CH2 Setting a new world standard in **green building design**

Design snap shot 19: Modelling

Summary

Introduction

This summary discusses the use of modelling in the design of CH2.

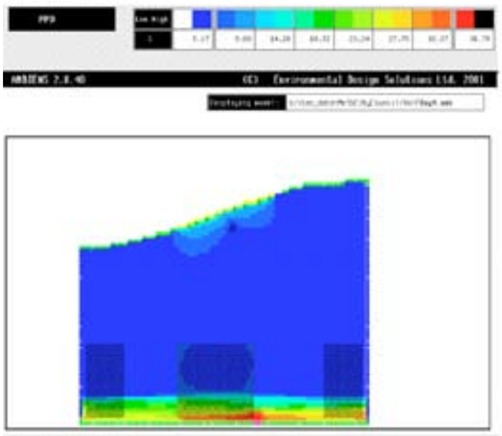


Figure 1. Computational Fluid Dynamics showing thermal comfort (AEC)

Drivers and objectives

The main objective of the modelling was to provide timely input into the design process by testing assumptions and innovations developed by the design team.

The modelling provides operational and cost certainty in the design of buildings, presenting a range of visuals tools and statistics, allowing various options to be evaluated against each other.

Costs and benefits

It is cheaper to produce and evaluate virtual and physical models rather than produce full size mock ups or deal with remedial measures once the building is built.

Outcomes

Models are an integral part of the design process across different disciplines. Buildings are evaluated for a range of properties, from acoustic performance to visual appearance. Modelling allowed a range of options to be explored for CH2 so that the building's performance could be optimised.

Through the use of the modelling, ventilation strategies were developed, tested and fine tuned; lighting analysis and design was carried out; glare studies ensured optimum use of natural and ambient light; and certainty was brought to decision making on competing options.

Lessons

The right model has to be used for the right purposes. The limitations of each of the models have to be recognised and the results adjusted in an appropriate fashion.

Models are merely a tool to evaluate different options but this does not replace common sense or experience in the way such buildings work. Models can sometimes give erroneous results. Also, as these models simplify complex relationships in the functioning of the building it is the assumptions behind the simplification which need to be understood as they impact on accuracy.

Computational Fluid Dynamics (CFD) can take a model from a Computer Aided Design (CAD) system and model it thermally using the complex mathematics of fluid movement.

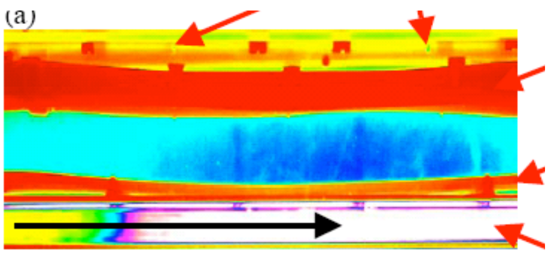


Figure 2. Salt bath image – colours represent different temperatures

A physical salt bath model allows the viewing of air flows, simulated using salt water, at many places in the building simultaneously. Coloured dyes can be used to see air flows with analysis of results by the use of computer enhanced images. Again, this is not a method without limitation as it simulates air flow through various levels of salt in water, it has difficulty with cooling elements such as chilled panels.

More detail

The main design decisions were made and verified using Computational Fluid Dynamics (CFD) modelling, occurring between January and June 2003 – at the very early stages of the design process. Salt bath testing was carried out later in the design process to verify and test some of the results and design options, and particularly to explore the low air flow assumptions (May-July 2003).

Modelling was also carried out to determine the most efficient and effective method of reducing energy loads from heating and cooling the building.

Computational Fluid Dynamics

This process was used to evaluate the best position of the ceiling chilled panels, night purge, room air distribution and underfloor air supply design.

Chilled ceiling panels

An analysis of the air velocities show uncomfortable zones ranging from too much wind velocity, causing a draught, to a lack of mixing of air.

