Report

Sustainability - Natural Ventilation Feasibility

MERIDEN SCHOOL – CENTRE FOR MUSIC AND DRAMA

Allen Jack & Cottier Architects

CONFIDENTIAL

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EXECUTIVE SUMMARY

There is an aspiration to naturally ventilate the atrium in the new Meriden School Centre for Music and Drama which would both enhance the indoor environment quality and improve the energy efficiency of the proposed building. The feasibility of a naturally ventilated space must take in to account the following considerations:

- Internal thermal comfort requirements
- External weather conditions
- Building envelope performance
- Use of space
- Acoustics
- Fire and smoke control

This study focusses on internal thermal comfort and provides advice on building envelope performance. Calculations have been undertaken to estimate appropriate opening requirements, which were then tested in an idealistic computational fluid dynamics (CFD) model, and compared to internal temperatures and thermal comfort to best practice design guidelines.

The CFD model was run under 4 different external weather conditions, which included peak summer and winter design conditions, as well as an extreme summer day. Each model identified that acceptable internal thermal comfort could be achieved based on the following control strategy:

Outside temperature	Openings	Spill
Less than 15°C	Close all louvres	Spill air from classrooms at 20 °C, potential for destratification fans if required
15 °C – 25 °C	Louvres vary up to maximum L0 = 3.5m^2, L1 = 2.5m^2, L2 = 6.5m^2	Spill air from classrooms at 22 °C
25 °C or more	Close low level, open high level (fractional)	Spill air from classrooms at 24 °C, potential for ceiling fans at higher temperatures to improve comfort.

In order to achieve comfortable conditions, the following recommendations are made:

1. There is an opportunity to increase air movement, particularly in warmer conditions. Ceiling fans would work well in this instance, with fans distributed throughout the space, increasing air movement on that floor alone.
2. It is critical that the building is well sealed; this includes the operable louvres.
3. A high performance building envelope is required to limit heat transfer through walls, glazing and the roof.
4. Appropriate internal comfort during warmer and cooler periods (i.e. less than 15°C or above 25°C) relies on spill air from ground floor classrooms.

To gain further understanding of how this space is likely to perform throughout the year, including with air leakage (mainly through doors), occupant and lighting loads (when appropriate) and realistic insulation levels, a dynamic thermal model exercise is recommended.

1 INTRODUCTION

1.1 Purpose

There is an aspiration to naturally ventilate the atrium in the new Meriden School Centre for Music and Drama which would both enhance the indoor environment quality and improve the energy efficiency of the proposed building.

In terms of ventilating this type of transitory space, there are three key options, with many other strategies operating as a hybrid:

- Full natural ventilation – conditions follow the trends of those experienced outdoors with no active heating or cooling applied.
- Full mechanical ventilation with air conditioning – internal conditions are controlled between specific temperature bands, and the building envelope needs to be sealed well.
- Mixed mode – in favourable outdoor conditions, the building runs in natural ventilation mode. During hotter or colder periods, the envelope is sealed and heating and cooling is provided mechanically to the space.

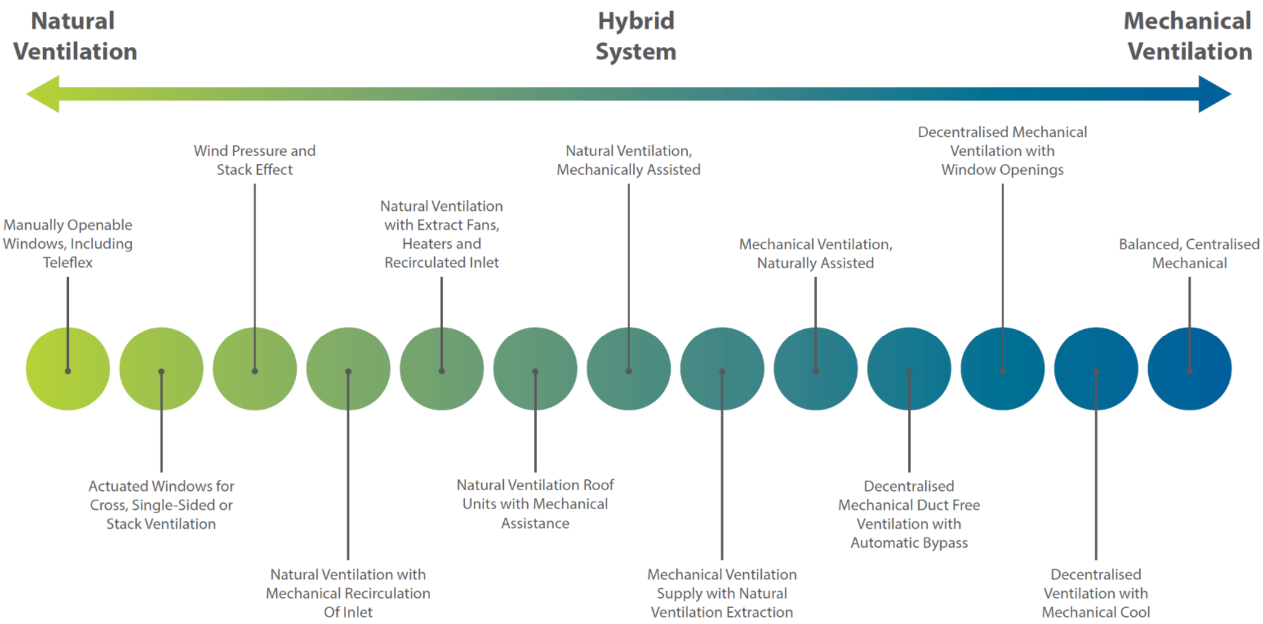

Figure 1: Strategies for natural ventilation (UK Education & Skills Funding Agency's Building Bulletin 101: Guidelines on ventilation, thermal comfort and indoor air quality in schools)

1.2 Design Considerations

In order to select which strategy is most appropriate for the building, a number of variables must be considered:

1.2.1 Internal thermal comfort requirements

- Is there a defined range which is required, or can temperatures be allowed to float if more air movement is provided? An understanding of likely peak conditions is required in order for the school to define whether this is acceptable.

1.2.2 External weather conditions

- What percentage of the year can be expected to operate in the "comfortable" range, and what extremes may occur?
- What control is required for temperature, wind, humidity and solar gain?
- Are there any local sources of adverse air quality, such as roads, generator stacks, etc?

1.2.3 Building envelope performance

- What the building envelope is made out of – large areas of glass must have good solar properties to reduce the additional heat entering the space whilst not compromising natural daylight availability.
- High and low thermal mass constructions have advantages and disadvantages in different locations and for different operational styles.

