Technical Research Paper 06

CH_2 Energy Harvesting Systems: Economic Use and Efficiency

Contents

Disclaimer

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An Australian Government Initiative
AusIndustry
6 star rating
green star Office Design v1
This rating represents World Leadership

Preface

Council House 2 (CH$_2$) is a visionary new building that is changing forever the way Australia – indeed the world – approaches ecologically sustainable design.

With its Six Star Design Rating granted by the Green Building Council of Australia, CH$_2$ is one of the cleanest and greenest buildings on earth.

This paper, one in a series of 10 technical papers, investigates the design and systems of CH$_2$ prior to occupancy and availability of operational performance data. The papers have been written by independent authors from Australian universities, as part of the CH$_2$ Study and Outreach Program – a coordinated effort to consolidate the various opportunities for study, research, documentation and promotion generated by CH$_2$.

The aim of the CH$_2$ Study and Outreach Program is to raise awareness of sustainable design and technology throughout the commercial property sector and related industries.

While the pre-occupancy research papers are a valuable resource, they do have some limitations. For instance, these studies have been written before operational experience. This means the authors' views are based on existing knowledge, which can be difficult to apply when significant innovation exists.

Many of the innovations in CH$_2$ have been subject to limited, if any, rigorous or directly relevant research in the academic field, which is reflected in the lack of literature cited for systems such as the shower towers and phase change materials used in the cooling system.

Another major limitation is the exclusion, by academics generally, of industry experience of new technologies. The extensive knowledge gained by industry is often not well documented and can be difficult to access through traditional academic channels.

One example, where industry expertise exists, is the use of phase change materials for reducing peak cooling loads and energy use in commercial and institutional settings, such as offices, hospitals, prisons and factories.

In addition, to enable the authors to complete their task, they have based their study on CH$_2$ project reports prior to the design being finalised. This means some of the descriptions of systems and findings in the papers are to some extent out dated. In particular, findings related to the wind turbines and the heating, cooling and ventilation systems have changed somewhat as a result of final design decisions.

To reduce the impact of these limitations for readers, the Council has provided additional comment as footnotes in some papers.

It is important to inform readers the target audience for these papers is professionals and academics involved in the research, design, engineering, construction and delivery of high performance buildings. This helps to explain the technical detail, length and complexity of the studies.

Although these papers may be of interest to a range of audiences it's important that readers, who possess a limited knowledge of the subjects covered, obtain further information to ensure they understand the context, relevance and limitations of what they are reading.

For more information or to make comment and provide feedback, readers are invited to contact the Council. The details are available at the end of this document.

We hope you enjoy reading these technical studies and find they are a useful resource for progressing your own organisation's adoption of sustainable building principles and encouraging the development of a more sustainable built environment.

Foreword

In 2000 the City of Melbourne made the decision to embark on a revolutionary new project called Council House 2 (CH_2). The decision was due to a pressing need for office space for its administration and the desire to breathe life into an under-used section of the city.

The project gave the Council the opportunity to exercise its environmental credentials by creating a building that was at once innovative, technologically advanced, environmentally sustainable and financially responsible.

This approach allowed the Council to insulate itself against exposure to rising energy and water prices, the diminishing availability of resources and the uncertain long-term availability, while providing a healthy workplace attracting the best workforce in a labour-constrained market.

CH_2 has been designed to reflect the planet's ecology, which is an immensely complex system of interrelated components.

From the revolutionary cooling storage system in the basement to vertical gardens and wind turbines on the roof, the building has sustainable technologies integrated throughout its 10 storeys.

Although the majority of the technologies and principles adopted in the building are not new, never before in Australia have they been used in an office building in such a comprehensive and interrelated fashion.

This includes innovations such as: using thermal mass for improving comfort; phase change material to reduce peak energy demands and energy use; generating electricity onsite from natural gas; and using waste heat for cooling and heating.

Through CH_2, the Council plans to trigger a lifestyle and workstyle revolution. The building will be used as a living, breathing example, demonstrating the potential for sustainable design principles and technologies to transform the way industries approach the design, construction and philosophy of our built environment.

As with many revolutions, there are sceptics. The Council's response has been to patiently press ahead with the construction of CH_2 while actively and energetically encouraging lively debate.

Some of the papers in this pre-occupancy study and outreach series make compelling points in favour of the case for sustainable development. Others reflect a more subtle or sometimes overt scepticism that may be encountered throughout the community.

The City of Melbourne welcomes all of this debate but in the long term intends to demonstrate the effective performance of CH_2 and prove the doubters wrong. Collectively, the studies demonstrate the enormous value to be gained by researching the case for sustainable development and the scope for much more study and documentation in this field in the future.

The City of Melbourne wants CH_2 to be copied, improved on and enthusiastically taken up throughout Melbourne and far beyond.

Technical Research Paper 06

CH_2 Energy Harvesting Systems: Economic Use and Efficiency

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Abstract

This paper examines the City of Melbourne's new office building known as Council House 2 (CH_2), as a case study of world class energy performance. In particular, it investigates how the integrated design of conventional independent systems has the potential to deliver significant savings to the City of Melbourne, along with better environmental conditions to building occupants. In turn, these may contribute to satisfaction, wellbeing and productivity gains. This paper concludes that CH_2 has the potential to be an iconic example of effective implementation of Ecologically Sustainable Design principles, and therefore act as an international demonstration project. Energy consumption of less than 50 per cent of current benchmarks for Melbourne office buildings is expected. Energy harvesting is a new concept introduced in this paper to better describe the design decision process. It is the process of capturing or reusing energy from potential squander, waste and nature.

Keywords: energy efficiency, harvesting, thermal comfort, CH_2.

Introduction

Environmental depletion, global warming and consequential climate changes are key issues for today's generation of commercial buildings. These changes have been explained scientifically to be the result of excessive greenhouse gas emissions generated from the burning of fossil fuel since the industrial revolution (Lawson, 1996; Steele, 1997). The time lag between actions and changes in environmental systems determines that decisions made now will affect subsequent generations and the future of our environment.

Australia has the highest greenhouse gas emissions per capita in the world (SEAV, 2001). Commercial buildings are large energy consumers, as energy is the lifeblood of contemporary office buildings. No office building can function properly without energy supply. Energy intensity is increasing and is also making a significant contribution to peaks in electricity demand, particularly with increased reliance on air conditioning (ABARE, 1999). According to the Property Council of Australia (2001), commercial buildings in Australia generate more than 35 million tonnes of CO_2 a year.If no action is taken to reduce growth, this figure is projected to double within a decade.

Harvesting energy from office buildings provides a way of meeting increasing energy needs, without adding to greenhouse gas emissions. This approach recognises that building design and systems integration are key strategies for achieving significant greenhouse gas emission reductions over the longer term, although other abatement measures may be more attractive in the short term.

While the majority of energy consumption occurs in existing buildings, new and refurbished buildings present major opportunities to leverage capital investment and incorporate new approaches to building design and construction.

To be a credible leader in energy management within the community, the City of Melbourne must first ensure its own energy consumption is as efficient and effective as possible. The CH_2 project therefore had to meet a minimum 5 star energy level, and comply with the energy targets set out under the Council's Energy Management Strategy and accompanying Energy Policy.

CH_2 is a new office accommodation project being constructed by the City of Melbourne, and is anticipated:

- to demonstrate the Council's commitment to effective greenhouse action, providing strong leadership to the community;
- to reduce greenhouse gas emissions arising from the Council's operations;
- to drive cultural change across all government agencies in energy management and the integration of environmental considerations; and
- to display energy reduction targets and realise carbon dioxide (CO_2) savings through cost-effective action, without compromising productivity and working conditions, and assist in holding down electricity costs over the medium term.

This paper will document the energy harvesting systems within CH_2, and assess these with respect to international best practice. Included in this paper is an assessment of related industries within Australia, and identification of areas for improvement in meeting the needs of the expanding Ecologically Sustainable Development (ESD) industry.

The paper outlines an integrated approach to energy harvesting and suggests some solutions based on research and current good practice. Firstly, it includes an appraisal of energy use in existing office building stock in Australia. Secondly, building energy benchmarking schemes are reviewed. Thirdly, the potential opportunity for energy harvesting in office buildings is defined. Fourthly, a brief description of energy harvesting systems in CH_2 is provided, along with an analysis of the success of the system integration in CH_2. Finally, a conclusion is offered.

