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A Novel Approach for the Evaluation of the Dynamic Thermal Behaviour of a Building by Continuous Monitoring using Autonomous Infrared Thermography

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Abstract

In this paper, a novel approach is utilised for longitudinal study to evaluate the dynamic behaviour of a building using autonomous infrared thermography. This unique test has been conducted to investigate the dynamic performance of a building continuously over several days. This paper presents the monitoring process to investigate the behaviour of a poorly insulated building using infrared thermography. The experimental work is conducted over 13 days and an image is captured every hour for analysis. The results show that poorly insulated walls significantly contribute to heat losses and the most significant location and time for such losses have been identified. Based on which, the paper suggests some simple measures to improve insulation. This suggested approach has been found beneficial to understand the dynamic thermal behaviour of buildings over significant period of time.

1. Introduction:

The 2008 Climate Change Act has committed the UK government to reduce 80% of its 1990 carbon footprint by the year 2050 [1]. Statistics have shown that about 40% of carbon emission is emitted from buildings. Approximately 90% of homes are heated with a gas-fired central heating system and it is estimated that the domestic space heating alone accounts for approximately 11% of the country's carbon emissions [2]. The United Kingdom's housing stock is older than that of most European countries. Numerous houses date back to the Victorian era (1837–1901 AD) [3] and it is also predicted that by the year 2050 over 70% of the current stock of buildings will still be occupied. According to [4] as at 1990, 22% of houses were built before 1919, which were constructed without wall cavities and are of solid wall build, having poor heat retaining abilities. Moreover, based on the same reference, 39% of homes in England were built before the Second World War and 59% were built before 1965. It is understood that houses built after the 1920s, are likely to have cavity walls but were not filled with any insulations. It was not until 1965 that building regulations were introduced. Research show that "buildings don't consume energy but people do" [5]. In an average UK home, over 60% of the used energy consumption is for space heating, 24% for hot water and the remaining 16% usage is for electrical appliances and lighting [6]. Around 4 million UK householders spend more than 10% of their income on energy bills. On average, they spend between 2.7 and 8.4 per cent on gas and electricity and 0.5 to 3 per cent on water. To enhance the understanding of energy efficiency in UK homes, seven main factors have been identified by [7] which are: building fabric; heating system; occupancy behaviour; comfort; health, life style; fuel poverty and government policies.

The UK government has introduced many measures to reduce the carbon footprint produced from its housing sector which include the loft insulations of domestic housing as well the replacements of inefficient boilers. This is in addition to the introduction of the Green Deal to insulate internal and external walls of solid brick homes. Between March 2014 and March 2015, 410,000 homes had cavity wall insulation installed. 320,000 and 49,000 houses also had loft and solid wall insulation respectively within the same period. [8]. As an outcome of such additions, the percentage of homes with insulation has reached 70%, 73% and 4% for loft, cavity walls, and solid wall insulation respectively [9]. These insulation measures have resulted in an estimated annual savings of over one billion pounds on national heating bills in the UK [8].

There are many factors that could influence energy consumption in homes including occupants' behavior, household characteristics, energy price and how much the householders can afford to spend on energy. End use energy efficiency and fuel poverty is one of the major issues in the UK social housing sector. It is estimated that about 10% of households in England live in fuel poverty [8]. A good understanding of how occupants use a building can provide a possibility of promoting the building's energy efficiency through changing occupant behavior [10-15]. Another innovative method for understanding building energy related issues is the use of infrared thermography which has been successfully applied in various sectors. The use of infrared thermography to measure thermal performance of buildings has seen an increase in recent years where references [16-20] have all concluded its benefits. This paper presents approach where a longitudinal study is performed to evaluate the dynamic thermal behaviour of a building using infrared thermography. This unique test has been conducted to investigate the dynamic performance of a building over several days. This research is utilised to monitor the behaviour of a poorly insulated building using infrared thermography to explore its performance and identify the most critical areas in the building and the nature of heat losses.