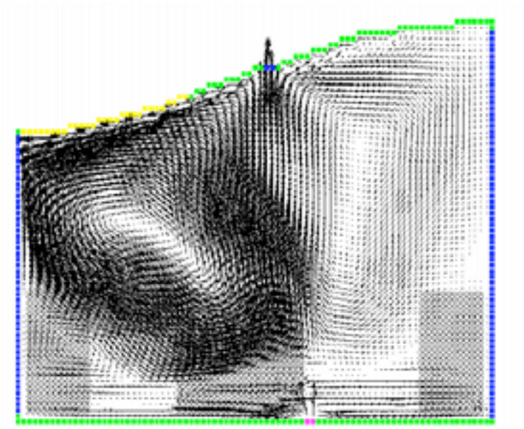


Figure 3. Cross section of office space, showing the effects of the chilled ceiling on air movement (AEC)

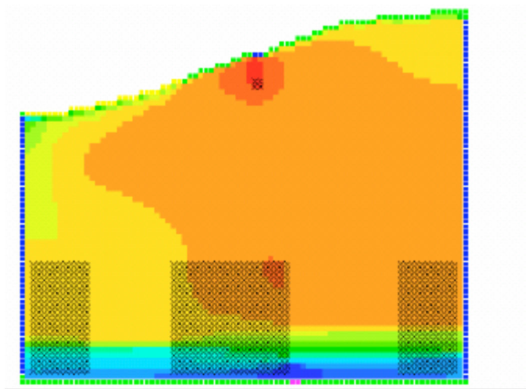


Figure 4. Cross section of the office space, showing effects of the chilled ceiling on air temperatures (AEC)

Other factors that were analysed were the mean radiant temperature, air temperature and the thermal comfort rating. From all of this data the results were compared to find the most suitable location for the panel (see Snap Shot 16: Chilled panels and beams).

Night purge

Heat will build up in the concrete ceiling from incidental gains such as people, lighting and equipment. During the night the slab is 'flushed' with cool air to remove the heat, ready for the next day. The night purge strategy was modelled using Thermal Analysis Software (TAS) and CFD. Different free/open window areas (from 0 to 5%) were modelled as a percentage of floor area to show their effectiveness in space cooling through out the year.

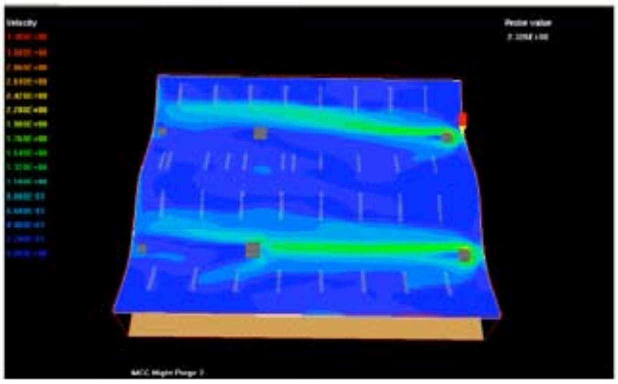


Figure 5. TAS modelling velocity of air moving across the thermal mass ceilings (AEC)

Room Air Distribution

Modelling was done on the distribution of air throughout the room. The image below shows that the air distribution profile, while inhibited by the data/electrical cables (grey lines) covered the whole floor plate providing sufficient air distribution. The pressure modelling showed a dead spot to the left (orange) and made recommendation to avoid this through a perforated baffle plate in the floor void.

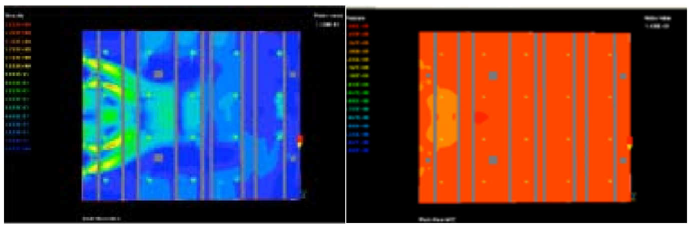


Figure 6. Modelling velocity (blue) and pressure (red) of air distribution through room (AEC)

Analysis of ventilation strategies

When deciding the best design of ventilation devices two different modelling techniques were used. The first was bulk air modelling and the second was the CFD for night cooling, as described earlier.

