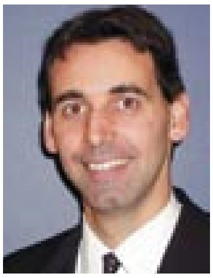
INNOVATIVE DESIGN - BATISO AND NIGHT SKY COOLING



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ABSTRACT

High performance green buildings will increasingly require the use of innovative design approaches to provide enhanced occupant comfort with reduced energy consumption.

'BATISO' / active structural mass and night sky radiative cooling are two innovative design approaches that offer the prospect of delivering extremely low energy consumption with high occupant thermal comfort.

'BATISO' or active structural mass cooling has been used successfully for many years in a large number of European commercial offices and special purpose buildings. These systems typically utilise the building's exposed structural mass to provide radiant cooling in conjunction with a separate ventilation system. This paper examines a number of opportunities and issues involved in the design of buildings utilising 'BATISO' style systems in an Australian context

Night sky radiative cooling provides a mechanism for generating passive chilled water at temperatures that are usable for air conditioning applications. This innovative approach provides the opportunity to reduce or eliminate the use of refrigerative air conditioning in suitable building applications. This paper also examines the principals of night sky radiative cooling and the opportunities to integrate it with other building systems.

Two brief case studies are presented to demonstrate the effective application of active building mass and night sky radiative cooling in an Australian context.

Keywords: active structural mass, thermal comfort, environmental sustainable design, chilled water generation

Introduction

The desire to produce greener and more sustainable buildings has required engineers to go beyond conventional building design. This design intent now extends beyond energy efficiency to explore approaches that lead to enhanced occupant comfort and improved indoor environment quality.

In this area of innovation there are valuable lessons that can be learned from the experience of overseas markets. However in importing new techniques we need to consider the needs and expectations of our own market.

This paper explores the use of two innovative techniques in use overseas that are beginning to be applied within Australia.

BATISO / active mass cooling

BATISO (also known as: thermo-active slabs, active mass cooling, concrete core conditioning etc.) has been used for several decades in various forms to assist in providing comfort to building occupants. It is only since the mid to late 1990's, however, that it has begun to be used more widely to cool and warm commercial buildings. Its growth in popularity, particularly in Europe, has been due to its ability to provide high levels of thermal comfort for very low energy consumption and relatively low capital outlay.

The term BATISO comes from the amalgamation of two words, batiment and isotherm, literally meaning a "constant temperature building". Essentially the design consists of hydronic pipework embedded in the structural mass of a building that is used to regulate the building's temperature (see Figure 1). In this way the structural mass of the building is actively used to directly store and transmit heat or cooling energy to the occupied space.

The intensity of the energy input typically required is also low, meaning that low grade energy sources can be used. This is referred to as "low exergy" design, where the term exergy describes the inherent energy potential wasted in an energy exchange process. This approach allows for the design of systems with inherently low energy use and high efficiency.

Thermal performance

A BATISO system provides cooling to the occupied space mainly by direct radiant heat exchange between the room and the exposed structural slab. Traditional suspended ceilings are not used such that all services need to be run exposed below the soffit, or more typically concealed in a raised floor plenum.

As a predominantly radiant system, the cooling potential of BATISO depends on the heat exchange coefficient of the cooled surface and the temperature difference between it and the space. The design cooling power for a typical BATISO

Figure 1 – pipework installed prior to the concrete slab pour [3]

system in Europe is around 30-40W/m^2 at a room temperature of 25-26ºC. Theoretically, performance in the range of 60-100W/m^2 is possible, however, this is highly dependant on the concrete slab design and thermal comfort limitations.

This cooling power will not be sufficient to meet the total cooling requirements of many Australian buildings. In most office buildings, however, this should be sufficient to cover the cooling requirements of internal loads such as lights, people and equipment. A high performance façade design with effective shading would be required to reduce perimeter loads within the BATISO systems range of operation.

A separate ventilation system is also required to provide outside air to the occupied space. In many cases this can be a 100% outside air system providing ventilation at or above code requirements and also giving some or all of any additional cooling required.

In many European examples the BATISO system delivers the bulk of the cooling capacity with natural ventilation or displacement ventilation providing the rest. The cooling water supply to the BATISO system is often sourced from ground water or fed from water cooled in dry coolers or cooling towers overnight. In many cases a supply water temperature of 17-19ºC is sufficient to provide the level of cooling desired.

Because of the storage capacity of concrete it is possible generate cooling overnight and store it in the structure for use the next day. The heat exchange coefficient between the pipes and concrete is several orders of magnitude greater than that between the concrete and the air, so energy can be effectively stored and retained. This provides benefits in peak load shedding and also allows for the use of more passive chilled water generation.

