ABSTRACT

There is increasing interest in Life Cycle Design with the purpose of raising sustainability and reducing energy and material consumption. By increasing energy efficiency, selecting more suitable materials and lessening maintenance requirements it is practical to reduce life cycle cost.

Conventional Heat pump air conditioners operate to effect a healthy and comfortable indoor environment. They are large consumers of energy, partly due to the need to exhaust air (with consequent energy wastage) from the conditioned building so that healthy ventilation air may be introduced in its place.

Rather than drawing all the energy from community electricity and gas supplies, the designer should design these systems so they recover as much energy as is feasible from both building exhaust air and the environment. A low life cycle cost solar air conditioner design is described that obtains under peak load more than 90% of its energy from a combination of building exhaust air and insolation with a reduction in life cycle cost approaching a factor of 10. In basic terms, with a reduction of a factor of 3 in energy consumption along with a life increase also of a factor of 3 it is possible to approach a factor of 10 improvement in product life cycle cost.

INTRODUCTION

The imperative for society to reduce its materials and energy consumption by improving the energy efficiency and longevity of products is thoroughly detailed in [5, 6 and 22].

This paper presents the case that some functional products have very large scope for improvement, by way of its example of a particular type of air-conditioning system.

The concept of “Factor 10” as outlined in [6] has far reaching implications relating to the environmental damage to the planet being caused by the combination of increasing population, materials and energy consumption and release of environmentally damaging products. “Factor 10” requires that humans immediately take actions to improve our products and processes by a factor of 10 in order to avoid disaster for future generations.

In a commercial environment, consumers are highly influenced by cost, particularly initial cost. The system presented in this paper was novel in 1970 and has demonstrated very large savings in energy consumption in several hundred installations. In addition the installations of the system have demonstrated longevity benefits in the years since. Despite these benefits it has not reached the status of having widespread recognition.
The main reasons for this lack of “progress” seems to be that the initial cost of systems to date is comparatively high and consumers do not seem to recognize long term benefits of improved energy efficiency and longevity in the same way as they understand the benefits of low initial cost.

This paper therefore focuses on life cycle cost with a view that the promotion of the potential for very large life cycle cost reduction will eventually gain recognition for this and other products whose development is hampered in the way that this one has been.

A wide range of conventional heat pump air conditioning products is available for summer and winter air conditioning that employ vapour compression cycles in which synthetic halocarbon chemical refrigerants are used [1]. Due to the ozone depleting and global warming potentials of earlier types, these are being phased out with new ones. The long term environmental, efficiency, safety and sustainability properties of the new gases are still to be discovered.

The design evolution of conventional vapour compression systems is partly driven by price competition of the factory manufactured packaged modules and partly by the objective to minimize installation space by reducing footprint of packaged equipment and ductwork as well as installation cost. Consequently, a recent trend is, to circulate the refrigerants through buildings by relatively compact insulated pipes rather than delivering conditioned air via more bulky ductwork. These compact systems are known as split systems in which the (separate) compressor-condenser module may supply refrigerant to multiple fan coil units positioned throughout the rooms of the building. Not only has this practice reduced the quantity of ventilation air but it has increased the potential for refrigerant leaking into the building and then into the ventilation air and environment [2].

These systems are largely driven by grid-electricity and place excessive demands on electricity supply, especially during extreme climatic periods. Because of the large energy demand of vapour compression systems, it is often customary to design the intake of ventilation air to a minimum level set by health codes. As an example of the significance of the energy requirement for ventilation air, the minimum health code requirement for commercial buildings is often of the order of 20 % of the total air supplied to the rooms. This mere 20% may well require 50 % of the energy handling capacity of the refrigeration plant on a hot humid day.

Thus the objective of having high indoor air quality (IAQ) [3] by increasing filtered outside air for ventilation is incompatible with the objective of minimizing energy consumption unless a non conventional sustainable design is used [4]. Designers face a huge challenge when designing low energy air conditioning systems with the intention of achieving high IAQ and major life cycle improvements [5] such as those required by the emerging concept of “factor 10 design” [6].

In this paper, two systems that fall into the category of non conventional sustainable design are described. Both of these systems, after a period of research in Australia’s Commonwealth Scientific and Industrial Research Organization, have had exposure in the field that may be described as early stage pilot manufacture at a virtually custom manufacture level. They are known as the Indirect Cycle Energy Recovery (ICER) system and the Dual Indirect Cycle Energy Recovery (DICER) system, both to be described in detail later in this paper. Both of these systems supply 100% outside air.

