TOWARDS ENERGY EFFICIENT BUILDING ASSETS: A REVIEW ON SUB-TROPICAL CLIMATE

A.A. CHOWDHURY POST GRADUATE STUDENT
M.G. RASUL SENIOR LECTURER
M.M.K. KHAN ASSOCIATE PROFESSOR
FACULTY OF SCIENCES, ENGINEERING AND HEALTH
CENTRAL QUEENSLAND UNIVERSITY
ROCKHAMPTON, QUEENSLAND-4702, AUSTRALIA

ABSTRACT

The energy efficient building asset is the key to a building's stability. To approach the concept of energy efficient building assets in a sub-tropical climate, building assets must adopt a number of innovative strategies to take advantage of subtropical climate. The importance of energy efficiency improvement in building asset is elaborated with the justification of the utilisation of the low energy cooling technologies. Appropriate energy efficient technologies for building systems particularly Heating, Ventilation and Air Conditioning systems (HVAC) for subtropical/ warm humid climates are presented. The effectiveness of climate-responsive building design and space-conditioning strategies within the building assets in sub-tropical Queensland, Australia is reviewed and discussed.

INTRODUCTION

In many countries, the structure of energy consumption by different consumer groups is characterised by a high share of the building sector. In hot and humid region, use of air conditioning is progressively growing. In 2002, Australia generated 210.3 billion kilowatt-hours (bkWh) of electricity and consumed 195.6 bkWh. The Energy Supply Association of Australia (ESAA) has predicted that consumption will grow rapidly in coming years, rising to 206 bkWh by 2008, with the majority of growth in consumption concentrated in Queensland, New South Wales and Victoria. According to the report published in 2000 by Built Environment Research Unit, Public Works Department, Queensland, Australia; Space Cooling in Queensland's residential and commercial buildings accounts for approx. 32% of the state's total annual electrical energy consumption. In Western Australian, about 26% is used for heating and cooling and 16% for refrigeration. This paper reviews basic efforts towards energy efficient role of HVAC for ensuring high performance buildings in operation and design. The strategies for effective HVAC systems for subtropical climate are explained and immerging HVAC technologies are described in this paper. It can be assumed that with integrated and holistic approach to HVAC and building design, performance of existing building can be improved.

IMPORTANCE OF ENERGY EFFICIENCY IMPROVEMENT

Increased energy efficiency in building can provide financial benefits through reduced electricity bills. Improvements in energy efficiency also play a part in reducing energy use, contribute to the competitiveness, and assist in better managing energy demand within the assets. The Queensland Government Energy Management Strategy is a whole-of-Queensland Government energy efficiency initiative. Queensland Government departments use about 860 million kWh of electricity annually, costing approximately $86 million. That electricity generates greenhouse gas emissions equivalent to those produced by 909,880 cars. Greenhouse gas emissions are harmful to the environment, contributing to global warming. Australia has officially recorded its warmest year on record. According to annual Australian climate statement 2005, Bureau of Meteorology indicate that the nation's annual mean temperature for 2005 was 1.09°C above the standard 1961-90 average, making it the warmest year since reliable, widespread temperature observations became available in 1910. Despite some regional variations, the warm conditions in 2005 were remarkably widespread. All States and Territories, apart from Victoria and Tasmania, recorded 2005 mean temperatures amongst their top two warmest years on record. Australian temperatures have increased by approximately 0.9ºC since 1910, consistent with global warming trends. So the trend of temperature increase will certainly increase space cooling cost and energy consumption. This is the time to evaluate major energy consuming elements for the betterment of Australia.

ENERGY EFFICIENT BUILDING TECHNOLOGIES

For energy efficient buildings, a methodology of several steps can be considered towards energy conservation in building assets. First is focused on standard methods of energy efficiency, the second one supports the energy-savings measures and the third one is economical feasibility. Thermal modernisation of old buildings is performed to achieve significant reductions in energy consumption and to improve indoor-climate conditions. The reduction of energy demand in buildings can be achieved by improving building envelope elements, by reducing heat losses in local heat distribution systems and local heat sources etc. A new proposal for the Directive of the European Parliament and of the Council on the energy performance of buildings is the indicator of policy in the building sector. The Directive indicates the necessity and possibility of savings through the implementation of traditional and modern options based on improvement of the building envelope, with the focus on thermal insulation and glazing, improvement of other installed equipment, e.g. lighting and air conditioning, introduction of environmentally friendly energy generation installations, introduction of bioclimatic building design and orientation etc.