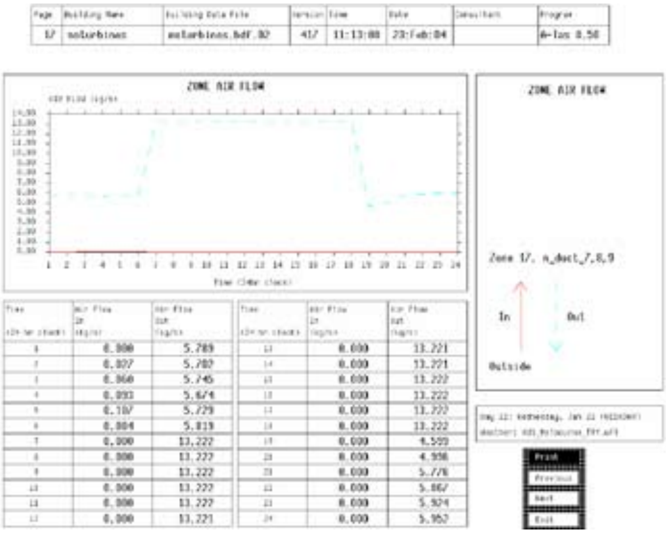


Figure 7. TAS software showing bulk zone air flows (AEC)

The building was modelled with openings and orientation. From this, and weather data from Melbourne, a range of results were produced. The TAS software was able to determine air velocities and the amount of heating and cooling load in each zone of the building. Conditions on still and windy days and different times of the year were considered with the ventilation allowing comparisons to be made.

Low flow air movement

One of the challenges with testing the performance of the CH2 design was the extensive use of low flow air movement to support the heating and cooling strategies. The building has been designed to, wherever possible, use passive air movement (heat rising) aided by mechanical systems. This presented a challenge for the project as there is not a great deal of research on low flow air movement. The Sustainable Energy Authority of Victoria funded a project to investigate the proposed design using salt baths through Dr Gary Hunt at the Division of Fluid Mechanics, Department of Civil & Environmental Engineering, Imperial College, London.

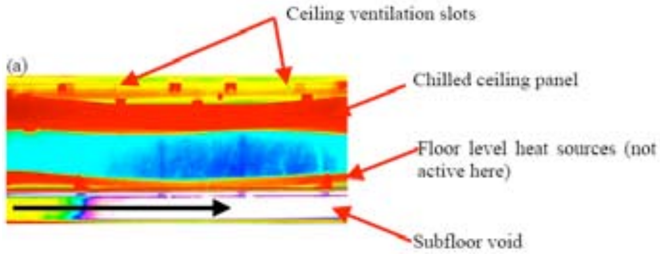


Figure 8. Types of analysis the modelling facilitated – showing air movement over a floor plate (Division of Fluid Mechanics, Department of Civil & Environmental Engineering, Imperial College, London)

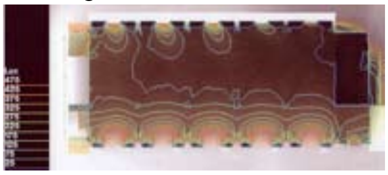
Results were taken at a range of time intervals to determine the amount of cooling occurring with the range of surface and air temperatures represented by different colours on the diagrams above.

The reasons for using salt solution in the water are three-fold. First, it is easy to visualise the flow by adding coloured dyes or using a shadowgraph. Second, it is possible to measure the detailed velocity and density fields inside the model using the latest digital image-processing techniques. These techniques give measurements of the flow field within the model and show how the stratification evolves as a result of changes in the ventilation rate, etc. Third, the use of salt in water enables high Reynolds numbers (measure of turbulence) to be achieved in small models. Water is a less viscous fluid than air and it is possible to obtain large density differences using high salt concentrations which give large flow velocities. This dynamic similarity means that quantitative information can be obtained from small-scale models and extrapolated to full-size buildings.

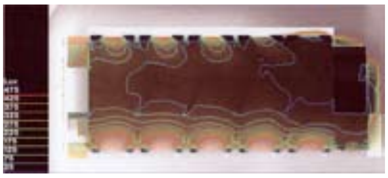
Figure 9. 1/35 scale model of a section of the CH2 building (Division of Fluid Mechanics, Department of Civil and Environmental Engineering, Imperial College, London)

Computer Lighting Analysis

The north and south facades comprise two main elements - air ducts and windows. Given that the size of the air ducts (both supply and exhaust) needs to increase as you move up the building computer simulations were used to test the implications of the resultant smaller windows. This analysis showed that this would not compromise natural light levels. The series of images below shows the analysis of light entering at each level.