Extent of overseas use

At the time of writing, the author is unaware of any commercial buildings in Australia that have effectively applied a BATISO or active structural mass design. As previously noted, the system is widely used in Europe and is gaining in popularity, particularly in countries such as Germany and Switzerland. There are also a growing number of BATISO systems operating in the UK and Canada.

A typical small speculative office development in Germany would comprise openable windows for natural ventilation, exposed concrete slabs and a raised access floor. Therefore it is fairly simple to add the necessary pipework and water systems to provide additional performance via BATISO cooling and/or heating.

However the application of BATISO is not limited to small scale office developments alone. In Germany some of the most high profile and prestigious office developments of recent years have used a BATISO system to meet at least their base cooling load. Some of these buildings include: Post Tower in Bonn (Figure 2), Highlight Towers in Munich (Figure 3), Munchner Tor in Munich, Prisma and MAX in Frankfurt, Nord LB in Hannover and many more.

While on a recent study tour in Germany, the author was told that one (of about 4-5) local piping manufacturers supplied

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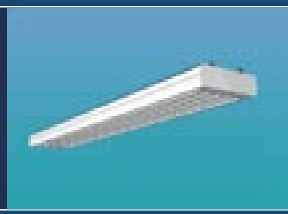

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Figure 2 - Deutsche Post Tower, Bonn [4]

Figure 3 – Highlight Towers – Munich (under construction)

around 800,000m^2 of active mass piping installation in the past year alone [2]. BATISO systems have also been used in homes, museums and other public buildings.

BATISO comfort and control

Because it is largely a radiant system, the thermal comfort achieved by a BATISO system is quite unlike that obtained from an all air mixed system. The human body emits about 45% of its energy via radiation with the rest being convective and evaporative. Therefore most air conditioning systems fail to capitalise on the ability to use radiant heat transfer to improve comfort.

With a BATISO system the space operative temperature is often used to describe the comfort performance. Operative temperature is the average between the mean air temperature and the mean radiant temperature. It is analogous to the comfort temperature that the human body actually feels. At an equivalent operative temperature a BATISO system can have a mean air temperature one or more degrees higher than an all air system and deliver similar or better comfort levels. Experience with operating BATISO buildings in Europe suggests that very high levels of occupant thermal comfort are achieved [1].

Because of its radiant heat transfer a BATISO slab is able to respond to changes in load very quickly (at the speed of light). However due to its relatively low capacity, space temperature changes are achieved more slowly. This is effectively a thermal flywheel effect where temperature fluctuations are limited and cooling capacity spread over a longer period. The slabs are effectively self zoning requiring fewer control zones with air systems or natural ventilation used for fine tuning.

Controls for a BATISO system are typically very simple with only on/off two port valves for each piping control zone. Temperature control for the slab can be either a constant slab temperature set-point based on external temperature or a more complex arrangement that references room temperature. Cut offs based on room dew point temperature for condensation control is sometimes employed. It appears, however, that the BATISO slab system can be more forgiving for condensation due to the relatively high surface temperatures and its ability to re-evaporate moisture.

BATISO design and modelling

A BATISO system will require detailed cooperation between the architectural, services and structural disciplines of a design team. Such an integrated design solution requires significant understanding of the requirements from all parties. In an Australian context it also represents a significant departure from what would be a typical design process.

The successful design of a BATISO system requires the use of dynamic thermal analysis. In particular, the software tool used needs the ability to accurately model the heat exchange and storage characteristics of the embedded pipework and concrete slab.

Many of the dynamic thermal simulation programmes in common use in Australia are not equipped to accurately model these interactions. The most common software used in Europe for BATISO systems are TRNSYS and IDA ICE. Both of these programs solve mathematical models of building systems and have custom written models to accurately represent a BATISO system.

Issues for Australian use

There are a number of issues with the way that BATISO systems are applied in Europe that may require re-consideration for Australian use.

The first of these relates to the design criteria applied to the design. While German external design temperatures can exceed 32°C, their codes allow the internal space temperature to rise to 26°C. This assists a BATISO system as the higher the room air temperature, the more cooling capacity the system will deliver. It should be noted, however, that the operative temperature will typically be lower than the mean air temperature, thus improving thermal comfort. For Australian projects we need to carefully consider the internal design criteria to be used based on actual occupant comfort.

Germany also has tight code restrictions relating to air velocities and thermal comfort parameters, including radiation. This effectively limits the capacity able to be delivered from the radiant slab. The author's general perception is that Australian building occupants are less culturally sensitive to these factors than Europeans, allowing the available cooling capacities to be increased.

