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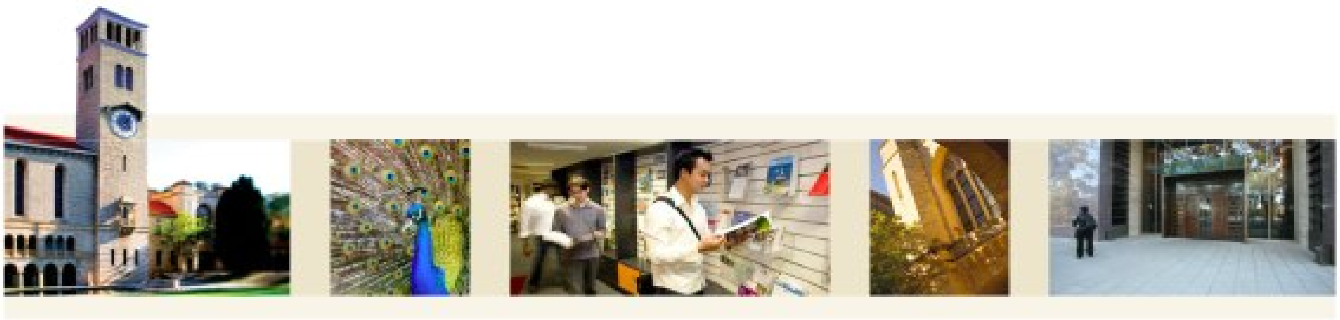
Feasibility of Natural Ventilation in the Mechanical Engineering Building



Project Summary

In pursuit of UWA sustainable development goals, this study investigates the possibility of using natural ventilation in the Mechanical Engineering building at the university's Crawley campus. The building currently uses a number of mechanical heating, ventilation and cooling (HVAC) systems which offer some opportunities for improved energy efficiency. To study the existing building and services, a model of the building has been created using state of the art thermal simulation and analysis software. A selection of natural ventilation schemes have been modelled in order to study the feasibility of replacing, or reducing the energy consumption of, the mechanical ventilation currently used. This report describes the modelling project and discusses the results of the feasibility study conducted.

The scope of work for this project, as stated at the outset, has proved to be somewhat over ambitious. The complexity of the software chosen for the task has slowed down the pace of the modelling task. While ODS Design Studio is an excellent package and it leverages the power of the EnergyPlus to ensure high quality whole building simulation, it is at an early stage of development. Hence it is poorly documented and suited more to experienced professionals. This has slowed the progress on the basic models which must be made before quality investigations of possible alterations to the building can be made. To deal with this reality, it has been proposed to reduce the scope of the project and focus on investigating the feasibility of natural ventilation for the mechanical engineering building as constrained by the local climate and the building.

Acknowledgements

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Planned Project Scope

1. Complete audit of existing mechanical services in building including Chilled water loops, additional heat/cool services, ducting, fans, diffusers etc.

2. Identification of possible natural ventilation schemes in building (consult with Facilities Management / HVAC engineer)

3. Create a computer model of the Mechanical Engineering building and its mechanical service

4.Validate the model with actual data (energy consumption etc)

5. Model various natural ventilation schemes

6. Investigate additional energy efficiency measures (e.g window insulation films) to supplement natural ventilation proposal

7. Analyze the model and select the most favorable alternatives

8. Outline costs of proposed scheme and compare to energy savings estimated

9. Main deliverable will be a set of recommendations for utilizing natural ventilation in the Mechanical Engineering building

Revised Project Scope

Referring to the planned project scope above, the planned revision of the scope will be:

1. Unchanged

2. Unchanged

3. Unchanged

4. After discussions with FM, it was decided not to proceed with this.

5. Fewer of the proposed options will be investigated, rather than fully implemented models for each of the options, the modelling will focus on the feasibility of an ideal natural ventilation scheme .

6. Modelling reduced solar gain is still planned.

7. Replace this element with a discussion of how to implement the modelled scheme in the existing building.

8. Cost of the imageINK film can be found

9. This deliverable will be the final report which will describe the relevant design principles, the key features of the feasibility study, the constraints imposed by the building and climate and

- Compare closed building and night-cooled building

- Quantify the effect of reduced solar gain through existing windows

Literature Review/Case Studies

style: point or argument (Author,Year)

The use of night cooling to reduce energy consumption in modern buildings is discussed in (Koloktroni et al, 1998). The strategy is found to be particularly effective in moderate climates and for high thermal mass construction. (Wang et al, 2009) et al study the use of night cooling by mechanical means for light-weight constructions and temperature climates.

The thermal comfort criteria by which natural ventilation strategies are judged are discussed (Fordham,2000) who argues for an extending the narrow criteria, set out by the ASHRAE standard [ref]. Extensions include accounting for air movement and peoples tendency to acclimatise to local weather. Acclimatisation is accounted for in the work of (Szoaky,199??) [pull ref from miriam] and the SET values for Perth, discussed in [miriam's] Honour's Thesis are used here to quantify the comfort conditions unique to Perth, WA.

The impact of climate on passive cooling potential is quantified by (Artmann et al, 2007). The climatic cooling potential characterises the climates impact on the thermal behaviour of a building in terms of degree-hours. The CCP is defined as a summation over a period of nights of the product of building temperature and outdoor temperature. Useful night-cooling is said to occur for CCP values of 100kH or above (Artmann et al, 2007)

Methods for integrating the fundamental principles of natural ventilation into buildings are discussed by (Mansouri, 1998).

Case Studies

City of Melbourne's Council House 2

City of Melbourne's Council House 2 achieved Australia's highest energy efficiency rating, the Greenstar 6 Star certification (esd design guide, YEAR). It features phase change materials and air-conditioning is achieved with 100% fresh air and chilled ceiling panels. The building uses night ventilation. The building implements a night cooling system using openable windows and stack effect. See Figure 1. Applying such a scheme to the UWA Mechanical Engineering building could be problematic. There is a security concern with having windows opened at night. The concern is perhaps lower for the first and second story windows. Secondly, the scheme relies on effective cross-ventilation and clear flow paths to the vertical column. To be effective, the path for airflow must be continuous, which it is not. The interior spaces are broken by the central corridors. To effectively apply this simple natural ventilation scheme requires dealing with these two issues. However, an idealised version of such a night purging scheme was applied, ignoring these issues, in order to quantify the potential benefit it can deliver.

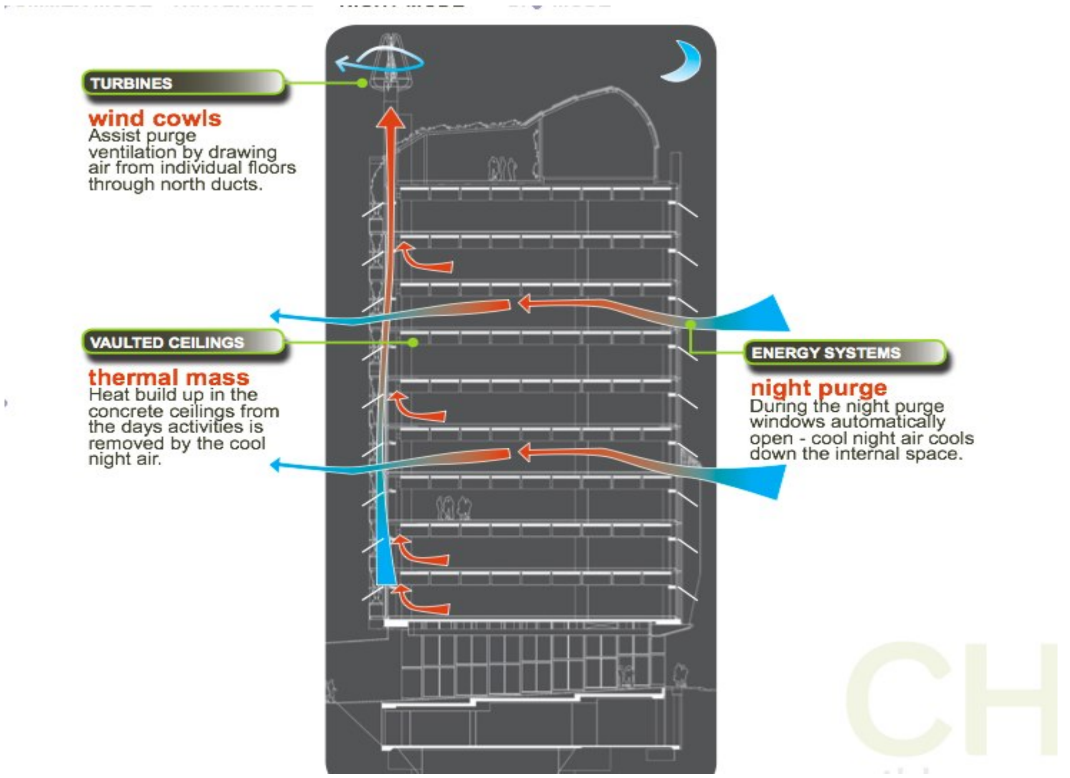


Figure 1: Night cooling at Melbourne's City Council Building

Grove House at Thames Valley University

Grove House at Thames Valley University in the UK underwent a substantial renovation to implement a natural ventilation scheme. The main features of the scheme being a passive stack and facade ventilation system, the use of night-cooling and solar panels for electricity generation. Windows were replaced to include air inlet grilles to ventilate a plenum space adjacent to the internal floors. Air flows along the thermal mass of the concrete slabs and is drawn into stairwells which serve as passive stack devices where air is drawn out at the rooftop. The scheme is fundamentally similar to the one implemented in the Melbourne Council building, however, the facade deals with the security issue of openable windows. The system requires airspace adjacent to the internal floors continuous to the stairwells. To apply this scheme to the UWA Mechanical Engineering building, extensive work would be required to provide such a continuous space for airflow. In the buildings core, there are three stairwells which could provide the necessary vertical spaces. A lack of ceiling space in the building is the other main hindrance to applying such a scheme.

Figure 2: Facade Ventilation devices

Zion National Park Visitor Centre Utah

The final case study examined is the Zion National Park Visitor Centre in Utah. The local climate dry and mild, with warm summers, similar to Perth's. The Visitor Centre is a landmark project for passive design. The key features of the building are its open plan, with high windows oriented to catch the winter sun and exclude the summer sun, a cooling tower using water evaporation to provide a low energy source of temperature and humidity control and trombe walls to provide passive heating in winter.