1.2.4 Use of space

- How will the space be used – whilst there may be a requirement to use some areas of the atrium for performances and ad hoc teaching, the majority of the space will be used for students transiting through and therefore strict temperature control is less important.

1.2.5 Acoustics

- Meriden have advised that the atrium be an active space and so the transfer of outdoor noise in to this space is less of a driver. Transfer of noise from this space into teaching and staff areas however must be considered. A solution to mitigate noise from music rooms located at ground level (which will be relied upon to provide spill air) needs to be developed by the Acoustic and Mechanical consultants.

1.2.6 Fire and smoke control

- Before progressing too far down the natural ventilation path, it is crucial to involve a fire engineer to determine how the building will operate in fire mode, and whether that places any constraints on the ventilation design and location of openings.

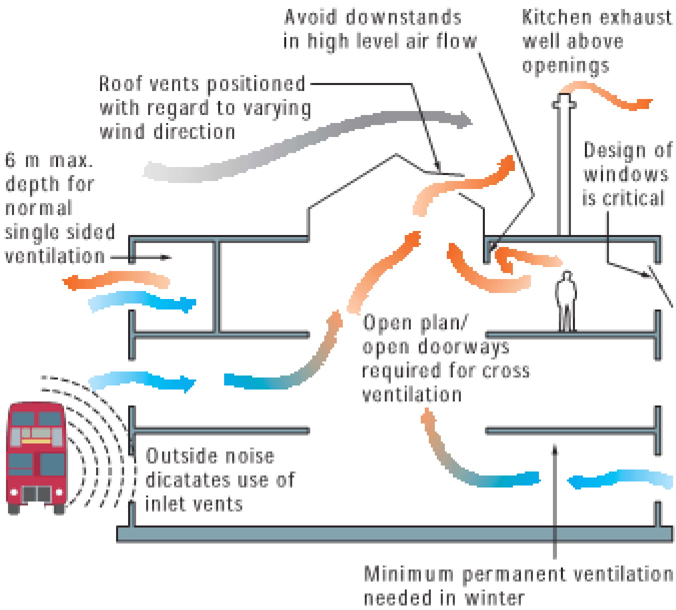

Figure 2: Characteristics of a naturally ventilated building (CIBSE AM10)

1.2.7 Proposed strategy

This study will focus mainly on items 1.2.1 and 1.2.2 for a fully naturally ventilated scenario. The outcome of this study is to provide advice on the extent of openings required and their approximate locations in order to achieve the defined acceptable levels. Further work will be required as the design progresses to look at glazing and materials, and operation and controls to optimise "comfort". This study should also feed in to any acoustics and fire engineering design principles.

1.1 Revision History

Revision	Date	Reason for Issue
0.1	04/04/2019	Draft for comment

2 OVERVIEW OF ENVIRONMENTAL REQUIREMENTS

2.1 Planning Policy

Meriden School's specific Planning Secretary's Environmental Assessment Requirements (SEARs) make reference to qualitative ventilation requirements which have been considered in this feasibility assessment. Requirements include:

- Demonstration of good environmental amenity including access to natural daylight and ventilation, and acoustic separation;
- Consideration of amenity impacts including solar access, acoustic impacts, visual privacy, view loss, overshadowing, and wind impacts; and,
- Consideration of projected impacts of climate change, specifically hotter days, and gustier wind conditions.

Schedule 4 Schools – Design Quality Principles of *State Environmental Planning Policy (Educational Establishments and Child Care Facilities) 2017* (SEPP) and the *GANSW Design Guide for Schools* are also referenced in the SEARs. Relevant SEPP requirements are focused around amenity, namely the inclusion of "appropriate, efficient, stage and age appropriate indoor and outdoor learning and play spaces, access to sunlight, natural ventilation, outlook, visual and acoustic privacy, storage and service areas." While the Design Guide focuses around natural ventilation as a means of providing good acoustics, responsivity to local climate (e.g. sun, wind and aspect), and initiatives to reduce embodied energy and emissions (i.e. passive design principles).

2.2 National Construction Code 2016

Part F4 of the National Construction Code (NCC) 2016 discussed Light and Ventilation of buildings, with FP4.3 stating the following:

A space in a building used by occupants must be provided with means of ventilation with outdoor air which will maintain adequate air quality.

For a space to be naturally ventilated, a ventilated area that totals 5% of the floor area of the room being ventilated must be provided by openings, windows, doors or other devices which can be opened.

Ventilation may also be "borrowed" from an adjoining room, and is deemed relevant for this building to provide tempered air rather than direct outside air during peak heating and cooling conditions.

2.3 Best Practice Guidelines

2.3.1 Best Practice for Schools

In addition to the qualitative requirements above, the UK Education & Skills Funding Agency's *Building Bulletin 101: Guidelines on ventilation, thermal comfort and indoor air quality in schools*, Version 1 (BB101) has been referenced for quantitative requirements around best practice natural ventilation design for schools (Figure 3). This standard has specifically been used to define acceptable thermal comfort in the building in lieu of an Australian equivalent. These requirements are summarised in Table 1.

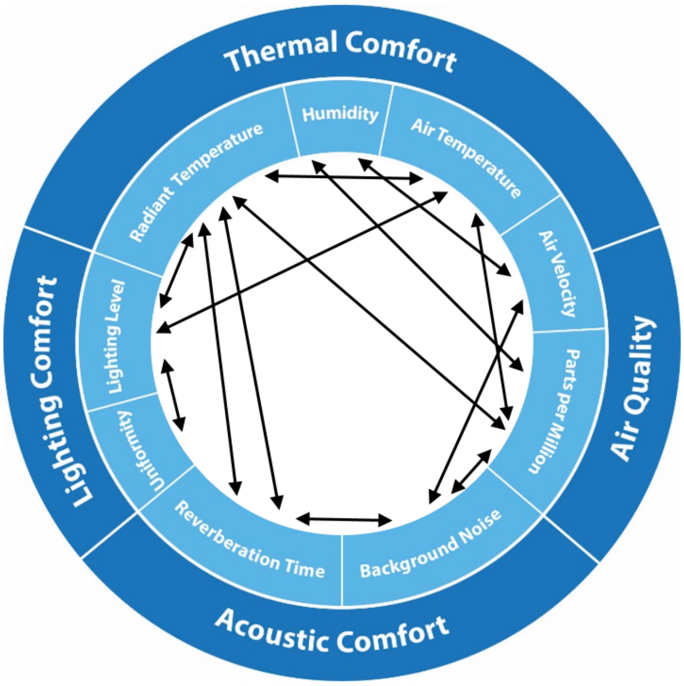

Figure 3: Design factors for ventilation in schools to ensure high levels of Indoor Environmental Quality (Building Bulletin 101)