2. Methodology

For this work, a unique test has been done to investigate the dynamic performance of a building over several days. This test is an attempt look at the behaviour of poorly insulated house with solid walls to understand the behaviour of the building in Nottingham between 26th of February and 8^{th} of April 2013 for over 320 hours. An ethical approval process was put in place to ensure the exact location of the building is anonymous. An image was captured every hour for comparison. Figure 1 presents the setup where Flir A310 was installed externally looking at the building to measure its performance. Infrared data was captures and transferred digitally to Matlab for analysis.

Figure 1: The installation process of the autonomous infrared camera

3. Results and Discussion

Figure 2 presents an example of the infrared image obtained and a visual image of the monitored building.

Figure 2 : An Example of the infrared results obtained for the group of buildings.

The images are captured and calibrated to a different colour-map, see for Figure 3, where several animated videos of the behaviour of the building are developed and presented.

Figure 3: Infrared thermal behaviour of the building which was monitored for 13 days continuously for energy performance.

For quantitative analysis of the infrared data, consider Figure 4 which includes several points of interests on the infrared image: Point 1 presents the infrared radiation of the sky, this could also be used to evaluate the clarity of the sky. Point 2 is the temperature of the chimney; this could also indicate heat losses as well as the functionality of the heating system. Point 3 presents the wall of the loft. Point 4 presents first floor wall under the window (opposite to the radiator). Point 5 presents first floor wall. Point 6 shows the south facing wall. Point 7 presents ground floor wall under the window (opposite to the radiator). Point 8 presented ground floor wall and point 9 presents the ground temperature.

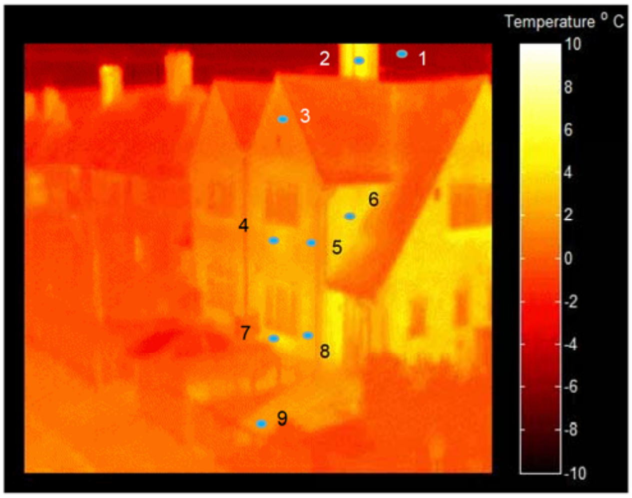

Figure 4: Comparison between the points monitored for analysis from the infrared images.

Figure 5 presents a comparison between the relative temperature of the loft wall (point 3) and the first floor wall (point 4). Notice that there is about 3°C difference on average. This is due to loft insulation and the effect of solid walls.

