>>> SEAN McGOWAN REPORTS

Thermal energy systems — what you need to know

Increasingly, building designers are turning to thermal energy to help deliver sustainable outcomes. Thermal energy systems come in many forms, from thermal mass to chilled water storage and phase change materials — and are delivering results in a range of applications.

With today's focus on more responsible building design, including sustainability, occupant health and comfort, indoor air quality and importantly, low energy consumption, thermal energy systems are emerging to play an important role in delivering these outcomes.

While some forms of thermal energy have been used by man to provide thermal comfort for hundreds, if not thousands of years, more recent developments are delivering both measurable and sustainable benefits.

HVAC&R Nation takes a closer look at five thermal energy systems, and discovers what you really need to know.

Thermal mass

Thermal mass is the ability of a building material to absorb and store heat, before releasing it at a later time. Therefore when used correctly, it can provide cooling during warmer months, and heating during cooler months.

> "Thermal mass is the quiet achiever of the building world," says Chris Arkins, associate with Steensen Varming Australia.

"It has characteristics that when understood and applied in an appropriate manner can provide opportunities not commonly available through more traditional systems and design approaches."

Building materials of high density, such as concrete, bricks and tiles are said to have a high thermal mass, while those which are lightweight such as timber have a low thermal mass. Therefore by using materials with a high thermal mass, and positioning them in such a way that they make the most of the sun's radiation at the right times of the year, thermal benefits can be exploited.

As the summer sun is positioned high in the sky, and the winter sun is positioned lower, shading techniques can moderate the thermal effects of the summer sun, and maximise the heat gain in winter when the sun is lower.

Thermal mass in a building acts as a thermal battery, or thermal sink – whereby in summer it absorbs heat, keeping the space comfortable, while in winter the same thermal mass can store the heat from the sun and release it during the night.

Thurgoona Campus, Charles Sturt University

According to Arkins, this process is called the "thermal flywheel" effect, where the greater the time lag of external construction the greater the effectiveness of the mass.

Thermal mass influences the internal temperature within a building by providing heat sink surfaces for radiation, conductive and convective heat exchange; by providing a time lag between peak external and internal temperatures and by providing a reduction in heat transfer across an external wall.

Thermal mass can also be used in mixed mode to reduce air conditioning loads, with the most common application being a nighttime purge cycle to precool the building mass and remove overnight residual internal heat gains.

"Energy savings are then realised through reduced morning pull down loads plus the convective cooling offered by the storage capacity of the mass," says Arkins, adding that in commercial CBD buildings, this can typically only be achieved through mechanical means; with the fan power required often offsetting the energy savings achieved.

Where it works

In areas that experience a large diurnal temperature range (that is, a large difference between daytime and nighttime temperatures), thermal mass works best, but in areas where the diurnal temperature range is small, thermal mass can make internal conditions worse by radiating all the heat at nighttime during a heat wave, and absorbing all the heat you produce on a winter night.

Thurgoona Campus, Charles Sturt University, Albury Australia

Experiencing hot windy summers, the Thurgoona Campus of Charles Sturt University in Albury has used thermal mass to hold warmth in winter and coolth in summer. Rammed earth exterior and internal walls between 300mm and 600mm have been employed, along with concrete floor slabs and suspended slabs to upper floors and ceilings.

The campus's main lecture theatre is buried under a grassed mound to take advantage of the thermal properties of the earth around it, moderating heat losses and protecting it from extreme ambient heat, while many of the buildings use stack-induced natural ventilation created by thermal chimneys.

Decoupled thermal mass

Decoupled thermal mass storage is a term used to describe situations where thermal mass is accessed outside the building envelope, such as the earth below the building, or depending on location, water from a river, lake or ocean.

Federation Square, Melbourne

The two most common applications of decoupled thermal mass are labyrinth systems which consist of tunnels built from a high thermal mass material that use air to transfer the thermal storage capacity of the labyrinth to the building; and geothermal heat exchangers that provide access to substantial thermal mass, with water used as the medium to transfer energy to and from the building to the earth.

Labyrinth designs are particularly effective in exploiting the diurnal temperature variations of a location to provide low energy cooling. For example, Australia's largest labyrinth lies under Melbourne's Federation Square and is 1600m^2 in size and 1.2 kilometres in length.

These systems work by flooding the labyrinth with cool night air, which in turn cools the high thermal mass material. During the day, air is drawn through the labyrinth where it is cooled before entering the building. In winter, the process is generally reversed.