Table 1: Summary of BB101 best practice thermal comfort requirements for schools

Guidance	Design Parameters
Thermal Comfort	
Room temperature in order to provide a comfortable environment suitable for teaching and learning, year-round.	*Halls (also including drama spaces)* Normal maintained operative temperature of 17°C when used for sports, or 20°C for examinations. Maximum operative temperature during the heating season of 23°C. *Teaching rooms* Normal maintained operative temperature of 20°C. Maximum operative temperature during the heating season of 25°C. *Circulation spaces* Normal maintained operative temperature of 17°C. Maximum operative temperature during the heating season of 24°C.
Air movement criteria	Draught criteria – change in temperature 4°C in winter, 5°C in summer, maximum air velocity 0.3m/s
Comfort categories in free running buildings (adaptive thermal comfort)	*Halls (also including drama spaces)* Recommended comfort category: IV from BS EN 15251 *Teaching rooms* Recommended comfort category: II or III from BS EN 15251 *Circulation spaces* Recommended comfort category: IV from BS EN 15251

The document defines three criteria to indicate whether overheating is likely to be problematic. Note that this is developed for a UK climate where temperatures are considerably cooler than those experienced in the Sydney region, and therefore some flexibility should be observed. The three criteria are:

1. the number of hours for which an adaptive thermal comfort threshold temperature is exceeded by more than 1^{o}C (total hours of exceedance) < 40 hours;
2. the degree to which the operative temperature exceeds the adaptive thermal comfort threshold temperature (daily weighted exceedance) < 6 in any one day;
3. the maximum temperature experienced at any occupied time (upper limit temperature) < 4^{o}C above the maximum adaptive thermal comfort threshold temperature.

3 INTERNAL COMFORT CONDITIONS

3.1 Comfort vs Temperature

Providing a comfortable thermal environment is about more than just providing acceptable temperatures. The key variables affecting thermal comfort are air temperature, air speed, humidity and solar radiation and it is a balance of these variables that result in a space being perceived as comfortable. Thermal comfort is a subjective measure of people's psychological response to the heat balance of the human body. The effects of the thermal environment on different people can vary greatly and this makes assessing the thermal comfort of a large group of people a complex issue. Therefore the feasibility of any ventilation solution should focus on thermal comfort rather than temperature alone.

3.1.1 Predicted Mean Vote

The most popular metric used to assess indoor thermal comfort is the predicted mean vote (PMV) and percentage people dissatisfied (PPD) variables developed by Fanger in 1970, and takes in to account the effects of air movement and heat from the sun, as well as air temperature. The levels of comfort and acceptability are based on an air conditioned space, and so therefore adaptive thermal comfort is used as an alternative for a naturally ventilated space.

3.1.2 Adaptive Thermal Comfort

The adaptive thermal comfort model is based on the premise that humans have the ability to adapt to different temperatures throughout the year, either by varying clothing levels, or as they get more used to elevated outdoor temperatures. There are a number of metrics available (EN 15251 in Europe and ASHRAE 55 in the USA), however they are based on the same fundamental principle. Given the reference to BB101 in this study, the European version is used in this study.

Acceptable temperatures are defined in terms of an operative, or comfort temperature, which is the average of the air temperature and the surrounding surface temperatures. In this analysis, it is assumed that all surfaces are the same temperature as air temperature, and therefore operative temperature is equal to air temperature. Comfort categories are defined based on outdoor running mean temperature, i.e. a weighted temperature over the previous 7 to 30 days average, and is summarised in

Table 2, taken from BB101 and BS EN 15251. As summarised in Table 1, halls and circulation spaces can extend in to category IV, although category III is clearly preferred. Green Star references ASHRAE 55-2013 for naturally ventilated spaces, which requires 80% acceptability for 1 point, and 90% acceptability for 2 points.

Figure 4 shows the categories graphically, based on outdoor running mean. This shows that there is a difference between acceptable thresholds, and further discussion on this will be required if the Thermal Comfort credit is targeted in a formal Green Star certification. For Sydney, the outdoor running mean for a recent 12 month period is shown in Figure 5.

Table 2: Summary of adaptive comfort categories

Category	Expectation	Suggested temperature range outside of optimal (°C)	Percentage of people dissatisfied (PPD)
I	High Used in spaces occupied by vulnerable persons	±2°C	< 6%
II	Normal	±3°C	< 10%
III	Moderate, acceptable	±4°C	< 15%
IV	Low Only accepted for limited parts of the year	More than ±4°C	> 15%