Other issues relate to more general areas of building design and construction including deletion of ceilings, the use of raised floors, the quality of glazing, external shading and insulation levels. The merits of each of these items can be justified on the basis of design requirements and economics. However they are often contrary to current local design practice and so require evaluation in their own right.

Night sky radiative cooling

Background

During the day the earth's atmosphere is warmed by solar radiation from the sun, providing the energy that we need to sustain life. But this solar energy flow needs to be kept in balance, and in simplistic terms, the earth does this by re-radiating part of the energy received from the sun back to the sky at night. In this way a balance can be achieved between the solar warming from the sun and solar cooling from the night sky.

Space is very cold and effectively acts as a radiant black body drawing radiant energy from warmer objects such as the earth. The effective temperature of the night sky is typically around 10 to 15 degrees cooler than the air temperature at the earth's surface, giving an effective temperature at times as low as –15oC.

The effective sky temperature encountered on any given night is dependant on a number of factors including air temperature, cloud cover and the moisture content of the air. When the sky is cloudy or when there is a relatively large amount of water vapour in the air, the effective sky temperature will be warmer. However particularly on clear, dry nights the effective sky temperature can be very low, drawing very large amounts of heat from the earth through this radiant exchange. This phenomenon can be observed when frost forms on a car windscreen even though the minimum overnight temperature has not fallen below 0oC. It is also the reason why it is possible to freeze to death in a desert overnight after baking during the day.

An example of this night solar cooling effect in action is provided in Figure 4. This graph shows actual measurements of roof temperature variations, recorded by CSIRO. Measurements were taken on the metal deck roof of a CSIRO building in Highett, Victoria, during a typical Melbourne summer week. The roof temperature data clearly shows that the roof heats up during the day to around 50oC. Then at night the roof cools to levels typically in excess of 10oC below ambient, even following very hot days. This clearly shows the effect of radiant heat exchange to the solar night sky occurring in Melbourne.

Night sky cooling technology

Night sky cooling is a technology that takes advantage of the solar cooling effect of the night sky to produce cooled/chilled water for building cooling applications.

The genesis of night sky cooling was developed in the United States and elsewhere around 30 years ago and originally consisted of pools or bags of water on the roof of a building that could be exposed to the night sky. This effectively acted as a passive barrier to solar heat by using the stored ‘coolth’ in the water generated from exposure to the night sky. Subsequent designs have used roof ponds covered by floating insulation with water sprays used to expose an upper layer of water to the night sky [6].

More recent design approaches consist of water sprays on the roof of a building used to expose water to the night sky. The water is then collected through the stormwater system and is stored in a large tank ready to be used to cool the building over subsequent days. The spray system is similar to that used in Australia to cool roofs on hot days except here the spray is turned on at night.

To date there have only been a handful of projects completed using this night sky cooling and all of those known have been in the United States within the past 10-12 years. In these projects the night sky water is typically used as a pre-cooler to conventional air conditioning or as a way to handle only base air conditioning loads.

A major limitation to using night sky cooling can be the local climate. If the proposed region has relatively high moisture content in the air at night or is cloudy, then the system performance and reliability will be severely reduced. If the project is located in a more dry and clear area, however, then consistently cool chilled water can be produced.

The other main limitation is the need for a large tank to store the water in and a piping system to distribute it. It can be quite simple to integrate night sky cooling with rainwater collection systems, however, and therefore increase its utilisation.

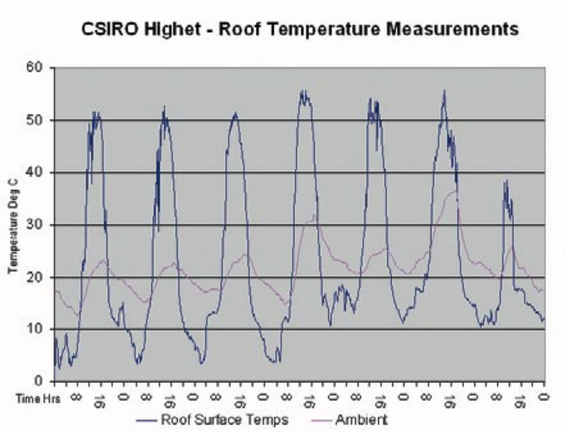
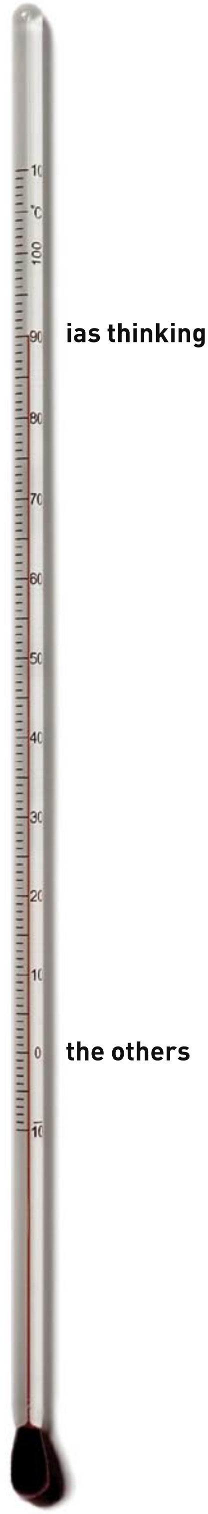


