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Innovative design of an educational physical simulation tool for investigating energy consumption in buildings for enhancing public engagement

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Abstract

Reducing carbon emission and energy consumption in buildings is becoming an important priority on global level. Buildings consume significant amount of energy for heating or air-conditioning in most countries. The drive to enhance the understanding of building insulation and its effect on energy use, is critical for improving public engagement to achieve reduce carbon emission towards more sustainable future. This paper presents the design and the development an educational and research simulation tool to study and understand the thermal performance and energy efficiency of buildings. The novel design includes small-scale multi-layered model of buildings where insulation layers can be added to or removed from the building model in a modular and interchangeable manner to allow changes to the thermal performance. The results show that this novel model will provide a new educational tool to enhance the understanding of energy consumption and insulation in buildings. The design can be used to engage the young generation regarding building insulation and energy efficiency. It also could provide an advanced research and teaching tool for energy in buildings, instrumentation and infrared thermography.

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Keywords: Building enegy efficiency; simulation; educational tool; Building energy consumption; Thermal performance; Innovation.

Introduction

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There is a need to improve public understanding and engagement towards energy conservation and sustainability, particularly in buildings. Moreover, teaching students and researchers on the effect of insulation and other changes in building features on energy consumption is becoming essential to improve scientific knowledge and public engagement. Currently there is a lack of useful educational tools in this field which is related to enhancing the understanding of the effect of altering the building envelope to improve the energy performance and thermal efficiency. Energy consumption in buildings in the EU accounts for about 40% of the total energy consumption [1]. According to the EU Directive 2010/31, the EU has a goal to reduce energy consumption and carbon emissions by 20% by the year 2020 [2]. The directive also emphasises that all new buildings have to be nearly zero-energy buildings by the same time frame.

However, many countries around the world have an old stock of houses that will still need improvement. To engage the public in this process, they need to understand the benefits of insulation to their quality of life, particularly in relation to their building temperature and financial savings. Thermal insulation is one of the most important factors that enhances the energy performance of buildings. With improved insulation, new and renovated buildings will provide an acceptable level of energy conservation. Significant research has been done in this area. For example, Al-Habaibeh et al. [3] has presented a case study of an existing university building, where the insulation has been improved, mainly by adding an internal doubled glazing. The study shows the thermal images of the building from 2005 before the renovation and from 2010 after the improvement, which demonstrates very clear improvement in the thermal insulation performance. Kim et al. compared the impact of adding insulation on energy consumption in cold and hot climate in USA. Computer simulation tool has been utilised to test the building under two different climatic conditions: cold climate in Michigan and moderate-humid climate in Florida. The results show that adding insulation in cold climate is highly recommended to reduce the energy required for heating in winter, but the insulation might not be effective in moderate weather conditions [4]. Tettey et al. [5] have analysed the implications of five different insulation materials on the primary energy use and CO_2 emission and the results show difference in insulation capability between 6-7% in relation to primary energy use. Other research work, has assessed the life cycle impact of different flooring materials in buildings [6] and the external wall thickness of expanded polystyrene on the life cycle saving, life cycle total cost and payback period [7]. Composite materials as insulation have also been found to be effective [8]. The implementation of mandatory insulation in New Zealand since 1978 shows higher internal temperature and decreasing energy consumption [9].

One of the issues is that it is normally difficult to engage the public in the insulation process and most of the research work stays within the industrial and academic sectors. Some attempts have been made to encourage the public and improve their engagement. A research presented by Goodhew et al. [10] has investigated the behavioural effect of visualisation of heat loss from residential homes and the consequences for energy saving using infrared technology. Using infrared images, the study enabled householders to see how the heat escapes from their homes in order to study the eventual motivational impact on behavioural energy conservation. The research concentrates on the ability to encourage residential energy saving measures through such visualisations. The results show potential energy conservation by using the demonstrated visualisation technology.