The basic rule should be to introduce standard well-proven energy efficient technologies and then to use new unconventional methods of energy conversion, storage and utilisation, including implementation of renewable energy. The future of energy-conservation measures depends on coherency between economics, energy efficiency and environment protection. The idea of energy efficient buildings can be implemented by applying innovative technologies and measures like bioclimatic building design and orientation which includes a concept of low-energy architecture; by using passive solar system for the building itself, either to gain as much solar energy as possible, or to protect the building from the sun, depending on season and climatic conditions, by applying day lighting; by integrating solar-active thermal and photovoltaic systems into building; by adding short and long term (seasonal) energy storage (e.g. underground thermal energy storage) etc. Utilisation of renewable energy and wastes in extreme cases leads to self-energy sufficient buildings. These buildings do not require energy to be supplied by external sources; the energy is produced and used at site. However, self-energy sufficient buildings need usually high-tech systems, which cannot be feasible for low cost buildings from the economic point of view.

The other type of modern energy-efficient buildings is intelligent buildings using Building Management System (BMS). The main aim of these systems are to control all systems in the building to assure the proper management of the energy demand, to conserve energy, to improve the comfort levels including indoor-air quality, and to increase the building's productivity through leveraging information. The idea of integrated building services functions is beneficial from the energy efficiency point-of-view. In addition, economic viable and embodied energy can be an important issue.

CLIMATE RESPONSIVE DESIGN FOR QUEENSLAND, AUSTRALIA

According to Energy Design Resource, climate-responsive design seeks to create inherently comfortable buildings that require minimum energy input. Such buildings take advantage of regional climatic characteristics that can help with comfort and efficiency, while minimizing the impact of any characteristics that may impair performance. So establishing climate zones is essential to predict the overall climate condition

Establishing climate zones

The wide variety of climates experienced in Australia gives rise to a need to consider climate in framing provisions. Climate zones can be defined using a variety of criteria, depending on the purpose. In the context of building regulations, climate zones are regions which are of sufficiently similar climate that a common solution for energy efficiency measures is possible and justifiable. Climatic variations will lead to considerable regional variations in the benefits of energy efficiency measures and must therefore be reflected in the provisions.

Dividing Australia into a limited number of climate zones provides a means of maintaining reasonable simplicity. Existing schemes vary in the number of zones used. In the interests of simplicity, it is desirable to keep the number of zones to a minimum, consistent with provisions which are broadly appropriate for each climatic region. Quite a number of climate zonings of Australia have been developed over the years. The number of zones ranges from 5 (Wickham 1962) to 18 (Ashton 1964) to 28 in NatHERS (Association for Computer Aided Design 1993). Climate zones have also been developed for building energy codes in other countries, for example, Brazil with 8 zones (Roriz et al. 1999) and United States with model energy code uses 18 zones.

The Bureau of Meteorology has developed a six-zone classification based on dry-bulb temperature (DBT) and humidity (Bureau of Meteorology 2000). The Bureau attempted to take into account wind speed and solar radiation but rejected these variables because the criteria became too complex and no longer gave contiguous regions (too many 'islands' appeared). The six zones were defined as follows and shown in Figures 1 and 2.

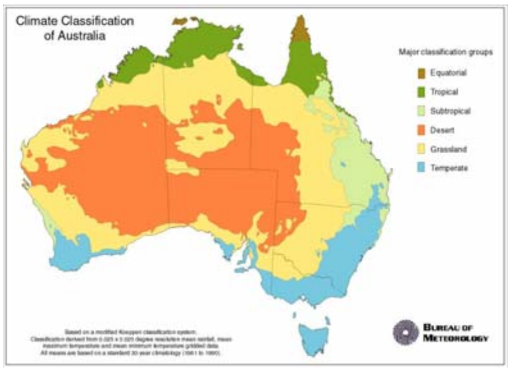

Figure 1. Climate classification of Australia (BMO, Australia)

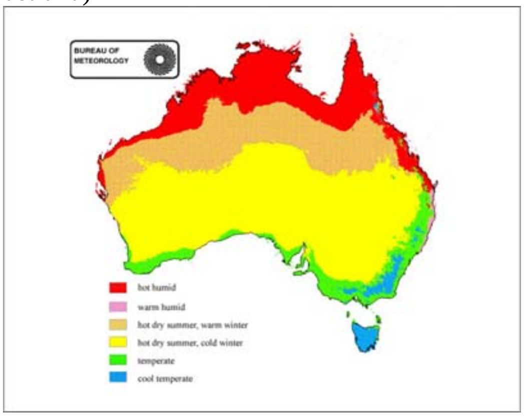

Figure 2. Climate zones for Australia (BMO, Australia)

A framework for understanding the climate comfort building relationship was proposed in 1953. This understanding was adapted to the psychometric chart and was further developed to produce 'building bioclimatic chart' (Givoni, 1969). Milne (1979) elaborated these further and developed boundaries for outdoor conditions in terms of temperature and humidity which could be made comfortable by various energy conservation and management techniques. Szokolay (1986) made some corrections to these in the light of more recent findings (such as the series of bioclimatic charts produced by Gagge et al. (1974) (of the J B Pierce Foundation) and further developed it into the CPZ (Control Potential Zone) method. The use of this method to develop eight climate zones for Queensland is described in Szokolay (1991). Only readily available monthly average data are used. The comfort zones on the psychrometric chart can be extended into a Control Potential Zone, which covers the range of outdoor conditions over which the strategy could maintain comfortable conditions indoors. For a given location, the 12-monthly outdoor temperature/humidity lines can then be plotted over the Control Potential Zone to assess whether the strategy is appropriate for that climate.

