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INFLUENCES OF LIGHTING CONTROL AND NATURAL VENTILATION ON ENERGY USE AND OVERHEATING FOR A DAY-LIT INDUSTRIAL BUILDING

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ABSTRACT

Overheating in buildings not only causes discomfort to the occupiers but – if it occurs regularly or over a sustained period – also leads to pressure for the installation of mechanical cooling. In addition to the initial cost and ongoing maintenance requirements of such systems there will be an increase in the overall energy use of the building. This paper investigates the thermal performance of an industrial building (retail shed) with rooflights by means of dynamic computer modelling. The effects of lighting control and natural ventilation on overall energy consumption and overheating were performed by using this model. The modelling results clarify that these methods substantially reduce overheating hours as internal heat is dissipated through the openings and lighting heat gains are cut. In addition, overall CO_2 emissions can be cut by over 25% by using daylight sensing controls. All in all, natural ventilation at ridges of the roof together with lighting control reduces overheating to commonly acceptable levels without recourse to mechanical cooling.

INTRODUCTION

It is evident that greenhouse gas emissions, principally Carbon Dioxide from the burning of fossil fuels, could siginificantly alter the Earth’s climate by strengthening the greenhouse effect (Roberts 2008). Predictions from climate models indicate an increase in global average temperature of up to 6°C and an increase in sea level of up to 1.0 metre over this century. The building regulations are legally enforceable regulations which with questions of the conservation of energy and the health and safety of occupants. Buildings are by far the biggest cause of Carbon Dioxide emissions in the UK and hence it is in the development of buildings that the greatest savings can be made (see Figure 1 to find how big contribution on CO_2 emissions from building sector). Energy efficent designs for buildings become critital to cope with this change. In fact, a problem about overheating inside buildings becomes more serious due to the global warming (De Herde et al. 1994, Dorota et al. 2009, Amato et al. 1984). Especially, day-lit buildings can easily have a potential to come into overheated working spaces. This paper focuses on the use of artificial lighting control scheme and natural ventilation to deal with this possible problem for these day-lit industrial buildings.

Natural ventilation is the process that relies on air pressure difference to supply and remove air through an indoor space by any natural means (Gratia et al. 2007, Manz 2004). Pressure differences can be caused by wind or the buoyancy effect created by temperature differences or sometimes differences in humidity. In either case, the amount of ventilation will depend critically on the size and placement of openings (normal forms as windows or doors) in the building. With an increased awareness of the cost and environmental impacts of energy use, natural ventilation in buildnigs has become an increasingly attractive method for reducing energy use and cost and for providing acceptable indoor environmental quality and maintaining a healthy, comfortable, and productive indoor climate rather than the more prevailing approach of using mechanical ventilation. In favorable climates and buildings types, natural ventilation can be used as an alternative to air-conditioning plants, saving 10%-30% of total energy consumption.

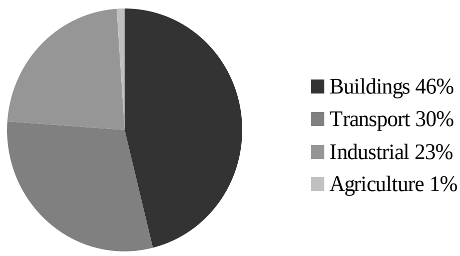

Figure 1 CO_2 emissions by sectors in the UK

It is useful to think of a natural ventilation system as a circuit, with equal consideration given to supply and exhaust. Due to high internal heat loads, natural ventilation for big warehouses, retail sheds and other similar spaces is often employed. Frequently, conventional or overhead doors are manually opened to provide ventilation. When natural ventilation does not suffice alone, large box fans are often employed to enhance air movement, which is out of scope of the research in this paper.

The use of daylight as the primary light source in buildings is of interest to those concerns with energy conservation because it is assumed to minimise the use of electricity for lighting (Kasule et al. 2000, Jenkins et al. 2007, Cheng et al. 2007). However, it is difficult to justify the cost of extensive daylighting on the basis of energy savings alone. So that, considering application of rooflights for the buildings to get daylight, lighting control is the way to control the thermal performance inside the building. Lighting control is always used to reduce or eliminate electric lighting automatically when there is an adequate contribution of daylight for a working space. A photocell component measures daylight levels, transmits the data to the control component, which then switches on or off lighting.

Therefore, the lighting is automatically regulated, adapting the light schemes to the use and surrounding of the working environment, and if desired, the settings can be overruled according to personal preference through a push button or remote control (Li et al. 2005, Franzetti et al. 2004, Ne'eman 1984).