Xie and Nourian [11] have presented an educational concept to improve design-based learning. The focus was on developing simple physical building models and modelling software. The tool and the curriculum units have been tested in three high schools with the involvement of about 200 students, and the results show positive response from the students. However, the suggested physical models have the advantage of being simple and low cost, but they have their own limitations in relation to the lack of modularity for the user. Haglund et al. [12] demonstrates a qualitative educational research using thermal imaging in science education at different school levels. The visualisation of the heat transfer has been applied in physical and chemical processes across all school ages. The results show that the IR camera in combination with simple well-designed theoretical activities can support their thermodynamic learning. For the above discussion, it is evident that there is a need for a modular and simple physical model of buildings that could benefit the education sector; but at the same time can engage the public and also benefit advanced research in the area of building insulation and efficiency.

The proposed building model

As discussed above, teaching and research tools for studying and simulating thermal performance in buildings in most cases are based on a single component or material based systems to test and measure insulation. In other situations, software-based simulation and modelling is used. Both scenarios fail to engage students and the public in relation to the effect of insulation and the modification of building features on energy consumption and the temperature of the building, particularly for the younger generation. This suggested educational tool combines a layer or more of detachable, interlocking and interchangeable insulation, combined with heating and/or cooling of the external and the internal volumes inside and outside the building to study the power consumption and the thermal parameters of the building. Developing the training process on real buildings is costly and time consuming, with difficulty in influencing the external environment. Computer simulation is normally based on assumptions and does not fully engage the learners in the training and learning process particularly for the younger generation. To address the limitations in existing educational and research tools for the investigation of building performance and energy efficiency, an innovative system has been developed as an educational and research tool for energy consumption in buildings, which comprises modular building models. The model consists of modular components and insulation layers with associated heating and cooling systems as an educational, training and research tool. Nevertheless, one of its advantages is that it can be used to engage the public due to its simplicity.

The proposed modular physical model of the building, see Figure 1, comprises a modular and layered structural system which can be easily modified with the introduction of thermal insulating layers and with an internal and external control of heating and cooling of the building model and the associated control of the simulated or realistic external environment. This educational kit will enable the teaching of the values of energy and insulation. This is in addition to the architectural and product design learning skills and knowledge that can be gained. The modular design allows insulation layers and building components to be interlocking and interchangeable to allow easy modification, assembly and disassembly, as shown in Figure 1.