Climate of Rockhampton

Rockhampton climate may be classified as Subtropical. The city is situated on the Tropic of Capricorn and lies within the southeast trade wind belt, too far south to experience regular north west monsoonal influence, and too far north to gain much benefit from higher latitude cold fronts. Rockhampton's average annual rainfall is a little over 800mm. Rainfall averages suggest a distinct wet and dry season, with the wet generally December to March and the dry June to September. Typical daytime temperature ranges are maximum 32^{o}C minimum 22^{o}C in the summer /wet season and maximum 23^{o}C minimum 9^{o}C in the winter/dry season. The average temperature profile and relative humidity for warm humid climate zone, Rockhampton are shown in Figures 3 and 4. The prevailing winds are predominately southeast but during spring and summer late afternoon northeast sea breezes give some relief from the higher temperatures. During winter and early spring the high pressure systems of the sub tropical ridge can be far enough north to replace the southeast trades with south westerlies winds behind the trough systems that split the high cells. Maximum temperatures in the low to mid 40's have been recorded in October to March. Minimum temperatures as low as zero have been recorded during winter.

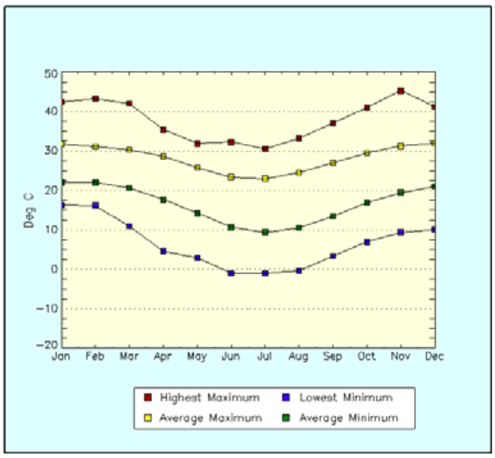

Figure 3. Monthly temperature for Rockhampton (BMO, Australia)

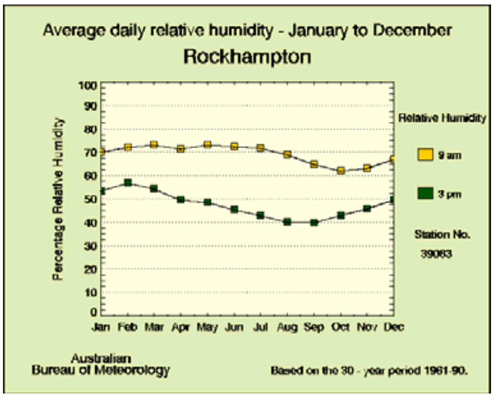

Figure 4. Average relative humidity for Warm Humid Climate zone, Rockhampton (BMO, Australia)

Establishing of Human Thermal Comfort

For humans to function effectively and efficiently, the environment they are in must provide for their thermal needs. According to the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), human thermal comfort is defined as, "…that condition of mind that expresses satisfaction with the thermal environment." ASHRAE Standard 55, "Thermal Environmental Conditions for Human Comfort," specifies that thermal comfort is achieved when 80 percent of sedentary or slightly active persons find the environment thermally acceptable. Although such definitions suggest that comfort is primarily a qualitative topic, ASHRAE and others have conducted research seeking quantitative approaches to predicting when people are likely to experience thermal comfort. Successive editions of the ASHRAE comfort standard gave the following comfort limits

55-66: 23 - 26^{o}C DBT 20 - 60% relative humidity
55-74: 22 - 25^{o}C ET* 5 - 14 mmHg vapour pressure
55-74: Winter 20 - 23.9^{o}C ET, Summer 22.8 - 26.1^{o}C; 5 - 14 mmHg vapour pressure
[ET = Effective Temperature, DBT = Dry Bulb Temperature]

However, a relative humidity of 30% is recommended, as relative humidity below 50% will dry out eyes and mucous membranes and above 60% will make the zone feel stuffy. The best temperature to keep the zone is 21-23^{o}C. Hence, still comfortable 21-26^{o}C range is acceptable.