How Energy is Used in Australian Office Buildings

Energy is not used for its own sake. It is one of many inputs to a system that produces useful and valuable outputs. In office buildings, energy is used to create a comfortable and healthy working environment, as well as powering equipment that is required to get work done. A typical breakdown of relative energy consumed by commercial buildings in Australia is shown in Figure 1. Greenhouse gas emissions are defined here as the amount of primary energy used, as opposed to the convention of measuring delivered energy. This approach takes into account the efficiency of energy production, truly reflecting the true energy resources consumed by buildings.

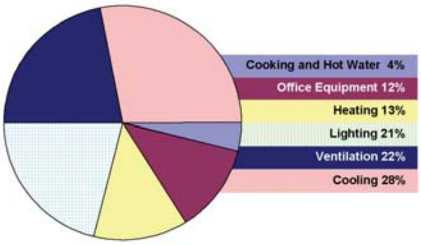

Figure 1: Commercial building greenhouse gas emissions (EMET, 1999).

The majority of energy consumed in Australian commercial buildings is dedicated to thermal comfort. This includes heating, cooling and ventilation services, which account for 63 per cent of total greenhouse gas emissions. Ventilation systems are also responsible for removing contaminates, and providing fresh air essential for health and wellbeing. The third largest single consumer is lighting systems, required for maintaining sufficient illumination for occupants to perform their work, and for safety and security purposes. Energy is also required to power all office equipment including computers, printers and photocopiers. In contemporary offices, almost every workstation is equipped with a desktop computer. These office machines account for approximately 12 per cent of overall greenhouse gas emissions in Australian commercial buildings. The ultimate purpose of all this energy consumption is to improve workplace productivity.

The average annual energy consumption per unit floor area of Victorian office buildings is compared against overseas data in Figure 3. Results indicate that, on average, office buildings in Victoria have the second lowest level of energy consumption when compared to selected countries in the Asia Pacific region. They also consume less than half of the energy used by their counterparts in the United Kingdom and United States. It is worth noting that these data are not normalised for climatic differences. As such, a conclusion that office buildings in Victoria are more energy efficient than those in other countries is not appropriate or accurate, as the climate in Victoria is milder when compared to either the humid, tropical climates of Thailand and Singapore, or the colder climates of United Kingdom and parts of the United States.

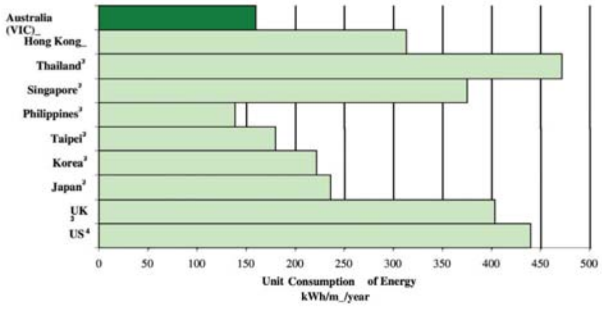

Figure 2: Comparison of average unit consumption of energy for office buildings in Australia with overseas data[1,2,3,4].

Building Energy Benchmarks in Australia and Overseas

Energy benchmarks for buildings provide a set of representative values on building energy consumption, against which users can compare a building's actual performance.

These benchmarks are designed to achieve two main objectives:

- to allow users to benchmark their building's energy consumption levels against that of their respective sector; and
- to help set targets for energy consumption by designers or building management professionals.

Benchmarks are based on surveys of buildings, and evaluation of systems considered good practice at the time. It is anticipated the establishment of benchmarks will lead to improved energy performance by average commercial buildings, and significant energy savings. Benchmarks are recognised as valuable tools for both government and the private sector to manage energy usage with respect to climate and specific building typology. If the energy consumption of a building falls outside prescribed limits, the design or building management team can seek advice for improving energy performance.

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1 PCA (1997). Victorian Energy Use Survey, Property Council of Australia Victorian Division, Melbourne
2 CDM (2002), Consultancy Study on the Development of Energy Consumption Indicators and Benchmarks for Selected Energy-consuming Groups in Hong Kong, EMSD, Hong Kong. www.emsd.gov.hk/emsd/e_download/pee/esab.pdf
3 Action Energy (2003). Energy Consumption Guide 19: Energy Use in Office, www.actionenergy.org.uk
4 Rating Energy Performance: Office Buildings, http://eber.ed.ornl.gov/benchmark/off.htm

There are two major types of building energy benchmarks:

- simple benchmarks which define overall annual energy consumption per unit floor area, or annual greenhouse gas emission per unit floor area; and
- detailed benchmarks with sub-benchmarks for most essential services, including lighting, cooling, heating, ventilation, equipment and vertical transport.

Comparison with simple benchmarks of annual energy use per square metre of floor area permit energy efficiency to be assessed, and enable remedial action to be taken. More detailed benchmarks can help pinpoint problem areas within a building.

A number of local and overseas energy benchmarks are summarised in Table 1. Some of these benchmarks include energy efficient guidelines that address issues of good management, along with proposed energy targets achievable through good design practice. Once again, the benchmark for Melbourne offices has the lowest overall energy consumption level amongst the four countries/regions listed, and reflects the phenomenon observed in the average energy consumption of various countries shown in Figure 2.

Examination of the detailed benchmarks of individual building services shows that Victorian benchmarks are more relaxed on lighting systems when compared to other countries. Both lighting power density (W/m^2) and lighting energy consumption (kWh/m^2/year) are significantly higher than other benchmarks.

Most of the other services' benchmarks are comparable with figures for the United Kingdom. One obvious exception is the heating energy requirement, as the UK climate has a higher number of days requiring heating. Another significant observation from Table 1 is that even though the Victorian benchmarks show half to three quarters of the energy consumption of the United Kingdom benchmark, the figures for greenhouse gas emissions are one and a half to two times that of the United Kingdom benchmark. This leads to concern about the selection of energy sources in Victorian office buildings, and further stresses the need to reduce energy consumption.

The Building Owners and Managers Association's (BOMA) 1994 design target included in Table 1 illustrates growth in energy consumption in cooling, ventilation and office equipment. Improved efficiency of building services and office equipment should lead to a reduction in energy consumption, and hence lower the benchmarks. These changes, contrary to the latest benchmarks, can gradually improve the energy performance of buildings over time by raising the energy efficiency target. However, the density of office space has become higher in recent years, resulting in higher ventilation and space-conditioning requirements. Likewise newer, more powerful desktop computers generate more heat, which explains the increased energy consumption of office equipment, and the increased cooling load required to remove the extra heat.

	Overall energy consumption (kWh/m^2/year)	**Overall CO_2 emissions ($KgCO_2$/m^2/year)**	**Lighting Power density (W/m^2)**	**Lighting energy consumption (kWh/m^2/year)**	**Cooling Energy Consumption (kWh/m^2/year)**	**Heating Energy Consumption (kWh/m^2/year)**	**Ventilation and Pump energy consumption (kWh/m^2/year)**	**Office equipment (W/m^2)**	**Office equipment (kWh/m^2/year)**
Australia									
BOMA 1994 New Building Design Target (Melbourne)	118	114	14	36	10	37	14	5	12
PCA 2001 Good Practice Benchmark (Melbourne)	186	196	15	39	17.5	47	28	NA	24
PCA 2001 New Building Design Target (Melbourne)	133	142	11	31	13	31	22	NA	15
ABGRS 5 stars		170							
UK[5]									
Energy Consumption Guide 19: Good Practice	225	85	12	27	14	97	30	14	23
Germany[6]									
Guidelines for sustainable building			10					25	
US[7] CBCES	252		14*						
Hong Kong[8] Best Practice	226								

**ASHRAE 90.1-2001.*

Table 1: Summary of Local and Overseas Building Energy Benchmarks.

