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NiteCool: Office Night Ventilation Pre-Design Tool

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Abstract

NiteCool was developed under the Energy Related Environmental Issues in Buildings (EnREI) DOE Programme and is designed especially for the assessment of a range of night cooling ventilation strategies. The program is based on a single zone ventilation model and is configured to analyse a 10m x 6m x3m cell of an office building. It is intended to be used at the early stages in the design process to help the designer to make informed decisions on the construction, opening configuration and operation of the building. The user input is restricted to a few parameters from which a weekly internal temperature profile is predicted together with the energy consumption and the peak cooling capacity requirement relative to a reference system (with no night cooling). In this way, various building and system designs can be investigated by manually adjusting parameters until the comfort/energy consumption design criteria are met. The program can also be used to calculate the size of openings required to achieve a certain flow rate under given design conditions. This is a very quick and easy way to investigate the feasibility of using natural ventilation to improve comfort levels in buildings.

Introduction

It has been established over recent years through research work and built examples that night ventilation is an effective low energy cooling technique for appropriately designed modern buildings, especially in climates with relatively low peak summer temperatures during the day and medium to large diurnal temperature differences such as those of the UK. Such weather combination allows the thermal mass of the building to use the cool night air to discard the heat absorbed during the day. Therefore, cooling using night ventilation is particularly suited to office buildings which are usually unoccupied during the night so that relatively high air flows can be used to provide maximum cooling effect. Buildings using night ventilation for cooling in the UK have been evaluated and reported with encouraging results [1-3].

Low energy techniques to avoid overheating have also been central to research efforts across Europe, especially in southern European countries. Night ventilation is one of the main techniques being investigated. In order to help designers to explore its application, a number of easy-to-use pre-design computer tools have been developed. Examples include LESOCOOL [4] which deals with natural ventilation systems that can be used to passively cool a building and it is based on one design day and SUMMER -Building [5] which uses the admittance method for the thermal simulations with real weather data and includes natural ventilation as one of the four low energy cooling techniques. In both tools, the user can define the building details and predictions include hourly internal temperatures, air flow rates, and in the case of SUMMER, energy savings.

The design tool described in this paper has been developed especially for UK office buildings and climate with the aim to facilitate comparisons with energy consumption and comfort benchmarks and provide the opportunity to explore quickly variations in internal heat gains, ventilation rates, occupancy patterns and external temperatures. External temperatures are user defined so that the user can investigate various scenarios such as a few warm days followed by cool weather and vice versa. In developing the model, it was critical that user input parameters are kept to the minimum and simulation time is fast.

Building configuration and calculation algorithms

The building model is based on a typical cellular office with dimensions 10m width, 6m depth and 3m floor-to-ceiling height and therefore it is a single zone model. It is positioned in the middle of a row of offices on the middle floor of a 3-storey office. This module has been derived as a suitable office for night cooling through previous research work [6]. Three variations of thermal mass are included: LIGHT, MEDIUM and HEAVY. The definition of the types is based on the materials used (concrete) and area of exposed thermal mass which is provided by the ceiling. LIGHT construction includes a lightweight exposed concrete ceiling (specific heat 1kJ/kgK, density 1200 kg/m^3 and thickness 0.15m, heat capacity 180kJ/km^2) MEDIUM construction includes a heavy weight exposed concrete ceiling (specific heat 0.85kJ/kgK, density 2100 kg/m^3 and thickness 0.15m, heat capacity 270kJ/km^2). HEAVY construction includes a heavy weight waffle exposed concrete ceiling, thus offering an increased area of exposed thermal mass. The external wall is a granite clad wall in the case of MEDIUM and HEAVY types and a metal clad wall for LIGHT type, both insulated with 10cm mineral fibre. External windows are all assumed to be clear float double glazing, internal partitions are lightweight plasterboard and the floor is carpeted.

The 3TC (3 Time Constant) [7] lumped parameter simulation method is used for the thermal simulations. In this method, the thermal response of each room has three time constants and rooms are modelled as networks of thermal conductance and capacitance. The 3TC algorithms are implemented within the design tool and allow the modelling of long term storage of heat in the building fabric.

There are four natural ventilation modes incorporated in the model;

- single sided single opening
- single sided double opening
- cross ventilation
- stack ventilation (buoyancy and wind)

The ventilation algorithms for the first mode are based on the work by Warren and Parkins [8] and the algorithms for the last three modes are based on those described in the CIBSE Applications Manual on Natural Ventilation [9]. The tool also uses a methodology developed under an ETSU sponsored project [10] which automatically sizes openings in order to achieve a user specific flow. This facility is available for all the four modes of natural ventilation.