Level 8



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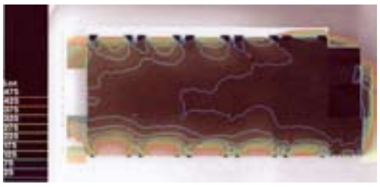
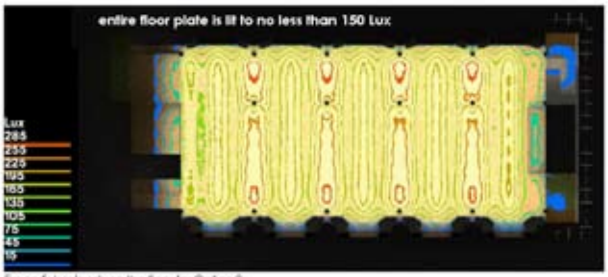


Level 2

Figure 10. Natural lighting study (AEC)



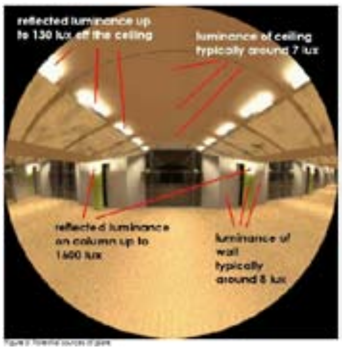


Figure 11. Artificial lighting study (AEC)

The vaulted roof, discussed earlier was also a technique to improve the amount of natural lighting filtering to the deeper parts of the floor plate.

Demonstration Model

The shower towers were another element that required quantitative analysis. The CFD model did not have the formulas for such an innovation, so these needed to be developed by AEC. The physical testing described below had a dual role of demonstrating one of the elements of CH2 and verifying these assumptions.

The shower towers work by drawing in outside air from 17 metres or more above street level and channelled into the shower towers on the south side of CH2. The towers are made from tubes of lightweight fabric 1.4 metres in diameter. As the air falls within the shower tower it is cooled by evaporation from the shower of water. The cool air is supplied to the retail spaces and the cool water flows to the basement where it is used to pre-cool the water circulating through the chilled ceiling panels, reducing the load on the PCM system.

Figure 12. Mock-up of the shower tower and thermometer for Sustainable Living Fair Melbourne 2004

The model of the shower tower was a metal frame 2.5 metres tall and 400mm in diameter, with a clear plastic bag, especially sourced for the application, slid over it. The sizes and dimensions were based on the AEC formulas used in the modelling. The tower sat in a 'pond' of water nominally 150mm deep. Water was pumped from the 'pond' to the top of the tower, where it fell from a 100mm shower rose.

The temperature of air coming out of the bottom of the shower tower was measured and compared to the outside air temperature (and the relative humidity). A recording of the temperature for the weekend was made.

The results of the shower tower mock-up at the SLF 2004 show a reduction of temperature between 4 and 13°C. An interesting lesson from this exercise is how easily some elements can be mocked-up and demonstrated to the general public and what a positive response this can evoke from people.

Physical mock ups are usually the most useful in demonstrating new technology. Although accurate results cannot be demonstrated the general principles are demonstrated to a range of people who may not be able to read schematics.

Full Scale Mock Up

A prototype of the office space in the Council's own buildings where the project team works daily was a very rewarding initiative. The benefits over a computer animation such as the one shown below, is that you can see, feel and touch the space and the elements in it. This gives a much better perspective to discuss issues for the project team as not everyone has the ability of visualising spaces and understanding them from plans or computer images.

Figure 13. Computer model of the office spaces with precast concrete ceiling-floor system

Figure 14. Prototype full scale of the office spaces with precast concrete ceiling-floor system

In the actual sourcing and installation of the systems, problems were experienced and were solved before starting large scale construction.

Figure 15. Trialling different lighting systems and prototypes

19 Modelling

Research into the best approach to heating and cooling

AEC carried out extensive research into the energy and greenhouse effects of various design techniques used to deliver heating and cooling needs. The information below is taken from their report on the CH2 air conditioning design strategy, and demonstrates the relative effect of the options described earlier in this snap shot, and their interaction with each other.

The need for heating and cooling

The AEC report firstly determined that the building would predominantly need cooling in order to maintain comfortable working temperatures.