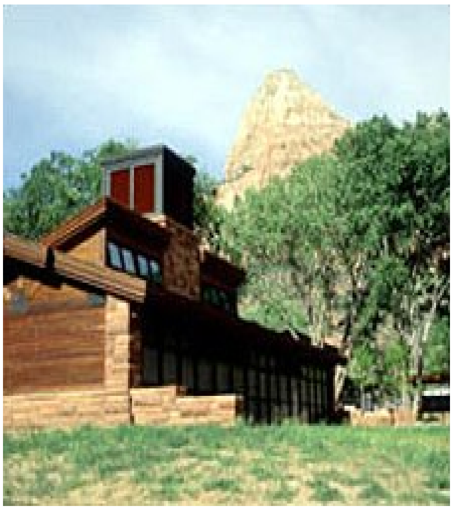
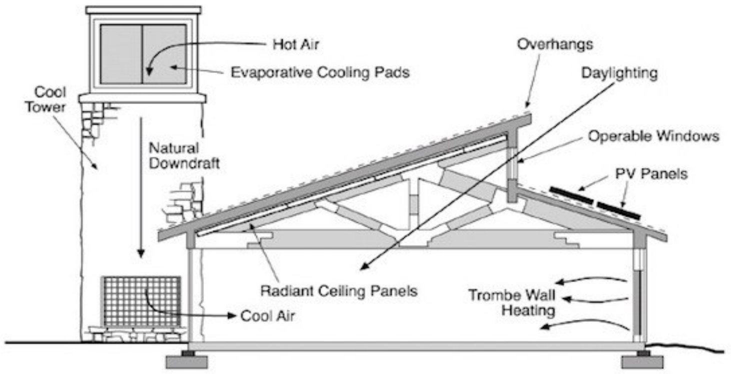


Figure 3:Photo of the Visitor Centre showing cooling tower and high windows for exhaust air



Source: NREL and NPS drawings.

Figure 4: The passive design features of the Visitor Centre

The Visitor Centre provides an example of an ideal implementation of passive design and natural ventilation. It highlights the potential of passive design features when incorporated into the building design from its inception. The relevance of this case study to the Mechanical Engineering building at UWA is the use of cooling towers combined with low openings for intake air and high openings for exhaust air. The climate in Perth dictates that some source of cooling will (most likely) be needed to maintain comfortable conditions. Cooling towers may be able to provide this cooling at a low energy cost.

Building Description

The mechanical engineering building at the University of Western Australia's Crawley campus is a large sprawling building. It consists of nine main blocks and two lecture theatres. The core of the building consists of the A,B and C blocks. Peripheral to this core, there are several large workshop and laboratory area, which are generally large spaces with high ceilings. Each building is divided on its east west axes by a central corridor. Both the south and north facades are glazed, with the northern facades generally having more internal blinds shading the rooms on that side. The building was constructed in the 1960's and consistent with that period, the construction materials are a mixture of concrete, brick, metal roofing and clear glazing. The building was not designed for a mechanical HVAC system. This is apparent in the inclusion of some passive design features and also in the lack of ceiling/inter-floor space available for ducting and pipework. The passive features of the building are the east/west orientation of block's main axis, the prevalence of external shading on the northern facades and the shallow depth of the north/south extent with openable windows on both of these sides. Through its long service, the building has undergone several refits and renovations, including a mechanical HVAC system being installed in the late 1990's. This system is described in more detail in the (HVAC section). The original interior morphology [must introduce Mansouri before this] had to be modified to allow this system to operate effectively and this has left the building in a somewhat contradictory state. It does not have the closed, air-tight type spaces necessary for effective air-con designs nor the open, well vented spaces ideal for natural ventilation design. The original scope of work called for a model of the entire building, however, given its size and the complexity of modelling spaces with so much variation, it has been decided to model the main core of the building, the A,B and C blocks. These can be seen in the image below, noticeable as the central section with the darker roof.

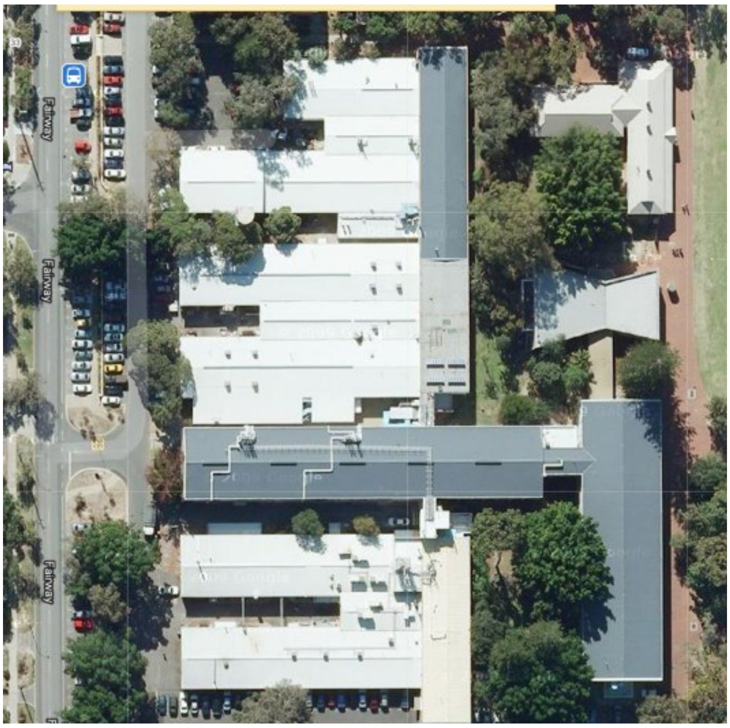


Figure 5: google maps image of the Mechanical Engineering building. The core of the building has a darker shade of roofing material

Existing heating, ventilation and cooling system

The core of the Mechanical Engineering building is serviced by a variable air volume (VAV) HVAC system that was retrofitted to the building in 1998. The building, constructed in the 1960's, constrained the HVAC system in a number of ways. Centralised plant was not practical, given the spread out nature of the building. Thus, there are several plant rooms located around the building which serve nearby spaces. In some cases, the corridors are used for return air plenums. For this reason, and to maintain independence of the thermal zones served each air handling unit (AHU), doors have been installed in long corridors through the B and C blocks. The ceiling spaces through these buildings provide very little room for the required ducting and services and in some cases a lowered ceiling is noticeable. However, the ceiling spaces throughout the building are not uniform. The air handling units are served by chilled water from the UWA central plant. The central plant uses evaporative towers to produce water at 5C for use throughout the University. Facilities Management note that during peak periods the chilled water demand can be greater than the plant's capacity and when this occurs, rolling supply reductions occur.

The air handling units are VAV devices with variable speed fans (VSF) and outdoor air economisers. This is an optimum arrangement for energy efficiency. The air volume delivered by the AHU to each zone varies according to the load on the system. In the rooms that each AHU serves, a user can switch on the air-con as required. The AHU will deliver air according to the required load, calculated with input from the room's thermostat. The typical sequence of events on a given working day is as follows. At the beginning of the day the variable speed fan will be off and there will be no air flowing through the AHU. As the rooms are occupied, the air-con switch is pressed by users in those rooms, the AHU will begin operating. The VSF will spin up, it will settle at a speed which provides for a static pressure drop of about 150pa. This air flow will pass over the chilled water coils, cooled to the set point. Temperature sensors in the room provide feedback to ensure the air is at set point. An economy cycle operates such that if the outside air temperature is suitable for heating or cooling it will be used instead of supply air. When it is not suitable, for example on a very hot day, the volume of outside air delivered is determined by the fresh air requirement, which is usually about 10 l/s/person. An on-site weather station provides calibrated outside air temperature and relative humidity information for the University wide facilities management system (FMS)

In addition to the VAV system supplied by the AHU's there are also areas served by fan coil units(FCU's) and evaporative units. Two FCU's located outside G88 and G91 serve those rooms. The large spaces in the water research lab and the mechanical engineering workshop are served by evaporative units. It is found that these large spaces can be efficiently cooled in this way and that in Perth's climate, this is effective for all but a few days of the year, when the relative humidity is too high for effective cooling.

Local climate

The extent to which natural ventilation can provide a comfortable internal environment is dictated largely by the local climate. To achieve the necessary fresh air ventilation rates [need to set up AS fresh air requirements] and maintain cool indoor air temperatures during long hot summer periods are often conflicting requirements. The extent of this conflict varies with the seasons and with climate. In temperate climates, the outdoor conditions will coincide with satisfactory thermal comfort for a considerable proportion of the year. In hot humid climates there is a small proportion of the year when outdoor air can be used to ventilate an indoor space without raising the temperature to an uncomfortable level.

Thus an assessment of the local climate is a necessary starting point for a discussion of the feasibility of any natural ventilation scheme.

The climate in Perth, WA is classified as dry Summer sub tropical under the Koppen classification and is characterised by dry and hot summers and mild winters. During the warmer months, the local weather is dominated by high pressure systems bringing dry easterly winds. This summer pattern is accompanied by a sea-breeze. Which, when it occurs, brings a cool change in the afternoons. As initial modelling and advice from FM show that the Mechanical Building does not often require heating, the focus throughout this study is on the Summer conditions and the availability of cooling measures.

The annual trend of minimum and maximum temperatures is shown in figure FIGURE. Summer maximums in the high 30's are typical, with cool evenings being the norm. Winter maximums in the high teens, and minimums above freezing are typical. What is also apparent in the figure below is that the diurnal variation through the year is relatively constant. During the milder seasons, this translate into a reasonable level of night cooling potential.