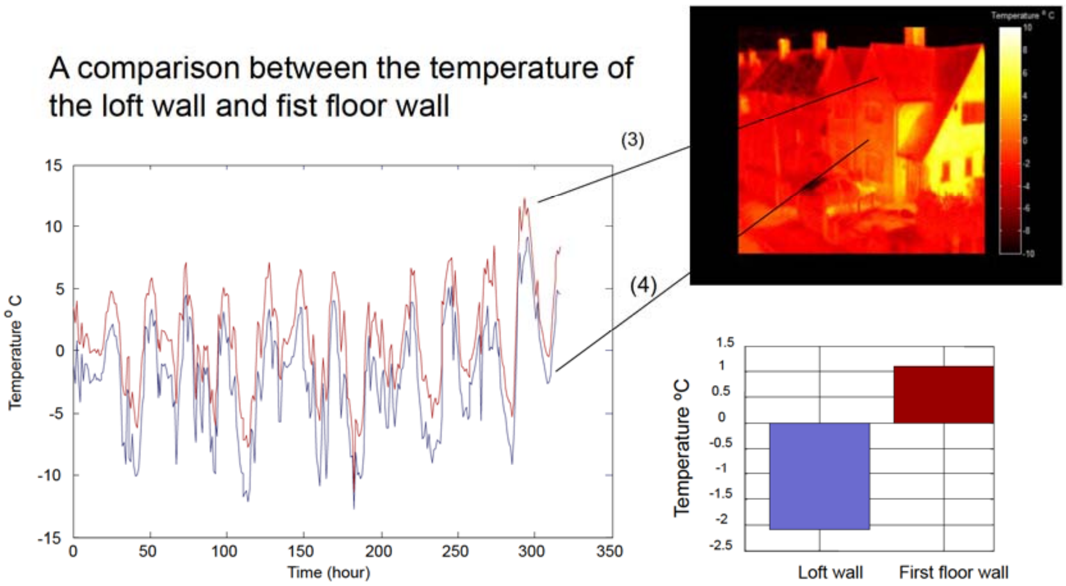

Figure 5: The loft wall is always lower than first floor wall by about average 3 °C due to loft insulation.

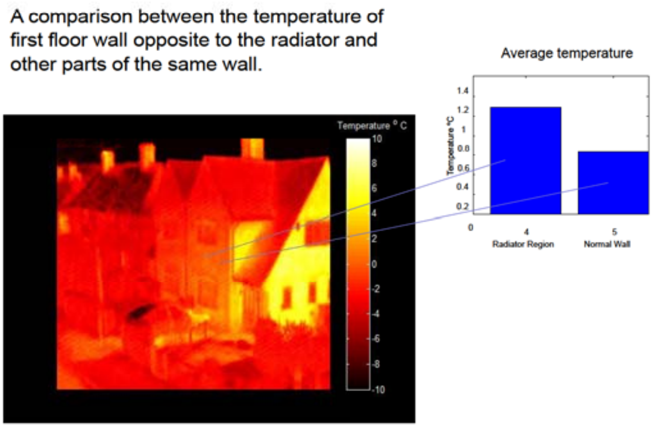

Figure 6: A comparison between different areas of the first floor.

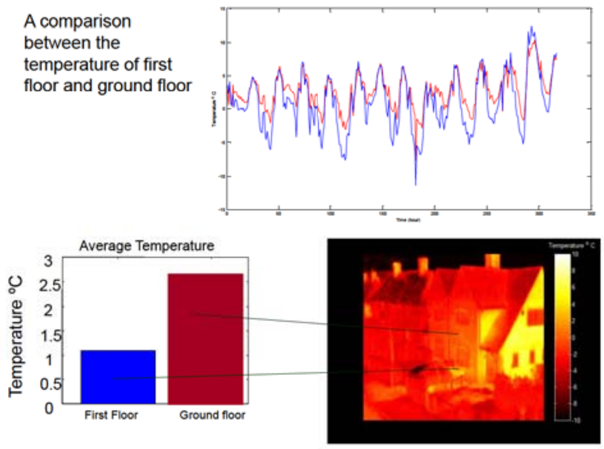

Figure 7: A comparison between first floor and ground floor.

Figure 6 indicate that the temperature of the wall behind the radiator is much warmer than other parts of the wall. Figure 7 indicates that that ground floor is always warmer than first floor wall, particularly during the colder periods. The average difference is found to be about 2 °C.

4. Conclusion

Old buildings are expected to lose significant heat through solid walls, single glazing, poorly insulated loft and chimney structure with the use of inefficient boilers. This paper has presented part of the results for monitoring an old and poorly insulated building using infrared thermography over significant number of days. The building has loft insulation and solid walls. The introduction of loft insulation has been found significant to reduce the loft temperature and hence heat losses via the roof and loft's walls. The dynamic analysis of infrared thermography has confirmed the performance of poorly insulated buildings. Infrared thermography result has shown the significant heat transfer via the walls. Further work is needed to quantify the payback period of each energy saving measure taking into consideration post occupancy behaviour.

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