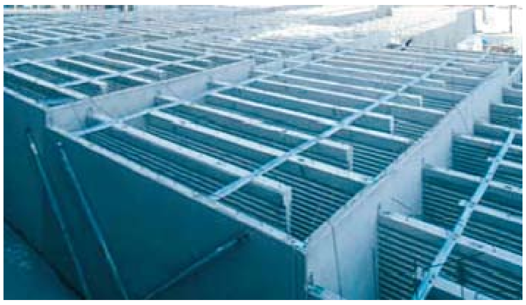
Where it works

Again, decoupled thermal mass systems take advantage of large diurnal temperature ranges, so areas that experience this type of climate are prime candidates for this system.

Federation Square, Melbourne Australia

Below Melbourne's Federation Square lies a 1600m^2 concrete labyrinth which provides energy efficient cooling and heating to the complex's Atrium and other areas.

It works by pulling the cool night air off the adjacent Yarra River through the labyrinth, which in turn cools down the thermal mass walls, and is used during operational hours to cool the Atrium via a low velocity displacement system at floor level, as well as provide environmental climate control and act as a pre-cooling system for other areas of the complex.



Federation Square labyrinth

"In peak summer conditions, the labyrinth is capable of delivering air to the Atrium at up to 12°C below the external ambient temperature, equivalent to conventional air conditioning, but using one tenth of the energy consumption and generating less than one tenth of the CO^2 emissions," explains Arkins.

Other installations

- The Earth Centre, Doncaster U.K.
- National Museum of World Cultures, Gothenburg Sweden

Ice storage

Using ice for thermal comfort has been used for centuries, and not just by the Eskimos.

In modern times, ice thermal storage has been successfully implemented in many building projects around the world, where it can reduce first costs in some cases, as well as increase lettable space.

"The use of low temperature water from ice storage allows savings in piping, pumps and air handling equipment," explains Ramez Naguib, international marketing manager for Baltimore Aircoil Company.

Ice thermal storage systems generally produce ice at night taking advantage of off-peak electrical tariffs, and therefore helping to reduce peak demand on electrical supply. This ice is then stored until cooling is required, at which time water is circulated through the ice storage area before being distributed to the system to provide space cooling.

An ice storage system offers two major benefits. Firstly, it can take advantage of off-peak electrical tariffs, and secondly, it can reduce the chilled water flow requirements by half.

"An ice storage system with supply and return water temperatures of 2°C and 13°C versus a traditional system using 7°C to 13°C requires almost half the water flow, pump BHP and smaller pipes," says Naguib.

"In addition, when low temperature air distribution is also used, additional savings are realised from smaller ductwork, smaller fans as well as less energy consumption and increased usable space."

The fact that this system has traditionally been an open loop has delayed its widespread adoption, however new ice-on-coil technology allows designers to have a closed loop system.

In Australia, however, such systems have not proven popular, with only handful of older buildings using the system. While electricity suppliers prefer the system because of its use of off-peak electricity, its high energy requirements mean it's unlikely to be popular anytime soon.

Where it works

Ice storage has been used effectively in major projects around the world, including the U.S.A. and Japan where its use in district cooling projects is both popular and effective. In Australia its use is limited.

Centex Building, Dallas Texas, U.S.A.

The Centex Building in Dallas is one of the United States' most energy efficient buildings, thanks largely to its ice storage system. By combining the use of fourteen ice tanks with two high efficiency electric rotary water-cooled chillers, the normal peak electrical load of a building such as this has been dramatically reduced.

The chillers cool a glycol solution to – 4°C to produce ice in the storage tanks, which are then used for eight hours starting from noon to provide efficient cooling to the building while using only one chiller.

This partial ice storage system provides up to 7400kWh of cooling capacity, with the melting ice providing 40% of the building's cooling requirements on a 38°C day, and a much higher percentage during cooler months.

Other installations

- Grosvenor Place, Sydney Australia
- Cosmo Square, Osaka Japan

Chilled water storage

Chilled water thermal storage systems, like ice storage systems, offer the ability to move electricity requirements to off-peak, while leveling out electrical demand by operating chillers for longer, but at more constant loads, largely at night.

A chilled water thermal storage system takes chilled water produced by chillers and stores it in a purpose built holding tank until it is required by the HVAC system for cooling.