The structure of the tool

The data describing the current state of the buildings design is contained on five tabs on the main form of the program. These are;

- Building,
- Weather,
- Day Ventilation,
- Night Ventilation and
- Control Strategies.

Building input parameters

There are only eight main variables which describe the building and are controlled by the user:

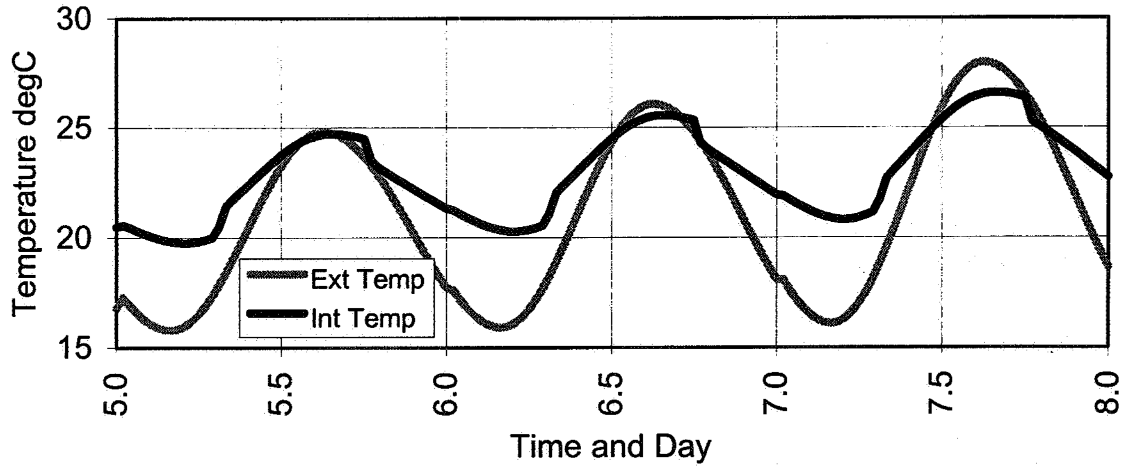
- Internal Gains
- Infiltration airflow
- Orientation
- Glazing ratio
- Building weight
- Occupied period
- Solar protection and shading coefficient
- Site location for the calculation of solar position.

Weather

Calculations can be carried out either over a month or over the entire cooling season (assumed to be May to September). Each month is assessed by simulating the building for 7 days and energy data is multiplied up using appropriate factors. Data for each day can be set separately in terms of the risk that a certain weather combination will be exceeded. By defining a risk of (say) 5%, the weather data is selected such that the weather will only be hotter than the calculated weather data for 5% of days in the particular month. This defines the maximum and minimum daily temperatures. Hourly data is generated from this by assuming a daily sinusoidal temperature series. Each month has a fixed temperature lag from noon.

The weather data is calculated using the banded weather data in the CIBSE Guide [11]. This is used because it provides coincident data for external dry bulb temperature, solar radiation data and mean daily windspeed, all of which are important in assessing room heat gain and ventilation cooling potential. More specifically, the weather data banded on temperature rather than that banded on solar radiation has been used. This is because periods of high temperature rather than high radiation are likely to present a greater design risk in buildings which are using ventilation cooling, since by their nature, they are likely to be well shaded.

A different risk factor can be selected for each day in the week. This enables the user to vary the sequence of weather to which the building is subject. This could be a sustained period of very hot weather or a cooler period followed by a warming-up period (Figure 1).