METHODOLOGY

Model of the building

The industrial building modelled in this paper is a portal framed shed with one storey and one ridge/pitched hip roof, which is illustrated in Figure 2. The floor area of the building is 2322m^2 with the retail area of 2200m^2 (there is a space used as office at the rear of the shed) on which this research work was based. The height of the building is 9 metres (from ground to eaves). In addition, Figure 2 shows the rooflights arrangement (in parallel but different length to avoid construction underneath, e.g. office at the rear and entrance porch from the front of the building) on the top of the roofs, which takes 15% of floor area of the building. There is no rooflight at the side hip roofs. Light transmission rate of 0.762 for rooflight panes is used.

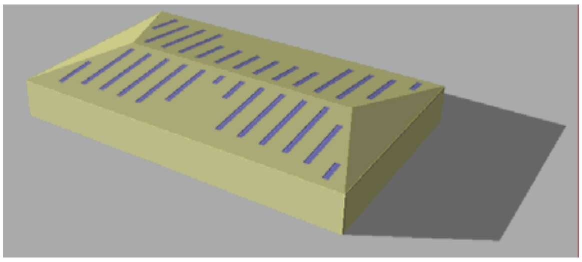

Figure 2 3D model of the building

The walls and roofs of the building are constructed by metal cladding panels with elemental U-values shown in Table 1 below. The real weather data for southeast England were applied for this model. The building was heated in winter only with set point of 18ºC, so that there is no cooling/air-conditioning in summer. In order to cool inside in summer for coping with possible overheating problem, natural ventilation was introduced by using two ridge openings on the top of the roof with dimensions of 0.2m×40m each.

Table 1
Elemental U-values for the building

ELEMENTS	W/m^2 K
External walls	0.26
Internal walls	0.30
Roof	0.20
Ground floor	0.17
Rooflights	2.80

Artificial lighting was set as automatic ON/OFF control operation by using photocell sensing control equipment based on the level of daylight availability. Lighting level was set to 500lux that comes from general design guidance for industrial buildings (CIBSE Concise Handbook 2001) with maximum lighting gain of 5.6W/m^2.

The building is orientated with entrance porch facing southwest. Air infiltration rate of 0.5ach is applied for this building. This building operates from 8am until 8pm Mondays to Sundays.

Daylight analysis

The standards for day-lighting should be complied with daylight availabilities (i.e. daylight factors, daylight uniformity ratios, daylight illumination levels). Natural light should be the prime means of lighting, with electric light to supplement it. Roof-lights can reduce electric lighting requirements but can result in increased heat losses.

In many industries, the most common means of admitting daylight is through a rooflight. Full guidance on the design and effects of rooflights and windows can be obtained from the CIBSE Window Design Guide. Electric lighting is usually designed as though there were no daylight, in terms of achieving the desired illumination levels. However the lighting designer should be fully aware of the degree of daylight and sunlight in order to assess the suitability of some form of control system.

The daylight factor (DF) is a very common and easy to use measure for the subjective daylight quality in a room. It describes the ratio of inside illuminance over outside illuminance, expressed in per cent. The higher the daylight factor, the more natural light is available in the room.

It is expressed as

$$DF = \frac{E_{in}}{E_{out}} \times 100\% \qquad (1)$$

where DF is daylight factor, E_{in} is inside illuminance at a fixed point (lux) and E_{out} is outside horizontal illuminance under an overcast (CIE standard overcast sky) or uniform sky (lux).

The average daylight factor is the ratio between the mean illuminance in a space and that from an unobstructed sky externally expressed as a percentage. In calculation terms, the sky is generally assumed to be standard CIE overcast sky. Daylight factor in this model was calculated using a computer program Lumen Designer that determines the daylight factor on predefined grid and takes the average. The average daylight factor was therefore used as a guide to control the use of artificial lighting inside building when real weather data are introduced.

Dynamic thermal simulation

Thermal modelling and simulation was performed dynamically by using EDSL Tas program on hourly-calculated cycles. The real weather data showing hourly records were integrated into the model. The modelling results can show either detailed operational parameters such as internal temperatures, humidity, air flow rate through apertures etc or the summarised values for each week, month or the whole year, e.g. heating/cooling loads, solar gains and internal gains. In addition, the program can handle complex lighting control, different ventilation schemes, multi-zone airflow and timed aperture opening controls etc.