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[5] Energy consumption guide, www.actionenergy.org.uk

[6] FOBRP (2001), Guideline for Sustainable Building, Federal Office for Building and Regional Planning, Germany

[7] CBCES (2000), Energy Information Administration: 1999 Commercial Buildings Energy Consumption Survey

[8] CDM (2002), Consultancy Study on the Development of Energy Consumption Indicators and Benchmarks for Selected Energy-consuming Groups in Hong Kong, www.emsd.gov.hk/emsd/e_download/pee/esab.pdf

ESD Office Buildings and Benchmarks

The predicted energy consumption of three ESD office buildings, including CH$_2$, are shown in Table 2. Only ESD buildings in Melbourne are included, eliminating the effect of climatic difference and allowing direct comparison of figures. It is worth noting there are other ESD labelled buildings in Victoria (SEAV, 2000); however, figures on detailed energy consumption targets are not available. To the author's knowledge, there is no published data on measured energy performance for any ESD labelled building in Victoria.

	Overall energy consumption (kWh/m^2/year)	**Overall CO$_2$ emissions (KgCO$_2$/m^2/year)**	**Lighting Power density (W/m^2)**	**Lighting energy consumption (kWh/m^2/year)**	**Cooling Energy Consumption (kWh/m^2/year)**	**Heating Energy Consumption (kWh/m^2/year)**	**Ventilation and Pump energy consumption (kWh/m^2/year)**	**Office equipment (W/m^2)**	**Office equipment (kWh/m^2/year)**
Building T[9] – Target	100	NA	NA	25.0	13.3	6.7	NA	NA	12.5
60 L[10] – Prediction	34	NA	7.0	6.0	7.0	13.0	NA	5.0	6.0
CH$_2$[11] – Prediction	58.6	68.6	8.0	5.5	1.7	12.6	8.0	4.3	11.5

Table 2: Predicted Energy Performance of Selected ESD buildings and the CH$_2$ Project.

It can be seen that all three buildings have predicted significant reduction in energy consumption over the building energy benchmarks in Table 1. CH$_2$ has the lowest energy consumption in most of the categories, except office equipment and the overall figure for usage. The less impressive result in the office equipment category results from a higher occupant density when compared to 60 Leicester Street, Carlton (60L). The energy harvesting systems in CH$_2$, which will be examined in the next section, should perform well. One of the most significant energy consumption savings in CH$_2$ has been achieved through the design of the space conditioning system. CH$_2$ is predicted to reduce energy consumption for cooling by 83 per cent compared to the strictest energy benchmark, and 76 per cent of the best performing counterpart in Melbourne. The lighting performance of CH$_2$ will be 18 per cent of the toughest benchmark. Even with the disadvantage of a very deep floor plan, CH$_2$ is still predicted to achieve lighting energy consumption lower than 60L.

Energy Harvesting in the CH$_2$ Building

Energy harvesting systems are defined in this paper as systems that convert on site energy potential into energy services that are required for the building to function. This is different from the prevailing concept of energy production systems, which convert energy available from nature directly into electricity or usable heat.

It is important to understand that building occupants need energy services rather than energy supply. By the same token, energy harvesting systems do not necessarily harvest energy in the form of electricity. Under this definition, any system that can contribute in the provision of services without extra energy input can be seen as an energy harvesting system.

This service-based paradigm for energy harvesting systems helps to clarify the nature of the services that require energy inputs, and facilitates alternative methods of achieving the required outcome. The correct definition of a service requirement is an important step towards identifying the potential for energy efficiency improvement, as it allows unconventional thinking. For example, building occupants need a comfortable thermal environment that does not necessarily need to be created by an air conditioning system. During days when outdoor conditions are pleasant, open windows[12] can provide the same, if not higher, level of comfort without any consumption of energy.

[9] SEAV (2000), Energy Smart Building Design, SEAV, Melbourne

[10] 60L (2004), www.60lgreenbuilding.com, Australian Conservation Foundation

[11] ACE (2004), report: VCML250280\0\2\AR30509

[12] City of Melbourne note: Windows in CH$_2$ are only designed to open at night, to allow cool night air to flow through the building and remove heat stored during the day in the thermal mass of the concrete ceiling panels. This operation is referred to as night purge.

Energy harvesting can be divided into three main categories:

- harvesting from squander – aimed at reducing energy consumption by improving efficiency and eliminating oversupply of services;
- harvesting from waste – aimed at recovering energy that would otherwise be dissipated into the environment as waste; and
- harvesting from nature – aimed at collecting energy or an energy service from the ambient environment, and delivering it to the building occupants.

Under these three categories, the choices made in the selection of technologies and energy sources are investigated, and an interpretation is provided as to useful services.

The design of CH_2 incorporates a number of energy harvesting features. These features are grouped into the above categories, enabling systems to be analysed in terms of their influence on the building’s energy consumption. An overview of the energy harvesting systems proposed for CH_2 is presented below. This is followed by a review of the individual components used for energy harvesting systems, and their expected performance in the Melbourne climate.

The CH_2 building is located in Melbourne (latitude 37°49’S and longitude 142°30’E), the capital of the state of Victoria in the southeastern part of Australia. The climate is classified as temperate. However, the weather in Melbourne is highly inconsistent, and is sometimes described as ‘four seasons in one day’.

Figure 3: shows in the reference weather year; there are 414 occupancy hours (08:00 – 18:00) that have outdoor air temperature above 24ºC and 3234 occupancy hours below 21ºC.

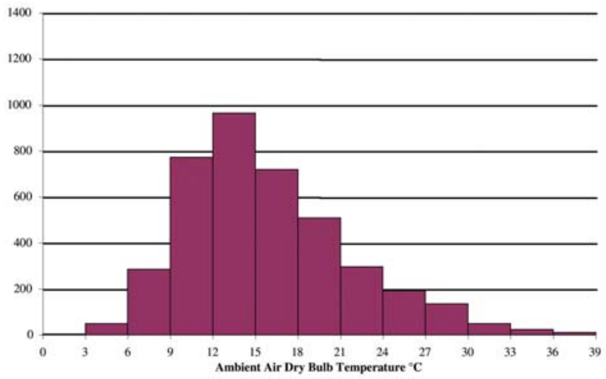

Figure 3: Frequency of Dry Bulb Temperature to Occupied Hours.

Harvesting from Squander

In the CH_2 project, the design team took an unconventional approach when setting up the service standards. The design moves away from the industrial norm, to allow alternative approaches for the provision of services. This is most evident in two key areas: the lighting provision for the office spaces, and thermal environment conditions.

Lighting Requirements

In a conventional open plan office, the lighting system is designed to provide a uniform task lighting level on a work plane height over the whole office space. This practice is focused on the flexibility, or easy rearrangement and subdivision of the space. According to the Australia Building Greenhouse Rating Scheme (ABGRS) (SEDA, 2004), the occupant density is 18m^2 of office space per occupant. On average, each workstation has 2m^2 of desk surface, plus 1m^2 of table surface of meeting rooms and discussion areas per occupant, considered as the work plane. Therefore, conventional practice results in over-illuminating more than 85 per cent of the office area that should only be provided with ambient light.

The separation of task light and ambient light is the basis of the energy-efficient lighting scheme in CH_2. The lighting system in CH_2 comprises general lighting with an ambient level of 150 lux, and local task lighting above individual workstations. This provides a light level of 320 lux, which can be adjusted up to 400 lux by occupants (LSA, 2003). The adjustability of individual task lights for each workstation is enabled by an addressable lighting control system that adjusts lighting to suit the occupancy trend and time of use. A local dimmer control is integrated into the computer screen as an icon. This device provides three lighting control options of high, medium and light. The ‘light’ option causes a slider to appear with a save button, enabling the user to set their workstation light level according to their own preference. The local light fittings automatically return to the ambient level of 160 lux when the computer or monitor is switched off.

This control system is beneficial to office workers, as they can adjust their preferable light level when performing onscreen work, or turn up the light when doing paperwork. The lighting control features of CH_2 can deliver considerable energy savings as a result. There is no figure provided by the consultant, however a recent article from the Property Council of Australia indicates that adjusting lighting when people go out for lunch or leave early can achieve a 25 per cent lighting energy cost reduction for general office areas (Hennessy, 2004).

Energy Efficient Lighting

Apart from sophisticated lighting control systems, CH_2 will also have energy efficient fluorescent T5[13] luminaires in all office levels. The power density of the lighting system is limited to 8W/m^2. T5 fluorescent lamps are more efficient and last longer than conventional T8 lamps. The standard luminaires provide both downlight and uplight in order to even out the indoor light level, which in turn reduces contrast in the space. Electronic dimmable ballasts enable a better light quality and control, resulting in less energy use.