Predicting Thermal Sensation

ASHRAE has developed a thermal sensation scale that assigns a numerical representative for thermal sensations ranging from hot (+3) to neutral (0) to cold (-3) and all points in-between (1997 ASHRAE Handbook of Fundamentals, page 8.12). Based on their research, ASHRAE has developed regression equations to predict thermal sensation for men, women, and men and women combined, in response to temperature, humidity, and duration of exposure.

The two most significant elements of thermal comfort are temperature and humidity. If temperature and humidity are regulated uniformly, then a thermal acceptability of 90 percent may be achieved, which exceeds the ASHRAE Standard 55 requirement of 80 percent. The temperature within a space is the most conspicuous element of thermal comfort, and is the only element that occupants generally have control over in buildings via the thermostat. According to ASHRAE, an "average" person (wearing seasonally appropriate clothing and performing a primarily sedentary activity) is most comfortable when the dry bulb temperature is between 20.56°C and 27.22°C.

Thermal discomfort may result when humans are subjected to non-uniform (asymmetric) thermal radiation. Research indicates that occupants begin to feel discomfort when radiant temperature asymmetries are higher than about 18° F (1997 ASHRAE Handbook of Fundamentals, page 8.13). Various combinations of temperature and relative humidity that provide acceptable thermal comfort can be plotted on a standard psychometric chart in order to define the human "comfort zone". The implication is space conditions that fall within this zone are likely to provide acceptable thermal comfort for most people. However, it is important to note that each person's comfort zone will vary depending upon the individual's amount of clothing, metabolic activity, and other factors. Surprisingly, with the diverse range of climates, living conditions, and cultures around the world, most people would choose to be within the same temperature range when clothed similarly and performing at the same level of activity. However, regional adaptation does occur and should be considered.

SPACE-CONDITIONING STRATEGIES

Rockhampton encompasses a wide range of temperature and humidity conditions. Therefore most HVAC systems are designed to provide comfort through mechanical cooling. While this traditional approach to cooling can provide acceptable comfort, it does not always do so in climate-responsive or energy-efficient way. After various issues of climate, human comfort, and thermal mass, selecting space conditioning strategies is the final consideration. Although HVAC systems should be sized to provide comfort during the hottest and coldest conditions that are expected for a particular location systems should be designed and optimized to provide their most efficient performance during average weather conditions. Air conditioning may often be eliminated in mild climates if the right combination of climate-responsive design features is implemented. Effective solar control, appropriate building materials, and internal load minimization (e.g., efficient lights, Energy Star office equipment) can reduce or altogether eliminate the need for mechanical cooling. Especially in coastal regions, the use of operable windows in perimeter spaces along with forced ventilation at 100 percent outside air in core spaces can keep conditions well within acceptable ranges of temperature and humidity for most of the year. Eliminating traditional mechanical cooling systems has numerous benefits, including reduced construction cost, lower maintenance requirements, less noise, and significantly lower energy costs. The right combination of approaches and mechanical system approaches can take almost any outdoor weather condition and shift it towards the comfort zone. For buildings having both operable windows as well as traditional mechanical cooling expands the comfort envelope and minimizes potential energy waste. The following strategies are required to enhance energy efficiency and comfort by taking advantage of a climate's predominant characteristics.

Ventilation

Our climate is changing. As temperatures increase there will be a growing need to control internal building temperatures. For many building types, cost-effective sustainable options in combination of high thermal mass and night cooling are the perfect solution where steps are taken to minimise heat gains. In the future, this technology has an important role to play in providing a passive and more sustainable alternative to air-conditioning. In buildings where mechanical air-conditioning cannot be avoided ventilation can still provide a means that significantly reduce the energy required to operate the plant and the associated carbon dioxide (CO_2) emissions. For many buildings a basic Fabric Energy Storage system using natural ventilation is all that is required to provide satisfactory internal conditions and prevent overheating problems. More demanding applications may require increased cooling capacity provided by supplementing natural ventilation with mechanical ventilation, typically in the form of a mixed-mode system.

Ventilation for night cooling requires an air change rate in the order of 2 to 5 per hour [BRECSU, Avoiding or Minimising the Use of Air-Conditioning, Report 31, HMSO, 1995]. The optimum rate will depend on each building's specific characteristics. Elevated air change rates will improve the cooling rate to a limited extent, but the two are not directly proportional. This is because the cooling rate is also affected by the length of time the air is in contact with the slab. High air change rates results in less contact time. To allow sufficient time for night cooling, the occupancy period should ideally not be more than 10 hours [The Impact of Thermal Mass on Building Performance, Arup Research & Development, CCANZ, 2004]. Buildings occupied for longer periods may not be suitable for FES with natural or mechanical ventilation, requiring instead water-cooled slabs which enable heat removal at a faster rate.