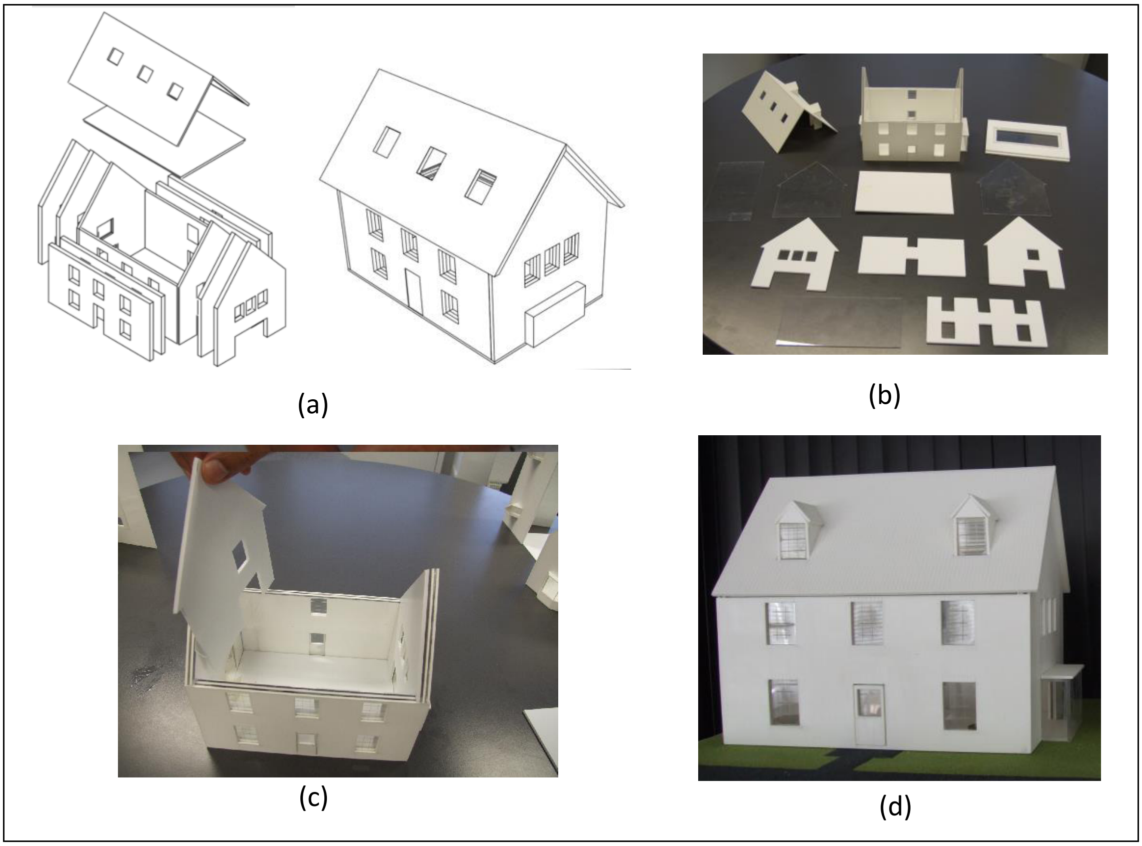

Figure 1: An example of the 3D CAD of the building model and the insulation layers (a), photos of the insulation layers and the physical building of the model (b), the model being assembled (c) and the complete building model assembled (d).

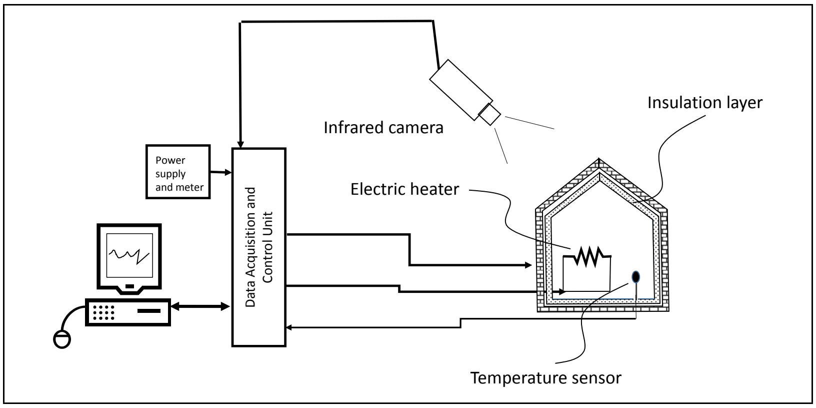

Figure 2: A schematic diagram of a possible application including the heating, monitoring and control systems.

The design and building process of the model and the insulation layers could help students to design and build their physical model using suitable CAD software and with the help of a laser cutter, the components could be easily manufactured. This process could particularly help product design and architecture students.

Energy Efficiency Application

The schematic diagram, as shown in Figure 2, illustrates an example of how the building model could be used to test energy efficiency. The original building model can have one or more insulation layers internally. The building could be heated by an electric resistive heater (or a light bulb) or heated or cooled by means of a heat pump (e.g. Peltier effect). A temperature sensor is used to monitor and control the internal temperature. The building model can be housed in an environmental chamber to control and monitor the external environment of the building. The system can be connected to a power supply and a meter to monitor the energy consumption. The system can be monitored by an infrared camera to see the energy loss of the building to study the thermal performance in different climate scenarios and different insulation levels.