Indoor Thermal Requirement

The dominance of deep open plan offices in air conditioned ‘glass boxes’ in the last few decades has convinced people they cannot work without air conditioning. Air conditioning has therefore become a necessity in the mindset of contemporary office developers, regardless of the climatic potential of the building location. Many developers overlook the fact that occupants simply require a comfortable thermal environment. The term ‘thermal comfort’ can be defined as a sense of wellbeing with respect to thermal conditions (ASHRAE 55; ISO 7730). In such a state, a balance between the heat generation from the body (metabolism) and the heat loss through respiration and the skin is achieved (AEC, 1999; Szokolay, 1995; Givoni, 1974; Fanger, 1970). Thermal comfort is influenced by six objective factors: dry bulb temperature, humidity, air speed, mean radiant temperature[14], clothing level and metabolic rate.

Considerable energy is wasted through the common practice of establishing the universal set-point temperature control of 22.5ºC for indoor temperatures in a building, because it does not allow for occupants to dress according to the seasons. In the cooler months of the year, the temperature can be set at the lower end of the comfort range because occupants tend to be dressed for milder weather. In summer, however, when people ‘dress down’ for the warmer weather, the temperature setting can be set in the upper end of the comfort range (Hennessy, 2004).

For CH_2, the space thermal condition is specified by three parameters, namely air temperature, humidity and resultant temperature. A more relaxed air temperature set point of 21 to 25ºC can reduce the need for space conditioning. The decision to use resultant temperature as a key design parameter allows the design team to incorporate more energy-efficient methods of thermal space conditioning. In contrast, conventional air conditioning designers only specify dry bulb air temperature set points, and relative humidity limits, which the CH_2 design team believe greatly overlook the importance of the radiant component[15] in achieving thermal comfort through space conditioning.

Chilled Ceilings

Chilled ceiling systems provide cooling for occupants, by changing the temperature of the ceiling panel surface instead of only cooling the supplied air. Cooled water running through chilled ceiling panels fixed to the ceiling can cool the space via natural convection and radiative heat transfer. Radiative heat exchange has been found to be more effective at modifing the thermal sensation of the human body (Givoni, 1974; Fanger, 1970). Therefore, the system can operate at a higher chilled water temperature compared to ordinary air cooling systems. The ability to operate at higher chilled water temperature has a large influence on the energy-efficient performance of the primary cooling and chilling systems.

Chilled ceilings are not entirely new technology for space cooling. The technology has existed for more than 50 years (TIAX, 2002) and is more popular in Europe, where about 100,000m^2 have been installed in central European countries from 1995 to 2000 (Facão & Oliveira, 2000).

In general, radiant ceiling cooling reduces space conditioning energy consumption in several ways:

- In space cooling mode, energy savings accrue from delivering higher chilled water temperatures (16ºC in the CH_2 project) to radiant ceiling panels, to meet more sensible loads than conventional air conditioning systems. This allows the chiller evaporator temperature to rise, and improves chiller efficiency as the temperature difference across the system is lowered. Due to the higher chilled water temperatures used in chilled ceilings, water cooled by evaporative cooling towers can be utilised directly for much of the year without the need to operate the absorption or electric chiller units.
- Figure 7 shows the frequency distribution of ambient wet bulb temperature during occupied hours, and indicates that 83 per cent of occupied hours have a corresponding wet bulb temperature lower than 15ºC. During the other 17 per cent of the time, the cooling tower can be combined with a chiller to handle the heat load or the energy storage capacity of phase change material freed up by nightcooling (Facão & Oliveira, 2000), as proposed in the CH_2 project.
- The combination of radiant ceilings with displacement ventilation[16] also reduces energy consumption, by moving only the air required to satisfy fresh air supply. The use of water instead of air for cooling reduces energy consumption required for cooling transfer, as water has a higher heat capacity than air. Radiant ceilings also reduce the added heat load dissipated by ventilation fan motors reaching the conditioned space (Dieckmann et al., 04).

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[13] T5 luminaires is a 5/8” diameter fluorescent tube.

[14] Mean radiant temperature is defined as the weighted average temperature of all exposed surfaces in a given space.

[14] The radiant component is defined as the thermal sensation of the occupants caused by heat exchange with the surrounding surfaces by radiation.

[16] City of Melbourne update note: The final design for the CH_2 ventilation system does not produce true thermal displacement ventilation inside the occupied office space, as the vertical displacement flow of ventilation air is disturbed by the use of a chilled ceiling and swirl diffusers. However, the CH_2 system does achieve energy reductions for the reasons stated in the paragraph. The correct description for the air supply system is ‘under floor air supply using swirl diffuser’. Refer to the following web link, www.cbe.berkeley.edu/underfloorair/glossary.htm, for detailed definitions of UFAD, which is summarised here: “An underfloor air distribution (UFAD) system uses an underfloor plenum (open space between the structural concrete slab and the underside of a raised floor system) to deliver conditioned air, from the Air Handling Unit (AHU), directly into the occupied zone of the building. In contrast to true displacement ventilation systems, UFAD systems deliver supply air at higher volumes and higher velocities, enabling higher heat loads to be met. Although the supply air is delivered in close proximity to occupants, the risk of draft discomfort is minimised, as supply air temperatures are higher than those for conventional ceiling-based systems, and occupants have some amount of control (typically volume and sometimes direction and temperature) over their local air supply conditions.”

Since radiant heat transfer directly cools the occupants,this allows slightly higher building air temperatures, which further decreases building cooling loads. Overall, radiant ceilings have been shown to reduce cooling energy consumption by 25 to 30 per cent relative to a variable air volume (VAV) system (TIAX, 2002).

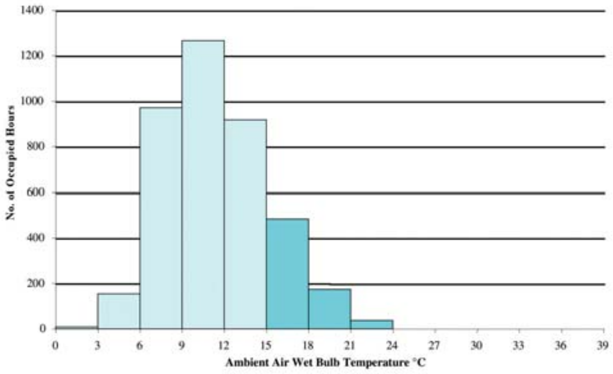

Figure 4: Ambient Wet Bulb Temperature during Occupied Hours.

Displacement Ventilation System[17]

True displacement ventilation systems generally supply fresh air to one side of the floor plate, at floor level at low velocity. The air gains heat from the occupants and equipment thermal buoyancy effects cause the air to rise up towards the ceiling, where it is then removed through ceiling-mounted exhausts. Thermal buoyancy driven displacement-type ventilation systems create an air layering effect or stratification, which acts to separate clean incoming supply air from the used internal air being exhausted. Stratification minimises mixing of air between occupied areas and improves overall air quality for occupants. Separation-based systems, such as displacement ventilation, reduce air conditioning energy consumption relative to conventional mixed air distribution, or dilution-based ventilation systems, in three ways:

- Displacement[18] ventilation systems lead to an improved co-efficient of performance (COP) of the chiller, due to higher supply air temperature when compared to conventional variable air volume (VAV) systems. However, the ability to control humidity[19] is significantly sacrificed. This is particularly important in the CH_2 project, as the chilled ceiling system has no ability to remove latent heat and there is a risk of condensation on the panel surface[20]. The higher the standard volume of fresh air supply, the more this condition is eased (IEA annex 28, 1995).
- The stratification of room air results in a higher average air temperature than that produced by mixing ventilation, reducing building thermal loads by as much as 15 per cent from heat transfer through the building envelope. (Hamilton, 2004).
- The higher supply air temperature increases the potential for utilising cooling towers or outdoor air to meet the cooling need.