The issue for estimating overheating inside building is normally regulated by percentage of occupied hours over certain temperatures that is expresses as

$$\chi_i = \frac{\sum t_i}{\sum T} \times 100\% \qquad (2)$$

where i is a certain temperature (ºC), χ_i is in percentage (%), $\sum t_i$ is total hours over temperature i and $\sum T$ is total occupied hours.

CO_2 emission is another rating to evaluate the thermal performance of the building at energy utilising aspect. It is always calculated by the following equation through the conversions from the energy uses

$$CO_2 = f \times \frac{E}{\eta} \qquad (3)$$

Where CO_2 is Carbon Dioxide emission (kg/m^2/year); f is conversion factor; E is energy consumption (kWh/m^2) and η is efficiency of conversion. For grid electricity, the efficiency of conversion is obviously 1.0. For natural gas, conversion factor is 0.194 (with total heating efficiency of 80%), and for grid electricity this figure is 0.422.

RESULTS AND DISCUSSIONS

Daylight distribution inside the building

The daylight distribution on the floor of the building is shown in Figure 3. There is a rectangular area at rear of the building without daylight availabilty occupied by an office block. The image shows a good accordination between daylight availability on the ground floor and the rooflight arrangements on the top of the roof, which is illustrated in Figure 2 previously. The further calculation presents the shed ground floor with average daylight factor of 9.84%.

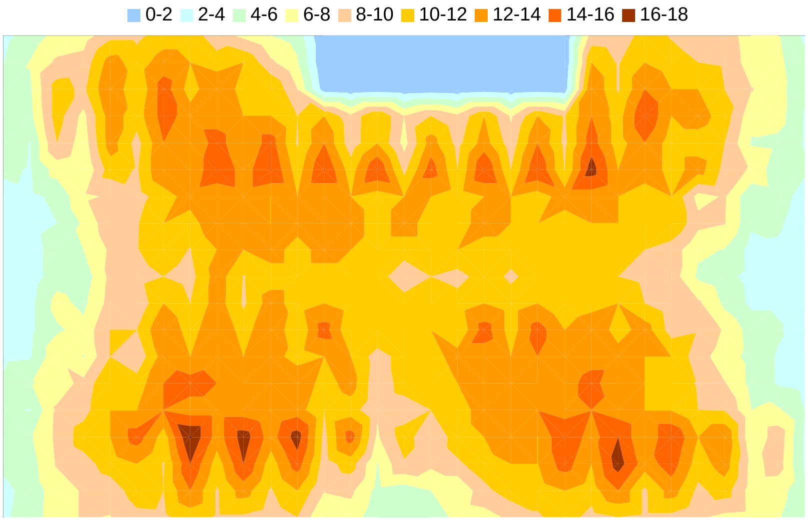

Figure 3 Daylight factor distributions on the floor of the building

Heating and lighting energy

The main energy consumption of the building is summarised in Table 2 below. 'LC' in the table means lighting control, and 'Vent' stands for ridge open natural ventilation. The figures in the table are in kWh per floor area (m^2) per year. With automatic ON/OFF lighting control, there is about 70% lighting savings found for the whole shed, while the heating loads increase for only about 13%. Inprovement by ventilation through introducing ridge openings only causes less than 1.5% extra heating demands because the ventilation is only happened in summer for the most of time of the year. However, it is shown later in this paper, a reduction for overheating could reach a siginifant level by using this type of natural ventilation.

Table 2
Energy Consumption (unit: kWh/m^2/year)

CASES	HEATING	LIGHTING
No LC no Vent	51.74	26.57
LC no Vent	58.81	8.42
Vent no LC	52.47	26.57
Both LC and Vent	59.44	8.42

CO_2 emissions

Figure 4 depicts the CO_2 emissions from the operational energy consumed by the shed. As mentioned previously in this paper, heating is created by natural gas with conversion factor of 0.194 and lighting is generated by grid electricity with conversion factor of 0.422. Observation found there was almost no change for CO_2 emissions after ridge open natural ventilation was added (only about 1.5% difference). However lighting control brings in much less CO_2 emissions (about 25% reduction was observed) compared with the case of no lighting control. Therefore, lighting control is of great interest to use energy wisely and to make buildings more friendly to environment.