Displacement Ventilation (DV)

Although displacement ventilation, an alternative to conventional mixing system, were originally used for industrial buildings these days it is found useful for office building as well. Lin et. al. (2005) investigated on the typical office building and found that DV system produced superior indoor air quality. It has designed to minimize mixing of air in the occupied zone and use 2.5-3 air changes/hour (Schultz, 1993). It is achieved by conditioned air at a lower temperature than desired room temperature and indoor temperature depends upon changes with height. In different studies, ISO 7730 (1995) and Loveday et al (1998) individually suggested air temperature gradient 3K/m as satisfactory for displacement ventilation. By supplying air at 17^{o}C instead of 13^{o}C, displacement ventilation saves on chiller energy compare to usual air conditioning system. It also saves thermal energy compare to traditional air conditioning systems because displacement ventilation maintains room temperature at 23^{o}C whereas traditional systems maintain 21^{o}C. Apparently it reduces comfort. Comparing the cooling differential index which is 8K and 6K for displacement and traditional systems respectively, for same heat load, displacement ventilation require higher flow rate than traditional systems. A displacement system uses less energy compare to traditional system because it cannot cope large load and is appropriate for constant small load of 25W/m (Levermore, 2000). In hot and humid climate, displacement ventilation can be operated throughout the year with supply air temperature between 18^{o}C to 20^{o}C. Trox (1997) suggested that it can be operated as a Variable Air Volume system. Lin et. al. (2005) illustrates that displacement system can be affected by imbalance in the heat source within the office space.

Mixed Mode Ventilation

The term mixed-mode typically describes a system that combines natural and mechanical ventilation. It provides many advantages of natural ventilation, as well as other benefits like greater control over internal conditions, weather-proof night ventilation, improved ventilation on still nights, ability to offset higher heat gains where stack ventilation is not possible, greater building flexibility to cope with changes of usage, occupant density, internal loads, etc. For most active systems a mixed-mode approach is generally preferred to full time mechanical ventilation, which affords building occupants very little control over their environment. Natural ventilation also realises the benefits of free cooling, i.e. ventilation without fan operation because fans account for a significant proportion of the energy used in mechanically ventilated buildings. The combination of centralised plant supplying an underfloor ventilation system is particularly effective format in mixed-mode systems. This solution provides good convective heat transfer with the top of the slab, enabling thermal linking on both sides in buildings with exposed soffits. A centralised air handling plant enables the heat lost by ventilation during the winter to be minimised by incorporating a heat recovery device such as a cross-flow heat exchanger, designed to recover heat from exhaust air to preheat incoming fresh air. During summer nights, a damper controlled bypass prevents the heat recovery device from warming the incoming fresh air. On very hot summer days, the incoming fresh air can be pre-cooled at times when the exhaust air is at a lower temperature. The effectiveness of pre-cooling can be enhanced through the addition of evaporative cooling of the exhaust air before it passes through the heat recovery device. These can cool the fresh air without increasing its moisture content, and can lower the supply temperature by several degrees depending on the ambient and internal conditions.

Night Ventilation

Night ventilation should take maximum advantage of ambient conditions whilst avoiding overcooling, which will result in uncomfortable conditions at the start of the day, and may result in the subsequent need to reheat the space. Mixed-mode systems should default to natural ventilation whenever possible so the energy consumed by running fans is minimised. To achieve these objectives a number of different control strategies, which vary in their approach and complexity can be used. The relative attributes of these control strategies have been investigated by the Building Services Research and Information Association (BSRIA), which undertook site monitoring of four high thermal mass buildings constructed in the 1990s. BSRIA's key conclusion was that a complex control strategy is not necessary to maintain comfortable conditions and to achieve energy savings in systems with mechanical ventilation. The careful selection of the control set-point to initiate night cooling was identified as being of great importance.

Shaviv et. al. (2001) reported night ventilation and thermal mass are as effective as passive cooling design strategy in hot and humid climate. An analysis carried out to predict thermal performance of the building stated that a reduction of 3-6^{o}C maximum indoor temperature in a heavy constructed building can be achieved compared to maximum outside temperature without operating an air conditioning unit. According to Shaviv et. al. (2001) the exact reduction depends the amount of thermal mass, the rate of night ventilation and the temperature swing of the site between day and night.