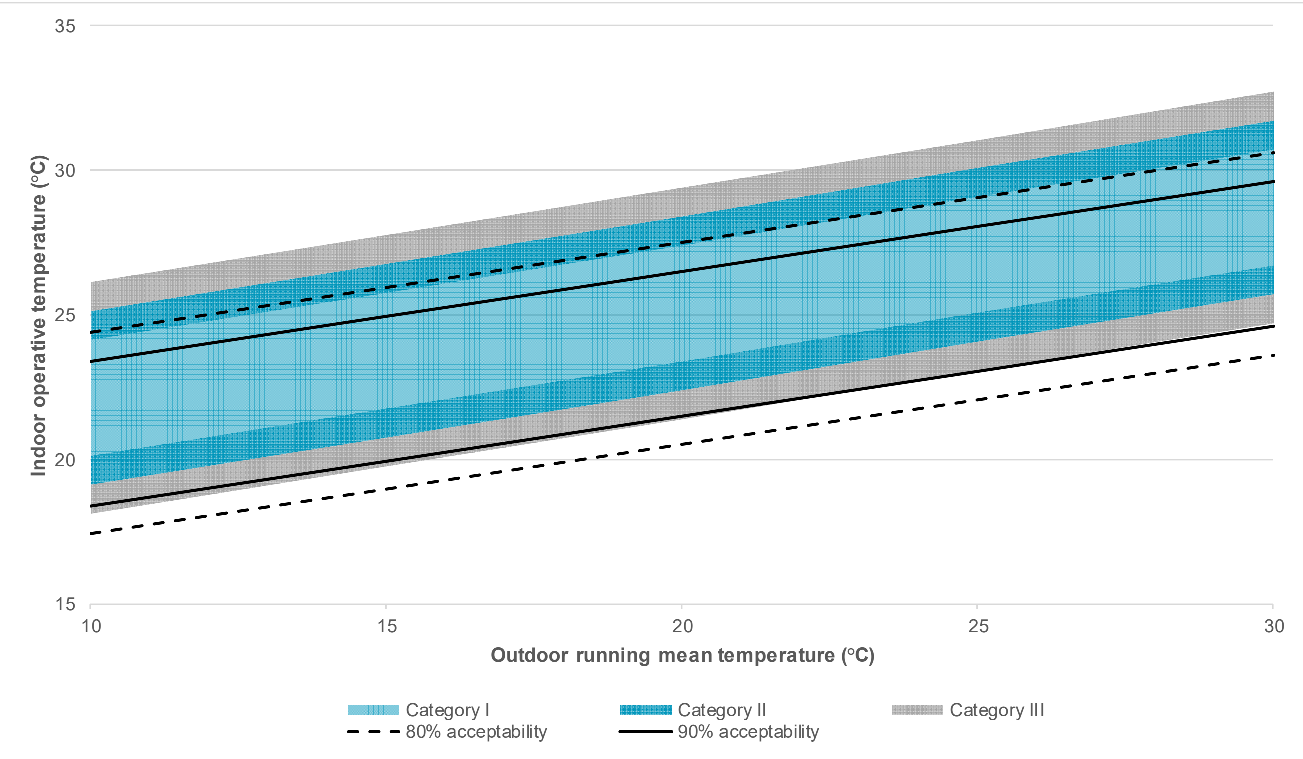

Figure 4: Acceptable levels of operative (comfort) temperature for different space types (see Table 1)

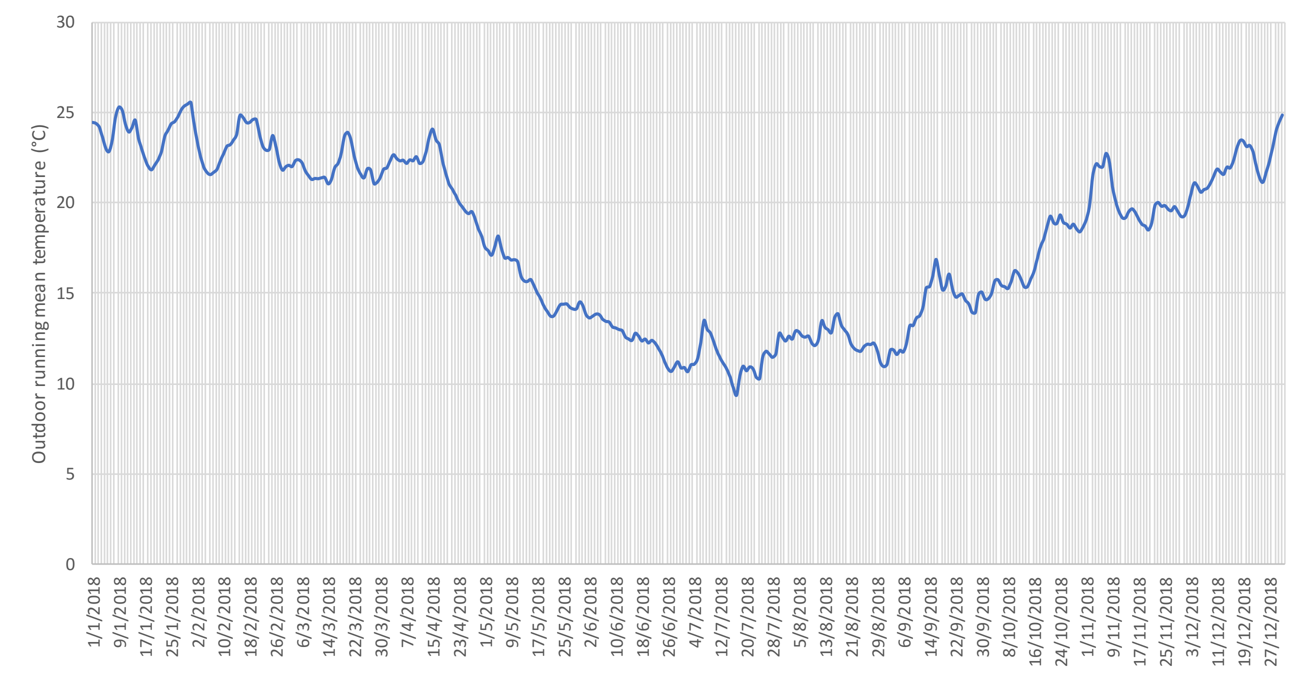

Figure 5: Outdoor running mean temperature in Sydney in 2018

3.1.3 Benefits of Increased Air Movement

During summer, increased air speed can improve the feeling of comfort. This can be due to the use of fans, or by good volumes of air flow through the building. Figure 6 shows the air speeds required to improve comfort, based on offsetting the operative temperature. Air speeds of up to around 0.8m/s are likely to be tolerable, which results in around a 2.5°C reduction in operative temperature.

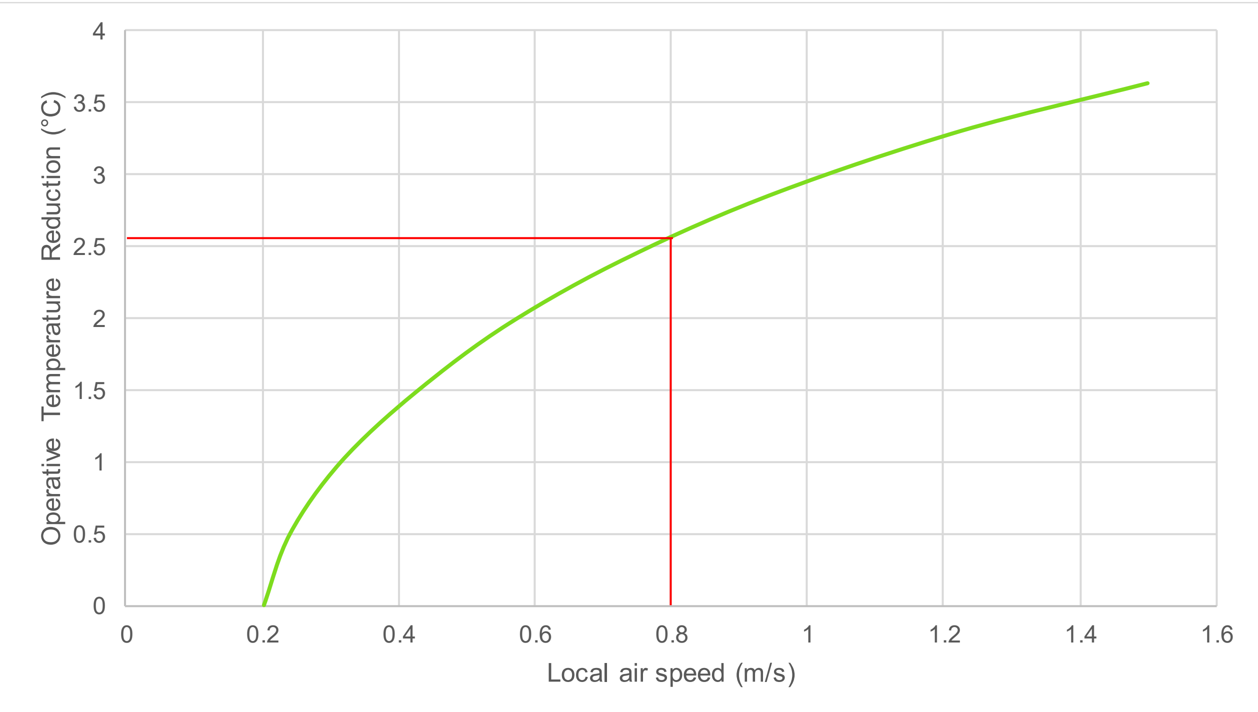

Figure 6: Offset in operative temperature for increased air movement.