Figure 4 – CSIRO Roof Temp Measurements, Highett [5]



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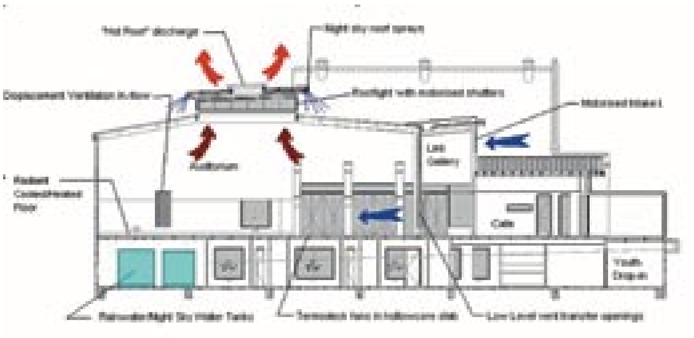

Figure 5 – section through the auditorium

Figure 7 – Kangan Batman TAFE ACE stages 1 and 2

Case study 1 - Essendon Baptist Community Church

This project consists of an extension to the existing church buildings to provide a 400 seat auditorium, café, bookshop, teaching rooms, offices and a youth drop-in centre. The existing church is also to be remodelled to comprise foyers, servery, offices and amenities. A link gallery separates the auditorium and café/bookshop and provides connection through the building. The project is currently in construction (see Figure 5).

Night sky cooling at Essendon Baptist

Thermal modelling has revealed that the 400 seat auditorium and associated spaces that will require some form of cooling to maintain comfort conditions throughout the year. As a local community church there was a real necessity to minimise the capital and particularly the running cost of any cooling systems proposed. Given that the church could not afford to either install or run a conventional air conditioning systems, it was decided to explore the use of a night sky cooling system.

A comparison between the 4pm dry bulb temperature and the calculated tank storage temperature achieved for a full year in Melbourne is shown in Figure 6.

An advantage of the church project is that the peak cooling requirement is a weekly occurrence, allowing the several good nights in the week to be used to generate chilled water.

The night sky system itself is very simple comprising a pumped reticulation system to the roof and spray nozzles arranged around the raised roof section. Water is stored in two large poly tanks in the basement that are connected to the stormwater system and a filter. One of the tanks is also used to supply rainwater for toilet flushing and irrigation.

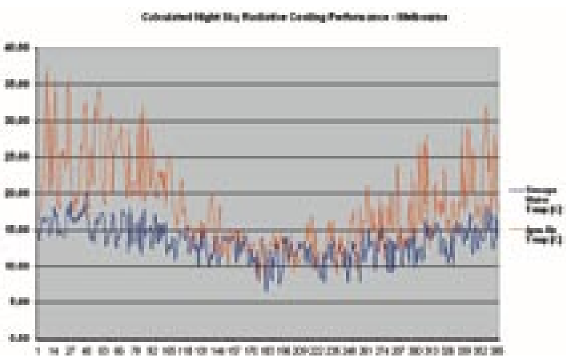

Figure 6 – calculated night sky cooling for Melbourne

There are a number of innovative aspects to the use of night sky cooling at Essendon Baptist.

• This will be the first project to utilise this form of night sky cooling Australia.

• In this project the night sky cooling is being used to satisfy all of the peak cooling demands without the need for any refrigerative cooling.

• The night sky water is used to cool, the building by a combination of two innovative methods:

• Radiant floor cooling using hydronic pipes embedded in the floor screed (also used for heating)

• Displacement air conditioning provided by full fresh air fan coil units delivering air to the auditorium.

In this case a more conventional hydronic floor heating system has been modified to also provide cooling. The result is a system that will not deliver full cooling performance in itself but will assist by improving comfort through the radiant exchange from the slightly cooler floor surface.