Radiant cooling

Radiant cooling as an alternative air-conditioning system was first investigated in laboratory studies in European countries in early 1990s (Wilkins et. al.,1992 and Niu et. al. 1995). Then the system started its applications in combination with displacement ventilation systems [Mertz et. al., 1992 and Niu et. al. 1994]. Radiant cooling with displacement ventilation is more energy efficient compared to conventional air conditioning system (Feustel and Stetiu, 1995; Imarori et. al. 1999). In Europe, it is reported that a cooling tower could be useful to cool the water for supply to the radiant panel on the ceiling (Facoa and Oliveria, 2000). In recent years both simulation studies and experimental research on Hydronic radiant cooling and displacement ventilation have been reported (Loveday et. al., 2002; Alamdari et. al., 1998; Rees et. al., 2001; Mumma, 2001; Novoselac et. al., 2002). Feustal, 1995 claimed that cooling would be provided directly and more evenly to the occupants without causing draft.

Radiant cooling systems separate the cooling and ventilation tasks of a building conditioning system by employing a chilled-ceiling to treat cooling load and setting up an independent ventilation system. It is generally believed that a radiant system has three main advantages. First, the pump energy required to move heat in a water based system is much lower than fans in an air-based system. Second, radiant systems improve thermal comfort because heating and cooling are provided directly and more evenly to the occupants without causing drafts. Third, simple and effective zone control is provided. Because of these reasons, it can be employed in a warm humid climate. As a passive cooling alternative radiant cooling has higher potential for energy and peak savings. Applications of radiant cooling to warm and humid regions like Rockhampton are much more necessary. However, due to the long, hot and humid summer with an average dew-point exceeding 22.8^{o}C, radiant ceiling systems may require air dehumidification to avoid condensation and mould growth on the panels while cooling. The system also needs a ventilation system to maintain indoor air quality. To satisfy these requirements, a combination of radiant cooling with a dehumidification and ventilation system should be considered. As 100% of the cooling capacity cannot be met by in tropical climates, it is necessary to provide supplementary cooling by dehumidified and cooled ventilation air. However, there is a need to optimise the critical parameters of the hybrid system for instance ceiling temperature, ventilation air temperature (dry and wet bulb temperature) and supply volume flow rate in relation to the space cooling load and comfort criteria (Ameen, 2005).

Vangtook and Chirarattananon (2005) examined the situation in three stages i.e. night time, day time and whole day when cooling water is maintained at constant temperature (25^{o}C) without consideration on how water at such temperature can be maintained and cooling tower rated at 10kW to cool the return cooling water for active wall, radiant panel and conventional air conditioning. However, the value of temperature of cooling water from the cooling tower, internal load and set point temperature was no longer constant using cooling tower. But for sufficient thermal comfort air speed for radiant cooling was assumed at 0.5m/s where it is at 0.15m/s for traditional air conditioner. During night time application, they found significant result showing that the cumulative thermal load for active wall is 38.4% less than traditional air conditioning using constant temperature cooling water. The potential factor is that cooling water can be obtained at 25^{o}C using low energy, low cost means. Application of cooling tower at night time also represented the similar thermal load without any cost towards thermal load. Major energy saving occur here. Whole day application comprised of supplementary measures to pre-cool ventilation air and to increase air speed around the occupant. Application of constant temperature cooling water saved about 42% of thermal energy for both active wall and radiant panel. Water from cooling tower was used for whole day application and offered highest level of thermal load as all the cooling loads were removed by supplied cooling water. Day time load is dominant and highest level of thermal energy savings can be achieved using cooling tower.

Desiccant cooling

Desiccant cooling is an environmentally friendly system and is preferred in recent years due to global warming and other environmental problems. Over the years, various aspects of desiccant cooling have been investigated to establish its effectiveness as environmental friendly and economical alternative to the traditional systems, which are based on vapour compression cycles with respect to system parameter, climatic condition and loads (Halliday et. al., 2002). In HVAC systems combining chilled-ceiling with desiccant cooling, air dehumidification is required to maintain the indoor air humidity within a comfort zone and to reduce the risk of water condensation on chilled panels in hot and humid climates. Niu et. al. (2002) evaluate the system performance using a chilled ceiling with desiccant cooling and the energy savings potential by comparing with three other systems such as conventional all-air system, all-air system with total heat recovery, and radiant cooling with air handling unit (AHU) of a typical office. The results indicate that chilled-ceiling combined with desiccant cooling could save up to 44% of primary energy consumption, in comparison with a conventional constant volume all-air system. More interestingly, more than 70% of annual operating hours for desiccant regeneration could be accomplished by low-grade heat of less than 80^{o}C. Hirunlabh et. al. (2005) conducted an experimental analysis to investigate the performance and energy savings of the desiccant air conditioning systems. Under test bed condition, electricity savings was about 24% using 15% of outdoor air, 15% of return air (mixed with desiccant bed inlet) and 70% of indoor air (mixed with the dry air leaving the desiccant) ratio.