3.2 BCA Section F4 Requirements for Ventilation

The National Construction Code BCA Part F4 looks at the required ventilation rates that need to be provided. For natural ventilation, at least 5% of the naturally ventilated floor area must be openings, however this does not necessarily guarantee comfortable internal conditions. Relevant areas for the building are as follows:

Table 3: Naturally ventilated floor area in the CMD building

Level	Naturally Ventilated Floor Area (m^2)	
	Foyers & Lobbies	Amphitheatre
Level -2	0	0
Level -1	0	0
Ground floor	208	37
Level 1	160	0
Level 2	49	0
Total	454	
5% of naturally ventilated floor area	22.7	

Therefore, the area of ventilation openings must be at least $22.7m^2$ in order to comply with the BCA Part F4.

For mechanically ventilated spaces, the BCA references AS1668.2 which has the following requirements:

- Foyers and lobbies need approximately $1L/s/m^2$ of outdoor air; and,
- Amphitheatres need 10L/s/person of outdoor air based on $0.6m^2$ per person ($6L/s/m^2$).

It is these values that are used as target air flow rates for effective natural ventilation.

4 EXTERNAL WEATHER CONDITIONS

Hourly temperature data from Sydney Olympic Park from September 2011 to February 2019 has been analysed to consider how frequently "comfortable" outdoor temperatures are experienced. Only data between 7am and 5pm has been considered, and are shown in Figure 7. If January is excluded (school holidays), similar percentages are observed.

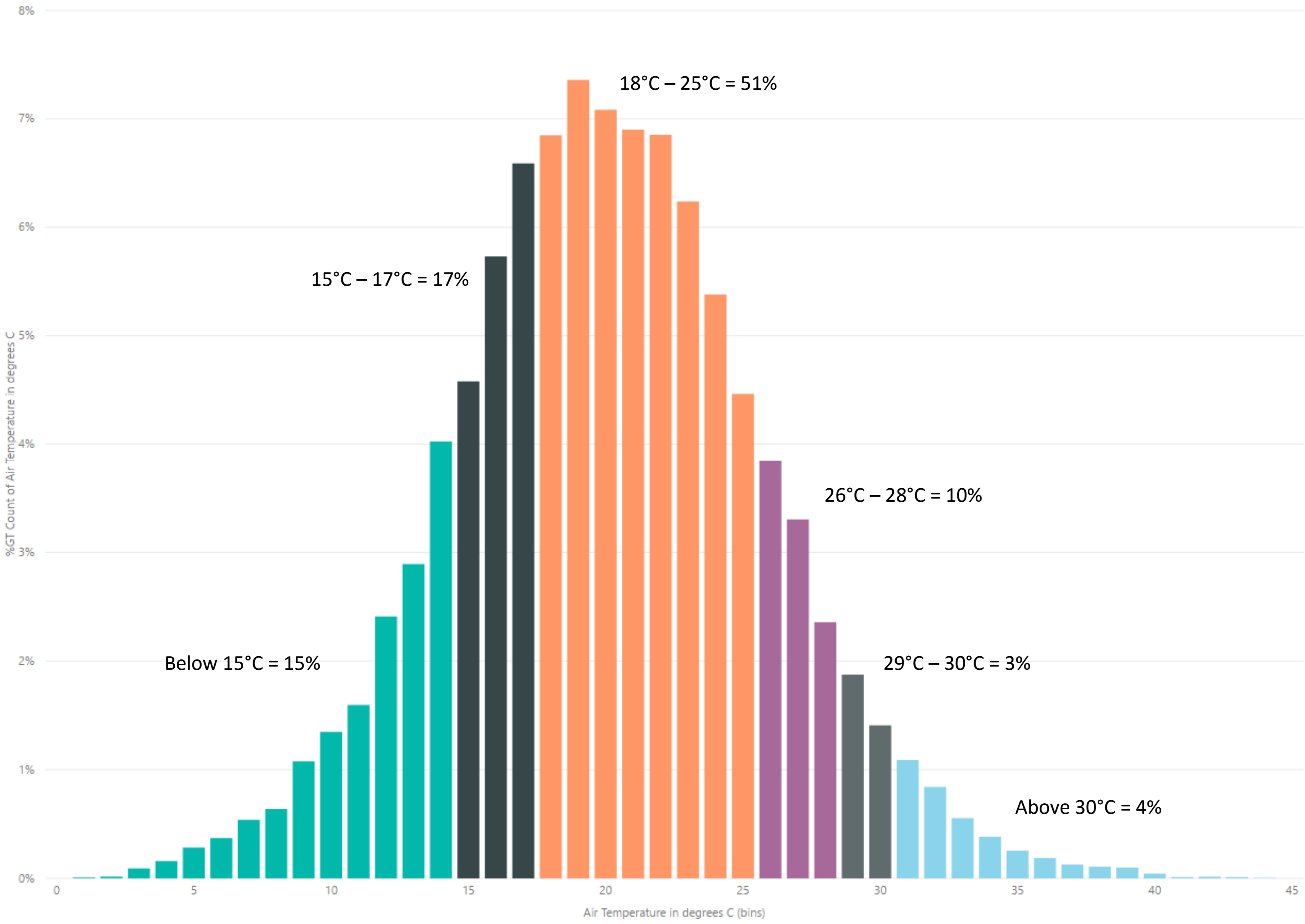

Figure 7: Air temperature ranges for Sydney Olympic Park, September 2011 to February 2019 from 7am to 5pm, based on hourly weather data from BOM.

Based on the calculations provided in later sections, natural ventilation is recommended when outdoor temperatures are between 15°C and 25°C (approximately 68% of occupied hours), which is a significant proportion of the year.

5 OPENING AREA ANALYSIS

A number of steps are required to assess the feasibility of natural ventilation in terms of thermal comfort and indoor air quality. A stack ventilation calculation is first undertaken to determine the approximate areas required on each level of the atrium, which is then followed by verification of thermal comfort using computational fluid dynamics (CFD).

