# Sensitivity analysis of a maritime located night ventilated library building

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ABSTRACT

This paper assesses the role of design and operational parameters in a night ventilated library building that has been designed for a maritime type climate. The design rationale behind the building is elaborated and decisions associated with the various design parameters discussed. A model of the building is created using the ESPr simulation program which after experimental validation is used to carry out parametric and sensitivity studies on the building. The role of different building design and operational parameters are examined including building mass, external gains, internal gains, ventilation duration, ventilation rates, as well as ventilation operational strategies.

## 1. INTRODUCTION

Considerable research findings have been reported on low energy buildings that incorporate night ventilation cooling (NV) subject to Continental and Mediterranean type climates (Blondeau, 1997; Givoni, 1998; Geros et al., 1999; Shaviv et al., 2001; Pfafferott et al., 2003; Pfafferott et al., 2004). However, there is less evidence of night ventilated buildings in more temperate maritime climates where cooler summers prevail (Fletcher and Martin, 1996; Kolokotroni and Aronis, 1999). Although maritime type climates are associated with less demanding cooling requirements, building evolution in these locations continues to exhibit designs that require considerable cooling. Furthermore, with the increasing occurrence of higher internal loads, a longer building cooling season is also becoming evident. These factors coupled with a reluctance amongst engineers and architects to explore low energy cooling alternatives continue to result in an over reliance on chilled water vapour compression air conditioning systems, often in situations where many building designs are inherently suitable for low energy concepts such as night ventilation cooling.

In a UK study, Kolokotroni notes that night ventilation cooling has been extensively studied at southern European locations, but that less work is evident on its integration in UK office buildings (Kolokotroni et al., 1998). Furthermore, Kolokotroni observes that the free cooling provided by night ventilation was capable of providing up to 20 kWh/m$^2$ cooling per annum, where the typical energy consumption for a standard UK office building being approx. 30 kWh/m$^2$ (CIBSE, 2000). However, with good practice, it is possible to reduce air conditioning consumption to below 15 kWh/m$^2$, meaning that night ventilation can potentially provide adequate cooling for most of the year in well designed office buildings typical of maritime type climates. Other UK studies have suggested similar propositions (Fletcher and Martin, 1996). In other investigations, Kolokotroni reports on desk optimisation studies carried out using simulation software (3TC) developed by BRE (Kolokotroni and Aronis, 1999). A variety of building parameters were examined including internal gains, building mass, glazing, solar gains, as well as climatic variables and operational parameters. The main conclusion of this study was that building mass and night ventilation rate were found to have a significant influence on building performance and NV effectiveness.

Pfafferott also considers the issue of design parameters, albeit for a continental German building (Pfafferott et al., 2003). In this work, a comprehensive parametric study using the ESPr simulation code is carried out. Pfafferott notes that simple building performance correlations could potentially be incorporated within basic controllers for optimisation of NV systems.

The objective of the current paper is to assess the performance of a naturally ventilated building which has been designed for a maritime climate setting. This was done through experimental testing and simulation analysis using ESPr. Furthermore parametric studies investigating key design and operation parameters are carried out.

## 2. BUILDING DESIGN ISSUES

The building that is the focus of the current paper is located in the south east of Ireland at the Waterford Institute of Technology (WIT) (Figures 1 and 2). The custom designed building was constructed in 1999 and serves as a library for approximately 6000 students. Its design was influenced by several factors including usage, location, site constraints, and climate. Architectural issues included flexibility, IT compatibility, space comfort constraints, energy efficiency and well the desirability to represent a progressive design image. Environmental design issues included, comfort, indoor air quality (IAQ), daylight, solar control, environmental integration and night cooling.

Figure 1: WIT Library Building (SW view).

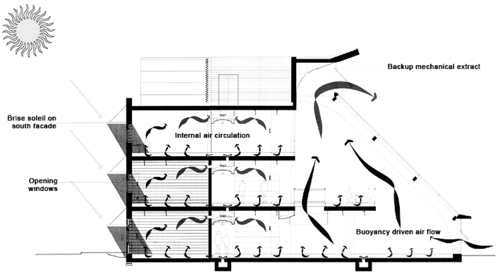


Figure 2: WIT Library Building (S-N cross section).

The issues of comfort, IAQ and solar control in the WIT building are now briefly considered.

*Comfort:* Comfort was a priority in the design of the building. The adaptive nature of occupants' responses to their environment together with optimised air quality, maximised daylight and good thermal comfort were all guiding design influences. Furthermore, the willingness of the client to subscribe to the principle of adaptive comfort ranging from 19 to 24°C air temperature in any day was expected.

