation properties of the house.

4. Discussion

This paper has explored the relationship between the occupant's behaviour in cold weather in buildings with a wide range of age and characteristics. It can be observed that thermal comfort as well as getting the necessary fresh air is a stronger driver when compared to energy efficiency. A significant variability has been found between different households, irrespective of the insulation, built year or the heating systems used. It has been found that, of the total number of thermal images, 54.8% of the windows in the images were open, when the outside ambient temperature was 3°C.

The American Society of Heating and Air Conditioning Engineers define thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation" [20]. Well insulated buildings are normally assumed to be more energy efficient, since they have less heat losses through the building's envelope. However, the findings show that people in well insulated buildings tend to open windows even, during very cold winter nights, for managing the thermal comfort of the house. For people to feel comfortable, a balanced thermal environment with the right air temperature, surface temperatures, humidity and absence of draughts is essential [21]. The most effective way to increase energy efficiency of a buildings is by providing proper ventilation systems, along with good insulation and improving occupant's behaviour.

5. Conclusion

The lengthy monitoring process of the status of windows in 17 houses clearly show the tendency of people to open windows even in winter times regardless of the age of the house. Researchers have not found no clear correlation between the age of the house and type with the tendency to open the windows. In relation to the infrared survey, the thermal images are captured during two winter nights, when outside ambient temperature is at 3 and 5°C respectively. It has been found that 54.8% of the windows are found open in the multi-storey buildings and 64.7% of the Gregorian houses had at least one window open. Although factors such as an airtight ventilation or good insulation affect temperature of a building, it can be argued that proper ventilation of building plays a major role in maintaining a well-balanced thermal comfort for the occupant. It can be concluded that regardless of the age and the insulation of buildings, people's behaviour such as opening and closing of windows play an important role in energy savings and buildings efficiency.

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