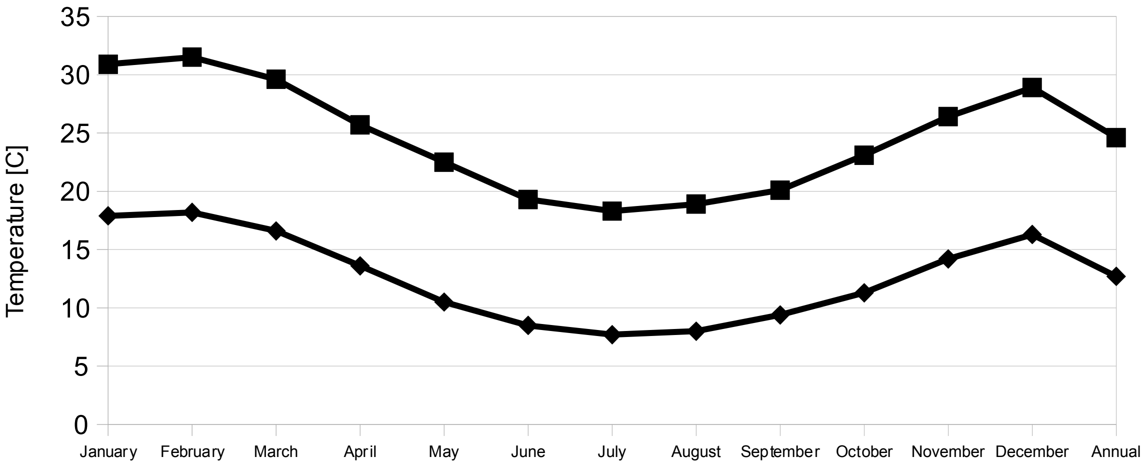
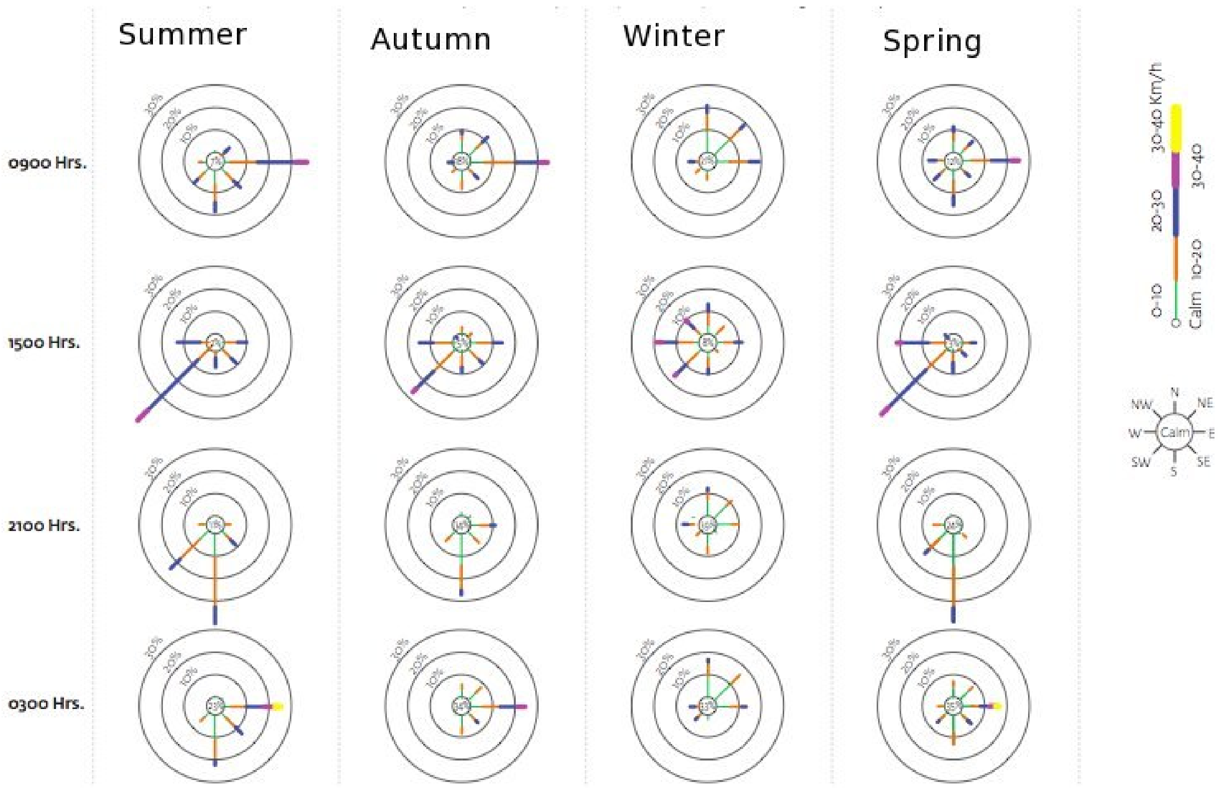


Figure 6. Monthly minimum and maximum temperatures

The prevailing wind is detailed in figure FIGURE below. The figure shows the prevalence of the southwesterly wind in the afternoon, providing a reliable cool-change to most hot days.



% depicts the percentage of total time wind velocity occurs.

Figure 7: Wind Roses for Perth's seasons, www.thinkbrick.com.au

The sea breeze is a southwesterly wind which generally picks up by mid afternoon and can travel inland further than the metro area. To quantify the possible cooling effect available from the sea breeze, weather data for the past 9 years from the Perth Airport was analysed. Based on a rough, but reasonable definition which states that a sea breeze occurs if

- the wind direction is between 180 -270
- the wind strength is 5 knots or greater (2.5m/s)
- the daily maximum was above 25C

With a total of 2564 days of wind and temperature data for the past 9 years there were 727 days with a sea breeze between 12pm and 12am, a mean value of about 28%, or 1 day in three. There were 336 out of 2564 days where the max was above 25 and there was no sea breeze.

The climatic cooling potential, expressed in degree-hours was calculated for a building temperature of 23C and the average CPP value for each month of the year is shown in figure FIGURE below.

The low CPP values for the hot months of December, January, February and March, (less than 40Kh) mean that there is limited potential for night-cooling in these months.

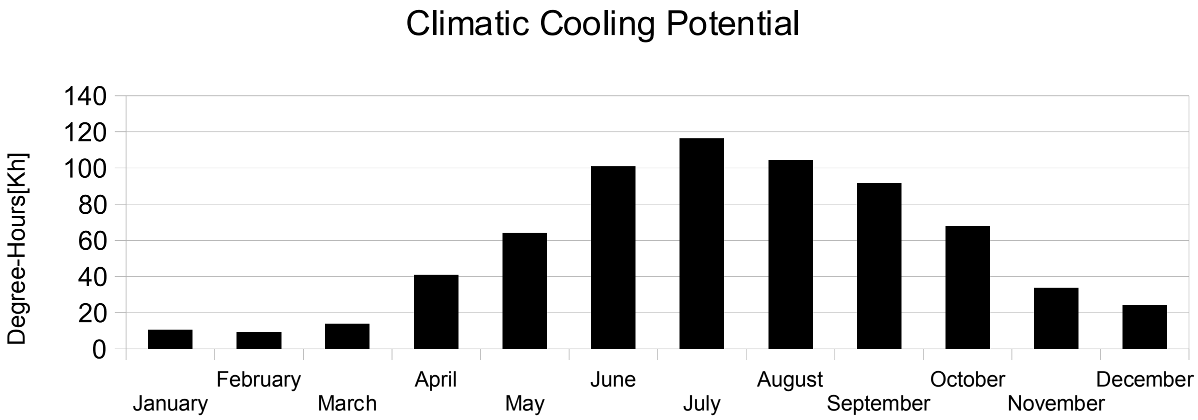


Figure 8. Climatic Cooling Potential

Options and Opportunities

Guided by this evaluation of the local climate and by the case studies discussed, a number of natural ventilation and passive design features were investigated;

1. Night-cooling through openable windows
2. Window films applied to existing windows
3. Operable shading devices
4. Day-time cooling with Cooltowers

These options provide an opportunity to reduce the energy consumed in cooling the Mechanical Engineering building. The building and the climate provide some constraints on the degree and nature of these opportunities. Using the thermal simulation and analysis methods that are consistent with the process of environmentally sustainable design, the feasibility of these options were investigated.

Modelling Software

ODS Studio

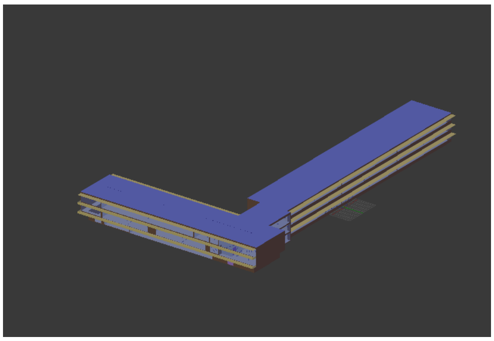


Figure 9: An image of the model, drawn in Blender

The modelling and analysis software used for this project was ODS Studio. ODS Design Studio brings together several open-source packages including Blender - a 3D design tool, EnergyPlus - the building simulation and analysis tool developed by the U.S Department of Energy and National Renewable Energy Laboratory, OpenFOAM - a computational fluid dynamics package and other packages not used here (Pitman, 2012)

The building geometry is modelled in Blender. Here the building's physical properties, its floorplan, construction materials etc are represented. ODS Studio translates these properties into the form required for EnergyPlus. This is encapsulated in the IDF, which is a text file containing a description of the buildings surfaces, construction materials, shading, HVAC system, internal loads (people, lights, electricity), the schedules on which the building operates (e.g times when it is occupied, times when the HVAC is on and off) and other required details. EnergyPlus will simulate this building over a given period and subject to an external environment described in a weather file.

OpenFOAM

Further modelling inputs are available by passing the building geometry to OpenFOAM and running CFD simulations, for example to examine the pressure distribution on the building facade under the action of wind. Due to time constraints, extracting the pressure distribution data from OpenFOAM was not achieved.

EnergyPlus

EnergyPlus is one of the most highly validated thermal modelling tools available. It is also opensource which means no licensing fees are necessary to use it. Further, it is very well documented and supported.

Model Inputs

In order to construct a useful thermal model of the building, a considerable amount of input data was required. This data consists of information which can be broadly categorised into;

1. Building geometry
2. Construction and materials
3. Windows and shading devices
4. Building use and occupancy; patterns of building occupancy and use.

5. Heating, ventilation and cooling system (HVAC)

5. Local weather conditions.

Building Geometry

The geometric and HVAC information was gathered from architectural and mechanical plans. Discussions with Tony Humphries from Facilities Management were also a very useful source of information on the building and HVAC operation. The architectural drawings provided the starting point for the model of the building. Well over 300 drawings were provided by FM. These drawings include original plans from created by the Department of Public Works in the 1960s and from various refits and extensions in the years since. The main floor-plan drawings were taken from drawings A224-02KY, A224-01KY, A224-GNKY, A224 and A124-157 (Site Plan). The building consists of several blocks, with the A,B and C blocks comprising the core of the building, modelled in this project. This core building is served by several air handling units. Blocks E,F and G house large workshop and laboratory spaces that are served by dedicated rooftop evaporative coolers.