Among several technologies available for air dehumidification, desiccant cooling is an attractive alternative. In past 10 years, there have been many researches on this technology (Waugaman et. al., 1993) since it satisfies the demands of the industry for a diversification of primary energy sources and a reduction in the use of CFCs. Hybridization of these systems has the potential to be an economically feasible proposition. In such application, air conditioning can be carried out by humidifying the air through desiccant (solid or liquid) followed by sensible cooling using water and then by an evaporator coil of a conventional vapour compression refrigeration cycle. The regeneration of the desiccant can be accomplished by condenser heat using low grade heat source for instance, solar energy or waste heat recovery from the system. Furthermore, regeneration of the desiccant is possible, even at temperature between 60^{o}C and 100^{o}C which can be supplied by ordinary flat plate solar collector (Ameen, 2005).

To facilitate the applications of radiant cooling to subtropical climates, a system combining a chilled-ceiling with desiccant cooling can be used. According to this concept, the sensible load is primarily treated by ceiling panels and the latent load and ventilation is accomplished by an auxiliary desiccant cooling system. Niu et. al. (2002) found that a chilled-ceiling saves much fan energy due to reduced air volume, and saves much chiller energy due to raised evaporating temperatures. Dehumidification by desiccant cooling saves much sensible energy due to the cancellation of reheat processes that are common with dew-point dehumidification. Much thermal comfort can be achieved from chilled ceiling with desiccant cooling. A chilled ceiling combined with desiccant cooling could save up to 44% of primary energy, in comparison with a constant volume all-air system. Total heat recovery could save 8% of potential energy when employed in a conventional all-air system. In addition, with chilled-ceiling, temperature and humidity control have been decoupled by using desiccant wheel for moisture removal and ceiling for temperature control. Desiccant cooling could be driven by low-grade thermal heat below 80^{o}C, a feasible applications of renewable energy to air dehumidification with chilled-ceiling combined with desiccant cooling.

Zhand and Niu (2003) reported chilled ceiling saves much fan energy due to reduced air volume and saves much chiller energy due to raised evaporating temperature compared to all air systems. Total energy savings amount to 47% with an AHU dehumidification and 30% with a desiccant dehumidification system. Mezzei et. al. (2002) obtained up to 35% savings on investment cost in summer season with reductions in thermal cooling power up to 52% by using three software codes for a retail shop. Dai et. al. (2001) reported an experimental study of a hybrid air conditioning system comprising of desiccant dehumidification, evaporative cooling and vapour compression air conditioning having 20-30% higher cooling capacity than the vapour compression system alone. Dhar and Singh (2001) presented the performance of four hybrid cycles for typical hot-dry and hot-humid weather conditions for the analysis of rotary dehumidifiers. Henning et. al. (2001) claimed that combinations of absorptive dehumidification with a conventional, electrically driven backup system allow for primary energy savings up to 50% at low increased overall cost.

Unlike conventional air conditioning system, which requires higher degree energy to run cooling cycle, desiccant cooling is a heat driven cycle. Although the starting cost for of the desiccant system is generally higher with respect to traditional summer operating cost of traditional air conditioning system, the cost can be slightly minimised using a de-rated system. Utilisation of integrated evaporative cooling for desiccant system and packaged total gas solid desiccant systems present high energy savings with a good capability to allow indoor thermal comfort. However, operating cost savings obtainable with desiccant systems depends on local climatic conditions, energy rates and overall performance of the desiccant. Moisture and thermal cycling wears the desiccant out and fouling of the pores occurs especially due to smoke and VOC's.

Thermal Storage Air Conditioning

Electric utility companies usually encourage the use of Thermal Storage Air Conditioning (TSAC) systems to reduce the cost required to generate peak electric power and has become well established in many countries like USA, Japan and Taiwan etc. Indeed, demand during peak hours can be eliminated by using off peak power. Utility companies have initiated different rate structures to penalize the use of peak hour electric power. In addition to the peak and off-peak energy rates, utility companies have imposed demand charges, based on the monthly peak demand. Most utilities offer rate incentives to encourage customers to consider TSAC which substantially lower life cycle cost, particularly due to longer equipment and system life (Dorgan and Elleson, 1994). In 2002, Australia generated 210.3 billion kilowatt-hours (bkWh) of electricity and consumed 195.6 bkWh. The Energy Supply Association of Australia (ESAA) has predicted that consumption will grow rapidly in coming years, rising to 206 bkWh by 2008, with the majority of growth in consumption concentrated in Queensland, New South Wales and Victoria. According to the report published in 2000 by Built Environment Research Unit, Public Works Department, Queensland, Australia; Space Cooling in Queensland's residential and commercial buildings accounts for approximately 32% of the state's total annual electrical energy consumption. There is significant potential to reduce this consumption, since the conventional HVAC systems typically do not take full advantage of the climate conditions and tariff rate structure in Queensland. Japan, Taiwan and Hong kong have taken the lead in the usage of thermal storage in air conditioning. So large-scale thermal storage air conditioning would only be viable when substantial redate for electricity usage during off-peak hours is available and higher demand charges are levied.

