Energy and Buildings 66 (2013) 562–570

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Modelling the cooling energy of night ventilation and economiser strategies on façade selection of commercial buildings

P. Roach*, F. Bruno, M. Belusko

Barbara Handy Institute, University of South Australia, Mawson Lakes Boulevard, Mawson Lakes, SA 5095, Australia

ARTICLE INFO

Article history:
Received 3 October 2012
Received in revised form 30 May 2013
Accepted 28 June 2013

Keywords:
Thermal mass
Night cooling
Façades
Low energy

ABSTRACT

Night cooling strategies are gaining popularity with the raise in profile of Green Buildings and Sustainable rating systems. The use of night ventilation to exploit lower diurnal temperatures to pre-cool the building structure in preparation for the following day's gains is well known; however, the role which the façade has to contribute to night ventilation is not fully understood.

Researchers are familiar with economiser cycles operation for central air conditioning systems and the ability of these to operate in night ventilation mode with simple modifications to the control strategy requires validation.

Simulations were carried out for a typical office building in Adelaide to demonstrate that a traditional economiser cycle operating 24 h each day under thermostatic control delivers energy savings. A number of façade structures were considered and the effect of varying the location of the thermal mass within the structure was investigated. The paper gives details on the model used for the simulations and discusses the results obtained. It was found that increasing the mass on the inside of the façade is preferred over the external for the warm marine climate zone of Adelaide, South Australia.

1. Introduction

The focus on internal thermal mass, exposing concrete ceilings, floors and internal walls, as a passive feature in energy conscious design has been received positively by engineers and progressive architects. It is common place to see modern "green buildings" to feature internal surfaces of bare, grey concrete. This salute to environmentally sustainable design is a step in the right direction but more can be done to improve on the current levels of thermal mass use in buildings and HVAC systems optimised further to exploit this passive thermal store. A combination of thermal mass and the means to fully utilise its benefit within buildings needs to be identified to ensure that appropriate design solutions are being used in the construction industry.

Research of night cooling systems in unconditioned buildings demonstrates a benefit [1]. The benefit for conditioned buildings in differing climatic locations requires validating. Previous research concentrating on the exploitation of "off peak" energy tariffs [2–4] demonstrates cost savings in conditioned buildings from increased thermal mass, but this does not always translate into a reduction in energy use.

Naturally thermal mass includes not only the internal elements of construction, but also the façade and furniture [5] and it has been demonstrated that thermal mass can be used to reduce energy consumption and improve comfort in buildings during the cooling season in the warm and humid climate region (3A) of Nairobi, Kenya [6,7]. Internal thermal mass has been shown to be at an optimum level for commercial offices in the range of 4.13 Kg/m^2 and 6.11 Kg/m^2 [8].

Passive, night time cooling, is used as a strategy for reducing energy in commercial buildings in Europe [9,10] and internationally [11] but little published research is available for the Australian Climate. Certain areas of Queensland have been researched [12] but this limited study does not include sufficient parameters to fully demonstrate the benefit of passive ventilation strategies, whether they be nocturnal or economiser based.

The literature shows that insulation is more critical in climates with extreme seasonal variations and small daily variations while thermal mass plays a more significant role in climates with large diurnal ranges [8]. The accessibility of this thermal mass and its location in the façade in relation to the control of 'free cooling' techniques is yet to be quantified and is not reported anywhere in the literature. The operation of a controlled internal environment utilising free cooling, particular out of occupied hours, will define the optimum position of thermal mass on a building.

The intent of this study is to demonstrate the effect that economiser cycles and night time ventilation have, when used separately and combined, to reduce the cooling energy in commercial office buildings, for a range of façade constructions.

* Corresponding author. Tel.: +61 409696037.
E-mail address: Phillip.Roach@postgrads.unisa.edu.au (P. Roach).

0378-7788/$ – see front matter.
http://dx.doi.org/10.1016/j.enbuild.2013.06.034

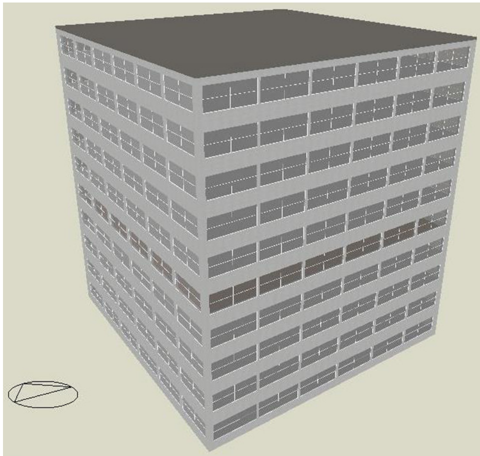

Fig. 1. Building model image.

