USING INFRARED THERMOGRAPHY FOR MONITORING THERMAL EFFICIENCY OF BUILDINGS -CASE STUDIES FROM NOTTINGHAM TRENT UNIVERS ITY

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ABSTRACT

Global warming and the continuous increase of energy cost are driving the need for reducing energy consumption. Buildings are responsible for approximately 50% of the UK energy consumption. Major part of this consumption is for heating and air conditioning of buildings. Nottingham Trent University is a leading university in the UK in relation to improving the performance of its buildings in order to improve insulation and energy consumption. The experimental case studies presented in this paper highlights some of the new measures taken to reduce energy consumption and enhance the sustainability of the University buildings. Infrared thermography is used to evaluate insulation measures and energy performance. The results indicate that enhanced insulation combined with modern sustainable technologies can significantly reduce energy consumption.

Keywords
Energy, insulation in buildings, infrared thermography.

1. INTRODUCTION

It is cheaper, at common energy prices, to save an extra unit of energy than to generate it, [Goldemberg et al., 1988]. Energy-intensive industries, road transport and cooling/ heating of buildings are the main sectors that could reduce their overall energy consumption significantly. Buildings consume a significant percentage of the total energy use, and space conditioning and heating amount to approximately 60.4% of the total energy end-use for the countries of Organization for Economic Cooperation and Development (OECD), [OECD, 1991]. In most countries construction activities range from 1 to 3% of existing number of buildings per annum, hence existing buildings are the ones that offer greatest potential for energy efficiency. Refurbishment of existing homes could reduce energy consumption by an average of 25%, [OECD, 1991].

Insulation plays an important part of reducing the energy consumption by reducing heat losses through the buildings envelop. In most cases this would involve simple and low cost measures such as double glazing, cavity walls insulation and insulation of loft space. Moreover, a major source of heat loss from a building is draft and air leakage. It is estimated about 40 to 60% of energy loss is caused by air leakage, [Colin, 2002]. In order to study and evaluate the effectiveness of insulation and air tightness, infrared cameras can be used to locate the position of the problem in most cases. Reference [Mui, 2006] suggests that an energy saving strategies may be in conflict with the criteria of indoor air quality and thermal comfort. A conventional air conditioning design may not be cost effective to achieve sufficient indoor environmental quality and at the same time reducing energy consumption. In order to optimise energy consumption in heating and air conditioning systems to prevent the deterioration of the indoor air quality and thermal comfort, a concept of the building environmental performance model has been developed by [Mui, 2006]. The suggested model is divided into two main modules:

the adaptive comfort temperature module and the new demand control ventilation module. It has been suggested that the new model could be used to reduce energy consumption.

This paper outlines some of the modern sustainable measures that Nottingham Trent University (NTU) has just completed in its largest and most exciting construction and refurbishment project to date. The Newton and Arkwright project has enabled an overhaul of the buildings, transforming them into beacons of sustainability. This aligns with NTU's ambition to inspire and embed environmental principles in all NTU activities, as demonstrated by NTU's EcoCampus project. EcoCampus is an Environmental Management System (EMS) and award scheme that has been specifically designed for universities. The aims of the EcoCampus Scheme are to assist institutions in moving towards environmental sustainability through good operational and management practices, [Nottingham Trent University, 2010].