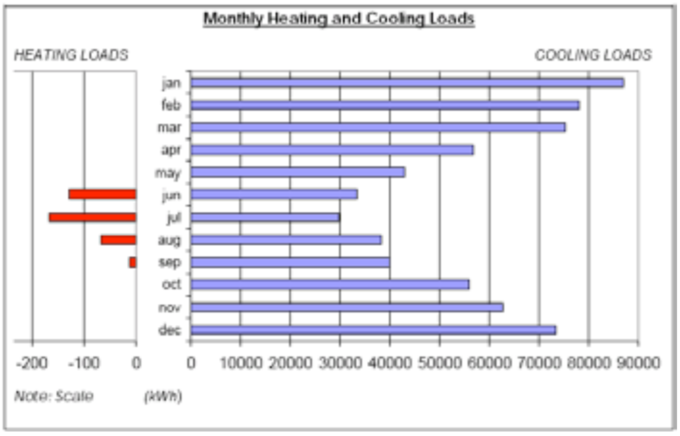


Figure 17. Heating and cooling loads (AEC report SFT30503)

Heating and cooling requirements can also be viewed on a per zone basis which facilitates efficient air conditioning design. For example, the centre zone will have totally different cooling requirements to the four perimeter zones, hence attempting to control the temperature in both the centre and the perimeter zones from the same air supply is neither efficient nor very effective.

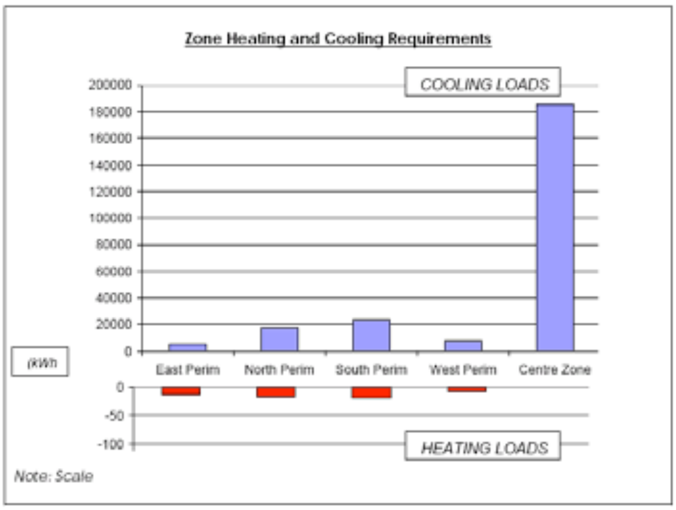


Figure 18. Heating and cooling loads for specific zones of the building (AEC report SFT30503)

AEC then modelled a number of scenarios which employed different combinations of the heating and cooling approaches being considered, in order to determine the most energy efficient option, with low greenhouse gas emissions. It also helped to determine the sizing of various plant, such as the cogeneration unit.

Model 1: The base model (traditional methods of heating, cooling and ventilation)

For the base model research it was assumed that a good practice VAV (variable air volume) air conditioning system would be used (rather than the displacement system later adopted). It was also assumed that the VAV air conditioning design would divide the floor plan into north and west perimeters, south and east perimeters, and the centre zone.

The air entering the office area would be a mixture of minimum fresh air requirements and re-circulated air from the space. This distribution is the traditional method of supplying air, common in most Melbourne office buildings. Cool air is blown in through the ceiling and dilutes the room air to provide an even temperature and contaminant level through the space.

Using the assumption that fresh air requirements are 10L/s per person and minimum air circulation rates of 6L/s per person for perimeter zones and 4.5L/s per person for centre zones, the expected energy consumption using the base model is:

- Total electric consumption = 173 424 kWh;
- Total gas consumption = 36 200 kWh;
- $C0_2$ emissions = 233 238 kg.

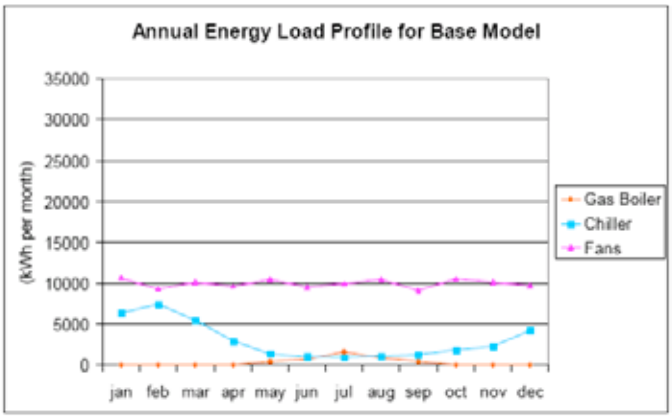


Figure 19. Annual base model energy load (AEC report SFT30503)

Model 2: Impact of adding a night purge

This model assumed an automatic night purge when under favourable conditions, to improve the fresh air quality and assist with cooling in the summer.