In general, displacement-type ventilation systems, used for cooling as well as supplying air for occupants' breathing needs, have higher fan energy consumption. This is because the system must provide a larger volume of air, at a higher supply temperature, to each space to meet the cooling loads (Hamilton, 2004). In the CH_2 project, the ventilation system only has to handle the fresh air supply for occupant breathing requirements, as the majority of the cooling load is supplied by chilled ceiling panels. The ventilation system is designed to supply 1.5 l/s/m^2 of outside air to the building at 19ºC, with relative humidity lower than 65 per cent. These design parameters assist both chilled ceilings and the ventilation system to overcome their traditional weaknesses. The selection of an energy-efficient variable speed motor further improves the energy saving of the system.

Energy Efficient Office Equipment

In most conventional office buildings, computers at each workstation consume a significant portion of total energy use. This happens directly through the electricity consumed by the computer, and indirectly by the emitted heat and added cooling load placed on the space conditioning system. As network technology advances, personal computers at all workstations are being replaced by client desktop devices which share the computing power of a centralised server computer. This arrangement reduces the energy consumption of each workstation in CH_2 from 85W for a typical central processing unit, down to 8W for a thin[21] client desktop device[22]. The energy saving is further enhanced by adopting Liquid Crystal Display (LCD) monitors, which consume 30W of electricity instead of 80W consumed by a Cathode Ray Tube (CRT) screen. On direct electricity alone, it represents a 77 per cent saving. Savings are also achieved from the 60 per cent reduction in heat released to the space (AEC, 2003b).

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[17] City of Melbourne note: Although the system in CH_2 has some similarities to a displacement ventilation system there are important differences; refer to the previous footnote for details.

[18] City of Melbourne note: Although CH_2 does not use a true thermal displacement system, the coefficient of performance benefits are still achieved with the underfloor supply system due to the higher supply air temperature of 19ºC.

[19] City of Melbourne note: CH_2 has active humidity control of the primary air via a wet cooling coil and reheat.

[20] City of Melbourne note: The active humidity control employed for CH_2 will provide a better moisture-controlled environment than traditional HVAC in Australia. Low relative humidity and high supply temperatures will limit opportunities for mould growth. This is in contrast to the low temperatures and near-saturated supply air conditions of normal variable air volume (VAV) air conditioning, which offers up excellent condition for the growth of mould in ductwork. Mould growth is a primary cause of 'sick building syndrome', and therefore the approach of CH_2 is deemed to have major productivity benefits. In addition, swirl diffusers have been selected in place of displacement diffusers, due to their ability to effect moisture removal from the areas near the chilled ceiling panels in the shortest time.

[21] City of Melbourne note: A thin client, sometimes called a lean client, is a low-cost, centrally-managed computer often devoid of CD-ROM players, diskette drives, and expansion slots.

[22] City of Melbourne note: Following further investigation, a thin client system could not be included in CH_2 due to the incompatibility with the organisation's existing information technology and software systems. The energy savings and heat load reductions predicted in the AEC reports referenced, however, indicate significant benefits from selecting a thin client arrangement. Liquid Crystal Display (LCD) monitors, as proposed, have been included and selecting personal computer workstations, which have the smallest compatible central processing unit has helped to reduce heat loads from computers, although this is not as significant as could be achieved with a thin client system.

This reduction in heat load contributes to an 11 per cent drop in the peak cooling load of the space conditioning system (AEC, 2003f). The isolation of the server enables a dedicated system to remove the unwanted heat. This can greatly improve efficiency, because such systems do not need to deal with fresh air requirements and latent load, since the server room is not occupied by people.

Harvesting from Waste

Useful energy can be recovered from various waste produced in office buildings. In the CH_2 project, two systems are harvesting energy from waste heat. One is the combined cooling, heating and power (CCHP) tri-generation system, which recovers heat from on site power generation. The other is the air-to-air heat recovery system, which salvages thermal energy, both heat and 'coolth'[23], from exhausting the indoor air stream[24].

Combined Cooling, Heating, Power Tri-Generation System

Combined heating and power (CHP), or cogeneration, is the simultaneous production of usable heat and electricity in the same power plant. This is not a new technology; in Australia CHP is widely used in hospitals and industrial buildings where there is a need for large amounts of heat. In office building applications, however, it is not as popular because typical office buildings cannot utilise all the heat produced by the power plant. In the CH_2 project, the design team integrated the absorption chiller technology into the CHP system to create a CCHP tri-generation system.

The absorption chiller used in CH_2 requires no pumps or other moving parts, but does require a heat source to regenerate liquid absorbent. Heat absorption to regenerate the liquid absorbent replaces the compressor in conventional compressive chillers and creates the pressure difference required for running the refrigeration cycle. Absorption chilling is a key technology in the application of a CCHP system in office buildings because it offers the means to transform heat produced in the power generation process, which would otherwise be wasted, into cooling. This cooling capacity can then be used in the office space for space conditioning. In times of lower cooling needs, the cooling capacity can be used to cool the supply air to the gas turbine to improve the efficiency of gas turbine power generators.

This system significantly improves the primary energy efficiency of the absorption chiller/heat pump. In a traditional sense, an absorption chiller has a coefficient of performance of 0.68 (single stage) to 1.3 (double effect) which is low in comparison to the coefficient 4.0 of a conventional chiller system. However, this ignores the fact that the energy supplied to the chiller has an efficiency of its own. In Victoria, the typical efficiency for a coal power plant is 30 to 33 per cent, and with this consideration, the efficiency of absorption heat pumps can be very competitive.

In CH_2 a 60kW capstone dual mode gas microturbine will be used. The system will generate 60kW of electrical power and 105kW of heat to be utilised by the cogeneration plant for heating and cooling. This system will meet 10 per cent of the average daily electricity demand, and the required office heating and cooling load for 80 per cent of operating hours (AEC, 2003f).

There is no specification for the absorption chiller available, and critical analysis of the system is not practical. The gas microturbine power generator produces high grade waste heat at 35ºC that is capable of triple, double and single effect absorption chiller performance (Sweetser, 2000).

Heat Recovery System[25]

Air-to-air energy recovery heat exchangers are devices that allow heat exchange between fresh, outside air and exhaust indoor air streams, hence pre-conditioning the incoming air. Heat recovery systems can significantly reduce the energy needed to cool or heat the fresh air supplied to the office space. This system is normally placed in ventilation/air handling units which take in fresh air while exhausting indoor air. The exhaust air from the building's interior passes through one side of the heat exchanger, at a counter flow to the incoming fresh air which passes through the other side of the exchanger. A heat wheel is the most common type of heat recovery system. During the cooling season, the cooler indoor air passes through the heat wheel and cools that portion of the wheel. When the cooled portion of the wheel rotates into the hotter outdoor air stream, it pre-cools the incoming outdoor air. The heat exchanger may transfer sensible heat only, or it may transfer both sensible and latent heat.

Studies in the United States show that heat recovery systems can reduce annual heating and cooling energy consumption by 35 per cent for VAV air conditioning systems equipped with an economiser cycle in New York (TIAX, 2002). The anticipated energy saving in CH_2 should be significantly lower than the above figure, as Melbourne's climate is considerably milder than New York.

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[23] City of Melbourne note: The term 'coolth' is defined by the Shorter Oxford Dictionary as meaning coolness. Although this is not strictly a scientific term it is used in the architectural profession and by designers of thermal storage systems.

[24] City of Melbourne note: In the final design of CH_2 an air-to-air heat recovery system on the exhausted air stack outlet was not included. There are a number of reasons for this decision. Firstly it would create significant resistance to the natural flow of air up the thermal exhaust stacks and would require additional electrical energy to be consumed to push or draw the air out of the building using fans. Secondly, energy recovered from these systems is less beneficial in temperate climates such as Melbourne. Their installation provides greater benefit where significant cooling or heating is required. Thirdly and most significantly, in the case of CH_2, the primary heating and cooling loads are transferred by water, which flows in a recirculating path and thus conserves retained heating or cooling potential. Since CH_2 does not use air to fulfil its primary cooling needs, the potential to recover energy from exhausted air is concomitantly reduced.

[25] City of Melbourne note: This system has not been included in the final CH_2 design for the reasons explained in the previous footnote.

Harvesting from Nature

Nature is the source of all forms of energy. Harvesting renewable energy that is available onsite can offset the greenhouse gas emissions from consuming fossil fuel.