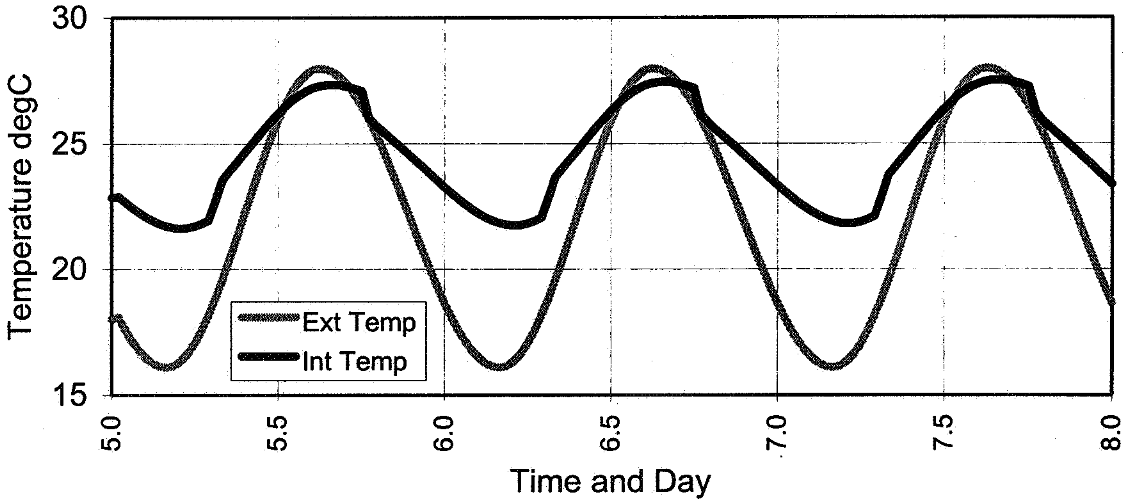


Figure 1: Shows the last three days of one week simulation to demonstrate the effect of external air temperature sequence on predicted internal dry resultant temperatures. A warming up period was chosen for the first graph. A risk factor of 20% was chosen for Saturday to Tuesday, 10% for Wednesday, 5% for Thursday and 2.5% for Friday. Internal temperature was predicted to be 26.6°C on Friday (last day). A risk factor of 2.5 % was selected for all week for the second graph. This resulted in a temperature of 27.5°C during the last day. Note that the peak temperature for the building exposed to gradually increasing external temperature (first graph) is almost 1K lower than that for a constant 2.5% risk.

Cooling systems and reference HVAC system

Two different systems may be used to cool the design building; one for day time and the other for night. Data for these is independent, and is contained on separate tabs but day occupied period cannot overlap with the night cooling period. There are nine different cooling systems incorporated in the program: three mechanical ventilation, four natural ventilation and two active cooling systems as follows:

Mechanical Systems
- Mechanical ventilation by supply fan
- Mechanical ventilation by extract fan
- Balanced mechanical ventilation by supply and extract fans

Natural Ventilation Systems
- Single Sided single opening
- Single Sided double opening
- Cross ventilation
- Stack ventilation

Active Cooling Systems
- Fan coil system
- Displacement ventilation system

It should be noted that mechanical systems are characterised by their Specific Fan Power and Coefficient of System Performance. The four natural ventilation systems have a design feature which allows the user to size and position openings to achieve a desired flow rate under design conditions.

Design Mode for Natural Ventilation Systems

Design mode can be used to size and position openings to achieve a design flow under design internal and external conditions. Outside temperature and wind speed are required along with the corresponding design inside air temperature. The program picks up as default, the inlet and outlet pressure coefficients from the Wind Pressure form. These defaults can be edited if required. The program then sizes the ventilation openings based on a methodology developed under an ETSU sponsored project [10] which is summarised in the CIBSE Applications Manual on Natural Ventilation [9].

A test mode is also available if the user knows the sizes of the openings; these can be specified and the flowrates calculated based on the design weather and internal air temperature. Other parameters (e.g. vertical separation of openings) can also be varied whilst keeping the opening sizes fixed in order to assess the impact on the flowrate through the room. Once the opening sizes have been finalised, these sizes can be copied to the system tab on the main form and the system is evaluated in the normal way.

Energy Savings Comparisons

One of the important features of the tool is the facility to compare the fuel used for the chosen design system to a reference HVAC system. The reference HVAC system is considered to be a standard solution to the design problem. No night ventilation is applied and the day cooling system defined on the main form is replaced with the system on the Reference HVAC form. Apart form the ventilation system, all other building and environmental parameters remain as for the design building. Two reference HVAC systems are available: (A) Displacement ventilation system and (B) Fan coil system. There are two ways of defining the set point temperature of the reference HVAC system. The default option is to allow the program to automatically choose the set point such that the reference system provides a similar level of comfort to that maintained in the design building. The set point temperature is taken as the average temperature an hour either side of the peak temperature found in the design building. The second option is to enter a constant set point temperature.