2. INFRARED THERMOGRAPHY AND TEMPERATURE OF BUILDINGS

Infrared thermography can contribute in understanding the thermal efficiency of buildings and contribute in detecting local problems and air leakage locations. Infrared thermography is a non-destructive testing methodology that is used to determine the surface temperature of objects. From heat transfer viewpoint, objects transfer heat by three means: conduction, convection and radiation. Conduction is the transfer of heat through solid objects. Convection is the transfer of heat through the movement of a fluid such as air and radiation is the transfer of heat energy via electromagnetic radiation emitted by the object. The radiation emitted by the object includes the infrared radiation which can be detected by infrared systems. The amount of infrared radiation emitted by an object is partly a function of the temperature of the object, see section 5 of this paper. The available infrared cameras in the market normally work between 0.7 μm and 20 μm. For the calibration of thermal cameras a black body is used which is defined as being a perfect absorber as well as a perfect emitter. Also, a black body does not reflect infrared radiation from other objects in the surrounding area and its temperature is proportional to its infrared radiation. Objects in real life, such as buildings, do not always behave as an ideal black body. In order to describe the capability of a surface to emit energy compared with a blackbody, Emissivity value (ε) is used, defined as the ratio of the thermal radiation emitted by a surface at a given temperature to that of the black body for the same spectral and directional conditions. The emissivity of a black body equals 1 and Emissivity of any other type of surface is less than 1 and greater than or equal to 0. The advantage of using infrared technology is that significant amount of information can be captured in a relatively short period of time, [Al-Habaibeh et al., 2007]. The analysis can be performed either manually by examining temperature of objects or by automatic image processing techniques. Figure 1 presents a infrared and visual image of Newton Building at an ambient temperature of about 6^{o}C. The individuals standing on the steps (1) present the maximum temperatures in the image. Double glazed front windows (2) show significant insulation properties. The external concrete structure (4) is at about ambient temperature. Notice that the temperature of the rotating glass doors (3) are at slightly higher temperatures than (2) due to the absorption of internal heat when in use. The rotating doors are considered one of the most efficient energy saving door systems when compared with other systems. In order to reduce measurement error, the infrared data used for calculating energy savings in this paper is captured from the same angle and with the absence of direct sunlight.

3. NEWTON AND ARKWRIGHT SUSTAINABLE FEATURES

Nottingham Trent University has just completed its largest and most exciting construction and refurbishment project to date. This project is a flagship regeneration development for the University and for Nottingham city. It is focused on two historic buildings in the heart of Nottingham City Centre and the NTU City Campus. Newton is an imposing 10 storey 1950s building constructed of Portland stone which dominates Nottingham's skyline, whilst Arkwright, is a 19th century gothic style building where DH Lawrence studied as a young man. Both are grade II* listed and have suffered from particularly poor sustainability credentials in the past. The project has preserved these listed buildings to be used for their original purposes. The Newton and Arkwright (NA) project has huge relevance to the sector, largely because of the variety of challenges provided by the two huge buildings (gross area 31,990 m^2). Both are Grade II* listed and were subject to a series of planning restrictions. The Newton and Arkwright project has enabled an overhaul of the buildings, transforming them into beacons of sustainability. This aligns with NTU's ambition to inspire and embed environmental principles in all NTU activities, as demonstrated by NTU's EcoCampus project. The environmental features and energy saving measures of this project include:

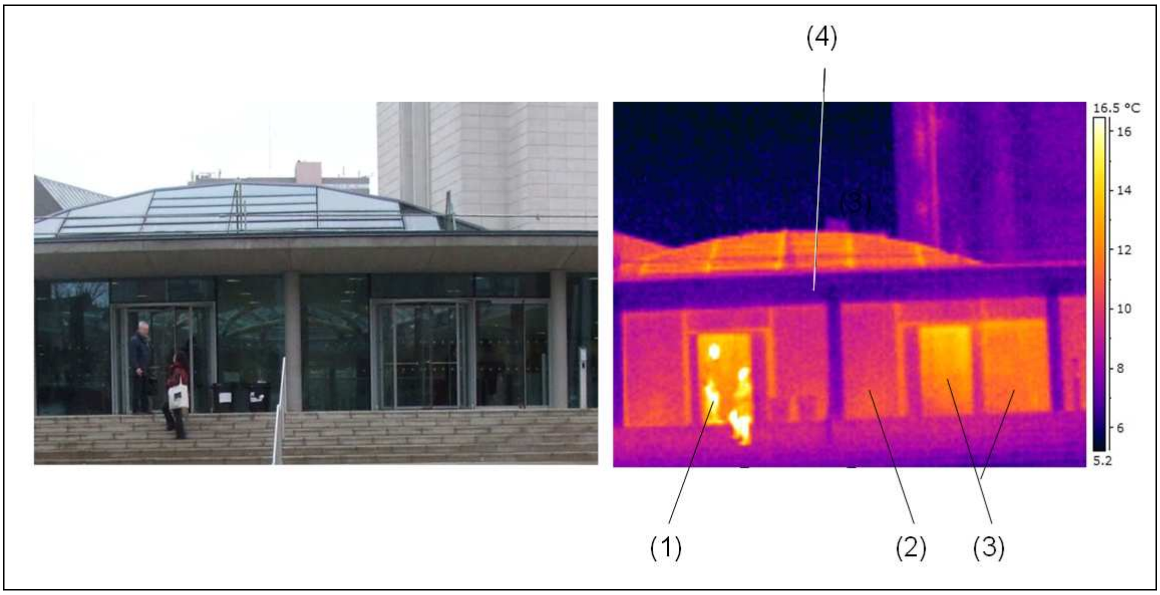

Figure 1: Infrared technology can be utilised to capture significant amount of information in an efficient way.

1. Retention and expansion of Nottingham's District Heating scheme throughout the development. In this scheme municipal waste destined for landfill is transformed into heat providing hot water for key buildings in Nottingham City Centre. Based on District Heat provider statistics and DEFRA conversion factors, the scheme uses 145000 tonnes of waste and saves 149000 tonnes of carbon dioxide annually. Indeed, the CO2 rating of the district heat is 0.154kg/CO2 per kWh compared to 0.185kg/CO2 per kWh for conventional gas fired boilers (16% less).
2. Sedum roof, see Figure 2, situated on the lower levels off Newton, approximately $2500m^2$ in size. Benefits include insulation properties (warm in winter, cool in summer), biodiversity creation within a city centre environment (which will help to support the local Redstart bird population for example), precipitation interceptor reducing the risk of localised flash flooding, improved local air quality from flora photosynthesis, reduced urban heat island effect and a reduced maintenance regime for the roof.
A final demonstration of the environmental commitment central to this project is through NTU's resident Peregrine Falcons. Since 2001 a pair of falcons have nested on the roof of the Newton building and this has continued during the project.

Figure 2: Example of sustainable features at Newton Arkwright Project, Sedum roof (1) and tined glass with automatic control to improve ventilation in warm conditions (b).

3. Vastly improved insulation through additional secondary glazing on Newton building façade (original windows protected, blinds in between which can be controlled by building users to control solar gain). The energy savings as a result of these measures will be discussed in detail.
4. Modern chilled beams for temperature control are serviced by highly efficient heat reclaim systems, predominately supported by thermal wheels (typically recovering 75-85% of the energy in air bound for extraction).
5. Occupancy sensor lighting throughout and daylight control on perimeter lights. In additional, internal room layout improvements to reduce lighting requirements by maximising natural light. Tinted glass in the Central Court to reduce solar gain, see Figure 2-b.
6. Fresh air supply (free cooling) to high occupancy areas such as lecture theatres and ventilation systems fitted with heat reclaim devices. Systems also include Pumps and fans with variable speed drives, only using power for current demand.
7. Electric chillers in Newton are installed, however they are most energy efficient when running at ½ load, so NTU is installing three (predicted demand could be met with just two running at full load). For example, running at full load one chiller will produce 3.9kW of cooling for every 1kW of electricity, however running at half load 5.16kW of cooling is generated from the same amount of electricity. This is based on statistics provided by the manufacturer.
8. Low energy system (e.g. 18°C constant then occupancy sensor triggers heating to 21/22°C). This is part of a fully integrated Building Management System (BMS) which estates staff will control to maintain best possible efficiency

In additional to the above, there has been a drive from the human-factor side to encourage sustainable transportation. For example, the project included basement shower and locker facility for cyclists, walkers or joggers (staff and students). Adjacent link with Nottingham bus and tram network; including NTU's own tram stop. Guaranteeing the future life of the buildings by removing long term maintenance problems and addressing Disability and Discrimination Act issues. First rate waste management system, with recycling facilities provided for all users including organic waste, plastics, metals, paper, card and glass recycling.