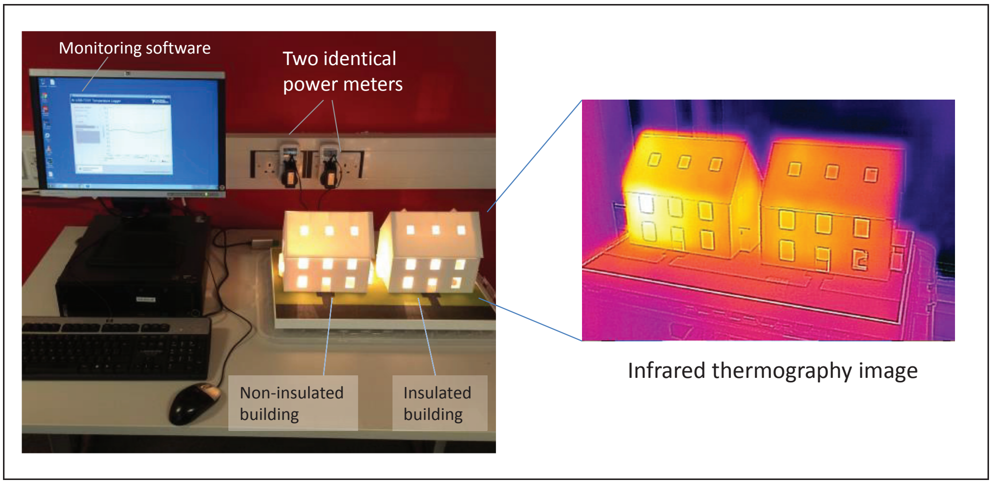

Figure 3: A completed control and monitoring system using two buildings one with insulation and one without insulation and the associated infrared image.

Figure 3 presents the experimental work for two systems; where two power meters are connected to two separate buildings, one with insulation and one without insulation. Two K-type thermocouples are connected to a PC via a data acquisition card for monitoring the temperature of the two buildings. Both building models are heated by identical light bulbs and the temperature is controlled by identical thermostats. Both systems are switched on at the same time and a comparison between the energy consumption and the behaviour is achieved via identical power meters, see Figure 3. The use of infrared thermography, Figure 3, has indicated clearly that the non-insulated building model has much warmer surface temperature which a clear indication of significant heat loses.

Temperature and Power Analysis

To compare the energy and temperature difference between the two building models, the house models are placed in a chamber with air conditioning applied to create a cold external temperature of 13 ºC. The house models is heated with an identical 14 watt halogen bulbs. Power monitoring system is connected to each house model to measure the electricity consumption. The heating system is controlled by a thermostat to turn the heating OFF when the internal temperature reaches the room temperature (21 ºC). The internal temperature is monitored by two thermocouples, to assess the temperature pattern. As show in Figure 5, the heating turns ON when the internal temperature inside both houses is the same at 15.3 ºC. The temperature inside the insulated house starts to rise rapidly reaching the target temperature just after about 3 minutes. The non-insulated house heats up very slowly, and after about 20 min it reaches steady state at about 17 º as its highest temperature; with significant steady state error. After just 15 minutes the temperature in the insulated house became stable at 20.5 ºC as lowest when the heating turned OFF and then reached 21.5 ºC as highest when the heating is turned ON again. The heating ON/OFF cycle has been found to be around 50 seconds long (see Figure 4). However, the temperature in the non-insulated house varied between 16.5 and 17.0 ºC despite of the fact that the heating is turned ON continuously.

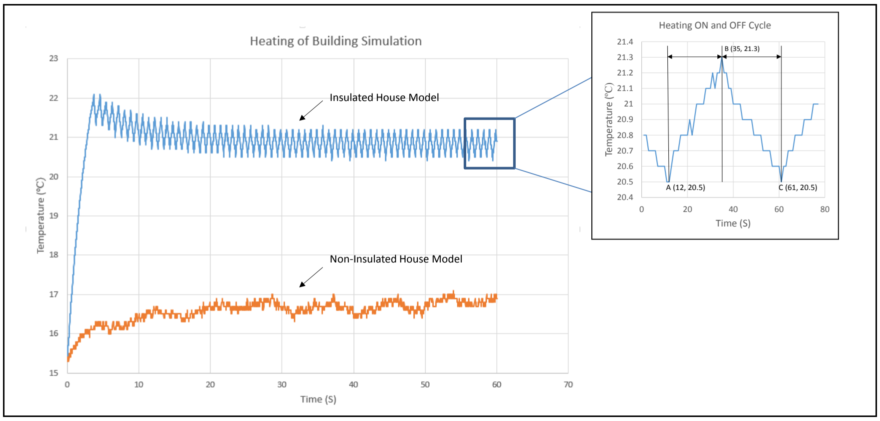

Figure 4: The temperature profile of the two building models.

From Figure 4, when the energy consumption is considred, it has been found that the non- insulated building consumes double the energy despite the fact it never reached the required temperature.

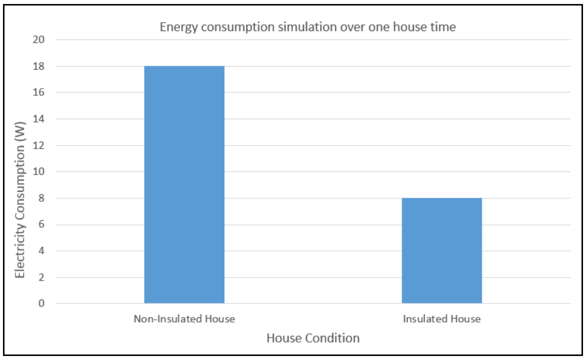

Figure 5: A comprasion of energy consumption between the two building models.