5.1 Operational Control

In order to optimise the internal conditions of the atrium, a number of operational controls are required. For example, when it is very cold outside, louvres will need to be closed to prevent the ingress of cold air. Similarly, when it is very hot, hot air needs to be kept out of the building. During mid season, and for nearly 70% of the year as shown in Section 4, the atrium will follow outdoor conditions and operate naturally.

Table 4: Proposed operational control

Outside temperature	Openings	Spill
Less than 15°C	Close all louvres	Spill air from classrooms at 20 °C, potential for destratification fans if required
15 °C – 25 °C	Louvres vary up to maximum L0 = 3.5m^2 L1 = 2.5m^2 L2 = 6.5m^2	Spill air from classrooms at 22 °C
25 °C or more	Close low level, open high level (fractional)	Spill air from classrooms at 24 °C, potential for ceiling fans at higher temperatures to improve comfort.

5.2 Stack driven ventilation calculation

CIBSE AM10: Natural ventilation in Non-domestic Buildings provides the basis for calculating the areas required for effective stack driven ventilation.

The following assumptions have been used as the basis for the initial opening area analysis:

- All openings are a louvre style with a discharge coefficient of 0.3;
- Doorways have not been included in the opening areas (doors assumed closed);
- Opening heights above ground floor are approximately:
  - Ground Floor: 3.5m
  - Level 1: 6m
  - Level 2 (highest point in the atrium): 9m
- No more than 3°C warmer at outlet; and,
- Flow rates (1L/s/m^2 and 6L/s/m^2).

A number of internal and external temperatures were applied to identify the largest size of openings required for effective ventilation. This occurs when outside temperatures are warmest, and there is limited temperature variation within the atrium. The resulting free areas required are as follows, and their approximate location shown in the markups in Appendix A:

- Ground Floor: 3.5m^2
- Level 1: 2.5m^2
- Level 2 (highest point in the atrium): 6.5m^2

Louvres have a typical free area ratio for between 0.3 and 0.6, and therefore the actual size of the louvre will need to be larger than the areas quoted above but the relevant factor.

5.3 CFD Model

A 3D CFD model was then created based on drawings provided by AJ+C Architects and the open areas calculated above. The CFD model is then simulated under a number of external weather conditions to assess the likelihood of comfortable temperatures being experience in occupied areas of the atrium. A number of additional assumptions on the building fabric are required:

- Glazing performance of U=4W/m^{2}K, SHGC=0.3 on north and west facades;
- Good insulation in the roof, at least R4.2. The CFD model assumes perfect insulation levels, i.e. no heat transfer from outside other than through glass.
- Ability to seal the building well during undesirable outdoor conditions. The CFD model assumes perfect sealing.

The resulting outputs from the CFD models are shown below for two main sections through the building for adjusted operative temperature (based on air movement). Additional floor by floor plots are shown in Appendix B.

Four scenarios have been simulated for this feasibility study:

1. Peak winter (design) – 4°C outside, no sun
2. Typical mid-season - 20°C outside, peak sun
3. Peak summer (design) - 32°C outside, peak sun
4. Extreme summer - 40°C outside, peak sun

5.3.1 Peak (design) winter conditions

Under this scenario, the outdoor temperature is 4°C, with no solar load. Classrooms are operating at full capacity with spill air equal to 10L/s/person transferring in to the atrium above the doors at 20°C.

The outdoor running mean temperature will vary day by day, and therefore so will the acceptable temperature requirements. Based on historical weather data, the 9th July 2017 has been selected as a cold winter day. The calculated outdoor running mean for this day is 10.5°C, which gives the following category bands:

- Category I – high expectation of comfort – 20°C – 24°C
- Category II – normal expectation of comfort – 19°C – 25°C
- Category III – moderate expectation of comfort – 18°C – 26°C

Figure 8 shows potential adjusted operative temperatures on a cold winters day, which are around 20°C. This means that a normal to high level of comfort can be expected provided the building is constructed in line with the assumptions in this report.

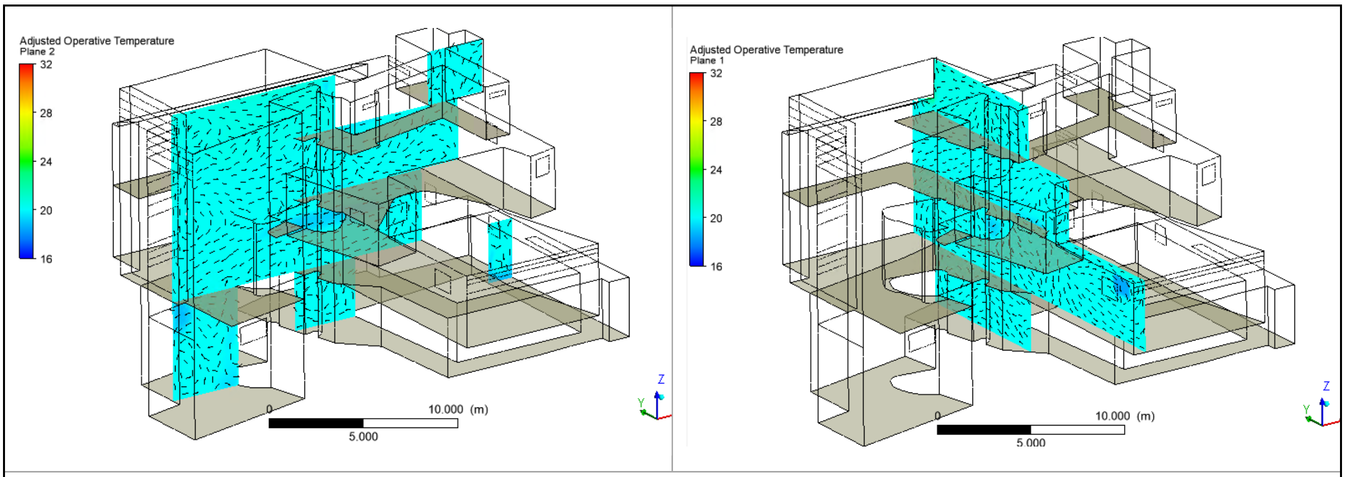

Figure 8: Temperature profile during design winter conditions

5.3.2 Typical mid-season conditions

Under this scenario, the outdoor temperature is 20°C, with high solar load. Classrooms are operating at full capacity with spill air equal to 10L/s/person transferring in to the atrium above the doors, however this is not critical to maintaining comfortable conditions.

As seen in Figure 9, adjusted operative temperatures during mid-season are up to 4°C warmer (sunny day) than outside, and therefore expected to be comfortable for students.