4. INSULATION OF NEWTON BUILDING

Newton building insulation has been significantly improved through additional secondary glazing on Newton building façade (original windows protected, blinds in between which can be controlled by building users to control solar gain). Newton building was monitored before and after refurbish between 2005 and 2010 using infrared thermography to monitor the thermal performance of the windows. The main total area of glass on both sides of the building is about 2172 m^2. In the past this was a single glazed area with significant heat losses during winter. Figure 3-a presents the performance of the building in 2005. It has been found that there is significant heat losses from the windows. In 2010 and after refurbishment, a similar infrared image was taken for the building, Figure 3-b. It has been found that the building performance has improved significantly with an average reduction in the external temperature of the building. It is estimated from the infrared images of Figure 3 that the average difference in temperature is at least 4^oC which indicate significant energy savings over the 2172 m^2.

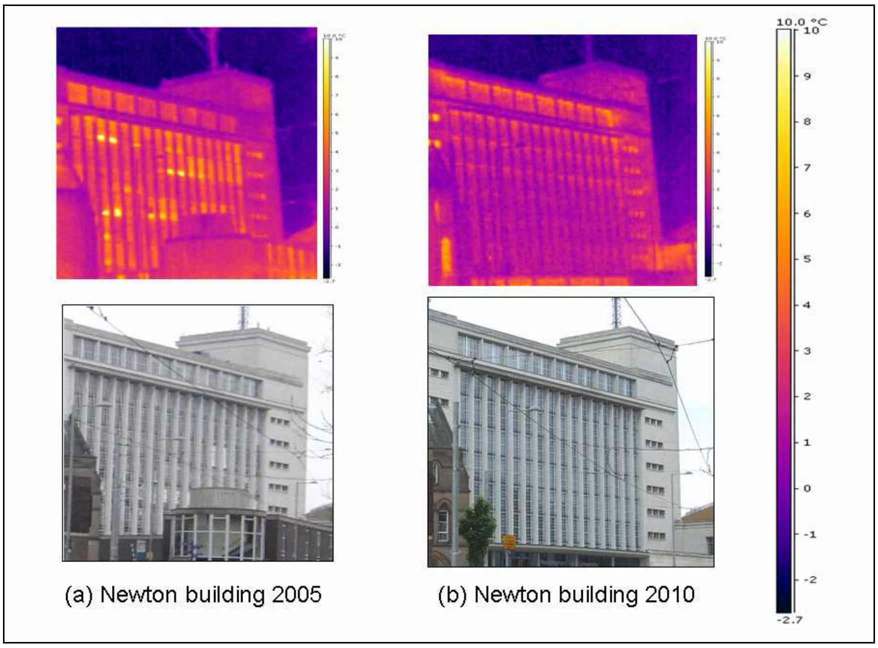

Figure 3: Normalised infrared images of Newton building before and after refurbishment.

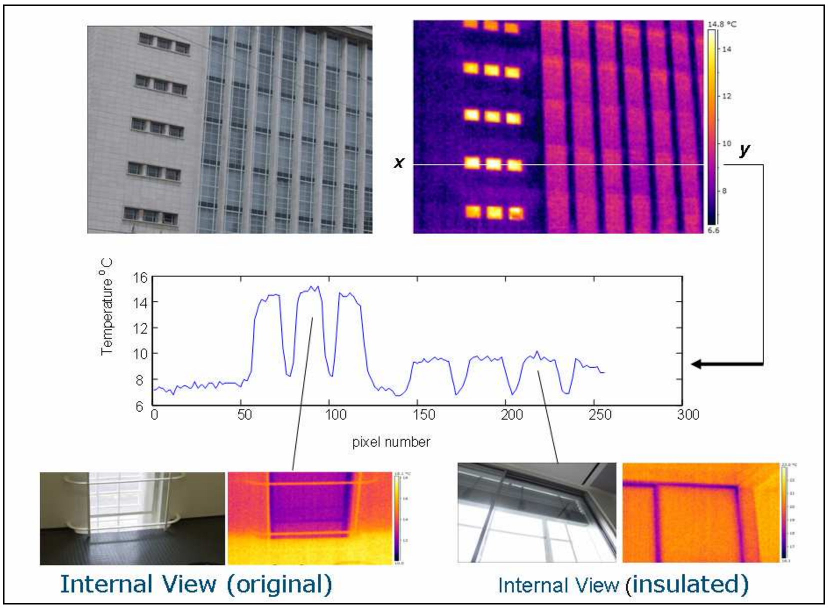

Figure 4: The effect of double glazing layer on the external temperature of the building.