As an example Tables 1-3 are provided tabulating the results of three different day systems using a range of night systems. The day ventilation rates are 4ACH for the fan coil system and natural ventilation systems and 3ACH for the displacement system. Night ventilation rates are 6ACH for all systems. Fan specific power is 0.75 for supply and 0.5 for extract. External temperatures are as specified for Figure 1A. Tables 1-3 show a range of potential energy savings or energy penalties when using mechanical ventilation at night. These values were predicted by specifying single values for delivered ventilation rates and fan specific power. In order to help the user to optimise the selection of the system parameters, the tool includes a parametric analysis facility. This is available for most of the user specified parameters in relation to the building, day and night ventilation systems. In the example demonstrated in Tables 1-3 the parametric analysis facility can be used to optimise the mechanical ventilation system by choosing appropriate ventilation rates and specific fan power values. Figure 2 shows four graphs as an example of such a parametric analysis.

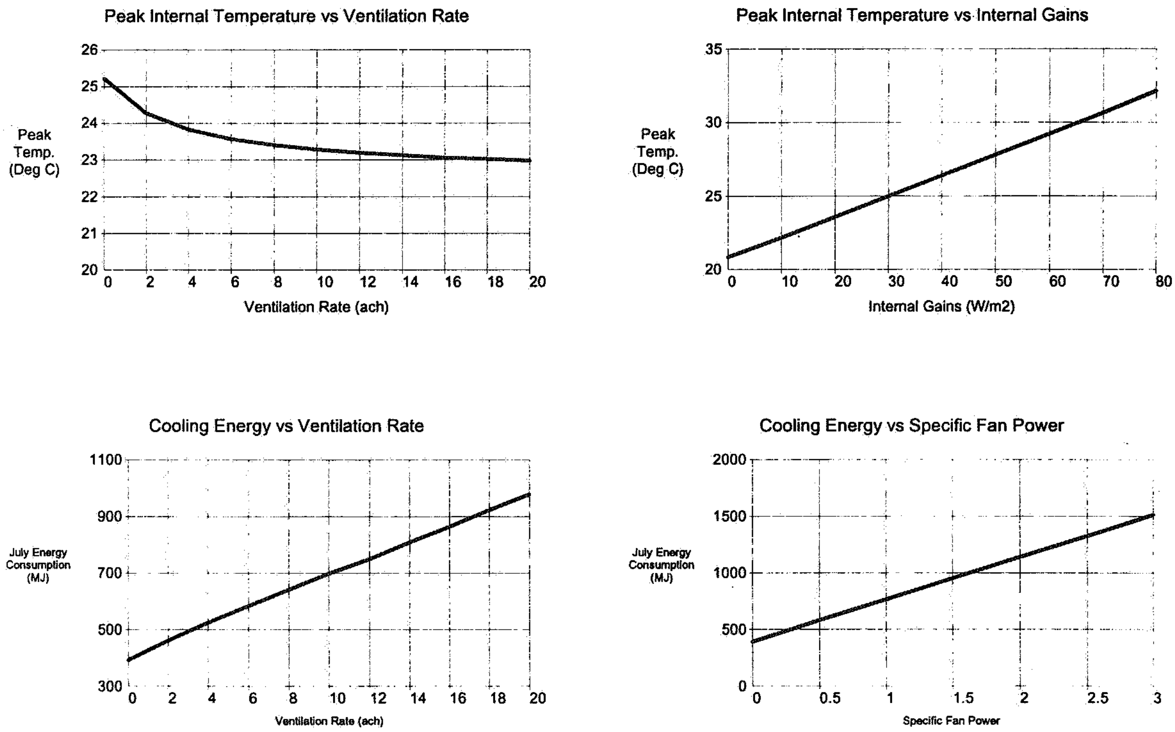


Figure 2: The effect of the delivered ventilation rate and the internal gains are shown in the first two graphs against the peak internal temperatures. The required cooling energy in relation to the delivered ventilation rate and specific fan power is shown in the next graphs.

Table 1: Day cooling is provided by a fan coil system using 100% fresh air. The same system is used as the reference HVAC system. It shows that night ventilation together with an active cooling system during the day provides the possibility of reduced cooling capacity and energy saving in some cases.

Night Cooling System	*Maximum Internal Temperature °C*	*Energy Saving %*	*Cooling Capacity Saving %*
No night system	24	0	0
Mechanical Supply	24	-8	22
Mechanical Extract	24	7	25
Mechanical Balanced	24	-33	22
NV cross	24	24	15
NV stack	24	28	20
Fan Coil	24	-46	19

Table 2: Day cooling is provided by a displacement ventilation system. A fan coil system with 100% fresh air is used as the reference HVAC system. It shows that night ventilation reduces the day peak temperature and achieve energy savings. It also shows that running the displacement system at night reduces day temperatures but the energy consumption is higher that the reference HVAC system.