The ICER system is for relatively dry climates, given first cost consideration, in which 100% outside air for ventilation is required by regulation (or is simply preferred). This requirement (or preference) is to meet specified psychrometric requirements such as for residential, healthcare and laboratory facilities. This system uses a combination of energy recovery and indirect evaporative cooling (IEC) [7] in a polymer plate heat exchanger (PPHE) [8].

The DICER system is not restricted to dry climates and is appropriate for buildings requiring the same indoor psychrometric condition as the ICER system. This system may be used in humid climates, and the ICER indirect evaporative cooling and energy recovery system becomes the DICER system [7] of air conditioning. This system uses a combination of energy recovery and indirect evaporative cooling in a polymer plate heat exchanger augmented with a small reverse cycle vapor compression (VC) unit – for heating or cooling mode.

Both the ICER and the DICER systems use significantly less total energy than conventional vapour compression systems.

Typical applications of these systems of air conditioning use energy recovery from the exhaust air in commercial (or similar) buildings, where 100% outdoor supply air is required to satisfy a ventilation code [9].

We propose that very large improvements in life cycle design (of the order of factor 10) are possible and should be a major objective for researchers in the air-conditioning industry.

We begin by describing systems that have been field tested by research and development organizations in Australia [4, 10 - 12]. We also discuss how field installations and testing have demonstrated their long-term viability for energy efficiency (including peak demand reduction), low maintenance and longevity. The development of these systems has involved a long and arduous history due to the fact that the conventional competing technologies have reached a comparatively mature stage where their initial cost, due in part to large manufacturing volumes, is highly competitive. Also the cost, availability of power and its greenhouse affect have not been of the serious concern that they are today.
Having discussed the advantages of these systems, some of their limitations are also pointed out. These limitations relate to the relatively high capital and installation costs of the systems as they are currently constructed. (accentuated by low manufacturing volumes and to some degree lack of compatibility with existing building practices).

Finally, this paper outlines our views on the potential for overcoming the problems in order to achieve the factor 10 life cycle improvements over conventional practices in the air-conditioning industry.

**NOMENCLATURE**

- $F_R$: Air mass flow ratio:
- $t_1$: Primary air dry bulb temperature at inlet to the PPHE.
- $t_2$: Primary air dry bulb temperature at outlet from the PPHE (°C).
- $t_3$: Space air average dry bulb temperature (°C).
- $\varepsilon$: Dry Effectiveness
- $\varepsilon$: Ratio of actual heat transfer to the maximum possible heat transfer
- COP: Ratio of useful cooling effect to net energy input

**DESCRIPTION OF THE PPHE**

The Polymer Plate Heat Exchanger (PPHE) is the central element in the two main systems (ICER and DICER) described in this paper. It is an air to air cross flow plate heat exchanger (Figure 1). For the purpose of promoting heat exchange, the plates are thermo-formed with small turbulence promoting dimples and edge welded as illustrated in the figure to provide separate flow passages.

The PPHE is employed in three ways:

1. Purely as an air to air heat exchanger to recover energy from the stale air as it is exhausted from the building space (usually via the vertical passages of the PPHE). This is normally a winter mode of operation.

2. In a dry summer climate, the exhaust air passages are normally wetted as illustrated in Figures 1 and 2, whereby water becomes a natural refrigerant and in dry climates provides the total cooling effect with the benefit of 100% ventilation of the conditioned space. This configuration is known as an Indirect Cycle Energy Recovery (ICER) system that is more fully described in the next section.

3. In humid climates, water alone as the refrigerant, may not at all times, provide sufficient cooling effect to de-humidify the incoming ventilation air. The configuration known as the DICER system that is illustrated in Figures 3 and 4 is employed to dehumidify the ventilation air. The DICER system includes a choice of a factory sealed small vapor compression (VC) unit, a chilled water coil or desiccant unit (not discussed in this paper) to provide dehumidification. The DICER system is more fully described in a following section.

**ICER SYSTEM OVERVIEW**

The ICER system [10] provides a simple and efficient method for conditioning building supply air in climates that have moderately humid conditions not exceeding a humidity ratio of 12 g/kg. The ICER system comprises a complete package with fans and water pump that performs the following:- filtration, ventilation, exhausting, energy recovery and cooling or heating.

![ICER System Diagram](image)

**Figure 1:** Polymer plate heat exchange (PPHE) diagram showing typical air flows in PPHE heating mode.

**Figure 2:** Circuit diagram illustration the principles of operation of the ICER system.

A circuit diagram (Figure 2) illustrates the principles on which the ICER system operates.