In order to quantify the effect of insulation, Figure 4 presents a comparison between the modified windows and the original single glazed windows. There is significant savings in relation to the 2172 m^2 that has been insulated. Line *xy* is plotted in Figure 4 to indicate the different in temperature. The temperature reduction is about 6^oC assuming the same internal temperature. However, since the original windows are serving the stairs with limited heating systems, the stairs are expected to be at less temperature and this indicate a difference in temperature of more than 6^oC. Figure 4 also presents the internal view of the both types of windows. It is clear that the newly added double glazed windows have significantly improved insulation when compared with the original windows. Figure 5 presents comparison between the thermal performance of Newton building between 2005 and 2010.

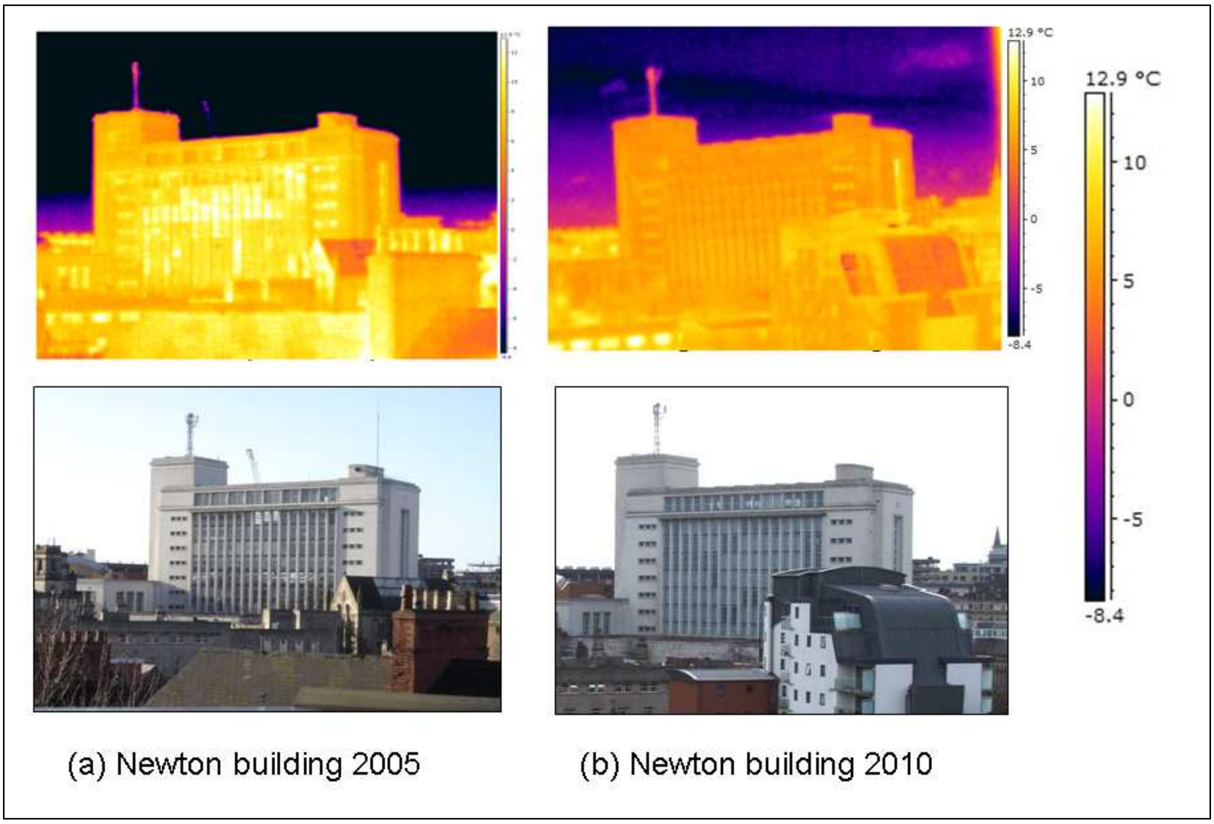

Figure 5: Comparison between the thermal performance of Newton building between 2005 and 2010.

5. QUANTITATIVE ESTIMATION OF ENERGY SAVINGS

This section provides approximate estimation of heat losses and savings made by installing the internal layer of double glazing. Thermal power, *P* is dissipated from the external surface of the windows, due to heat passing from the interior of the building through the windows by means of conduction, convection and radiation. Conduction losses are ignored in this work due to its expected marginal value in comparison to the other two.

According to Stefan-Boltzman law, the energy emitted in radiation is expressed as:

$$E = \varepsilon k(T^4 - T_C^4) \quad (1)$$

where E is the radiated energy $[W/m^2]$, k is Stefan-Boltzman constant 5.67 x10^{-8} $[W/m^2K^4]$, ε is the surface integral emissivity, T is the surface temperature of the object $[K]$ and T_C is the temprature of the surroundings [K]. In this study, ε is estimated to be 0.93 for the windows.

The sensible heat flux of convection [Hoyano et al., 1999] can be expressed as:

$$H = \alpha_c (T_s - T_{air}) \qquad (2)$$

where α_c is the convection heat transfer coefficient [W/m^2K], T_s is the surface temperature [K] and T_{air} is the air temperature [K].

As described in [Albatici and Toneli, 2010], the thermal power lost by convection and radiation can be estimated by combining equations (1) and (2) as:

$$P = 5.67\varepsilon_{tot}\left[(\frac{T_i}{100})^4 - (\frac{T_{out}}{100})^4\right] + 3.8054v\,(T_i - T_{out}) \quad W/m^2 \qquad (3)$$

where P is the thermal power dissipated through the windows [W/m^2], ε_{tot} is the emissivity on the entire spectrum (integral emissivity), T_i is the surface temperature of the element (windows in this case) [K], T_{out} is the outer environment temperature [K], $3.8054v$ is the convection heat transfer coefficient α_c with v is the wind speed [m/s]. Jurges' equation was used to calculate α_c based on the wind velocity near the building element at the time of measurement.

From Figure 4, it is estimated that the average temperature of the external windows without the internal double glazing is 15 ^{o}C and the external temperature of the modified windows are estimated to be 9 ^{o}C. In January, for example, assume the average ambient temperature is about 3.6 ^{o}C in Nottingham based on 24 hour average with average wind speed of about 2 m/s. From equation 3, the thermal power dissipation for original and modified windows is estimated to be 140.94 and 65.944 W/m^2 respectively. This is estimated to be 53.2% savings. For the total area of 2172 m^2, the total energy saved is estimated to be 162 kW. In month of January, the financial savings over 24 hours per day and 31 days is estimated to be about £11,972 based on the cost of 9.879p per kWh. The authors are currently working on the energy savings and the expected payback period in more detail to provide further accurate analysis.

6. CONCLUSIONS

NTU has demonstrated its vision to create a sustainable space which can be used as a best practice example to the sector to enable the march toward a zero carbon society.
The Newton and Arkwright project also contains first class examples of sustainable design. The paper presented case studies of sustainability focused development and comparison of using infrared thermography to evaluate some of the measures. Comparison study has been presented between the original windows in 2005 before refurbishment and in 2010 after adding internal doubled glazing. The refurbishment of Newton building has resulted in significant improvement in building insulation and thermal efficiency. For savings from the doubled glazing, it is estimated that the savings are at least 6^{o}C over an area of 2172 m^2 in a typical winter environment in the UK.

7. REFERENCES

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