Night Cooling System	*Maximum Internal Temperature °C*	*Energy Saving %*	*Cooling Capacity Saving %*
No night system	25.2	42	N/A
Mechanical Supply	23.8	5	N/A
Mechanical Extract	23.6	17	N/A
Mechanical Balanced	23.8	-20	N/A
NV cross	24.1	42	N/A
NV stack	23.9	42	N/A
Displacement Vent	24.2	-77	N/A

Table 3: Stack natural ventilation is utilised during the day. A fan coil system with 100% fresh air is used as the reference HVAC system. It shows that night ventilation reduces peak temperatures during the day by approximately 2°C.

Night Cooling System	*Maximum Internal Temperature °C*	*Energy Saving %*	*Cooling Capacity Saving %*
No night system	28.3	100	N/A
Mechanical Supply	26.6	62	N/A
Mechanical Extract	26.4	75	N/A
Mechanical Balanced	26.6	37	N/A
NV cross	27	100	N/A
NV stack	26.7	100	N/A

Control Strategies

Effective control of night cooling systems is important if the system is to operate in an energy efficient way and provide optimum comfort to the occupants. The Controls tab on the main form allows the user to customise the operation of the night cooling system, by controlling three aspects of the operation:

1) Operation times; ie the time to start and end the operation of night cooling system.
2) System initiation, i.e. the decision as to whether or not to initiate the night cooling each night. There are 4 control laws which can be selected for night cooling initiation:
   - Peak inside temperature during the previous occupied period must be greater than 23°C.
   - Average inside temperature during the previous day must be greater than 22°C.
   - Average outside air temperature during the previous afternoon (occupied period only) must be greater than 20°C.
   - Slab temperature at time of night cooling initiation must be greater than 23°C.
3) System continuation, i.e. if the system has been initiated, how long it should be on. Three control laws can be selected:
   - The current inside temperature is greater than the current outside temperature plus an offset of 2 degrees. This offset may be less for natural ventilation systems.
   - The current inside temperature is greater than the heating set point temperature (18°C). This is to avoid overcooling the space and having to heat in the morning to bring it up to acceptable comfort levels.
   - The current outside air temperature is greater than 12°C. Again this is to avoid overcooling the space.

All the above rules have been the result of an extensive study which included modelling and practical experience from monitored buildings [12].

Results and Parametric analysis

The following summary results are displayed in the main form of the tool:

1. Maximum and minimum dry resultant temperatures; which occur while the building is occupied over the analysis period.
2. Energy Saving; which is calculated as the percentage saving in cooling energy provided by the design system over the reference system.
3. Cooling Capacity Saving; which is calculated as the percentage saving in installed cooling capacity in the design building over that required for the building fitted with the reference system.
4. A graph button shows the variation of the dry resultant temperature with time over the last three days of the analysis.

In addition, the following graphical results can be obtained:

1. Parametric analysis graphs are available for all the important input variables (as demonstrated in Figure 2). These show the variation of internal comfort temperature, cooling energy or peak cooling capacity with the selected parameter.
2. Graph of dry resultant temperature and outside air temperature with time (Figure 1).

3. Solar with time shows the incident and transmitted radiation on the glazing plane in W/m^2.
4. Graph of cooling power and fuel use with time (Figure 3).
5. Graph of ventilation with time (Figure 4)
6. Temperature frequency distribution graphs.

As an example Figures 3 and 4 are presented where stack natural ventilation is used at night and mechanical extract at 2ACH during the day. The external temperatures are as specified for Figure 1A. The building characteristic are $20W/m^2$ internal heat gains, 0.5 ACH infiltration, south orientation, heavy construction, 0.4 glazing ratio, 8.00-18.00 occupancy hours and solar protection with 0.2 shading coefficient.