Daylighting

Artificial lighting systems contribute to 21 per cent of greenhouse gas emissions in conventional commercial buildings in Australia (EMET, 1999). Harvesting daylight can significantly reduce the reliance on electric lighting in CH_2. Substituting daylight for artificial light in office space is also an important strategy in reducing the cooling requirement for indoor comfort, as electric lighting contributes to a significant portion of internal heat gain. Daylight in spaces has been shown to increase occupant satisfaction and wellbeing, and improve worker productivity (Leslie, 2003; Capeluto, 2003). In recent years, use of daylighting combined with high performance lighting means that energy savings of between 30 to 50 per cent can easily be achieved while savings of 60 to 70 per cent are possible in some cases (ACE, 1999).

Introducing daylight into the office space is a challenge for CH_2 as the overshadowing effects from surrounding buildings seriously limits the daylight available for the lower floors. The design addresses this issue by progressively widening the windows on the northern and southern façade from top to bottom. This approach allows more diffused daylight to enter the office at lower levels, while restricting excessive solar radiation from striking the top levels. The glazing is specified to have a visible light transmittance above 50 per cent, with a solar transmittance below 35 per cent.

Daylight sensors are provided on the north and south perimeter rows of lighting. Two perimeter rows of fittings are located along the north and south boundaries of the office level. Daylight sensors (five along each side of the office) are provided to complement natural daylight, and achieve an average illumination of 160 lux. When daylight provides more than 160 lux, these fittings will be switched off. On a cloudy day, the daylight sensors will adjust the lighting levels accordingly. After office hours, the daylight sensors will be inactive.

Shower Towers

Outside air is drawn in from 14m or more above street level and channelled into the shower towers on the south side of CH_2. The towers are made from tubes of light-weight fabric 1.4m 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 is supplied to the phase change material, to remove heat stored within it. These shower towers act as conventional evaporative coolers without the need for a fan to drive the air supply. The air is dragged down by friction caused by the water falling under gravitational force, and also by the downdraft created by the evaporatively cooled denser air (AEC, 2003b).

Solar Stack

Ventilation stacks operate when a temperature difference exists between the ambient air and indoor space. Solar stacks are improved ventilation stacks, painted with a dark colour in order to absorb solar radiation, which then heat up the enclosed air and create an upward force through a buoyancy effect. Six solar stacks are installed in the north façade of the CH_2 building. The airflow rate in the stacks is governed by the vertical distance between the inlet and outlet, the cross-sectional area of the stack, and the temperature difference at the inlet and outlet (Chen and Bandopadhayay, 2001). As a result, the cross-sectional area of the solar stacks is gradually increased with height, so as to maintain a more consistent extraction flow rate among all floors. CH_2's solar stacks are designed as part of the exhaust path for the office daytime ventilation and night purge systems. As a result the stacks operate in two modes – day and night.

The night purge ventilation effectiveness of the solar stacks is further enhanced by the inclusion of wind turbine ventilators at the top, which operate when there is wind. The salt bath experiment also shows that the considerable height of the solar stacks contributes to night purge performance (CoM, 2004). There is a risk the solar stack will create back pressure on cloudy winter days when air inside the stack is colder than the indoor air, due to contact with the cold stack envelope (Bansal, 1993). In a purely naturally ventilated building this may cause backflow of exhaust air into the office, and in extreme conditions this could result in poor indoor air quality[26].

Wind Turbine

Wind energy is one of the most readily available renewable energy sources. The wind driven turbines proposed for CH_2 are designed to perform as ventilators to assist night purge air flow through the building and operate as electricity generators during the daytime. The common wind turbine enhances ventilation about 30 per cent over an open stack (Lechner, 2001). Six wind turbines will be installed on top of the north solar stacks. The wind turbines are predicted to improve the night purge ventilation of the building by about six per cent on windy nights, and will not contribute to ventilation on still nights or during the day (AEC, 2004). During the day the turbines will not assist air extraction, because an internal positive pressure needs to be maintained to ensure indoor environment quality.

[26] City of Melbourne note: The daytime mechanical ventilation system in CH_2 is configured to maintain a positive pressure of 5 Pascals (Pa) in the office space, therefore the risk of backflow is eliminated, although the consequence of back pressure will induce greater resistance to the supply air fans. While the increased resistance produced by backflow will cause greater fan energy consumption, the indoor air quality conditions will be maintained.

Phase Change Material

Phase change material (PCM) is a material that will change its phase at a designated temperature, in order to absorb or release large amounts of energy. It is the latest member of the thermal energy storage family. It has a higher capacity than water-based thermal storage systems, and is more efficient than ice-based storage systems (TIAX, 2002). To the author's knowledge, apart from ice thermal storage systems, there is no other PCM application in office cooling on a commercial scale[27]. Other thermal storage systems were also examined for application in CH_2. These systems included ground-coupled thermal storage and rock bed storage. Based on the microclimate analysis, the design team selected PCM as the thermal storage system for CH_2.

The PCM tank in CH_2 releases the heat gained during daytime cooling operations at night, and acts as a heat sink during the day. While PCM does not directly harvest coolness, it provides the storage for 'coolth' harvested by other components in the system, which can be utilised when needed. With the PCM in place, the cooling system can take advantage of cooler nighttime conditions to harvest coolth passively via the cooling towers. Figure 8 shows that the ambient wet bulb temperature is below 12ºC for 60 per cent of the reference weather year, which is the specified wet bulb temperature for producing cooled water below 15ºC to freeze the PCM. A Swiss study (Facão & Oliveira, 2000) showed that conventional wet cooling towers are greatly overpowered when operating in the airflow and spray water rate in the low hot water temperature range, which is required for PCM recharging. This leads to energy wasted in fan and pump operation.

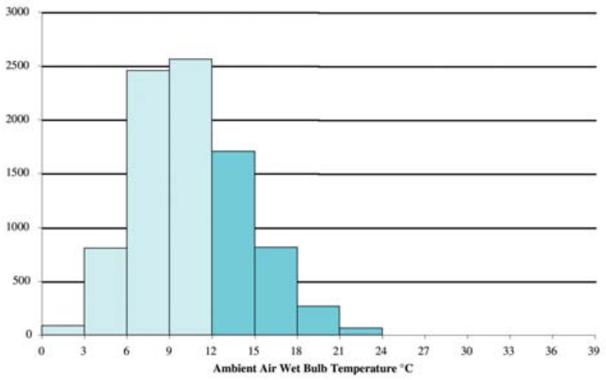

Figure 5: Annual Frequency of Ambient Wet Bulb Temperature.

Even in summer time, PCM allows the active cooling system to work more efficiently in two ways. First, it allows the system to operate to its full capacity since the PCM can satisfy the part load condition. It also reduces the hours of the cooling system's operation. Secondly, the PCM can shift the peak system load away from the highest outdoor temperature, improving the ability of the system to efficiently dissipate the rejected heat.

Night Purging and Thermal Mass

In Melbourne, night air is significantly cooler than daytime air as shown in Figure 10. This cool night air can be used to flush out the heat from a building's thermal mass. The pre-cooled mass can then act as a heat sink during the following day, and thus keep the indoor air temperature from rising as fast as it would otherwise.

CH_2 relies heavily on the thermal mass effects of its concrete ceiling to cool the building via a night purge ventilation system. Automatic windows on the north and south façades open to allow fresh cool air to enter the office space during the night, flushing out warm air and cooling the building's concrete ceilings. Sensors will be used to close the windows when they detect high winds and rain, or ambient temperature higher than concrete ceiling temperature. The wind turbines installed at the top of the solar stacks will further enhance the effectiveness of night-time purging, by inducing an extra volume of cool nighttime air to come in contact with the thermal mass.
On still nights, a mechanical ventilation system can be used to supplement the natural ventilation, although its operation will need to be balanced to achieve energy reduction objectives. Mechanical cooling may be used as required to provide the equivalent night purge benefits when a passive night purge is not available. The night purge function is predicted to reduce cooling loads by around 14 per cent on a typical summer day (ACE, 2004).