*Indoor Air Quality:* A mechanical ventilation system was specified as part of a fully integrated design. This ensured optimum air quality as well as facilitating an effective night cooled building.

*Daylight and Solar Control:* While the southerly exposed façade and high levels of installed IT suggested an active cooling system, the use of a brise soleil on the façade and low energy IT equipment helped minimised the cooling load. The brise soleil and a north-facing sloped glass roof allowed diffuse light into all areas.

Given the maritime climate location, solar and internal gains in such building typologies can lead to excessive temperatures between March and October. However in this case, the incorporation of a night cooling system avoided the need for an air-conditioning system. Instead, the mechanical ventilation system was closely integrated with the structural mass of the building, whereby cool night air is introduced at floor level, via a raised floor plenum, distributed throughout the space and extracted at high level. The result is maximum contact with the exposed mass thus optimising the heat exchange potential of the surface areas.

## 3. ESPR VALIDATION FOR WIT BUILDING

In this section, ESPr simulation data is compared with experimentally measured data from the WIT building.

### *3.1 Methodology*

Within the WIT building, a sub-section, the *Learning Centre,* located on the south façade of the ground floor was selected as it had a high concentration of IT equipment and is regularly occupied by students. The internal walls and ceiling of the zone are exposed concrete thereby allowing good thermal interaction with the space. Monitoring took place over a four week period between May and June 2003. The main monitored variables were distributed indoor air temperature, internal wall surface temperatures, inlet air temperature and inlet air ventilation rate. Mean radiant temperature was determined using wall surface temperatures which were normalised by an area-weighted approach.

*3.2 ESPr Model Details*

The model developed using ESPr utilised building geometric, operational and associated climatic data. Geometric specifications were determined from architect drawings and on-site assessment. Operational data included internal heat gains, occupancy, and ventilation details. Occupancy was recorded manually each hour. Internal gains were estimated based on occupancy. A hot wire anemometer was used to measure ventilation rate. Climatic data included ambient air temperature, relative humidity, solar radiation, wind speed and direction. All were monitored locally except solar radiation which was supplied by a local meteorological station.
A simulation model based on a three-week period was created. A 5-day start up period was employed to allow the simulation data to equalise with the building. during this period, no night ventilation was utilised in the building. The experimental values obtained for the indoor air and mean radiant temperatures were obtained and then compared to measured values obtained from the test programme.

*3.3 Results*

The results of the ESPr simulations are shown in Figures 3 and 4. The period selected was from Saturday June 1st, when the building NV system was activated, to Friday June 14, when shutdown occurred. Satisfactory agreement is observed in Figure 3 between the simulated air temperature and the actual measured air temperature. The mean bias deviation and root mean square difference were found to be 0.46°C with 0.88°C respectively. A larger discrepancy can be observed in the initial period which is attributed to non-operation of the building NV

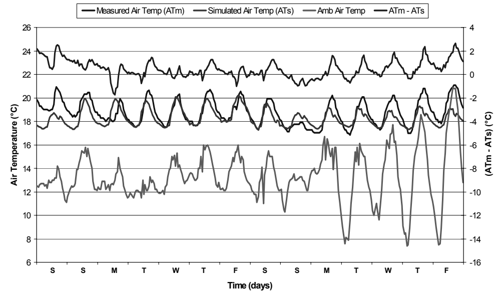


Figure 3: ESPr Validation: Air Temperature.

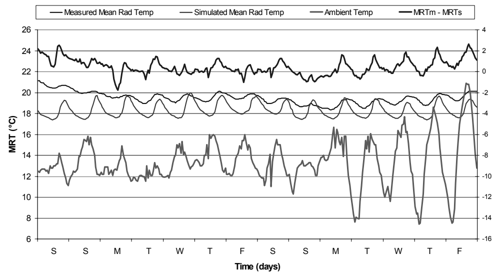


Figure 4: ESPr Validation: Mean Radiant Temperature.

system, whereas the ESPr model incorporated default night ventilation. However, as the week progresses, the effect of this diminishes.

Considering the results for the mean radiant temperature shown in Figure 4. For this data a mean bias deviation and root mean square difference were calculated to be 1.14°C and 1.35°C respectively. Again, the effect of the previous week is evident where no night ventilation took place. However, the mean radiant temperature of the building decreases as the night ventilation system begins operating.

## 4. PARAMETRIC STUDIES

In the following sections, building sensitivity to design, thermal mass, operational, ventilation and internal gain parameters is examined.

*4.1 Design and Operational Parameters*

The design features of the WIT building model were modified giving three simulation models as per Table 1. Design elements varied include thermal mass, glazing area and the ventilation system design.

*Model 1:* This model acts as a base case and is identical to that used in the validation studies.