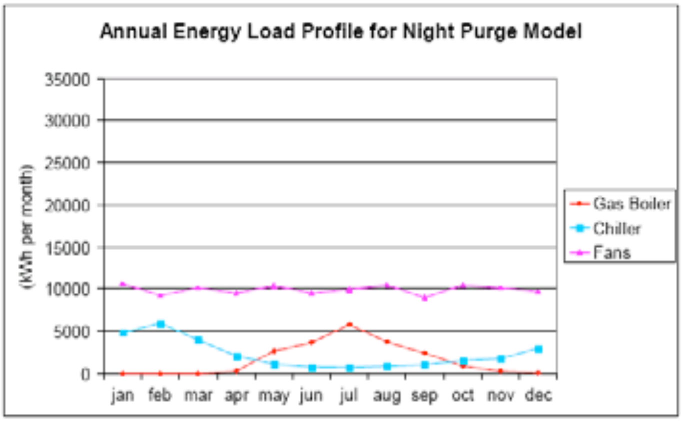


Figure 20. Annual base model with night purge (AEC report SFT30503)

The results show that the chiller load is significantly reduced in summer due to night purge cooling, but some additional energy is needed in winter to heat the building as the fresh air from the night purge would be too cold (a trade-off). The system has been designed so the night purge parameters can be adjusted once the building is in operation. This may mean night purging is restricted to the warmer months in order to maintain temperature in the winter, but with a loss in air quality.

Performance was modeled to be:

- Total electric consumption = 159 379 kWh;
- Total gas consumption = 19 484 kWh;
- C02 emissions = 217 660 kg.

Model 3: Night Purge plus Displacement Ventilation

This option includes the night purge, and the use of displacement ventilation rather than VAV. Air is introduced into the space at around 0.2m/s or less, usually through floor vents at 1-2°C below desired temperature levels. In comparison, the VAV system would need to supply air at 2.5m/s, and cool air at 6-10°C below desired temperature levels.

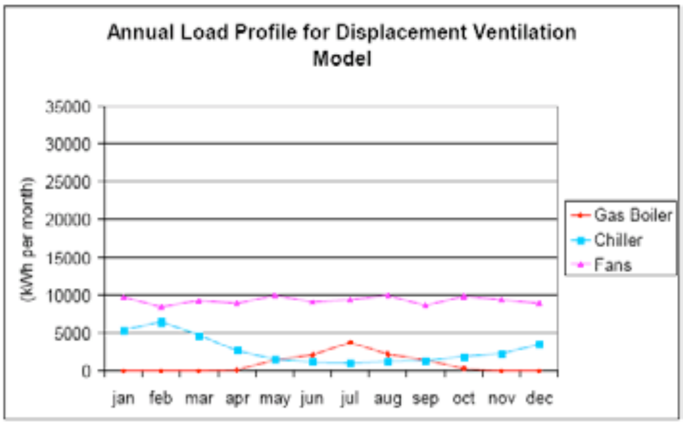


Figure 21. Night purge and displacement ventilation (AEC report SFT30503)

Electricity needed to supply the air (the fans) is slightly lower, but overall electricity use is slightly higher. But the main difference is that less gas is needed to heat the building in winter as the displacement ventilation produces better heating results.

Performance was modeled to be:

- Total electric consumption = 159 539 kWh;
- Total gas consumption = 11 084 kWh;
- C02 emissions = 216 110 kg.

Model 4: Night purge, plus displacement ventilation, plus chilled panels and beams

This model incorporates into the previous model, a chilled ceiling cooling system for the centre zones, and chilled beams for the perimeter zones. The chart below shows the effect of changing the cooling system (cold air to cold water). Heating will be provided at floor level via convective fin elements powered by a central gas fired boiler, and the chilled ceilings/beams are powered by a central electric chiller. A separate air handling unit will be also powered by the central gas boiler and electric chiller. In addition, air introduced to the space is de-humidified to ensure that there is no risk of condensation on the ceiling panels.

