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Innovative concept of an educational physical simulation tool for teaching energy consumption in buildings for enhancing public engagement

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Abstract

Buildings consume significant amount of energy for heating or air-conditioning in most countries. Therefore, educating the public and young generations to enhance their engagement and encourage them to reduce carbon emission and energy consumption in their daily life is becoming essential worldwide to drive continuous improvement towards more sustainable future. This paper presents an innovative educational tool to simulate energy performance and its use in educating university students and teaching school children about the subject. The paper outlines the developed educational tool and presents its benefits via two detailed case studies, with wide and diverse level of knowledge and learning outcomes. The educational technology includes a small-scale multi-layered model of buildings where insulation layers can be added to or removed from the building's envelop to influence energy performance. Qualitative and quantitative research has been conducted. The results show that the technology is capable of engaging the young generation and to help them to understand the thermal performance and energy efficiency of buildings.

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

1. Introduction

Currently, it is becoming necessary to improve public understanding and engagement regarding energy conservation and sustainability, particularly in the building sector. Additionally, educating pupils, students and researchers about the impact of insulation and further modifications of buildings on building energy consumption is becoming a central activity to expand scientific knowledge, public engagement and awareness in this field. This will allow them on the long term to take the right decision regarding energy saving measures. Today, it seems there is a substantial lack of appropriate educational tools in this

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area of research, which could contribute to improving the understanding and the impact of the building envelope on the energy efficiency and thermal performance. Energy consumption in the building sector in the EU stands for about 40% of the total amount [1]. The EU directive 2010/31, has a goal to cut down energy consumption and carbon emissions in the EU by 20% by the year 2020 [2]. The directive also highlights that all new buildings have to have nearly zero-energy buildings standard by the same period.

Many countries around the world with an old stock of houses are facing a big challenge to improve the energy performance of their existing buildings. To enhance the public engagement in this process, people need to understand and appreciate the benefits of adding insulation to their buildings, mainly in relation to the indoor comfort temperature and financial savings. Thermal insulation is an essential element that improve the energy performance of buildings. By adding insulation, new and renovated buildings will offer an acceptable level of indoor temperature and energy conservation. Today, there is significant research available in this area. Al-Habaibeh et al. [3] has published a case study of a renovated university building, where the insulation performance has been improved, particularly by adding an internal doubled glazing to the windows. The study provided thermal images of the building before and after the deep renovation. The image comparison demonstrates very clear improvement in the thermal insulation performance of the building. Hilliaho et al. [4] has investigated the impact of added glazing on balcony's indoor temperature, by the monitoring of 22 balconies in Finland for about 10 months period; the results showed that the glazed and unglazed balconies had higher temperature than the outside air by 5.0 ºC and 2.0 ºC respectively. Yousefi et al. [5] has investigated the impact of occupant behaviour on energy performance of building envelopes via simulation using occupants' data, the study emphasises the importance of occupants' engagement and the user selection of envelope materials on energy performance. A study by Aditya et al. [6] has analysed the research and benefits of building insulation in literature. It has found that one of the most effective ways of energy conservation is building insulation. It has been found to offer significant savings in the residential, commercial and industrial sectors. A study [7] has investigated the effect of strengthening the external insulation level on energy consumption for heating and cooling in buildings with various internal heat gain levels in Seoul, South Korea. It has found that the thermal insulation should depend on whether the building is envelope-dominated or internally dominated to decrease the building heating and cooling energy requirements. Another study has examined the change in outdoor temperature in Cameron and its effect on the indoor climate of buildings [8]. The research has suggested that the thermal insulation technology can be one of the leading methods for reducing energy consumption in new buildings. However, careful evaluation is needed for selecting the right thickness of the insulation material due to high insulation costs. Investigation of expanded polystyrene with specific thicknesses evaluated as optimum material for external wall based on the life cycle saving, life cycle total cost and payback period [9]. The mandatory insulation regulation in New Zealand since 1978 has resulted in higher internal temperature and decreased energy consumption [10].

The engagement of public in the insulation process is a big challenge, and the research work in this area is still limited at industrial and academic levels. Some efforts have been made to encourage the public in building energy conservation and improve their engagement. A research presented by Goodhew et al. [11] has explored the behavioural effect of visualising the heat losses from residential homes and its consequences for energy saving using infrared technology. The research provided thermal images for the householders to enable them to see the heat escaping from their homes in order to study any eventual motivational effect on behavioural energy conservation. The results have showed potential energy saving by using the demonstrated visualisation technology. An educational concept has been presented by Xie and Nourian [12] with aim to improve design-based learning. The concept is consisted of simple physical building models and modelling software. The educational tool and the curriculum units have been examined in three high schools with the participation of about 200 students. The results illustrated positive responses from students. However, the recommended physical models had the advantage of being low cost and simple, but they have some limitations in modularity for the user. Haglund et al. [13] has presented a qualitative educational research, where thermal imagery is used in science subjects at different school levels. The research has focused on visualisation of heat transfer in chemical and physical processes across all school ages. The results have shown that the thermal imaging in combination with simple well-structured theoretical activities could support the students' thermodynamic learning. The educational curriculum for different school levels worldwide highlight the importance of using different scientific equipment, for example, in taking measures, recording data, creating diagrams, increasing the degree of complexity, identifying scientific evidence, etc. The new national curriculum for year six in the UK [14] mentions very clearly the expected development criteria that the pupils have to reach in this school level. Particularly, at the key stage 2 level of this curriculum explains these objectives in detail:

- Planning different types of scientific enquiries to answer questions, including recognising and controlling variables where necessary.
- Taking measurements, using a range of scientific equipment, with increasing accuracy and precision, taking repeat readings when appropriate.
- Recording data and results of increasing complexity using scientific diagrams and labels, classification keys, tables, scatter graphs, bar and line graphs.
- Using test results to make predictions to set up further comparative and fair tests.
- Reporting and presenting findings from enquiries, including conclusions, causal relationships and explanations of and degree of trust in results, in oral and written forms such as displays and other presentations.
- Identifying scientific evidence that has been used to support or refute ideas or arguments.

The above literature review confirms the need for physical educational building models, which are simple and modular that could benefit the educational sector, enhance public engagement and assist advanced research in the field of insulation and building energy performance.
In [15] the authors have presented an innovative design of an educational simulation tool for exploring energy consumption in buildings towards enhancing public engagement. This paper integrates the physical simulation tool developed by the authors with teaching and learning activities for university students and school children to aseess its usefullness via two case studies.

2. The Educational Building Simulation Model

Fig. 1 presents an outline of the proposed building simulation. Fig. 1-a illustrates a schematic diagram of the developed building simulation for this paper, to examine its usefulness for teaching school children and university students. Fig. 1-b shows the actual model with an insulated building and non-insulated building and Fig. 1-c presents the infrared image of the two models during the experimental work. Each insulated building model is provided with one or more insulation layers internally or externally. The heating of buildings can be based on a light bulb, an electric resistive heater or a heat pump could be used for heating or cooling (e.g. Peltier effect). The heating system is controlled via a thermostat. The internal temperature is monitored by a temperature sensor, which can be connected to a PC or other portable display systems to show and record real time graph of data. The external temperature could be controlled and monitored by housing the simulation tool in an environmental chamber. To monitor and record the energy consumption for heating, the system could be connected to a power supply via a power meter with an associated display. The heat loss of the building model can be inspected by using an infrared camera to study the building thermal performance with different insulation levels and in different climate scenarios. For further details regarding the model, please refer to authors' previous work in reference [15].

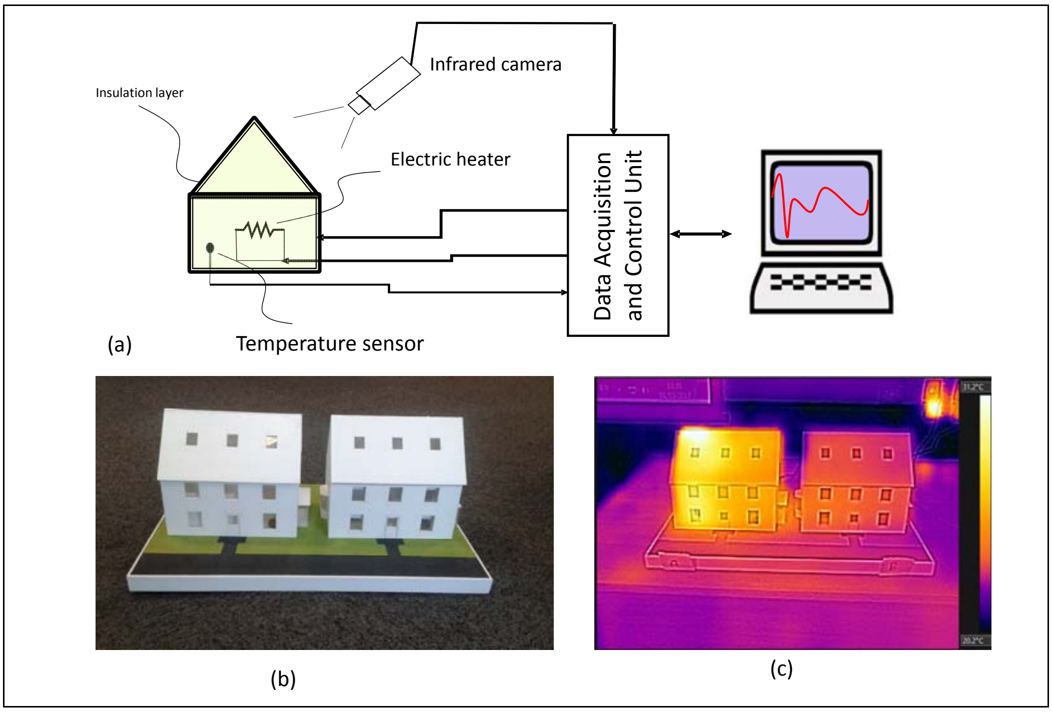
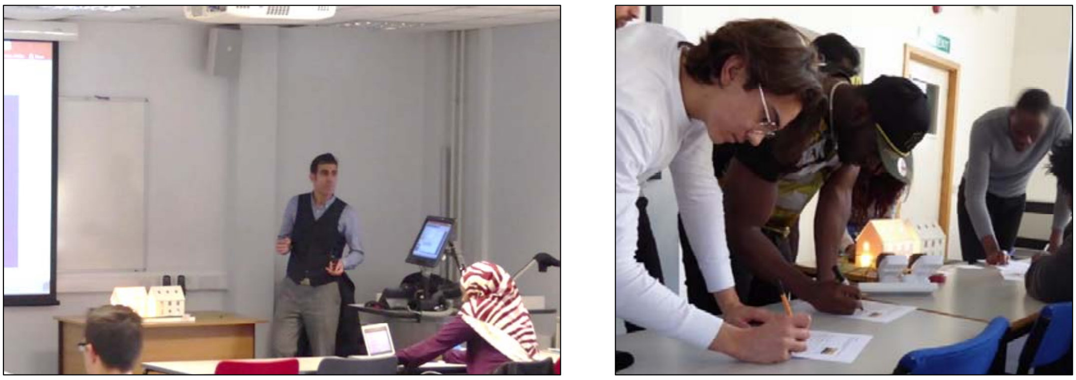