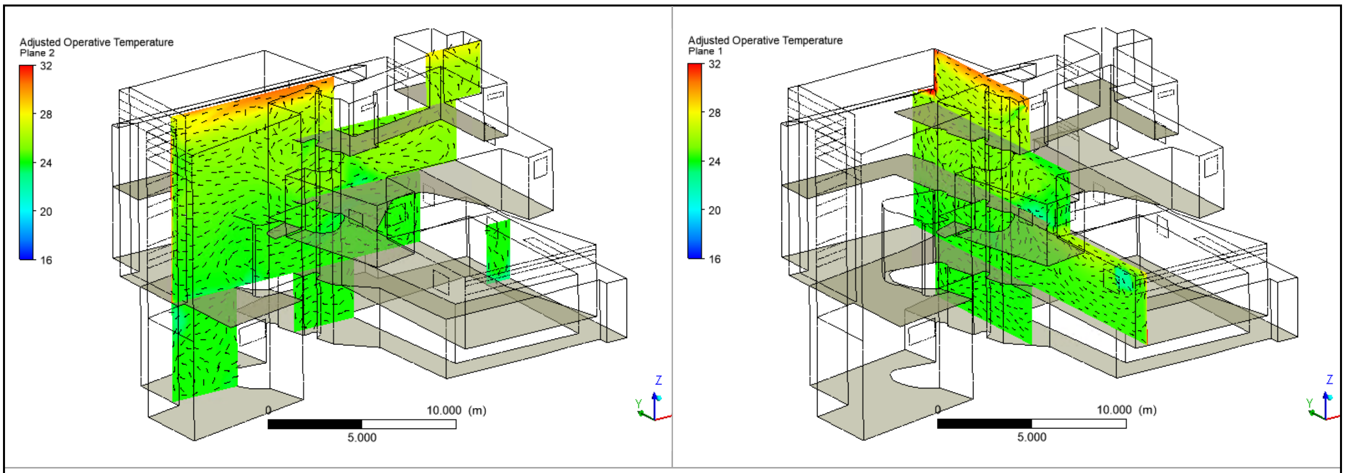

Figure 9: Temperature profile during typical mid season conditions

5.3.3 Peak (design) summer conditions

In line with peak mechanical load calculations, the outdoor temperature is 32°C, with high solar load. Classrooms are operating at full capacity with spill air equal to 10L/s/person transferring in to the atrium above the doors, however this is not critical to maintaining comfortable conditions. Figure 11 shows likely temperature profiles when there is no spill air on the ground floor.

Based on historical weather data, the 25th January 2015 has been selected as a design summer day. The calculated outdoor running mean for this day is 24.6°C, which gives the following category bands:

- Category I – high expectation of comfort – 25°C – 29°C
- Category II – normal expectation of comfort – 24°C – 30°C
- Category III – moderate expectation of comfort – 23°C – 31°C

Figure 10 shows potential adjust operative temperatures on a typical summer day, which are around 25°C-26°C. This means that high level of comfort can be expected provided the building is constructed in line with the assumptions in this report. This is largely based on utilising spill air from all classrooms, and allowing minimal outside air to enter through doors.

When spill air is not available on the ground floor, comfort temperatures throughout the atrium may reach up to 30°C on the top floor, which is still in the acceptable range for a normal expectation of comfort.

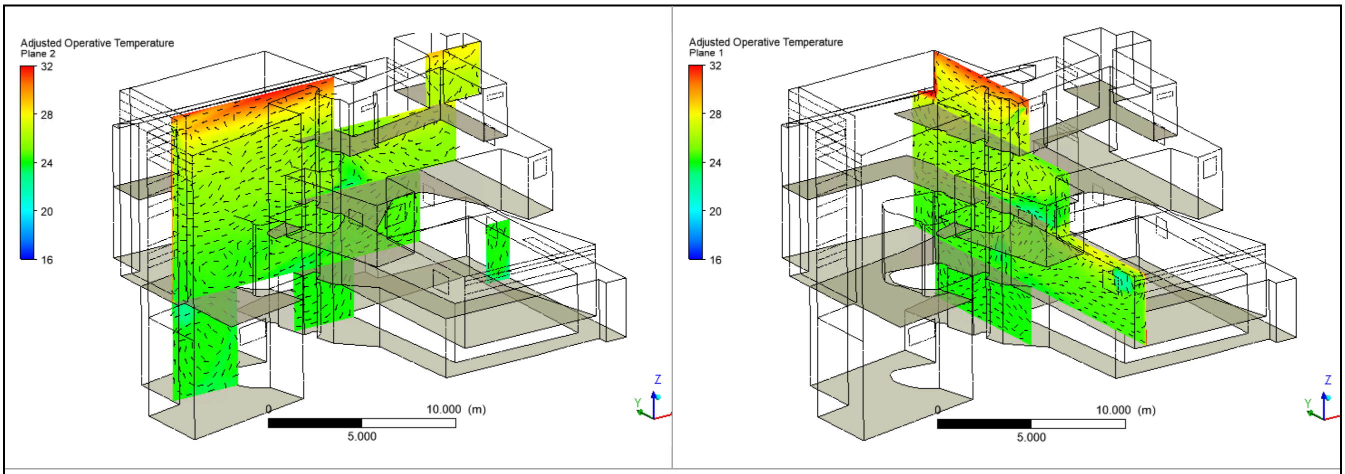

Figure 10: Temperature profile during design summer conditions (full spill air)

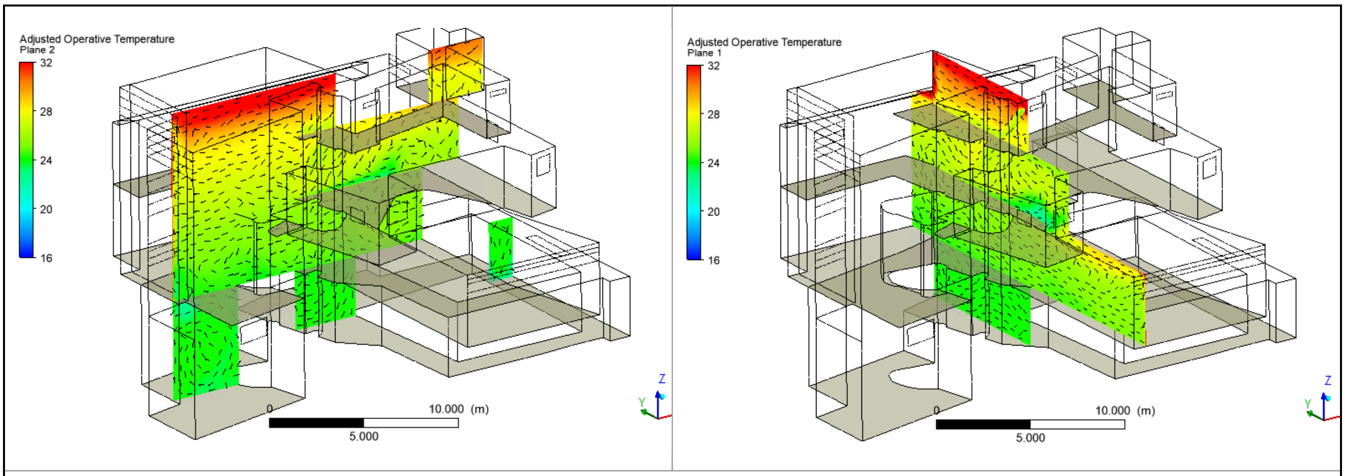

Figure 11: Temperature profile during design summer conditions (no spill from ground floor)