The use of displacement ventilation provides the remainder of the cooling required with minimal energy consumption. As displacement ventilation uses a higher supply temperature, it is possible to use the higher water temperatures obtained from the night sky cooling to cool the incoming fresh air by the required amount.

The church recently received funding through Sustainable Energy Authority of Victoria's VSII programme to fund the innovative solar technology components of the project.

CASE STUDY 2 - Kangan Batman Automotive Centre of Excellence

The Kangan Batman TAFE Automotive Centre of Excellence (or ACE), is the first stage of a new facility being built in Melbourne's Docklands. It essentially consists of two joined buildings, a two level teaching workshop and three levels of offices and classrooms. The building has been designed to achieve a 5 star Green Star rating with an energy performance well in excess of Australian Building Greenhouse Rating 5 star (Figure 7).

The air conditioning system design for office areas on the ground and level one utilises BATISO as its primary cooling source. The second floor office does not have a concrete ceiling and so uses active chilled beams with some assistance from the BATISO in the floor slab.

The BATISO slabs are formed of "bondek" slabs supported on conventionally formed band beams. The "bondek" and band beams are exposed to the space below with lighting

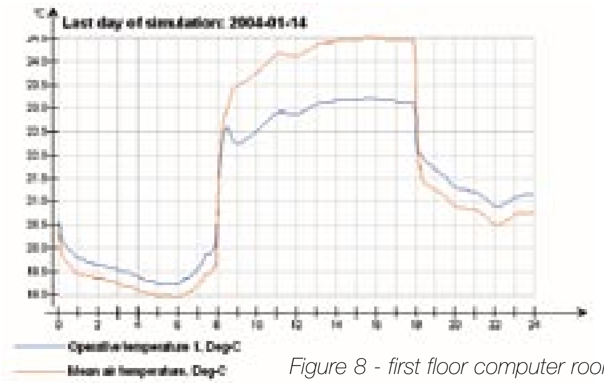

Figure 8 - first floor computer room temperature modelling

and other services suspended below. The pipework within the slabs is positioned above the bondek so that it is close to the steel ribs and within the reinforcing. This arrangement will provide relatively responsive radiant cooling to below with the ability to store energy within the concrete.

A 100% outside air system provides ventilation at levels in excess of AS1668.2 requirements. The outside air is conditioned through an air handling unit to provide additional sensible cooling and all of the latent cooling. Supply air is blown up onto the slabs to assist in condensation control and cooling effectiveness. The office areas are also able to be naturally ventilated by automated openings in the North façade and at the top of the three level entry atrium space. Figure 8 shows the temperature modelling results for one of the building's computer rooms.

In addition to a small chiller, the building includes a water spray system to use night sky radiative cooling system to produce passive chilled water. This system is intended to deliver the bulk of the cooling required through a year. A water spray system covers the large roof area and water is returned to a tank via the stormwater system. The water storage tank is a below ground "rainstore" type system with a capacity of 130m^3 divided into fivebaffled sections. ■

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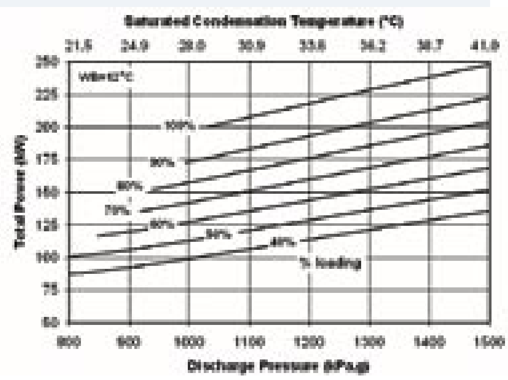
This paper has been peer reviewed. Visit www.airah.org.au for more information on the review process.

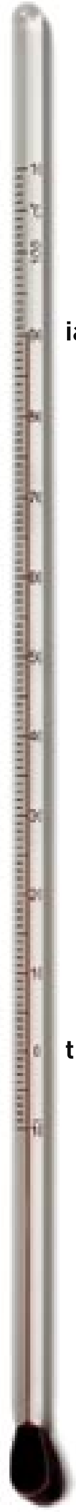
Correction

In the paper What is the optimum compressor discharge set point for condensers? printed in the August 2005 edition of EcoLibrium™ there was a misprint on page 27. Figure 4 was incorrectly repeated as Figure 5, the correct Figure 5 is shown left:

Figure 5 – total power (compressor plus condenser fans and pumps) as a function of discharge pressure and saturated condensation temperature for an ammonia screw compressor at different percentage loading, with an ambient wet blub temperature of 12°C and on/off condenser fan control (normal condenser selection).

The complete paper with the corrected figure can be downloaded from the EcoLibrium™ section of www.airah.org.au





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