Construction and Materials

The architectural plans also provided information on the construction materials used in the building. The building is constructed with a mixture of concrete, brick, timber and metal roofing. Glazing is 6mm float glass. Exterior walls without glazing are generally single or double brick, glazed facades are timber framed panels, with a insulation backed glazed panel on the lower third of the facade. The insulation levels through the building are assumed to be ??mm fibre panels in the ceiling space. Interior partitions are either light plasterboard construction or single brick in some older spaces. These construction materials are represented in the model using the data from the ASHRAE Handbook of Fundamentals on the thermal properties of common building materials, which is available as a dataset in EnergyPlus.

Windows and Shading

The shading has been modelled by including venetian blinds on the interior windows of the northern facade and by external shades along the east and west facades. The external shading comes from the balcony around the first and second floors. On the eastern side the first floor overhangs the underlying Clough First Year centre area. The shading has been modelled in EnergyPlus by describing these balconies as Shading. Hence the only effect of the surfaces in EnergyPlus is to throw a shadow, the thermal properties are null. The shading can be seen in Figures 4 and 5 below, which show the balconies on the eastern facades.

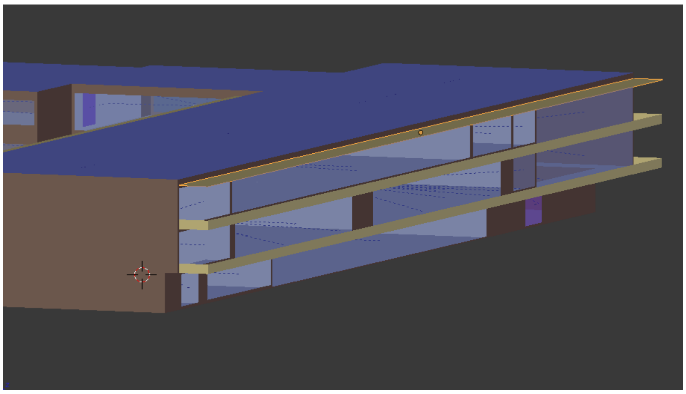


Figure 10: Isometric view showing eastern facade with shading in yellow

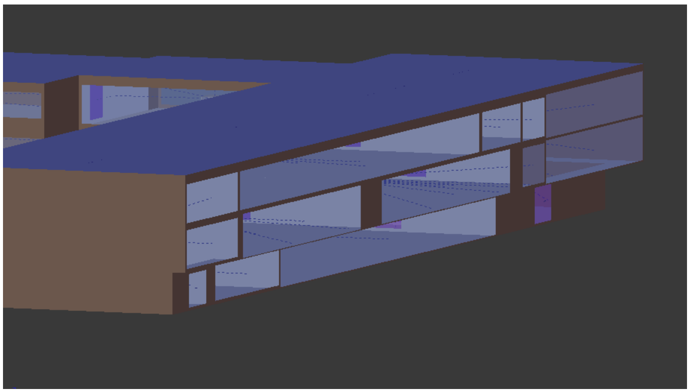


Figure 11: Isometric view showing eastern facade without shading

Building Use and Occupancy

With the exclusion of the building shell, the building use and occupancy is probably the most important aspect of the energy model. The thermal load which a HVAC system must meet comes from two categories, external and internal gains. The main external source of heat is solar gain. There are four main internal gains considered; people, lights, electric equipment and infiltration. Each of these internal gains has an associated schedule according to which the thermal load varies. These schedules and their peak values are described below.

Schedules

Occupancy

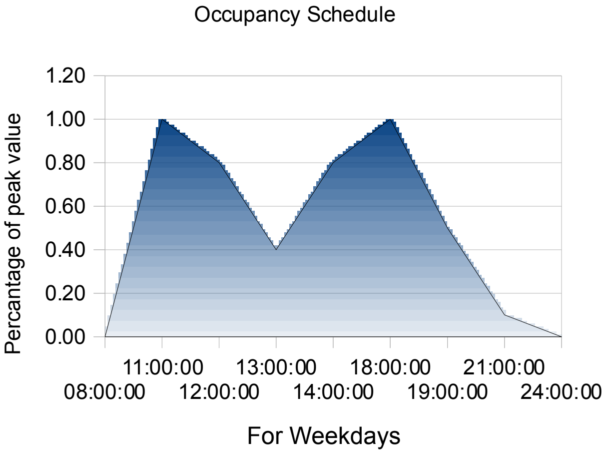


Figure 11

The occupancy levels have been set by specifying area per person. Consistent with typical office space densities, this is set at 1 person per 10 square metres. Energy Plus calculates internally the number of people in a zone from the floor area. The peak occupancy level then varies according to the schedule in figure FIGURE to the left. This schedule is typical of an office space, where levels fluctuate through the working day, with a lull around lunchtime.

Lighting

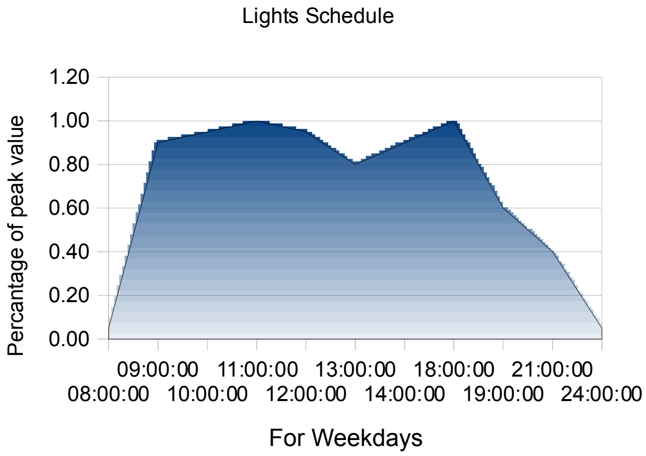


Figure 12

The lighting levels are set at a level consistent with a typical office space, of 10W/m2. EnergyPlus calculate internally the total lighting power in a zone from the zone floor area. The lighting levels fluctuate through the working day according to the schedule shown in figure FIGURE to the left. Lighting levels are set at zero over weekends and holidays.

Electric Equipment

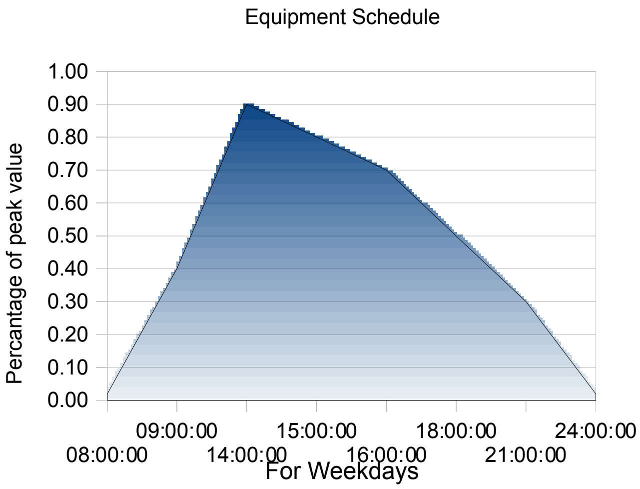


Figure 13

Equipment levels, accounting for the heat generated by equipment such as computers, desktop lamps, photocopiers etc, is accounted for by specifying an equipment level of approximately 3000W per zone. This level fluctuates according to the schedule shown in figure FIGURE.

Window Vent Schedule

The openable windows operate on a schedule which accounts for occupancy and temperature. During occupied hours, the windows can be opened when there is a temperature benefit to doing so. The window vent schedule sets a limiting temperature of 21.1 degrees. When the temperature in a zone is above this setpoint and the temperature indoors is higher than outdoors, the windows are opened. This corresponds to a common sense approach to window venting. It allows for cooling breezes to ventilate interior spaces. When the outdoor temperature is below this set point, which corresponds to the heating set point, the windows remain closed, helping to maintain a warm indoor environment.

Thermal Comfort Schedules

Activity

The heat generated by the occupants of the building is set at a level of 131W. This is consistent with a typical person performing some sedentary activity. The level is constant through the year.

Clothing

A clothing schedule specifies a constant clothing insulation level of 1clo for the simulation period. The quantitive unit of insulation provided by clothing is the clo. For example,

Example 1) Trousers and and short sleeve shirt provides 0.57clo.

Example 2) Trousers, vest, T-shirt, long sleeve shirt and suit jacket provides 1.14clo

To investigate the effect of the clothing levels on thermal comfort, the clothing schedule was varied to 0.6clo for the warm months of November to March and 1.1clo for the cooler months of April - October.

Air velocity

An air velocity schedule specifies a constant air velocity of 0.2m/s for the simulation period. To investigate the effects of increasing the air velocity to mitigate higher air temperatures the air velocity is increased to 0.8 m/s.

Work Efficiency

A work efficiency schedule specifies a constant level of 0 for the simulation period. This means that all of a persons metabolic activity is converted into heat. This is consistent with sedentary activity.

Ideal Loads HVAC

EnergyPlus provides the ability to model a simple, ideal HVAC network with a minimum of input required. The Ideal Loads network is a idealised system in which the zone is heated or cooled by the amount necessary to reach the user specified set points.[E+ input output ref] By removing the complications of the additional plant and equipment and the interactions amongst these components, Ideal Loads HVAC allows the user to study the effect of varying the internal and external gains on the zone comfort conditions with a minimum of distractions.

Airflow Network

EnergyPlus provides the ability to simulate the ventilation of a building due to wind. The Airflow Network can simulate airflows through multiple zones and the interactions between natural and forced ventilation. A simple Airflow Network was implemented, to capture the effect of ventilation through openable windows and cracks in the external facades. In order to manage the complexity of this simulation module, the settings were taken from example files detailing the ventilation of a low rise, rectangular building. The Airflow Network requires details on each surface of the building, in order to calculate the effect that a wind, from any direction, will have on the pressure distribution over that surface. Initially, the scope of the project included modelling the building in OpenFOAM, in order to extract the coefficient arrays necessary for the Airflow Network settings. However, the this step proved too complicated to solve in the available time. For an idea on the level of detail required, each external surface, of which the model has about 200, needs an array of 12 values, detailing the effect of a wind from an array of directions, 30 degrees apart. In order to calculate theses 12 values, the model must be placed in a simulated wind tunnel, the wind applied, and the pressure distribution calculated. Then the pressure over the area that each external building surface occupies mus be calculated and Bernoulli's equation solved to extract the wind pressure co-efficient value. This would mean that 12 CFD simulations would need to be run, with each run needing over 200 calculations. Obviously, this process would need to be automated, yet doing so would have been very time consuming. The alternative was to accept the approximation provided by assuming the building was rectangular. This will result in some errors to the pressure distributions calculated internally in EnergyPlus. However, the air change rates inspected show reasonable values and for the level of accuracy in the model as a whole, the approximation was decided to be acceptable.