Due to the large, often deep stratified holding tanks, made of steel or concrete, required for chilled water storage, these systems are typically used only where a large amount of space is available, and where the facility is a large electricity user, such as university campuses and hospitals.

CH2, Melbourne

Charles Darwin University, chilled water storage tank

Where it works

Chilled water storage is best used where electricity demand from HVAC plant is high, and where cheaper off-peak electrical supply can be taken advantage of. In Australia, chilled water thermal storage systems have been popular at facilities in Queensland and the Northern Territory, where cooling demands have placed stress on local electricity grids.

Around the world, chilled water storage, like ice storage, has been successfully implemented in district cooling projects.

Charles Darwin University, Darwin Australia

Australia's largest chilled water storage system operates at Charles Darwin University, in Darwin, where an 8.6ML chilled water tank provides a thermal capacity of 72,000kWh.

Commissioned for operation in 1998 in a bid to reduce 1.5MW from the university's peak electrical demand, the system uses two central chilled water plants to provide chilled water which is then stored and used during the on-peak period of 6am to 6pm. During these hours, all

Petronas Towers, Kuala-Lumpur

chillers, associated primary chilled water pumps, cooling towers and condenser water pumps remain off.

According to Steve Beagley, manager of operations, finance and asset services at the Charles Darwin University, the system has not only produced significant savings in energy costs, but it has also reduced the effective maintenance costs because of a reduction in the number of chillers, cooling towers and control systems required.

Other installations

- Douglas Campus, James Cook University, Townsville Australia
- Trigen-Peoples District Energy, Chicago U.S.A.

Phase Change Material (PCM) systems

While ice storage and chilled water systems have traditionally been the mediums used to shift the cooling loads of buildings from peak to off-peak, they are not without their issues, with ice storage systems in particular still requiring large amounts of electricity, and in turn producing large greenhouse gas emissions.

Other phase change materials (PCMs) however can be designed to work more efficiently than ice in certain locations.

"PCMs make use of the latent heat process to achieve high thermal density with constant heat output," says Chris Arkins. Latent heat is the large quantity of energy which needs to be absorbed or released when a material changes from a solid to a liquid state (fusion) or from a liquid to a solid state (crystallisation).

"These phase changes take place at constant temperature and the process of melting or freezing can be repeated over an unlimited number of cycles with no change to their physical or chemical properties."

PCMs can be organic or inorganic in make up, and designed to phase change at different temperatures. Organic PCMs include paraffin wax, which are both stable and non-corrosive and do not have supercooling properties (i.e. they don't need to be cooled below freezing point to crystalise). Importantly, they also have a high latent heat per unit weight.

Conversely, inorganic PCMs such as salt hydrate solutions have a much higher latent heat per unit volume, have higher thermal conductivity and are cheaper than organic PCMs, but are often corrosive and prone to supercooling.

According to Arkins, such materials therefore have the potential to be used to store substantial amounts of thermal energy where only a small change of temperature is permissible. For instance, some PCMs such as salt mixtures can phase change between 20°C and 24°.

"By comparison, with the same temperature limitations, a conventional sensible heat storage system such as water or concrete, would occupy a volume several times greater than a latent heat source."

Where it works

Phase Change Material systems have been developed in a wide range of encapsulations, including in-floor heating systems, while a popular French system uses a purpose-built tank filled with PCM nodules or spheres, around which heat transfer liquid is circulated to provide heat exchange.

Explore@Bristol eutectic tank

Explore Building, Bristol U.K.

The United Kingdom's first visible PCM cooling and heating system was installed at the Explore@Bristol science building in 1999. It uses a ten metre high eutectic tower (tank) made of transparent acrylic and is filled with thousands of purple spheres containing a salt-based PCM.

The tank is effectively a heat exchanger connected to the building's water system, which pipes water around the building for heating or cooling.

As the temperature in the building rises, either due to visitor numbers or the outside temperature increasing, the salts within these spheres begin to melt, absorbing the building's heat and in turn cooling the water.
As the building cools, the PCM in the spheres become solid again and in turn provide heat.

Other installations

- Petronas Towers, Kuala Lumpur Malaysia
- Stevenage Borough Council Offices, U.K.
- Council House 2 (CH2), Melbourne Australia ▲

Information in this article was sourced from the presentation *Thermal Mass: Its role in creating environmentally responsive building design* presented by Chris Arkins of Steensen Varming at AIRAH's 2003 Hybrid Building Conference in Melbourne.