5.3.4 Extreme summer conditions

To test the sensitivity of the natural ventilation performance, an extreme day has also been considered, with an outdoor temperature of 40°C, and high solar load. Classrooms are operating at full capacity with spill air equal to 10L/s/person transferring in to the atrium above the doors at 24°C.

The date to calculate outdoor running mean for this case has been based on cooler days leading up to the extreme day; the running mean temperature is 22.1°C, giving the following comfort categories:

- Category I – high expectation of comfort – 24°C – 28°C
- Category II – normal expectation of comfort – 23°C – 29°C
- Category III – moderate expectation of comfort – 22°C – 30°C

Will all openings closed apart from the large louvre at high level, and spill air from classrooms at 24°C, adjusted operative temperatures within the space are likely to be between 25°C at low level up to 28°C at high level. This is within the high level of comfort expectation, with flexibility for temperatures to increase slightly when doors at low level are opened.

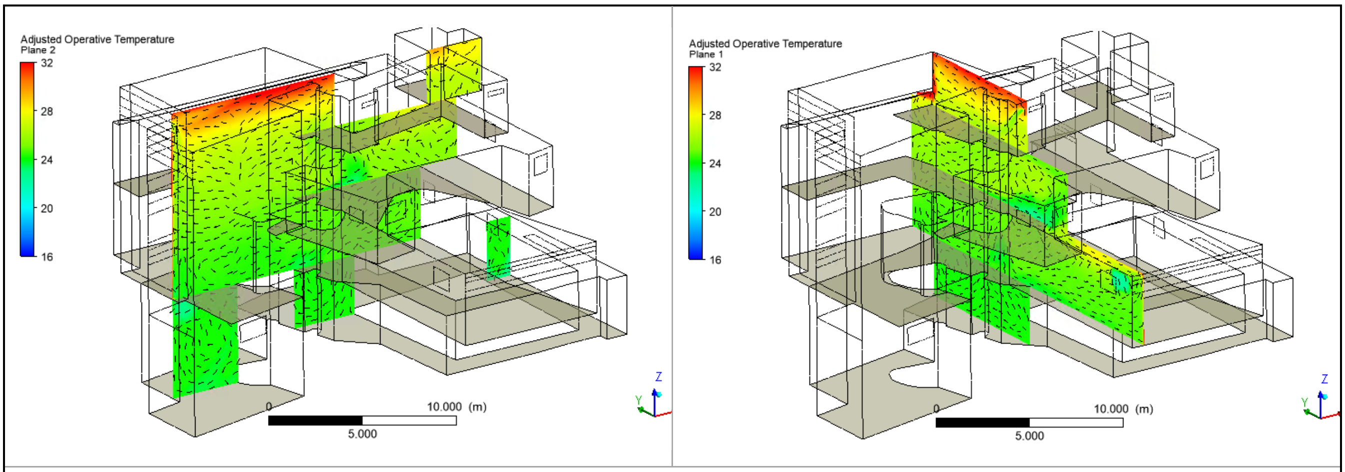

Figure 12: Temperature profile during extreme summer conditions

6 CONCLUSIONS

The CFD study has demonstrated that a full natural ventilation solution with spill air from classrooms is feasible for the CMD. The following conclusions can be drawn:

1. There is a risk of overheating on upper floors when some classrooms are unoccupied and therefore there is no spill air.
2. In the current simulations, whilst there is some air movement, there is an opportunity to increase this, particularly in warmer conditions. Ceiling fans would work well in this instance, with fans distributed throughout the space, increasing air movement on that floor alone. These should not be provided on the top floor however as it could negatively impact the stack ventilation as prevent hot air exiting through the high level louvres.
3. It is critical that the building is well sealed; this includes the operable louvres. When outside conditions are too cold or too hot, an effective barrier between outside and more comfortable indoor conditions is required. Products such as ALSPEC for sliding doors (Figure 13), and EBSA MP2 for louvres (Figure 14) could work well for this type of construction. (NDY do not endorse these products and recommend testing data be obtained from the manufacturer.)
4. A high performance building envelope is required to limit heat transfer through walls, glazing and the roof. This study has assumed a glazing solar heat gain coefficient (SHGC) of 0.3, and a highly insulated light coloured roof (minimum R4).

To gain further understanding of how this space is likely to perform throughout the year, including with air leakage (mainly through doors), occupant and lighting loads (when appropriate) and realistic insulation levels, a dynamic thermal model exercise is recommended. This type of model can be adapted to understand daylight quality as well as Section J compliance via a JV3 approach, and therefore will provide value across a number of aspects. NDY has separately recommended replacing our existing Section J DTS commission with a JV3 model, for a modest uplift in cost. As noted, this will provide additional benefits during design development, including simulation of additional environmental parameters such as daylight and glare.

Figure 13: ALSPEC ProGlide High Performance Sliding Door

Figure 14: EBSA MP2 glazed louvre system

6.1 Limitations

Norman Disney & Young will not be held liable for thermal comfort performance estimates, nor for the reliance by any party on those results, for any purpose. CFD models are necessarily simplified and idealised representations of actual buildings, and are imperfect in the way they simulate these, and in particular the air conditioning systems and controls. Assumptions have been made on a wide range of input parameters, such as building occupancy, equipment usage and the like. Calculations are based on the specified weather data, which will not be equivalent to the wide range of weather conditions that will be experienced in practice. Consequently, the results presented are only one possible representation of a building's potential performance.

Actual performance of the constructed building is dependent on many interrelated factors including the quality of construction, the quality of commissioning, and the ongoing management of the building. Significant differences between modelled and actual building performance can result.

Norman Disney & Young takes all reasonable professional care in the preparation of simulation studies. However, we stress that significant variation can occur in actual building performance due to circumstances beyond our control, and due consideration of this fact should be taken before relying on these estimates for any purpose.

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