Infiltration

For the passive model, the Airflow Network is disabled. In order to achieve a comparable level of night cooling, a design level of infiltration is set. This level is set according to a schedule that replicates the behaviour of the Airflow Network. During the warmer months, November to April, infiltration levels of 10 ACH occur overnight, dropping to 1 ACH during the day. During the cooler months, the infiltration level is a constant 1 ACH.

Assessment Criteria

To assess the effectiveness of the various natural ventilation and passive design features investigated, some criteria must be chosen by which to judge them. The criteria chosen are discussed below.

Indoor Temperatures

The most direct and simple criteria for judging the effectiveness of the various options investigated, is to compare the resulting air temperatures. As there are over 20 zones in the building model, one zone is chosen to conduct most of these comparisons.

Infiltration and Ventilation Rates

The fresh air rates delivered by natural ventilation are set by Australian Standard AS1668.2 2002. The required fresh air rate set by Table 4.2 for low activity levels is 5L/s per person. At a typical office density of 10m^2 per person, this equates to 0.2L/s/m^2 or 0.0002m^3/s/m^2 of fresh air.

This level of fresh air inflow can be used as a rough guide as to the rate of inflow due to the infiltration modelled with the Airflow Network through surface cracks.

The typical air change rate for an office or public buildings is 0.3 - 0.5 Air changes per hour, ACH. [ref this]. Air Changes per Hour is the a flow rate measurement. It indicates the flow rate at which a room's volume of air is replaced in one hour. This doesn't mean the air in the room is entirely replaced by fresh air, whether this occurs depends on the effectiveness of the inflow and outflow of air in the room. It simply indicates a rate of flow of outside air into a room sized volume of the period of time of one hour.

These two rules of thumb are used to verify the rates of infiltration and ventilation in the models.

Cooling Loads

The relative energy efficiency of the natural ventilation schemes investigated is found by comparing the loads required to maintain a heating set point of 21C and cooling set point of 24C. Using the Ideal Loads HVAC system available in EnergyPlus, these loads are found for each of the models. The Ideal Loads calculations in the EnergyPlus simulation state this energy in Joules, which is converted to kWh, for every hour of the year simulated.

Thermal Comfort

The community expectation of comfortable internal environments has arisen as a cultural consequence of the prevalence of mechanical cooling of buildings. Research into thermal comfort conducted in the 1960's by Fanger [paper] has become the basis of a internationally accepted standard for thermal comfort. This standard is laid out in ANSI/ASHRAE Standard 55-2004: Thermal Environmental Conditions for Human Occupancy. The criteria is known asFanger Predicted Mean Vote. There are six main physiological factors that determine thermal comfort.

	Physiological Factors in thermal comfort		**ASHRAE Thermal Comfort Scale**
1.	Metabolic rate	-3	Cold
2.	Clothing insulation	-2	Cool
3.	Air temperature	-1	Slightly cool
4.	Radiant Temperature	0	Neutral
5.	Air speed	1	Slightly warm
6.	Humidity	2	Warm
		3	Hot

These factors are the objective variables which allow a quantification of the more subjective notion of 'hot' or 'cold' . To capture the more subjective measure of a person's sensation of that environment, the ASHRAE thermal comfort scale is used. This provides a numerical scale to match to the sensation of 'hot' and 'cold'. The Predicted mean vote calculates the number which 80% of a typical group of people would   choose on this scale given the environmental variables at the time. Comfort ranges can be selected, for example, the AHSRAE standard sets the PMV range to -0.5 to 0.5. See figure FIGURE, which relates to 80% of occupants being comfortable.

The ability of people to adapt to their local climate is an important consideration in thermal comfort, which is somewhat overlooked by the Fanger predicted mean vote method. The effect of local climate is accounted for in the standard effective temperature(SET), a measure of thermal comfort detailed by Szokolay (Szokolay, 1987). The SET method provides a range of temperature and humidity conditions based upon a thermal neutrality temperature unique to a local climate. This range is displayed on the psychometric chart in Figure 14 below. The comfort range is outlined in red, while the blue data points indicate the hourly temperature and humidity values for the weather conditions as simulated.

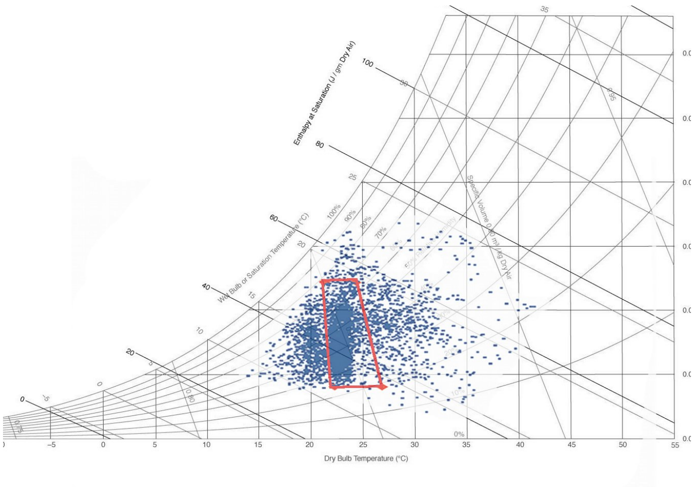


Figure 14

Results

The results presented here fall under two categories, firstly there are verifications of model inputs and secondly there are the quantities drawn from comparative studies.

Input Verification

Infiltration and Ventilation

Some simple verifications were performed to ensure that the models created produced reasonable results and that the dynamic performance of the model reflected the modelling intent.

To check that the infiltration values, achieved with the Airflow Network and the Design Air Specification, are reasonable, the air change rate was compared to the rule of thumb for modern well sealed building of 0.3 - 0.5 ACH. An effective cross ventilation scheme will achieve hundreds of ACH. Examining a typical zone for the average and maximum infiltration value verified an average of 0.39ACH and minimum of 0.11 ACH

To verify the ventilation rates, the air change rate was cross-referenced with the window opening settings, indoor and outdoor temperatures and heating and cooling set points. This method was necessary as there were a number of set points and schedule acting in concert to produce the required heating, cooling and venting.

This verification led to a fine-tuning of the WindowVentSched. The dynamic performance of all these settings can be hard to clearly imagine. It was found that contradictory behaviour was occurring where the windows were open and the heating load increasing to compensate for the additional cooling load introduced. To remove this contradiction, the heating set point schedule was modified so that the heating will not occur when the windows open. The control logic on the Airflow Network does not allow for a direct comparison between outdoor air temperature and the heating set point. A building management system would however, easily make this comparison.

Variable Air Volume HVAC System

The initial modelling involved a VAV HVAC, however this very difficult to simulate properly. The main issue being with the proper sizing of the main air handling unit heating coil. Investigating this issue, the results showed that the terminal reheat coils were doing all off the heating required by the zone while the main heating coil was doing none. Due to the complicated nature of the interaction between many different settings on several pieces of plant and equipment, the error causing this was not found. It was mainly for this reason, that the decision to model an Ideal Loads HVAC system was taken.

Window Glazing Properties

To verify the expected decrease in solar heat gain with the addition of the window films modelled, the output variable detailing the transmitted solar gain was examined for each of the four window films.

Cooltower

The operation of the Cooltower was verified by examining the flow rates of water and air through the towers and by examining the effect on the zone temperature. The initial setting of a minimum zone temperature of 16C was changed, as the internal conditions were too cold.

Shading

The proper operation of the blinds was verified by looking at the output variable Time Window Shade Is On, which shows when the shading is on and off. This was compared to the desired set points and the effect on the solar gain in the zone with and without blinds was compared.

Comparative Studies

The second broad category of analyses undertaken were comparative studies. These studies can further be placed into one of three investigations:

1. Closed versus Open building
2. Narrow versus Expanded thermal comfort criteria
3. Various window films

1. Closed versus Open building

In this first study, the baseline model, in which the building has an Ideal Loads HVAC network and an Airflow Network simulating openable windows (or an ideal cross ventilation scheme) is compared to a model with the same input except that the windows remain closed at all times. Thus, comparisons are made between a building in which all heating and cooling is done by a mechanical system and a building were the mechanical system is supplemented by night cooling and a window opening rule which states, in basic terms, that the windows are opened when there is a temperature benefit from doing so.

The goal of this study is to investigate whether openable windows can reduce the required cooling loads.

The method used to determine an answer to this question is to implement openable windows. The baseline model is varied by adding an Airflow Network to allow for night cooling of the building.

The results drawn upon to answer this question are the indoor air temperatures and the Ideal Loads Cooling energy required to meet the cooling set point. Figures below show the indoor temperature in a typical zone during a week from each season of the year, corresponding plots of the required cooling loads and finally these two data sets in one plot. This last plot helps to show how the night cooling effect reduces the cooling load required and also to show that there are periods in the year when simply opening windows will lead to comfortable interior conditions, bypassing the use of the mechanical system entirely.

It is important to note that in these two models, the Ideal Loads HVAC system does not have an economy mode. The economy mode would reduce the energy used to cool the building, by increasing the flow of outdoor air into the zone when the outdoor air is below the indoor air temperature. An economy mode should be standard on any modern HVAC network that attempts to achieve reasonably efficient operation. While it decreases the cooling energy required, it nonetheless using the mechanical systems - fans, ducting and associated electrical equipment. It thus doesn't solve the common sense contradiction of using a mechanical system to ventilate a building when simply opening windows and allowing the breeze to do free cooling.