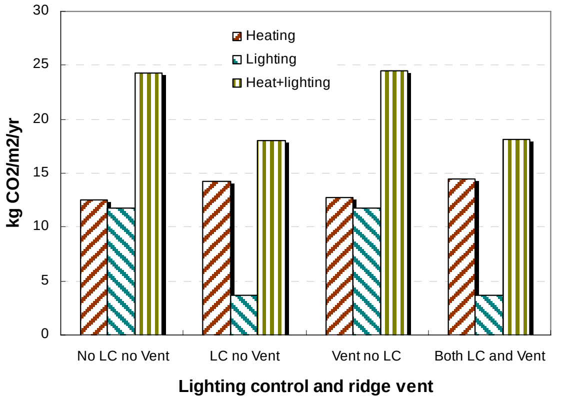

Figure 4 Carbon Dioxide emissions

Overheating

Overheating inside building is drawn as percentage of occupied hours over certain temperatures, detailed in Figure 5. The natural ventilation is an effective way to cool the shed space because it provides big air change airflow between inside and outside. The figure shows overheating drops from 17% to about 3% for the temperature of 28ºC between no ventilation and ridge open cases. It also can be seen from Figure 5, lighting control is another way to make contribution to the solution for the overheating problem, because it reduces internal gain of the building in a relatively big amount. By using ridge open natural ventilation and lighting control together, the building can make overheating to a considerably acceptable level.

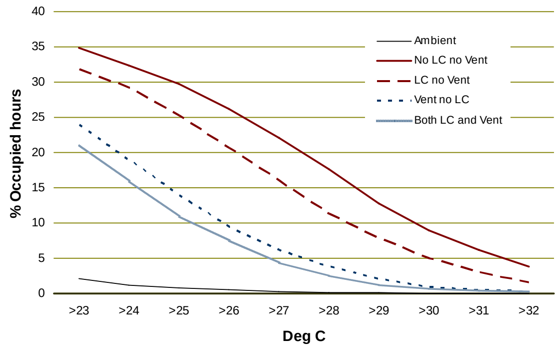

Figure 5 Comparison of overheating

Temperature comparison

As an example and detailed information to prove the benefits of using natural ventilation and lighting control, Figure 6 illustrates the temperatures of four different cases for three warmest days (in July) of the year. Ridge open ventilation makes big contribution for temperature drops with at least 4ºC. Lighting control because of supplying less internal gains contributes a smaller portion for temperature reduction (about 2ºC is observed). When ridge opening is added, the lighting control has less effect on the temperature drop because majority of work is taken by ventilating air. However, Figure 6 still shows more than 1ºC temperature reduction by adding lighting control for the case with natural ventilation. By using both methods, the temperatures inside the building can reach figures with satisfied thermal comfort.

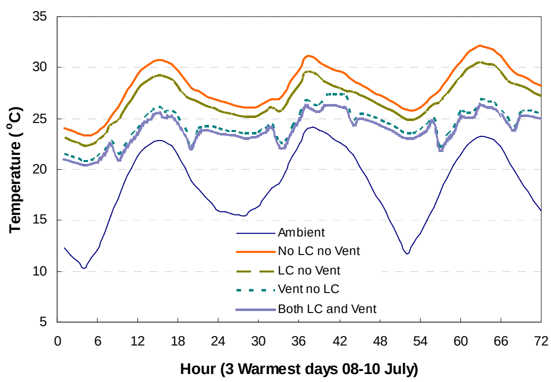

Figure 6 Internal temperatures for 3 warmest days 08-10 July

CONCLUSIONS

Passive design for buildings is very important to cope with climate change caused by greenhouse gas emissions. Thermal comfort requirement inside buildings normally acquire extra energy to maintain thermal parameters at a satisfied level. Overheating is an issue to cause thermal discomfort for buildings, especially for day-lit industrial buildings because rooflights bring in massive solar gains in summer.

For the industrial building with 15% glazed rooflights in this research, the use of lighting control reduces electricity use by about 70% throughout the year, with only 13% increase in heating. The increase of heating is because less heat is supplied by electricity via lights. Overall CO_2 emissions (for heating and lighting) can be cut by over 25% through the use of daylight sensing controls. Addition of natural ventilation at ridges to the above measures further reduces overheating to commonly acceptable levels without recourse to mechanical cooling.

Overall, automatic lighting control not only contributes to a relatively big energy consumption reduction, but also contributes to inside thermal issues like coping with overheating problem. This finding would recommend the industrial buildings to install lighting control system that is not prevailing installation now. Natural ventilation through opening at ridges of the building presents a big contribution to overcome overheating problem inside the shed space, which is a very economic and efficient way. In addition, compared to natural ventilation by cargo doors opening, ridge opening secures the safety of the building while applying this type of natural ventilation.

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