Table 1: Parametric Studies Test Matrix.

| Parameters | Model 1 (WIT Bdg.) | Model 2 Increased Thermal Mass | Model 3 Optimised Design |
|---|---|---|---|
| Building | Same | Inc. Mass Reduced Glazing | Inc. Mass Reduced Glazing |
| Ven. | Same | Same | Direct |

*Model 2:* This model has similar specifications to Model 1, except that the mass of the Learning Zone walls and ceiling were altered by specifying a heavier concrete construction thereby increasing thermal mass from 887 kg/m$^2$ to 1567 kg/m$^2$ based on floor area.

*Model 3:* This model is optimised to incorporate additional design modifications over Model 2. These include, (i) a decrease in the south facade glazing from 21m$^2$ to 13m$^2$, (ii) modification of the ventilation strategy by introducing direct nocturnal air, thereby removing any distribution gains to the ventilation air and (iii) increasing the duration of night ventilation from 6 to 8 hours.

Weather data utilised for all the parametric studies was based on the ESP UK default climate. A 12-day pre-simulation period was specified to allow the building model to equilibrate with its environment. A 9-day summer period in late July was utilised and a time step based on six minute intervals was specified in ESPr.

Figure 5 examines the sensitivity of dry resultant temperature to building thermal mass over the 9-day period. The dry resultant temperature is approximated by the average of the mean radiant and the indoor air temperatures. A ventilation rate of 10 ACH and internal gains of 32 W/m$^2$ were used. Considering the results, the following observations are made, (i) significant reduction in diurnal temperature swings are observed for the heavier building construction, (ii) increasing thermal mass alone (Model 2) resulted in a reduction in peak resultant temperatures by between 1 and 2°C, relative to the original building design (Model 1), (iii) the combination of increased thermal mass, reduced glazing area and a longer ventilation period (Model 3) resulted in reduced peak resultant temperatures between 2 and 3°C relative to Model 1, (iv) for Models 1 & 2, peak temperatures are above ambient by approximately 2°C and 0.3°C respectively on the hottest weekday (Thurs), (v) for Model 3 at the Thurs peak period, dry resultant temperatures remain below peak ambient air temperatures by approximately 0.8°C, (vi) indoor dry resultant temperature for Models 2 and 3 remains at or below 24°C, but is exceeded by Model 1, and (vii) it is possible to under cool the building at night without leading to indoor occupant discomfort the following morning.

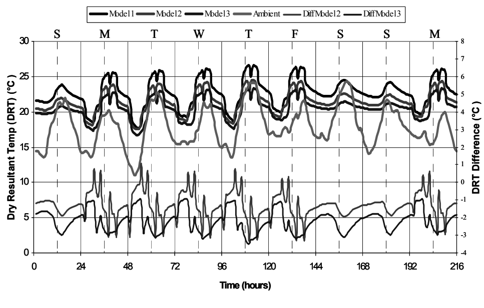


Figure 5: Dry Resultant Temperature: Models (1, 2, 3) (Internal Gains = 32W/m$^2$; Ventilation = 10 ACH).

### 4.2 Ventilation Rate Investigation

The effect of varying night ventilation operational parameters was considered by examining four different ventilation rates; 0 (base-case), 4, 10 and 20 ACH. Model 3 was used in this study and results are shown in Figure 6. Peak temperatures are observed to occur in the mid afternoon of each day. In general, an increase in night ventilation rate produces a decrease in the peak temperatures observed on the following day. Closer inspection shows that either 4 or 10 ACH both result in significant daytime cooling, the higher ventilation flowrate of 20 ACH does not result in a significant improvement beyond 10 ACH. Examining the calculated PMV values, it is observed that a ventilation rate of 10

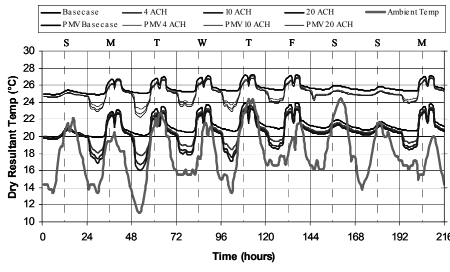


Figure 6: Dry Resultant Temperatures and ACHs (Model 3, Internal Gains = 32W/m$^2$).

ACH gives better performance than 4 ACH and results in a peak PMV value which does not exceed 0.5.