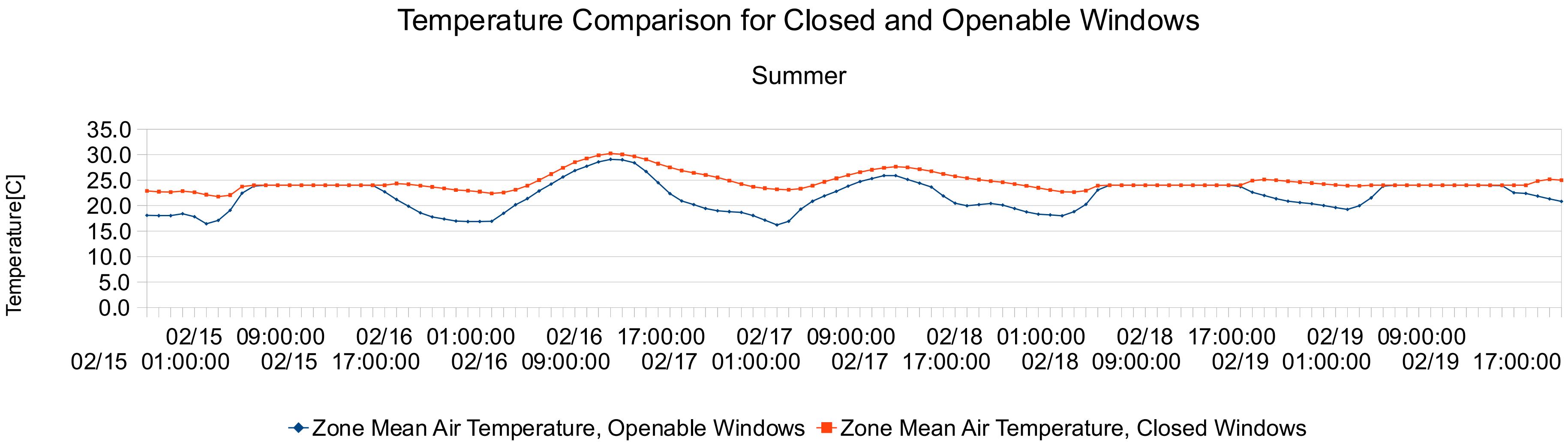


Figure 15

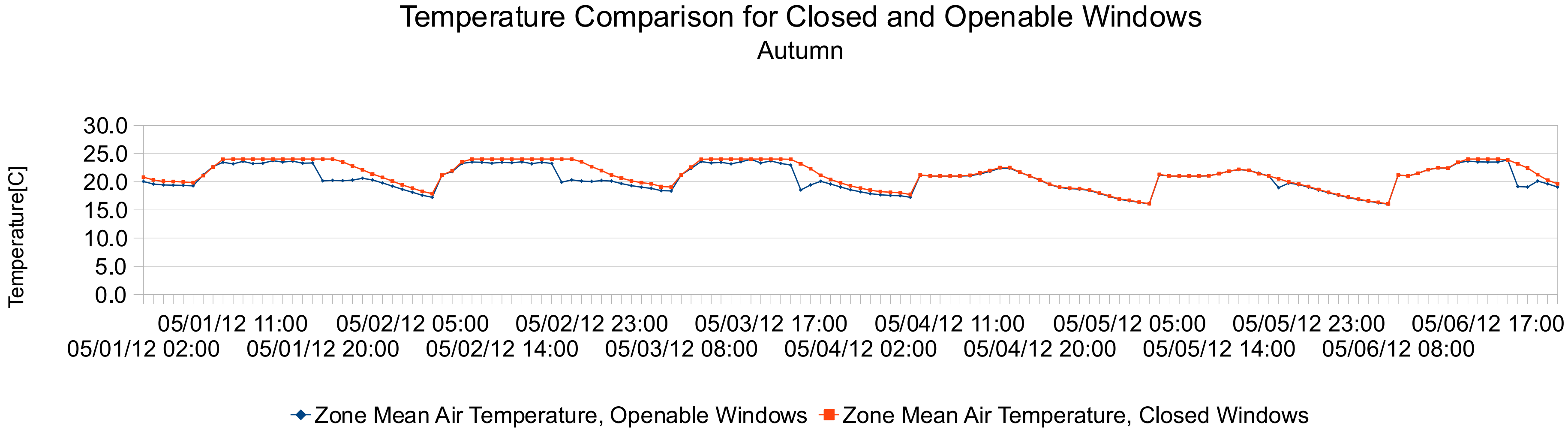


Figure 16

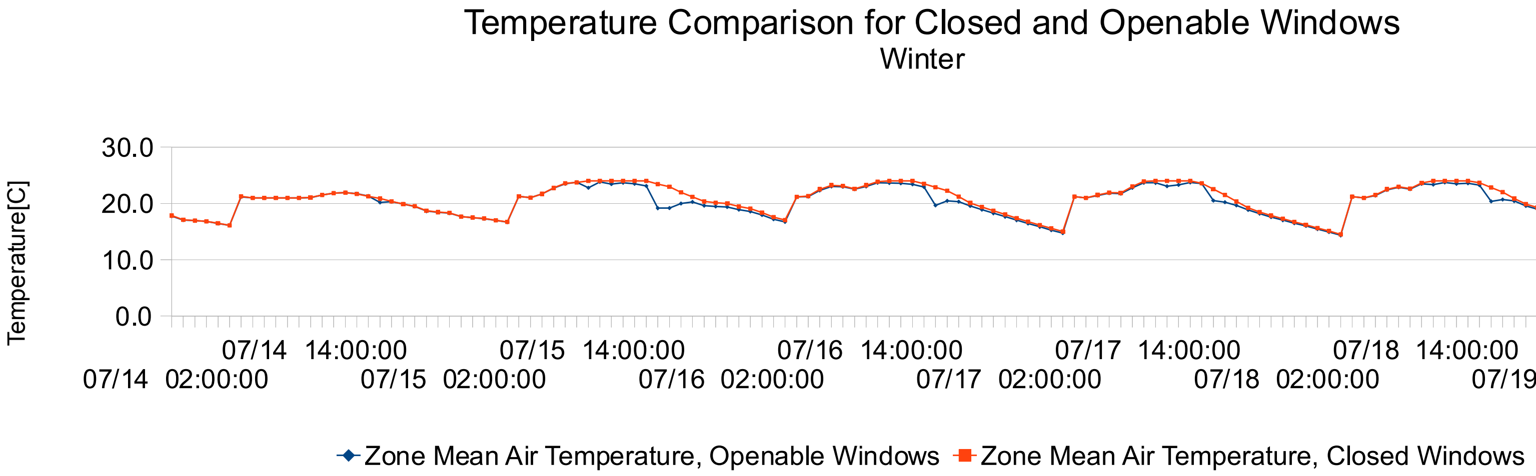


Figure 17

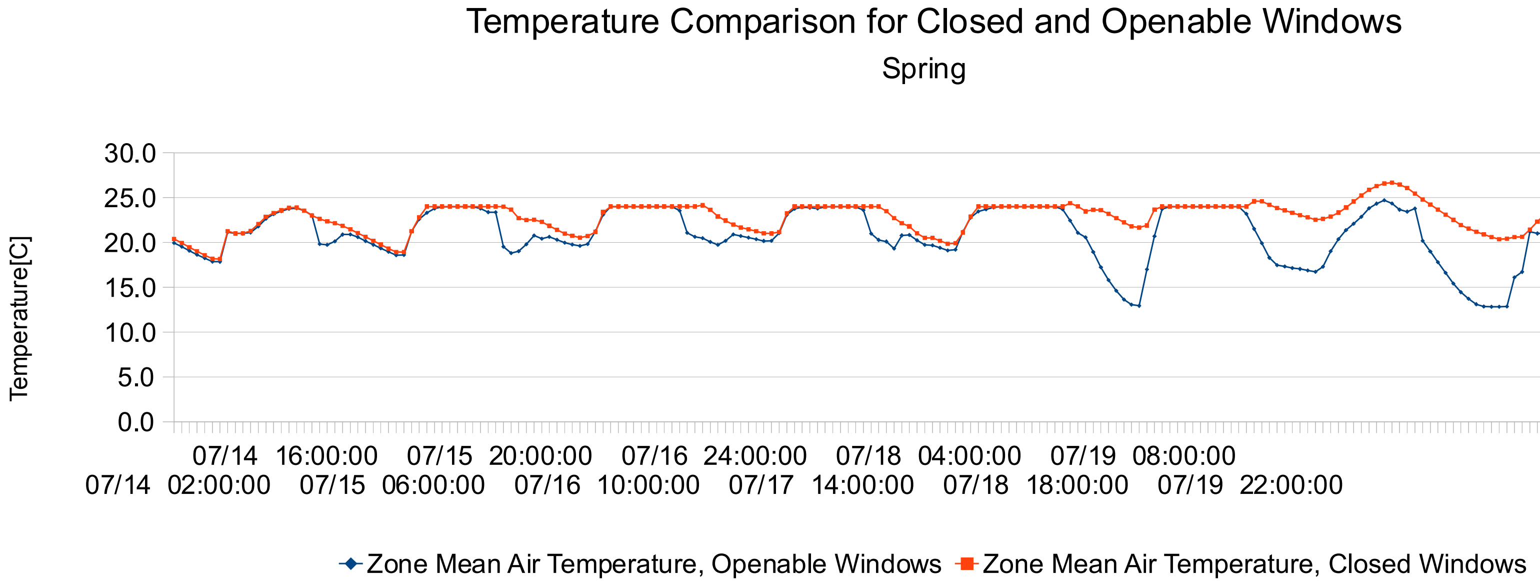


Figure 18

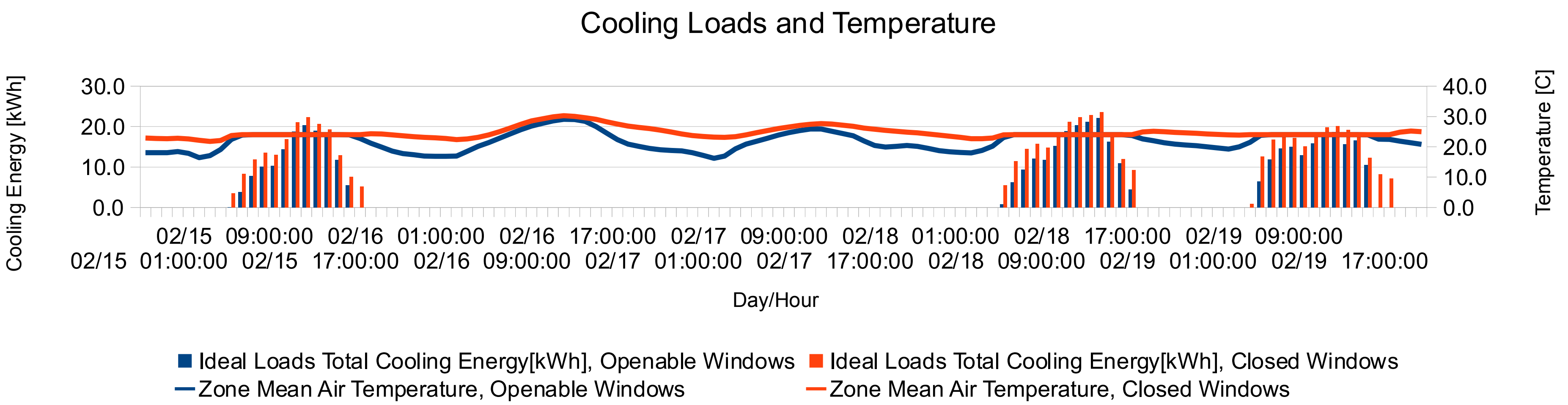


Figure 19

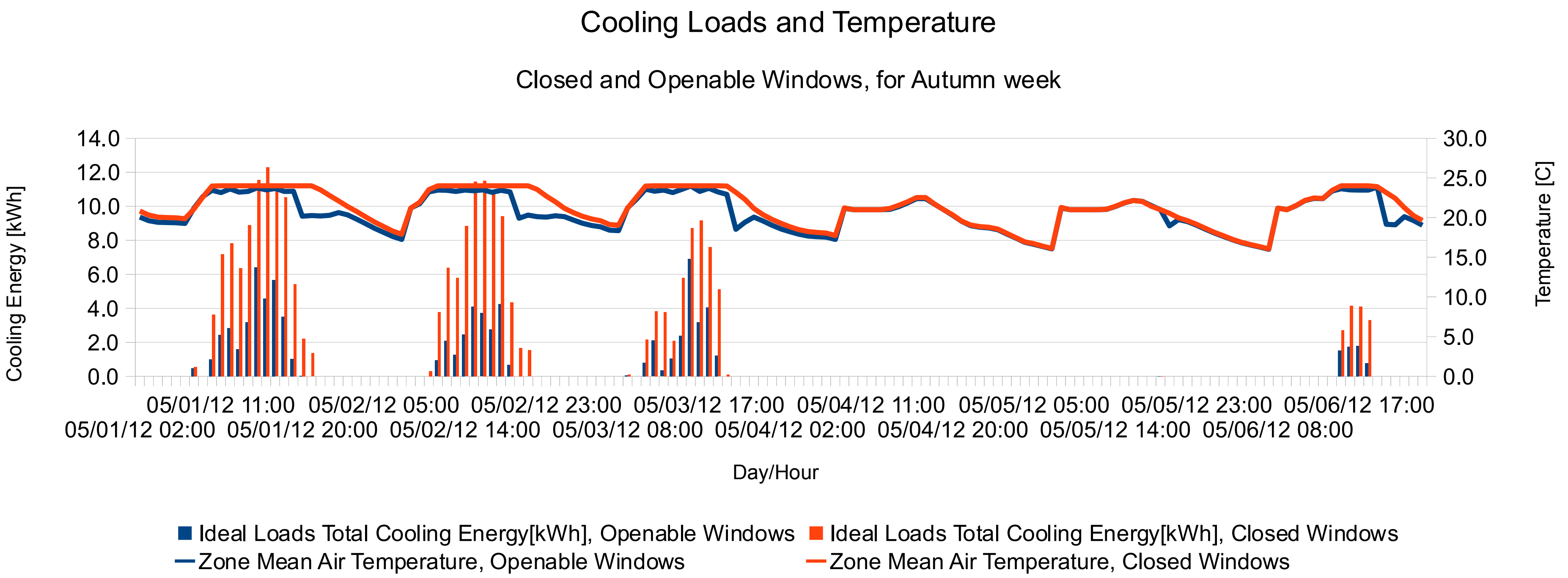


Figure 20

This investigation found the encouraging result that there is a clear temperature and cooling load benefit in the openable windows scenario and thus leads to further investigating the feasibility of a naturally ventilated building. To answer the question of whether such a building could provide a comfortable internal environment, the second comparative study investigates the thermal comfort critera

Narrow versus Extended thermal comfort criteria

The second set of comparisons involve studying a model of the building without a mechanical means of heating and cooling. The goal of this study is assess whether such a building could provide a comfortable internal environment. Two basic models, with the Ideal Loads HVAC system removed, are compared. Two parameters, clothing insulation and air velocity levels, were varied and the narrow ASHRAE standard was extended to account for these factors and for effect of adaptation to the local climate.

The results drawn upon to make these comparisons are; histogram data of thermal comfort as given by predicted mean vote values for all occupied hours of the year, scatter plots of temperature and humidity conditions and the comfort range as given by the Standard Effective Temperature method.

Discussion

The ASHRAE Thermal Comfort Standard provides a narrow definition of comfort range as being PMV values between -0.5 and 0.5. This is illustrated for two clothing insulation levels as shown in figure 3 This is a very narrow criteria and it is difficult for passive designs to achieve.

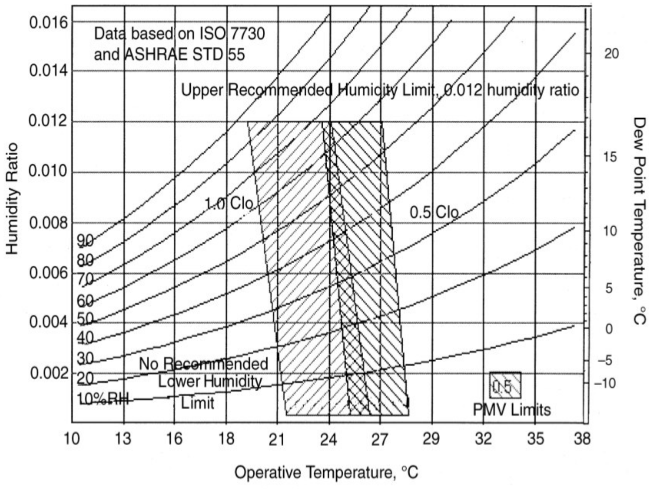


Figure 21: The ASHRAE Thermal Comfort Range

An expanded criteria is between -1 to 1 on the ASHRAE Thermal Comfort scale. Based on this expanded thermal comfort criteria, the results from the two models compared are shown in figure FIGURE, over the page. Using a constant clothing insulation level of 1clo and a constant air velocity level of 0.2m/s the results for the basic model show that the building provides a comfortable internal environment for 72% of the occupied hours. In the seasonally adjusted model the clothing insulation levels vary from 0.6clo in the warmer months to 1.1clo in the cooler months. In the seasonal model, the building provides a comfortable internal environment 75% of the occupied hours.