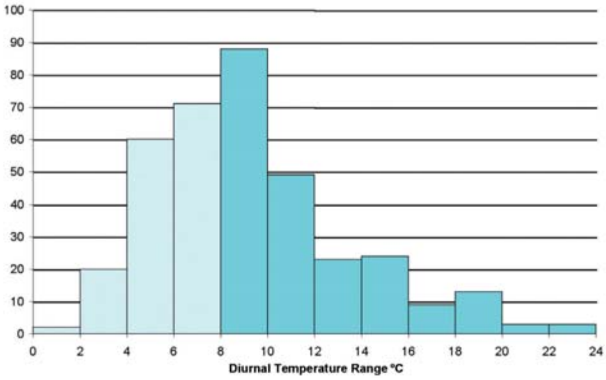

Figure 16 Frequency of Diurnal Temperature Range.

Solar Hot Water System

The solar hot water system captures and uses solar energy to heat the hot water supply for showers and basins.
This technology has a long history and is widely used in Australia on a residential scale. The solar hot water system proposed for CH_2 is designed for a hot water requirement of 2000 litres per day. The sizing process of the solar hot water system takes into account not only daily demand, but also the optimum amount of panels according to requirements, weather variations and cost implications.

[27] City of Melbourne note: PCM-based storage systems have been applied internationally on a commercial scale in many settings, including office buildings, banks, hospitals, prisons, colleges, schools, exhibition centres, breweries and industrial plants. Refer to project documentation included by the following PCM manufacturers on their websites: http://perso.wanadoo.fr/cristopia/english/products/documentation.html and www.epsltd.co.uk/.

A solar hot water system with a panel area of 26m^2 is anticipated to handle about 75 per cent of the hot water requirement for CH_2, translating to 20,000 kWh per year (AEC, 2003g).

Potential Implementation

The CH_2 project has taken many steps in developing an energy efficient building. Yet, there are a number of opportunities[28] to further reduce energy consumption.

Daylight redirecting devices such as louvres, highly reflective movable blinds, prismatic panels, and laser-cut panels, to name a few, have the potential to improve the daylight availability to the lower floors (Beltran et al., 1996). These daylight systems could improve the daylight penetration and distribution during overcast and clear sky conditions. Instead of installing daylight redirecting devices in the clerestory section of windows, a more dramatic design that redirects the winter sun through light pipes could also be considered[29].

Desiccant dehumidifiers could be incorporated into the air conditioning system for moisture removal. The benefit of desiccant dehumidifying is superior control over moisture content, by separating the sensible and latent conditioning. This can eliminate the over-cooling of the supplied air stream for moisture control, and hence reduce the need for chiller power. The typical regeneration temperature of a solid desiccant wheel system is 13ºC (Jain, 1995); the exhaust from the tri-generation plant, after powering the absorption chiller, should still be capable to operate such a system. As a result, the efficiency of the CH_2 integrated system could be further improved by extracting usable lower grade heat from the exhaust of the absorption chiller.

The adaptive comfort model has the potential to further relax the requirements on space thermal conditions (de Dear, 2002). In CH_2, the temperature design set point is considered to be conservative[30], and the upper end of the specified environment (i.e. 25ºC air temperature and 65 per cent relative humidity will result in a predicted mean vote (PMV) of -0.27 if ASHRAE summer clothing level is used). Although a PMV of -0.27 is within the 90 per cent comfort range, it is on the cool side of the PMV scale. A further extension of the temperature limit to 26ºC will result in a PMV of 0.1 which is still within the 90 per cent comfort range. The above PMV value is based on minimal air movement, and the mean radiant temperature is identical to the air temperature. The chilled ceiling system and the night purged thermal mass will reduce the radiant temperature.

A rooftop solar photovoltaic PV array was removed[31] from the CH_2 design due to the long payback of the system (AEC, 2003g). The estimate was based on a conventional PV array with a conversion efficiency of 13.5 per cent. There are alternative technologies that could improve the efficiency and shorten the payback period. Two examples of such systems are solar concentrator systems and improved multi-crystalline solar cells (AGO, 2003). The solar concentrator system uses sun-tracking mirrors to concentrate direct sunlight onto a receiver on the solar cell. This system has a further 15 per cent efficiency in converting sunlight into electricity. It also generates hot water from pipes running behind the receiver that significantly improve overall efficiency. The multi-crystalline solar cells work under the same principle as conventional PV cells, with a conversion efficiency of 17 per cent.

It should be noted the efficiency of PV cells decreases as the panel temperature rises. The utilisation of exhausted air from the solar stack to ventilate the PV cells has the potential to improve the conversion efficiency (Mei, 2003).

Discussion

The most important lesson learned from CH_2 is the importance of an integrated approach to energy-efficient building design. In conventional building design processes, each service is considered as an individual system and the members of the design team tend to work in isolation. Any improvements in energy efficiency are limited, as all systems are bounded by conventional practices. In contrast, the CH_2 design team treated the building as one system, with a series of services or components. This approach enabled the team to explore the inter-dependency of various components, and the possibility of drastically reducing energy consumption by chain reaction.

One of these chain reactions in CH_2 is that the building load is reduced by specifying low energy equipment and lighting systems, and by relaxing the space conditioning in both thermal and lighting requirements. This reduction in cooling load opens up the opportunity to use alternative cooling systems such as chilled ceilings and displacement ventilation systems, that might not be feasible with a typical cooling load. The common characteristics of these two systems is a higher than conventional chilled water temperature, which enables the use of cooled water for large periods of the year directly from cooling towers, without the need to operate energy-intensive chillers. It also makes the inclusion of PCM more economically viable because 'coolth' can be produced at night with reduced energy input.

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[28] City of Melbourne note: Some opportunities suggested here are not feasible due to the integrated design of the building, with respect to the multi-functional use of the structure for passive cooling, ventilation and the facilitation of natural lighting. This integrated design has influenced both the form of these elements and the limited inclusion of other opportunities, due to the interactive implication it would have for the effective operation of other connected design elements.

[29] City of Melbourne note: Light pipes were investigated and found not to be feasible as the number of levels that can be effectively lit in this way is limited to about three, and the added cost was prohibitive within the allocated budget.

[30] City of Melbourne note: CH_2 is designed to maintain the office at a resultant temperature of 21-23 degrees Celsius.

[31] City of Melbourne note: CH_2 final design includes 23 solar panels, which are equivalent to about 26 square metres of photovoltaic cells. These are located on the roof and will generate close to 3.5kW of electricity from the sun's energy. The amount of energy generated will be approximately equivalent to that required to power the movement of the louvres used to shade the west façade.

The remaining cooling demand can then be delivered by an energy efficient tri-generation plant.

Through this chain reaction small improvements in energy efficiency, achieved via the selection of individual components, have been multiplied to achieve a significant reduction in energy consumption (Pears, 2004).

Another lesson of CH_2 is that building energy benchmarks should only be considered as the starting point of an energy-efficient building target. Even though Victorian office benchmarks are the toughest of the four benchmarks included in this paper, ESD offices in Victoria show substantial savings over the benchmarks. The limited availability of energy consumption and building performance data has hindered mainstream office buildings from including ESD design features. To the author's knowledge, the available energy consumption data is based on the predictions of computer simulations. Experiences in the UK show the actual energy consumption of buildings can be more than three times the predicted consumption (Bordass, 2004). Although this result is often attributed to poor commissioning, operation and user understanding of the buildings' intended design, it damages the credibility of energy efficiency design principles.

Even the best energy harvesting systems cannot be successful if the operation control has error. Testing and commissioning is the key to closing the gap between the predicted design performance and the actual building. This will be essential for CH_2 due to the high interdependence of the services system. Control of each component must be coordinated to a level far beyond conventional independent systems. The inclusion of post-occupancy performance tests over the first year of occupation in the commissioning plan is a good starting point[32] for ensuring the designed performance is met (AEC, 2004b).

Conclusion

A new era of environmental and hybrid controlled buildings is dawning. The essence of this breed of buildings is a complete departure from the ad-hoc 'environmental buildings' with environmental add-on features applied. Evidence-based knowledge of actual system performance is required for this building type to flourish. The energy performance of CH_2 surpasses the design targets of all the energy benchmarks examined in this paper by at least 50 per cent. This high energy performance is achieved by integrating various energy harvesting technologies into the building as a complete system, and maximising the benefits of working with the local climate.