*4.3 Internal Gains Investigation*

The Learning Centre zone at WIT contained 43 personal workstations distributed over a floor area of 126m$^3$. A sensible heat gain of 84 W per person and 84 W per workstation (65 W box, 19 W monitor) was ultilised. This resulted three internal gains levels being applied to the space as follows: *Low* (23W/m$^2$), *Medium* (32W/m$^2$) and *High* (40W/m$^2$) based on occupancy. All analysis was carried out with a night ventilation rate of 10 ACH using the building Model 3 and all results are given in Figure 7. Increases in internal heat gains cause an associated increase in indoor peak temperature of approximately 1$^o$C for medium gains and 2$^o$C for high gains. During the week-end period, when no gains are present, the increased dry resultant temperatures are observed to gradually converge, before being offset on the Monday, once internal gains are again present. For all internal gain values, PMV values are observed to be within +0.5 during occupied periods for all internal gain values. Although PMV values drop significantly to values of between –1.5 and –2.0 during periods when night ventilation is active, the effect of the extended ventilation period to 0800 hrs can be observed as the recovery of internal dry resultant temperature and PMV values only occurs within a one to two hour period of the space being occupied for each daily period.

*4.4 Investigation of Night Ventilation Duration*

The effect of night ventilation duration is examined in Figure 8. Model 2 was used in this study as it exhibits a stronger sensitivity to the different strategies. A ventilation rate of 10 ACH was considered. For this study, night ventilation periods were divided into two-hour slots from 00:00hrs to 06:00hrs. Control strategy CTL1 is based on building ventilation for one period from 00:00hrs to 02:00hrs. CTL2 is for two ventilation periods from 00:00hrs to 04:00hrs, whereas CTL3 represents three ventilation periods from 00:00hrs to 06:00hrs.

Increasing the duration of night ventilation produces a reduction in peak daytime temperatures, as more heat is removed from the building during the night. This effect was observed for all cases of night ventilation, but is greatest at high ventilation flow rates (10 and 20 ACH). For example for night ventilation rates of 10 ACH, peak daytime temperatures were observed to decrease by up 0.25°C when night ventilation duration was extended from 2 hours to 4 hours, and up to 0.5°C when night ventilation continued for 6 hours.

A limiting case of increasing duration to reduce peak temperatures was not found in this study, however, if internal temperatures fall below 18°C, sufficient time must be given after the ventilation period to allow temperatures to increase to acceptable levels before the arrival of the occupants.

## 5. CONCLUSIONS

Although night ventilation has not been extensively utilised in maritime climates, it can provide adequate building sensible cooling, where the principle of adaptive cooling is accepted. In this study, ESP-r was utilised to carry out sensitivity analysis on a college library building where night ventilation is employed. First ESPr was validated for a building zone by comparing

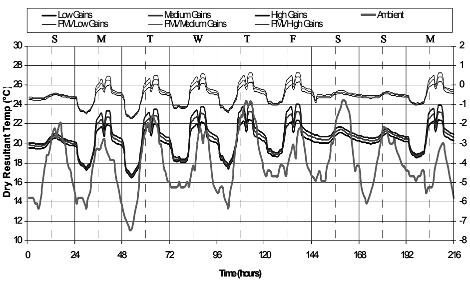


Figure 7: Dry Resultant Temperatures and Internal Gains (Model 3, ACH = 10).

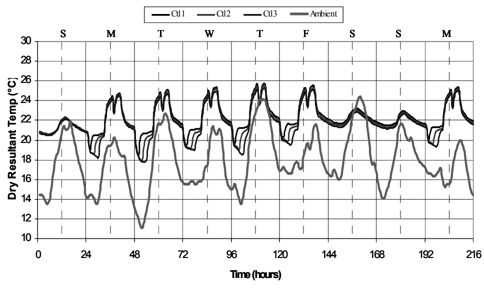


Figure 8: Sensitivity of DRT to Duration of Night Ventilation (Ventilation Rate = 10 ACH).

simulation predictions against experimentally measured data. A mean bias temperature difference of 0.45°C and 1.14°C between predicted and measured data was observed for dry resultant and mean radiant temperature respectively. Subsequent sensitivity studies examined the effects of thermal mass, building design and internal gains as well as various operational issues including ventilation rates and ventilation duration. Increasing the thermal mass by changing from low density breeze blocks to higher density concrete was observed to lower peak daily temperature by up to 2°C. Likewise increasing night ventilation rate up to 10 ACH was observed to decrease peak internal day temperatures by up to 1.0°C, however increasing ventilation rates beyond 20 ACH did not lead to significant improvement. Increasing night ventilation duration from 2 to 6 hours was also found to reduce peak day time temperatures by up to 0.5°C. Internal gains were found to have a significant effect on internal comfort with an increase in peak temperature of up to 1.0°C for a gain increase from $20W/m^2$ to $40W/m^2$. Finally in certain cases, night ventilation can continue to be applied after indoor air temperatures have fallen below 18°C, as temperatures recover to comfortable levels.

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