CONCLUDING REMARKS FOR SUBTROPICAL QUEENSLAND AUSTRALIA

The result of the implementation of energy efficiency strategies in building give improved indoor environmental quality, economic benefits and reduced pollution in both the local and global environment. When all energy performance and indoor climate standards are met and the proper quality of service is assured, the approaches to energy efficient buildings are developed. Technologies have afforded designers with artificial methods of providing comfort. That does not mean that weather patterns should be ignored. Often, the effort required for a climate-responsive design is not focused on technology so much as on initial consideration of a particular climate's challenges and opportunities, as well as methodical analysis of how different design strategies work in that climate's context. This simplicity when combined with climatic common sense allows buildings to work effectively. Although HVAC systems offer many opportunities for recovery of thermal energy, it is preferred to use less energy at first instance by efficient system through improved operating procedure. Techniques such as mixed mode ventilation, thermal storage based air conditioning, radiant cooling, desiccant cooling, and passive solar cooling are important in terms of energy use and indoor environment of building. Energy efficient approach enables building assets to reduce energy consumption, improve the working environment and reduce impacts of building operation. To ensure this, HVAC systems have an important role to play since many factor for efficient performance are directly or indirectly affected by the performance of the HVAC systems. An integrated approach is required to optimise assets operation for efficient building performance. A few HVAC technologies have been reviewed in the paper and currently many of those are being used successfully with performance improvements to cut operating cost and accelerate integration of the new systems within conventional HVAC systems. Different technologies reviewed in the paper can contribute to improve thermal performance of buildings with a decrease of cooling load. Combination of those strategies can further decrease cooling loads and develop energy efficient building of twenty first century.

The previous work suggests that Displacement Ventilation is feasible for subtropical Queensland through out the year and it will use less energy compared to a traditional system. The only limitation is that it can work with small load. The buildings of Rockhampton are pretty small and there is no high rise building. Studies on Central Queensland University office building (Engineering Building 30) suggested that load would not exceed 23W/m in any place as it does not contain any unstable heat sources.

Pre-cooling and Night Ventilation have prominent features in subtropical Queensland for passive cooling. The weather data shows that the average night temperature (highest 22^{o}C and lowest 9.4^{o}C) is suitable for pre-cooling and Night Ventilation. It will not only conserve night time traditional cooling cost but also offer a comfortable natural environment to the occupants. Complex control strategies are not required to maintain comfortable conditions. The pre-cooling will also reduce the starting load requirement of the building thermal mass thus offer saving towards peak demand charge. Cooling inside the buildings can be improved by the application of such cooling design. Combining evapo-reflective roof with night ventilation will increase such cooling more significantly.

Radiant cooling can be applied with cooling water sourced from passive means for subtropical climates. For instance, this strategy would be applicable to Rockhampton, Queensland because here cooling required for certain period of time specially at day time and usually low heat gain needs to be cooled to achieve thermal comfort. As suggested by Vangtook and Chirarattananon (2005), a cooling tower can be employed to provide cooling water for radiant cooling and for pre-cooling of ventilation air to achieve thermal comfort. No active cooling is required. For sophisticated condition, pre-cooling ventilation air with cooling water generated from active cooling can help to achieve thermal comfort superior to the case of conventional air conditioning. Substantial energy saving can still be achieved. In cases where cooling panels cannot influence air temperature sufficiently, it helps to reduce radiant temperature.

Desiccant cooling is also an established low energy cooling system and has got good track record over the years. For subtropical Queensland, it will also offer substantial monetary savings. To facilitate the applications in subtropical climate a system combining chilled ceiling with desiccant cooling is preferred for Rockhampton. It will save fan and chiller energy due to reduced air volume and raised evaporative temperature. Dehumidification by desiccant cooling will conserve much sensible energy and much more thermal comfort will result. If the system combining a chilled ceiling with air dehumidifier is maintained, the temperature and indoor humidity are decoupled and human comfort can be controlled independently.

There is significant potential to reduce energy consumption, since the conventional HVAC systems typically do not take full advantage of the climate conditions and tariff rate structure in Queensland. Ergon Energy (Electricity service provider) of Queensland, Australia offers special night rate for non-contestable consumer under tariff 31 super economy rate, which is 30% lower than usual peak hour rate. Based on the prevailing electrical tariff rates and demand charges under super economy rates thermal storage based air conditioning offer better incentives for Queensland's office buildings.

In the extremely hot and humid summer (November to February) in Rockhampton, passive cooling techniques alone may not guarantee comfortable conditions. Traditional mechanical cooling system may still be necessary.

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