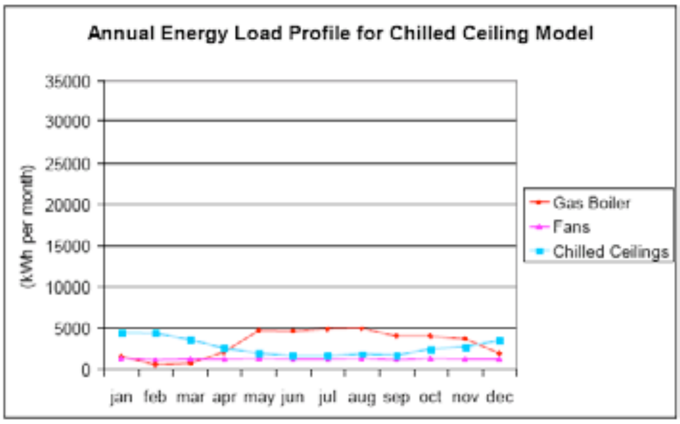


Figure 22. Impact of chilled ceiling panels and beams on loads (AEC report SFT30503)

This indicates that fan electricity consumption has significantly decreased along with chiller consumption, meaning that the total amount of electricity has been reduced. Gas consumption has increased very slightly due to the dehumidification of warm air in summer. The impact is:

- Total electric consumption = 97 358 kWh;
- Total gas consumption = 38 219 kWh;
- C02 emissions = 138 485 kg.

Model 5: Chilled Ceilings with 100% Fresh Air Intake

It was assumed in this model that the fresh air rates for the space have more than doubled from 10L/s/person to 22.5L/s/person and that air introduced to the space is 100% fresh air and not a mixture of return and supply air.

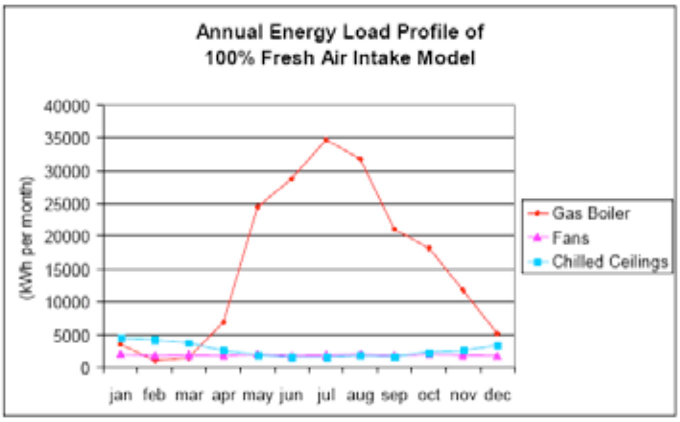


Figure 23. Impact of 100% fresh air intake (AEC report SFT30503)

The loads have significantly increased because of the use of the fresh air, particularly in winter, where the gas boiler has to provide more heat, compensating for the cold fresh air. This is the price paid for the IEQ benefits. The results are:

- Total electric consumption = 103 078 kWh;
- Total gas consumption = 188 735 kWh;
- C02 emissions = 177 759 kg.

Model 6: Impact of Phase Change Materials (PCMs)

The PCM tanks will be connected to the shower towers, cooling towers and the chilled elements.

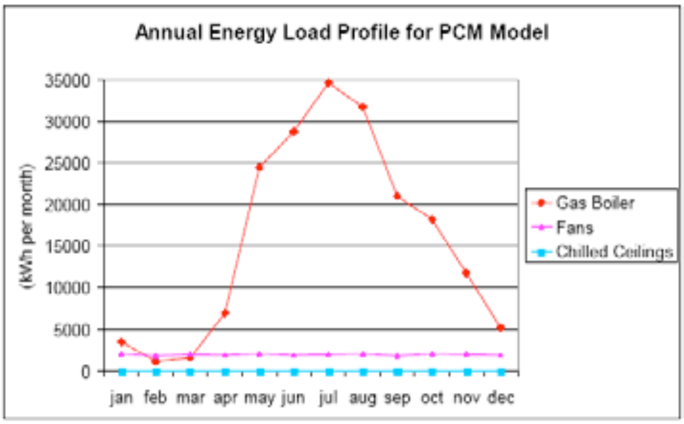


Figure 24. Impact of using PCMs (AEC report SFT30503)

In this model, the electric power used to cool the chilled ceilings and beams via a chiller has been completely eliminated. However, the gas boiler, chiller, and fan consumption remains the same because the fresh air system does not change. The results are:

- Total electric consumption = 72 663 kWh;
- Total gas consumption = 188 735 kWh;
- C02 emissions = 137 003 kg.