Conclusion

Reducing energy consumption in buildings is becoming essential to reduce global warming, decrease energy consumption and enhance long-term sustainability. Developing the teaching and training process on real buildings are costly and time consuming, with difficulty in influencing the external environment. Therefore, a new tool was needed to improve public engagement in this area and introduce the concept of building insulation and energy consumption in educational and public environment to enhance the understanding of the concept. This paper has suggested an educational tool which combines a layer or more of detachable, interlocking and interchangeable insulation, combined with heating and/or cooling of the external and the internal volumes inside and outside the building to study the power consumption and the thermal parameters of buildings. Moreover, the proposed kit can be used for advanced building research since it can significantly reduce the cost of the experimental work. This educational kit is expected to enhance public engagement, the teaching and learning process of students.

References

[1] "EU Energy and Transport inFigures, Statistical Pocket Book 2007/2008," Euro-pean Communities, Brussels, Belgium, 2008.

[2] EU, "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)," *Off. J. Eur. Union*, pp. 13–35, 2010.

[3] A. Al-Habaibeh, G. Anderson, K. Damji, G. Jones, and K. Lam, "Using Infrared Thermography for Monitoring Thermal Efficiency of Buildings-Case Studies From Nottingham Trent University," *7th Jordanian Int. Mech. Eng. Conf. 27 - 29 Sept. 2010, Amman – Jordan 2.*, no. September, pp. 27–29, 2010.

[4] J. Kim and J. W. Moon, "Impact of Insulation on Building Energy Consumption," *Build. Simul. 2009*, pp. 674–680, 2009.

[5] U. Y. A. Tettey, A. Dodoo, and L. Gustavsson, "Effects of different insulation materials on primary energy and CO 2 emission of a multi-storey residential building," *Energy Build.*, vol. 82, pp. 369–377, 2014.

[6] Å. Jönsson, A.-M. Tillman, and T. Svensson, "Life cycle assessment of flooring materials: Case study," *Build. Environ.*, vol. 32, no. 3, pp. 245–255, 1997.

[7] J. Yu, C. Yang, L. Tian, and D. Liao, "A study on optimum insulation thicknesses of external walls in hot summer and cold winter zone of China," *Appl. Energy*, vol. 86, no. 11, pp. 2520–2529, 2009.

[8] A. D. La Rosa, A. Recca, A. Gagliano, J. Summerscales, A. Latteri, G. Cozzo, and G. Cicala, "Environmental impacts and thermal insulation performance of innovative composite solutions for building applications," *Constr. Build. Mater.*, vol. 55, pp. 406–414, 2014.

[9] M. F. L. I. N. Camilleri, "The effect of mandatory insulation on household energy," *Branz*, vol. 130, no. 130, pp. 1–12, 2008.

[10] J. Goodhew, S. Pahl, T. Auburn, and S. Goodhew, "Making Heat Visible: Promoting Energy Conservation Behaviors Through Thermal Imaging," *Environ. Behav.*, 2014.

[11] C. Xie, E. Hazzard, and S. Nourian, "Infusing Technology Into Engineering Education," *Eng. Des. Educ. Res. Summit, P-12*, pp. 1–14, 2010.

[12] J. Haglund, F. Jeppsson, E. Melander, A. M. Pendrill, C. Xie, and K. J. Schönborn, "Infrared cameras in science education," *Infrared Phys. Technol.*, vol. 75, pp. 150–152, 2016.

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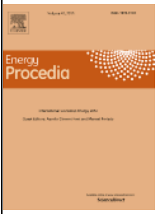

Biography

Professor Amin Al-Habaibeh is a professor of Intelligent Engineering Systems within the Product Design team at Nottingham Trent University. He is currently leading the Innovative and Sustainable Built Environment Technologies research group (iSBET). Amin's interest also includes condition monitoring, intelligent systems, sustainable technologies, product design and advanced manufacturing technologies.