Fig. 1. A schematic diagram of the proposed system (a), the actual building models with an insulated and non-insulated building (b) and a possible application including the heating, monitoring and control systems with infrared technology (c).

The educational building simulation tool, which is tested in this paper, consists of two identical building models, one with insulation and one without insulation. Both building models are provided with identical equipment and instrumentation, including a power metre with display, 14-watt bulb for heating, K-type thermocouple for monitoring of internal temperatures and thermostat for controlling of internal temperatures. Both thermocouples are connected to data acquisition with display to monitor and/or record the internal temperature of both buildings. A smart phone infrared camera (FLIR One) attached to iPhone 5 is used to detect the heat loss of the building models and engage the participants.

3. The implementation of the educational simulation tool

The simulation tool is tested in different educational levels, including primary school children and university students, see Fig. 2. The test sessions consisted of three main stages: demonstration and explanation of the system, hands-on application activity for the pupils/students and feedback and the evaluation of the educational tool in relation to its learning outcomes. The design and degree of difficulty of the sessions are planned according to the target group. The levels of the session varies between the basic version which is designed for primary school children (case study 1) and the more advanced version for university students (case study 2), taking into consideration the specific objectives and learning outcomes of the sessions. Additionally, Hawas et al. [15] presented a case study, where the educational simulation tool has been applied in a chamber to control the external temperature and create a cold environment. The concepts which are applied for university students are flexible and could fulfil a wide range of learning outcomes depending on the subject area, where energy in buildings is the main theme. However, other learning outcomes could include CAD design, manufacturing, instrumentation, software development, data acquisition, infrared thermography, materials, thermodynamics and heat transfer, etc. This paper presents two case studies, where the educational simulation tool has been applied at primary school level and university level in the UK.



(a) (b)

Fig. 2. Workshop sessions for primary school children and university students.

3.1 Case study 1 (primary school)

Based on the school educational learning outcomes for year six primary pupils, the learning activities of the session are:

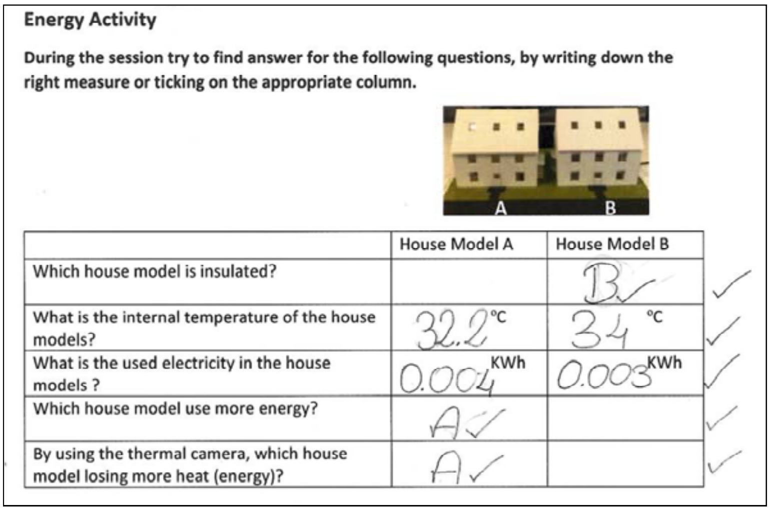
- Record the internal temperature of each building model.
- Record the energy consumption of each building model.
- Identify which building model uses more energy and why.
- Identify which building model reach the target internal temperature first.