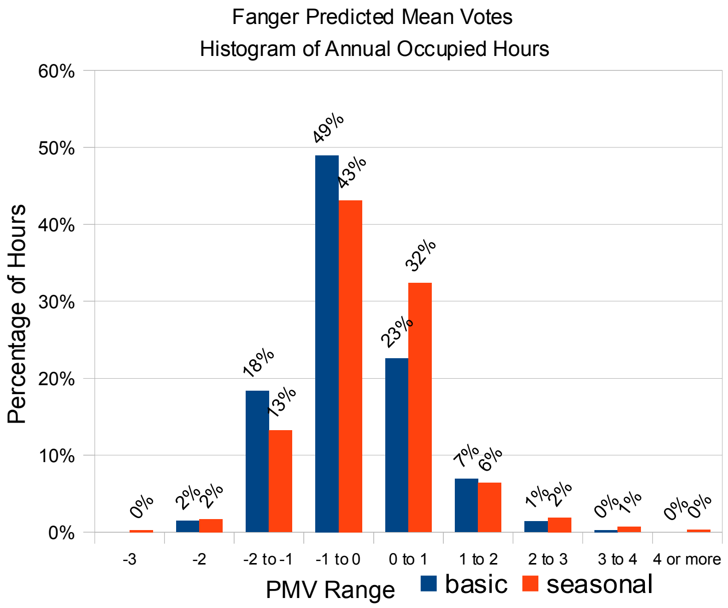


Figure 22

Thermal comfort criteria can be expanded to account for the effect of moving air on the skin, and to account for people's ability to adapt to the local climate. To quantify these expanded thermal comfort criteria, the Standard Effective Temperature (SET) uses a comfort range determined from a thermal neutrality temperature adjusted to the local climate. For Perth this thermal neutrality temperature is 23.25C and the SET range is shown in figure fIGURE. This figure clearly shows the spread in temperature and humidity values and the small percentage of which fit into the SET range. Approximately 40% of the occupied hours fit into this range.

What is clear then from both of these measurements is that the internal environment is not comfortable for a significant proportion of the occupied hours. The results here show that adjusting the clothing insulation values to account for the warmer and cooler months and increasing the air velocity to offset the effect of high air temperatures cannot significantly alleviate the discomfort people would experience in the building were it to have no source of day-time cooling.

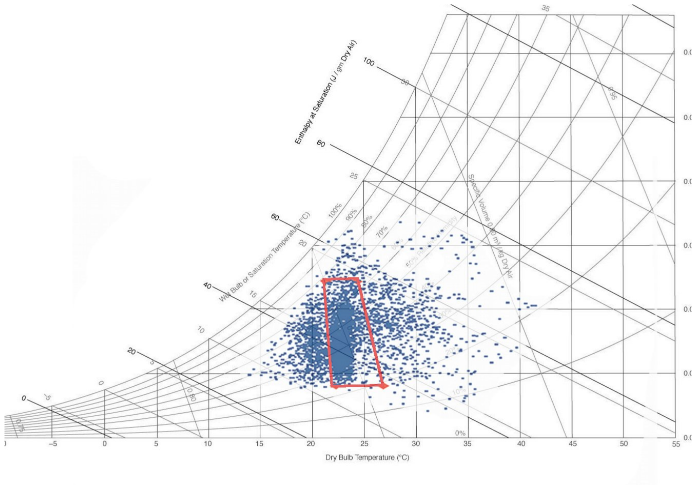


Figure 23

Passive Building

A source of cooling can be provided by a Cooltower. A cooltower uses the evaporation of water to provide a flow of cool air to a space. As the Zion National Park Visitor Centre case study shows (see Figure 2), this type of system is effective in hot, dry climates and can provide a reliable source of cooling with very low energy consumption (only a water pump is necessary)

Given the results found, which have shown that the natural ventilation options investigated would need to be supplemented by some source of day-time cooling, a system of Cooltowers has been modelled. This is despite the author's opinion that the system as modelled is not practical. This is because they would require significant vertical space and retrofitting ducting to the building interior to distribute cool air at low velocity. Nonetheless, a model was implemented in which these practicalities are ignored and the cooling potential available from a Cooltower is delivered to each thermal zone in the building model.