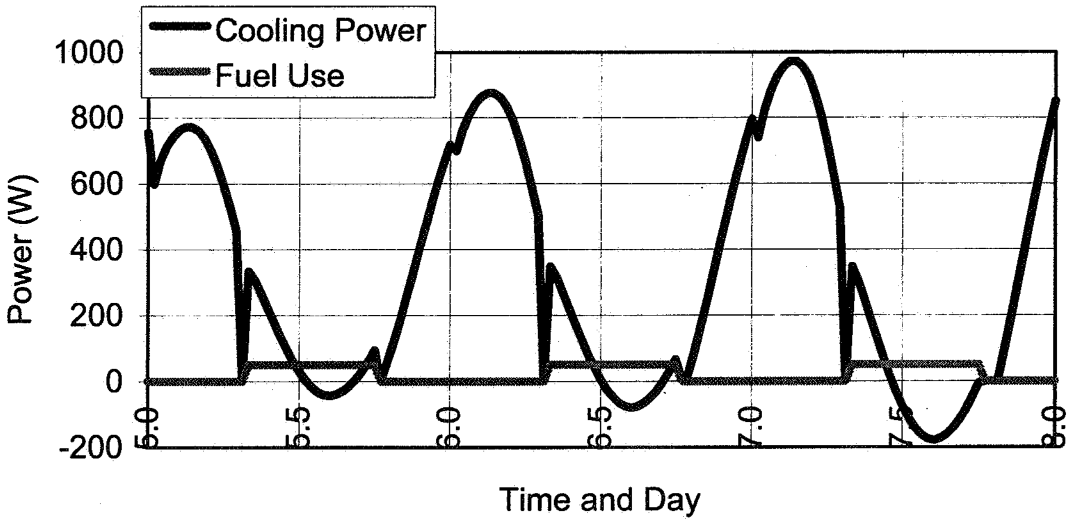


Figure 3: Cooling power and fuel use with time. The performance of the cooling systems can be assessed by observing the relationship between the two lines.

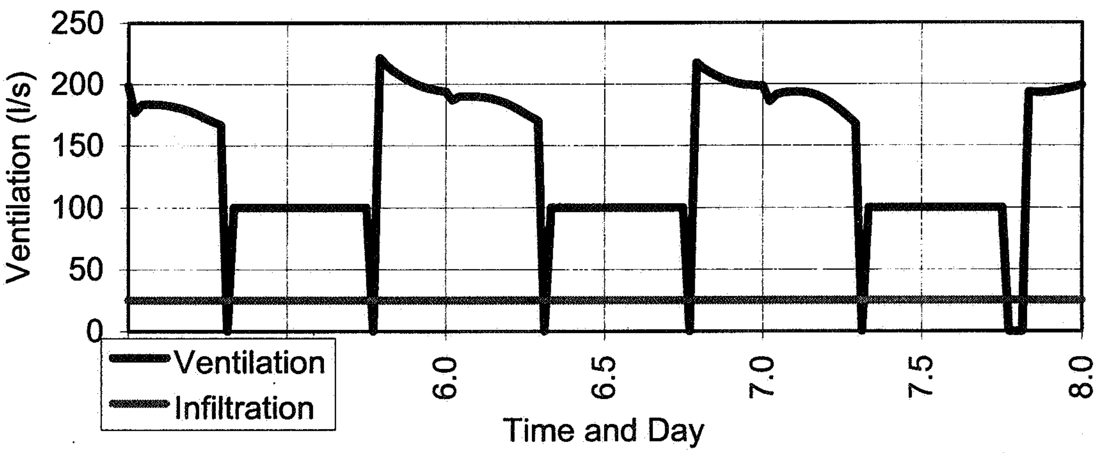


Figure 4: Graph of ventilation with time shows both the ventilation due to the cooling systems and that due to infiltration. This data may be useful in ensuring that sufficient fresh air is being provided.

Conclusions

This paper describes a pre-design tool developed especially for the UK office building and climate for assessing a range of night cooling ventilation strategies. The program is based on a single zone ventilation model, a given office configuration and the 3TC thermal simulation model. It is an easy to use pre-design tool with very fast simulation time which allows quick comparisons between three mechanical ventilation systems, four natural ventilation systems and two active cooling systems in terms of temperature, fuel consumption and cooling power. In the case of natural ventilation systems, the program has the facility of automatically sizing openings in order to achieve a user specified flow. The program also allows the user to investigate very quickly the effect of different external temperature sequences on the internal dry resultant temperature. It also includes a parametric analysis facility which can be used for design optimisation. Written in Visual Basic, the program has a user friendly interface, with a minimum number of input parameters and fast simulation time, all of which will allow its use by designers at the initial design stage.

Acknowledgments

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