- Identify which building model is insulated and which one is not insulated.
- By using an infrared camera, identify which building model is losing more energy.
- Describe the impact of insulation on energy consumption for heating.

The target group for this case study is a year six class with 20 pupils. When the demonstration of the educational simulation tool took place, the temperature in the classroom was around 22 degree Celsius; therefore, it required changing the heating setting of the building models to a higher internal temperature. The session has begun by turning the simulation model ON, and during the time, the pupils became familiar with the system and were requested to observe the behaviour of the both building models. After 30 minutes, an activity was applied and the pupils were asked to complete an activity sheet related to the behaviour of the building models.

The heating of the both building models turned ON at the same time. After only 3 minutes, the temperature inside the insulated building increased rapidly and reached 32 °C, while the temperature inside the non-insulated building raised slowly and reached a steady state temperature of 31 °C after 20 minutes. The temperature of the insulated building became stable after 15 minutes and reached 34 °C as the highest when the heating was turned ON and then decreased to 33 °C as lowest when the heating was turned OFF. After 30 minutes, when the heating of the non-insulated building was turned ON continuously the internal temperature stabilised between 31.7 °C and 32.2 °C as minimum and maximum respectively.

Fig. 3 presents an example of the activity sheet, which the participating pupils completed during the activity. The activity sheet works even as a feedback for the teacher to evaluate if the learning outcomes of the session are achieved or not. All pupils have completed the questions in the activity sheet with 100% correct answers. This is a good evidence which confirms the improvement of the technical skills, which are expected in the national curriculum [14] and shows the opportunity behind this educational tool.


Energy Activity

During the session try to find answer for the following questions, by writing down the right measure or ticking on the appropriate column.

A B

	House Model A	House Model B
Which house model is insulated?		B ✓
What is the internal temperature of the house models?	32.2 °C	34 °C
What is the used electricity in the house models ?	0.004 KWh	0.003 KWh
Which house model use more energy?	A ✓	
By using the thermal camera, which house model losing more heat (energy)?	A ✓	

Fig. 3. A typical energy activity completed by a pupil in primary school.

Following the activity session, the pupils were asked to complete a feedback questionnaire to evaluate their participation experience. The results show a significant improvement of understanding the role of insulation in saving energy within buildings, 90% of the pupils agree or strongly agree that the session has helped them to understand the energy saving benefit of insulation, see Fig. 4-a.

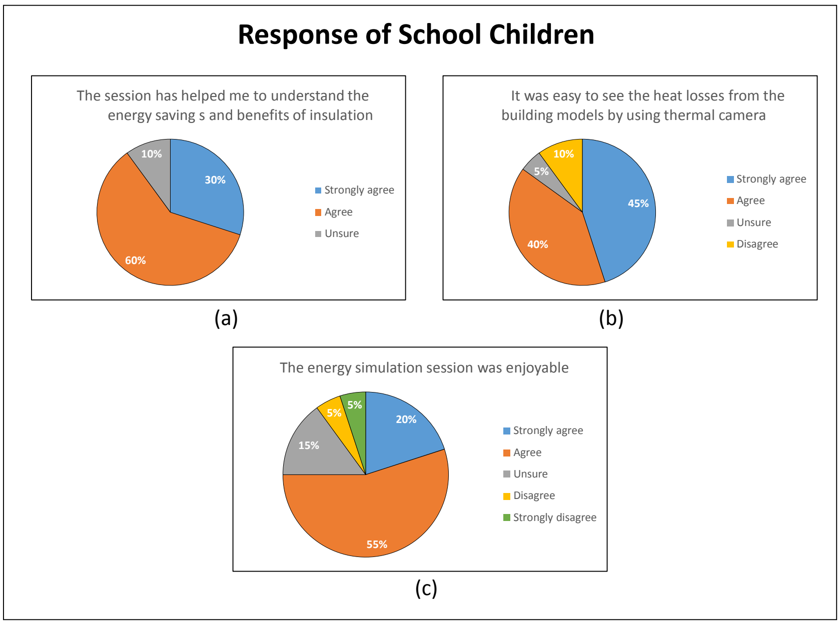


Fig. 4. The responses of school pupils regarding the usefulness of the session.