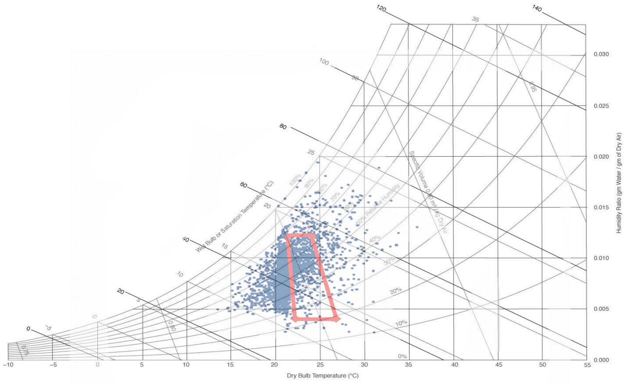


Figure 24: SET range and annual internal conditions for a typical zone

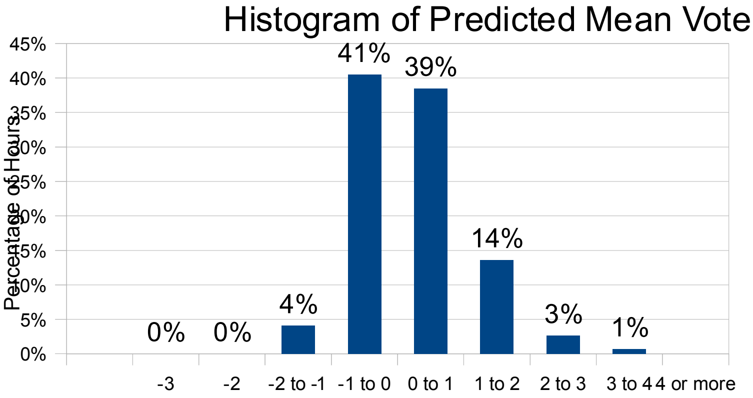


Figure 25

Further, in this model, the solar gain is reduced by implementing a system of internal operable blinds, which block solar radiation when its level exceeds 20W/m2. With these two variations in place, the results below describe the internal conditions. Figure FIGURE shows that the temperature and humidity conditions are generally cooler but more humid. The proportion of occupied hours found to be inside the SET range was a surprising 15%, far lower than the un-cooled models. However, this is because the temperatures are generally lower than the minimum boundary. If all hours below the maximum end of the SET range (the right hand side of the red box in figure FIGURE) are included, the building is comfortable during approximately 70% of the occupied hours.

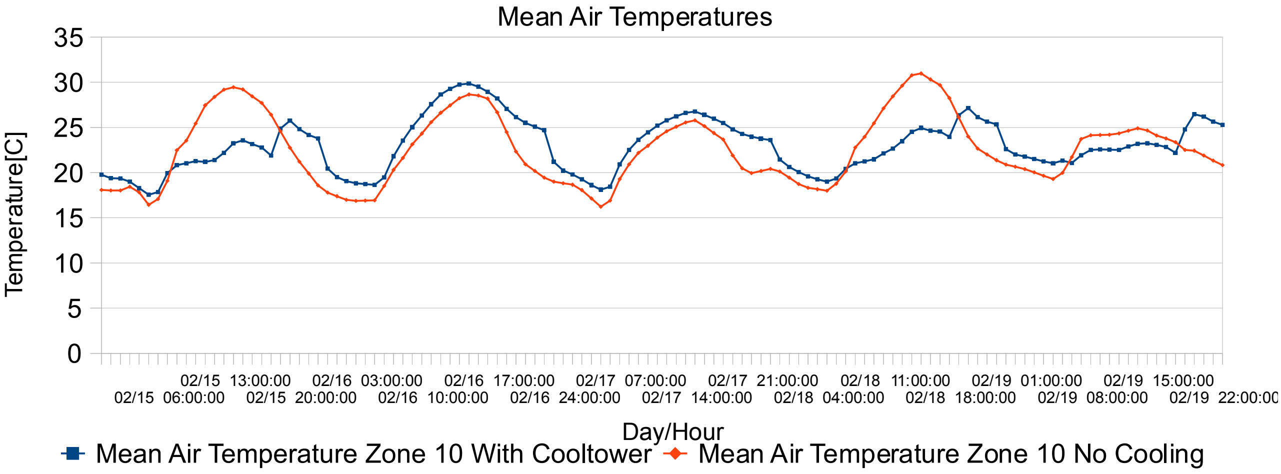


Figure 26

Figure FIGURE above shows a comparison of the temperature in a typical zone, with cooling provided by a Cooltower and without. During the weekend days in the middle of this range, no cooling is provided. During the times of its operation, the cooling tower clearly keeps the temperatures down, generally below 25C.

Window Film

Finally, the effect of the adding a window film to the existing building's glazing was examined.

Figure FIGURE shows that the optimal window film is the Sterling 20 type. This has the lowest Solar Energy transmitted and the highest visible light transmitter of the four films investigated.

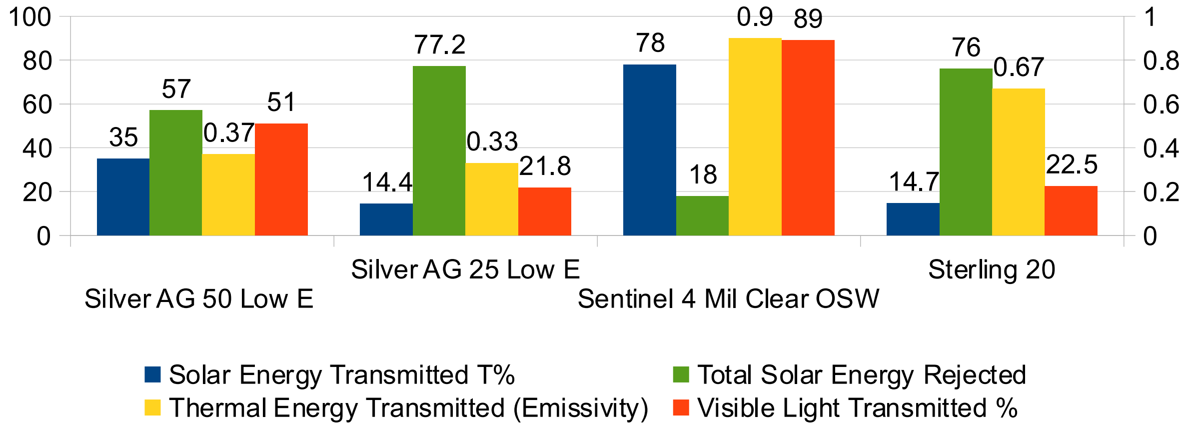


Figure 27

Each of the four films results in different annual heating and cooling loads. These are shown in figure FIGURE. Sterling 20 provides the lowest annual Cooling load at 266MWh. The associated heating load is slightly higher than the minimum which is achieved by the Solar 50 type. However, as previously stated, the focus throughout this project was on reducing the energy consumption associated with cooling the building. Comparing the Sterling 20 and Outside Weatherable (OSW) films, the Sterling 20 reduces the cooling loads by approximately 30%

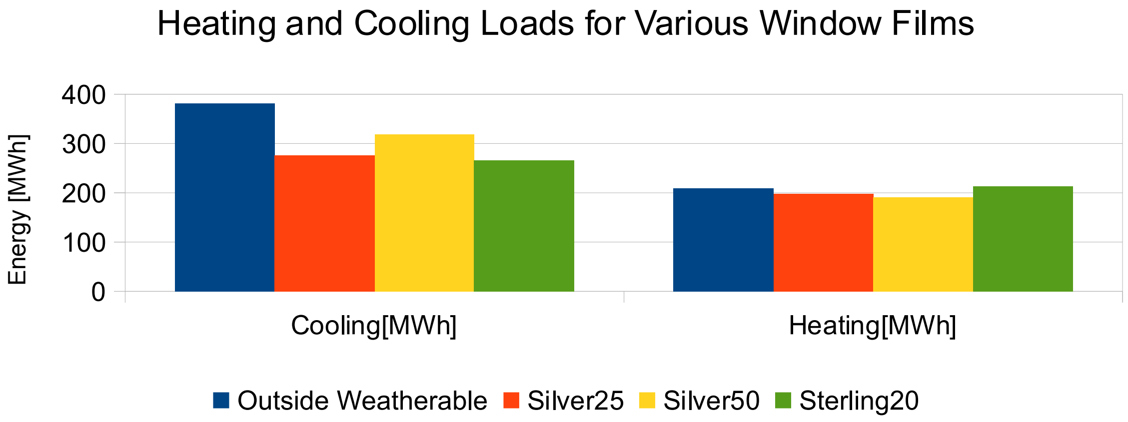


Figure 28

Summary Discussion

While the climate provides a rather limited potential for night cooling, the results show that an ideal cross ventilation scheme can reduce the energy required to cool the building. When cooling is needed the most, in the hot months of December, January, February and March, the climatic cooling potential is around 15degree-hours, well short of the 100degree-hours considered necessary for a viable night cooling strategy (Artmann et al, 2007). However, this measure doesn't account for the cooling effect of the sea breeze and still leaves open the opportunity to utilise night cooling, or perhaps an all-day cooling scheme, during the mild months. The results of the investigation into a building with no mechanical cooling system show that the internal conditions would be comfortable for a significant proportion of the year. This is true for the narrow definition that only a modern high energy consumption HVAC network can provide and also by any reputable measure which is broader than this. The results of a study of cooling provided by a low energy evaporative system using Cooltowers shows that an acceptable level of comfort is possible for most of the occupied hours, approximately between 70% and 80% by the two methods discussed. However, this system of cooling would not be practical to implement and may result in humidity levels that some people would not find comfortable. Finally, the results of the window film analysis show that a applying a window film to the existing glazing can reduce the cooling energy required by up 30% .

Conclusions

There are several conclusions to draw from this investigation into the feasibility of natural ventilation in the Mechanical Engineering building. Firstly, any scheme must account for the local climate which provides some potential for night cooling in the mild months, but demands some additional source of cooling in the summer months. Secondly, any scheme must deal with the constraints of the building's layout and geometry. The prospect of effectively ventilating a space with many interior partitions is a challenging one. Thirdly, it is possible to improve the energy efficiency of the building by enhancing the shading, by one or both of adding operable shades and window films to the existing glazing.

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