Cogeneration

It is assumed that any cooling/heating loads above 100kW will be powered through an absorption chiller fuelled by gas.

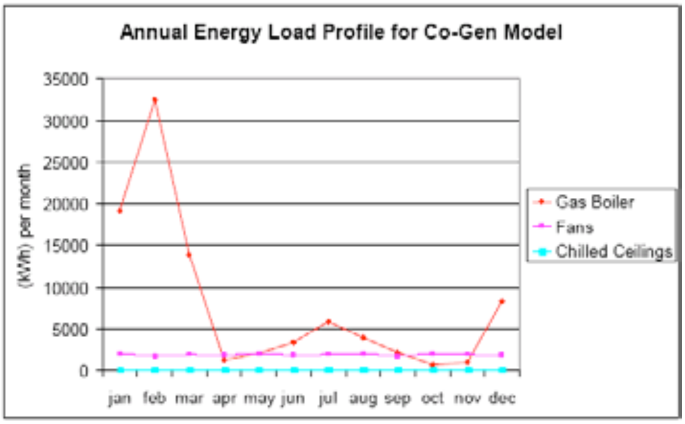


Figure 25. Impact of using cogeneration (AEC report SFT30503)

As a result, gas boiler consumption drops considerably to about one quarter of its previous usage which reduces both energy consumption and carbon emissions. Notice that in summer, gas boiler requirements remain significant due to large cooling loads demanded from the absorption chiller. In summary:

- Total electric consumption = 72 663 kWh;
- Total gas consumption = 94 427 kWh;
- CO_2 emissions = 117 198 kg.

Conclusion

The use of night purge, displacement ventilation, chilled ceilings, 100% fresh air intake and phase change materials has contributed to the decrease in electricity usage; however, gas consumption will increase. Overall however, carbon emissions are reduced by 27% because gas is six times cleaner than electricity as an energy source. However, through the use of waste heat from a co-generation plant, the increase in energy consumption has been offset completely. The energy consumption of the final model is less than that of the base model. These impacts are even greater when we compare carbon emissions.

The objective of a 'green' building is to minimise the emission of greenhouse gases, namely carbon dioxide emissions, through efficient energy usage. This will be dependent on energy utilisation between sources such as electricity, gas, solar, wind or energy from a co-generation plant, etc. In the state of Victoria, Australia, gas has a CO_2 co-efficient of 0.21 which is much less than the 1.34 co-efficient for electricity. This means that electricity pollutes about 6.4 times more than gas and electricity usage is most undesirable. Using these co-efficients, we can calculate carbon emissions for each model and the following comparative graph can be produced.

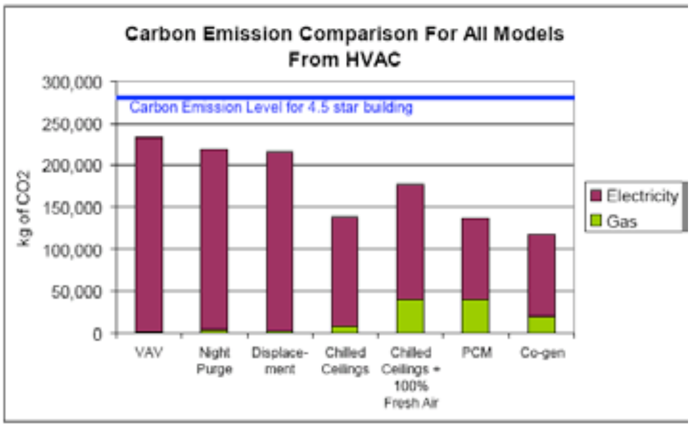


Figure 26. Results summarised in kg of CO_2 (AEC report SFT30503)

The last model which adopts a co-generation plant into a chilled ceilings/beam air conditioning system (with displacement air and night purge benefits) by far produces the least amount of carbon dioxide emissions. This is 44% of what a 4.5 star building would normally achieve under the Australian Building Greenhouse Rating scheme. The adoption of LCD flat screen monitors, which reduce cooling loads by around 12%, will bring this consumption down even further.