The CH_2 project highlights the value of the commitment to the integrated design process, and the willingness of all design consultants to invest time and resources to explore alternatives to conventional systems (Luther, 2003). New technologies, such as the PCM thermal batteries, and the innovative use of more conventional systems, creates a dynamic approach to the provision of services to building occupants. CH_2 is an exemplary energy-efficient building which can be expected to provide a first class working environment, with lower operational costs and greenhouse gas emissions than conventional office buildings.

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[32] City of Melbourne note: Commissioning and operational success for CH_2 is also supported by the involvement of the facilities managers, as part of the design and building delivery team, throughout the design and contracting period.

References

ABARE, (1999), Australian Energy Consumption and Production, Australian Bureau of Agricultural and Resource Economics, Canberra.

Architects' Council of Europe. (1999). A Green Vitruvius – Principles and Practice of Sustainable Architectural Design. James & James Ltd. London.

Action Energy, (2003). Energy Consumption Guide 19 Energy Use in Office, www.actionenergy.org.uk

AEC, (2003). Aircond Design Strategy. Advanced Environmental Concepts Pty Ltd., Sydney.

AEC, (2003b). Passive design report, Advanced Environmental Concepts Pty Ltd., Sydney.

AEC, (2003c). PCM operational report, Advanced Environmental Concepts Pty Ltd., Sydney.

AEC, (2003d). Technical Design and Overview + Building services Philosophy, Advanced Environmental Concepts Pty Ltd., Sydney.

AEC, (2003e). Design Development Report, Advanced Environmental Concepts Pty Ltd., Sydney.

AEC, (2003f). Cooling load reduction through use of TRT monitors, Advanced Environmental Concepts Pty Ltd., Sydney.

AEC, (2003g). Renewable Energy Report - Solar, Advanced Environmental Concepts Pty Ltd., Sydney.

AEC, (2004). Revised Building Energy Consumption, Advanced Environmental Concepts Pty Ltd., Sydney.

AEC, (2004b). Independent Commissioning Brief, Advanced Environmental Concepts Pty Ltd., Sydney.

AGO, (2003). Renewable Energy Commercialisation in Australia, Australian Greenhouse Office. Canberra.

Architects' Council of Europe. (1999). A Green Vitruvius – Principles and Practice of Sustainable Architectural Design. James & James Ltd. London

ASHRAE, (1992). ANSI/ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta.

ASHRAE, (2001). ASHRAE Standard 90.1-2001, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta.

Bansal, N.K; Mathur, R; Bhandari, M.S., (1993), Solar Chimney for Enhanced Stack Ventilation, Building and Environment, 28 3 373-377

Beltran L.O., Lee E.S., Selkowitz S.E., (1996). Advanced Optical Daylighting Systems: Light Shelves and Light Pipes, in Proceedings of the 1996 IESNA Annual Conference, Cleveland.

Bordass, B.; Cohen, R; Field, J. (2004). Energy Performance of Non-Domestic Buildings: Closing the Credibility Gap. Building Performance Congress, London

BOMA (1994) Energy Guidelines 1994 Victorian Division of Building Owners and Managers Association, Melbourne

Capeluto, I.G., (2003). The influence of the urban environment on the availability of the daylighting in office buildings in Israel. Building and Environment 38 752-754.

CBCES, (2000). 1999 Commercial Buildings Energy Consumption Survey, Energy Information Administration

CDM, (2002), Consultancy Study on the Development of Energy Consumption Indicators and Benchmarks for Selected Energy-consuming Groups in Hong Kong, EMSD, Hong Kong. www.emsd.gov.hk/emsd/e_download/pee/esab.pdf

Chen, Z.D., Bandopadhayay P., (2001). Solar Chimney- Current Understanding and Future Researches, Natural and Hybrid Ventilation Workshop, CSIRO, Melbourne.

Coley, D.A. Crabb, J.A., (1997). An artificial intelligence approach to the prediction of natural lighting levels. Building and Environment 32 81-85.

COM, (2004), Council House 2 Stories and lessons from the CH_2 project, City of Melbourne Council, Melbourne

de Dear R. J. and Brager G. S. (2002). Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. Energy and Buildings. 34(6) 549-561

Dieckmann, J; Roth, K.W. and Brodrick, J. (2004). "Radiant Ceiling Cooling." ASHRAE Journal, V46, 6, 42-43.

EMET, (1999). Baseline Study of Greenhouse Gas Emissions from the Commercial Buildings Sector, EMET Consultants and Solarch Group, Canberra.

Facão, J.; Oliveira A.C., (2000) Thermal behaviour of closed wet cooling towers for use with chilled ceilings, Applied Thermal Engineering 20 1225-1236

Fanger, P.O. (1970). Thermal comfort – Analysis and Applications in environmental engineering. McGraw Hill. New York.

FOBRP, (2001). Guideline for Sustainable Building, Federal Office for Building and Regional Planning, Germany

Givoni B. (1974). Man, Climate and Architecture. 2nd Ed. Van Nostrand Reinhold. New York.

Hamilton, S.D.; Roth, K.W. and Brodrick, J, (2004). Displacement Ventilation, ASHRAE Journal, American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta. 46 9 56-58

Hennessy, S. Making Energy Ratings Work http://propertycouncil.gravitymax.com.au/nat/page.asp?622=267236&E_Page=17720

Hennessy, S., (2004). Making Energy Ratings Work, http://propertycouncil.gravitymax.com.au/nat/page.asp?622=267236&E_Page=17720, Property Council Australia

IEA Annex 28, (1995). Review of Low Energy Cooling Technologies, International Energy Agency, London.

ISO. (1994). ISO 7730, Moderate thermal environments – determination of the PMV and PPD indices and specification of the conditions for thermal comfort. ISO, Geneva.

Jain, S.; Dhar, P.L.; Kaushik, S.C., (1995), Evaluation of Solid Desiccant Based Evaporative Cooling Cycles for Typical Hot and Humid Climate, International Journal of Refrigeration, 18 5 287-296.

Lawson B.I. (1996). Building materials energy and the environment. The royal Australian institute of architects. ACT.

Lechner N. (2001). Heating, cooling, lighting: design methods for architects, 2nd ed. New York: John Wiley.

Leslie, R.P., (2003). Capturing the daylight dividend in buildings: why and how? Building and Environment 38, 381-385.

LSA, (2003). Design Development Summary VCML250280\0\2\AR30509, Lincolne Scott Australia Pty Ltd, Melbourne

Luther, M.; Cheung, C.K., (2003). High Performance Low-Energy Buildings, Proceedings of the 1996 ANZSES Annual Conference 2003, Melbourne.

Mei, Li.; Infield, D.; Eicker, U.; Fux, V. (2003), Thermal modelling of a building with an integrated ventilated PV façade, Energy and Buildings 35 605–617.

PCA, (1997). Victorian Energy Use Survey, Property Council of Australia Victorian Division, Melbourne

Pears, A., (2004). Energy Efficiency – Its Potential: Some Perspectives and Experience. Background Paper for International Energy Agency Energy Efficiency Workshop, Paris

PCA, (2001). Property Council of Australia Energy Guidelines, Property Council of Australia Limited, Brisbane.

Rating Energy Performance: Office Buildings, http://eber.ed.ornl.gov/benchmark/off.htm

SEAV, (2000). Energy Smart Building Design, Sustainable Energy Authority Victoria, Melbourne

SEAV, (2001). Energy efficient government buildings, Sustainable Energy Authority Victoria, Melbourne

SEDA, (2004). ABGR Validation Protocol for Computer Simulations, ABGR National Administrator, Sydney.

Steele, J. (1997). Sustainable architecture : principles, paradigms, and case studies. McGraw-Hill, New York.

Sweetser, R., (2000). Absorption Technologies for Buildings: Cooling, Heating, and Power (BCHP) System, Heating/Piping/AirConditioning Engineering, New York. P.51-56

Szokolay, S.V. (1995). Thermal design of buildings. The royal Australian institute of architects. ACT.

TIAX, (2002). “Energy consumption characteristics of commercial building HVAC systems – Volume III : energy savings potential,” Final Report to US Department of Energy, Office of Building Technology, July. www.tiax.biz/aboutus/pdfs/HVAC3-FinalReport.pdf.

60L, 2004, www.60lgreenbuilding.com, Australian Conservation Foundation

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