2. Model and simulation

To analyse the effects of façade construction on energy consumption, a model building was simulated using Energy Plus, with data interpreted via the Design Builder Software. A standard building footprint of 32 m × 32 m, over 10 floors is recommended by the Australian Building Controls Board (ABCB) as being a common form of building for Australian capital cities (Fig. 1.) [13].

The intermediate fourth floor was simulated as part of the study, with a glazed opening percentage (GOP) of 60%. It has been previously demonstrated that GOP's in excess of 60% do not add benefit in respect of lighting energy reduction from increased access to daylight [14]. Whilst this only offers limited impact for the façade to influence the energy use within the building, it is more relevant by utilising an appropriate level of glazing since GOP's less than 60% are not common. Glazing is evenly distributed across all facades with no external or internal shading being applied.

A number of façade structures were investigated which enables a demonstration of the varying effects of locating thermal mass within the structure. Each structure utilises a differing combination of 200 mm concrete and 100 mm insulation (polystyrene). Render and/or plaster is applied to exposed surfaces of the polystyrene insulation for protection from internal and external elements (Fig. 2 and Table 1).

Simulations were run for a number of variables to investigate the dominant influencing factors in the selection of façade structures. The simulations were conducted on the model building with internal gains applied during the occupation hours of 0 W/m^2 and 40 W/m^2 to assess the implication of internal loads to the efficiency of the operation of the system. It is worth noting, that at 0 W/m^2 levels of internal equipment gains, occupancy gains are still present, which, for the assumed population density equates to around 8 W/m^2.

The level of internal gains has a major effect on the selection of the built form of a building. The change in operation of a building from Skin Load Dependant (SLD) to Internal Load Dependant (ILD) [15,16] has already been identified, but the combination of this analysis with a night time ventilation strategy is not fully understood for a wide range of global climate zones. It is already understood that high thermal mass in the external façade, in all but cold climates, is preferred [8] but this study was undertaken for a fixed level of internal gains and the assumption during the analysis was that the building as ILD.

Table 1
Façade characteristics.

		Mass (kg/m^2)	Thickness (mm)	*U*-Value (W/m^{2}K)
A	Concrete wall	420.00	200	3.196
B	External insulation	441.00	315	0.352
C	Internal insulation	436.50	315	0.351
D	Insulation	36.00	230	0.365
E	Composite	841.5	500	0.338

In addition to internal gains, the night ventilation rate and set point temperature were also varied in the following combinations:

Night ventilation Set Point temperature: 13 °C, 15 °C, 17 °C and 19 °C.

The control strategy was set such that as the mechanical ventilation system will be activated once the external ambient temperature is 2 °C lower than the current room temperature and will continue until the night set point temperature is reached.

Air Change Rate: 0 ach/h, 3 ach/h, 6 ach/h, 9 ach/h and 12 ach/h.

The air change rate applied for night ventilation or economiser operation is in addition to any outside air for occupancy requirements. During occupation hours therefore, when the air change rate is at zero, minimum outside air for the buildings occupants is still being supplied.

3. Variation in night ventilation set point results

Initially, the first simulations which varied the night set point temperature utilised an air change rate of 12 ach/h. Since the night ventilation function is really only applicable for cooling, an annual simulation of the cooling only energy was undertaken. It is assumed that thermostatic controls would inhibit overcooling during the heating season. The results are shown in Figs. 3 and 4.

As expected, the 13 °C set point resulted in the lowest annual cooling energy consumption for both the 0 w/m^2 and 40 w/m^2 options for internal gains. There is however a risk of overcooling from adopting this set point temperature and with only a marginal benefit demonstrated between the 13 °C and 15 °C set points, the risk is not considered appropriate.

A change in benefit between the 200 mm concrete wall and the externally insulated concrete wall is noticed however when internal gains are applied the difference is less pronounced at the 19 °C set point. This infers that it is the influence of the night ventilation strategy which is causing this difference, the benefit of which can be quantified from the results obtained.

There is a 6–7% penalty in energy use for selecting internally insulated facades over the composite or externally insulated built forms for 0 w/m^2 of internal gains. This difference reduces at 40 w/m^2 but the structures with internal thermal mass are still favoured. Externally insulated structures have been selected for this particular analysis since the sensitivity of the night ventilation air change rate with the internal thermal mass is being investigated. Utilising insulation at or close to the external face of the structure isolates the ambient night time conditions from the internal space. The results are shown in Figs. 5 and 6.

At the 40 w/m^2 gain level, there is little difference between the energy saved from each of the temperature settings. This can be partly due to the fact that the ventilation is running out of hour's whilst the gains are for occupied hours only. It is also an indication that the set point for the night ventilation is not critical. This would be useful in preventing overcooling during the year and inadvertent reheating for occupancy in the morning.

4. Variation in air change rate results

The next simulations changed the air change rate for the night ventilation system, with a set point of 15 °C, again calculating the annual cooling energy for Adelaide. The 15 °C set point was