The ICER system provides two air pathways, one for building supply and/or ventilation air (normally horizontal). In the cooling mode, this air loses heat energy and the other pathway which is for building exhaust air (normally vertical) gains heat energy. The directions of the air and water flows are
illustrated in Figures 1 and 2. Thus the exhaust air extracts heat from the supply air indirectly through the heat exchanger medium. The heat exchanger core is a cross-flow polymer plate heat exchanger (PPHE) where (in the cooling mode) water (the refrigerant) wets the exhaust passages providing indirect evaporative cooling in addition to the exhaust air energy recovery which occurs.

The effectiveness ($\varepsilon$) of the PPHE cross-flow arrangement is in the range of 0.75 to 0.85 in its cooling mode, depending on air flow as well as indoor and ambient conditions. This is a high effectiveness due to the high coefficient of heat transfer that is achieved by the plate designs [8]. Early prototype designs of ICER systems have been operating efficiently and reliably since 1981 with many being in extreme outdoor conditions with high salt content in the water supply. The plate material has maintained its integrity and performance for 25 years. Only one or two installations have required PPHE replacements after this time – demonstrating longevity. There are two modes of operation: cooling and heating by energy recovery. In the cooling mode the system attains a very high COP of over 12 [8] in contrast to typical vapor compression COPs of 2 to 3. Further, the COP of Indirect Evaporative Cooling systems tested by various researchers is concluded to be in the range of 12.5 to 22.3 [13]. Thus it is well established in the present state of the art that the COP of an indirect evaporative cooling system operating in a dry climate is very high compared to a vapor compression system. The high COP is due to the combination of evaporative cooling and energy recovery in the PPHE, for which the only energy input is the fan and the pump.

ICER system cooling mode:
Supply air is cooled as it passes through the primary set of passages in the PPHE. This air transfers heat to the exhaust air drawn from the building as this air flows through the wetted secondary set of separated alternating passages.

ICER system heating mode:
No water is circulated to wet the secondary passages in the heating mode. The exhaust air heats the supply air as it passes through the primary passages. Thus the supply air recovers building heat energy from the exhaust air. Additional heating may be provided indirectly (e.g. gas burner or hot water coil) to the supply air by adding a heating source in the exhaust air stream prior to the PPHE.

FIELD TESTS OF ICER SYSTEM
Early field tests were performed by the Australian organizations: Commonwealth Scientific and Industrial Research Organization (CSIRO) and Telecom in the 1980s. The aim of the tests was to establish the performance in practice and compare the energy usage between the ICER systems and comparative vapor compression systems for conditioning of telephone exchanges. The test results concluded that ICER systems provide ventilation air in large quantities with one fifth to one thirteenth the energy usage of vapor compression system for most parts of Australia [14].

Thus the field trials and performance monitoring concluded that for large scale applications, where ventilation air quantities are large, the ICER system could make a major contribution to global energy conservation.

Case studies conducted by other researchers have concluded that indirect evaporative cooling systems (such as the ICER system) could save between 40 and 70% of total demand for energy compared to traditional air cooled vapor compression refrigeration systems [15, 16].

DICER SYSTEM OVERVIEW
The DICER system (Figures 3 and 4) combines an ICER system with an auxiliary means for either or both dehumidification and heating of air supplied to a building. The unit may be sized to treat the ventilation component of a conventional system having some re-circulated air or alternatively, to provide 100% ventilation air to the building. Thus the DICER system is capable of treating all environments including both humid and cold climates.

Figure 3: DICER configuration, Figure legends: E/A – Exhaust air, PPHE – Polymer plate heat exchanger, S/A – ventilation/Supply air.

Cooling mode: The DICER system can have three embodiments: one containing a relatively small VC system that has an evaporator coil in the building exhaust air stream before it enters the heat exchanger and a condenser coil in the exhaust air stream after it leaves the PPHE as shown in Figure 3. The ventilation/supply air is cooled and if required dehumidified as it passes through the primary passages in the PPHE. The wet bulb temperature of the exhaust air is reduced in the evaporator so that when it is wetted in the exhaust air
secondary passages in the PPHE its dry bulb temperature is sufficiently lowered to both cool and dehumidify the supply air through the plates between the secondary and primary passages.

To cause a high level of wetting of the exhaust air, water is circulated through solid cone spray nozzles into the secondary passages from a lower water collection basin. The temperature of the basin water becomes close to the wet bulb temperature of the exhaust air after it leaves the evaporator coil. When dehumidification is occurring the condensed water also runs into the water basin. This water is then used for evaporation in the secondary passages and finally discharged as clean vapour into the outdoor environment. In many regulatory codes condensed water from dehumidifying coils is required to be disposed of by gravity or pump into the community sewerage system for hygienic reasons. So the DICER system has a sustainable benefit in this embodiment due to its not only saving water from the town supply but also the energy used in the sewerage system. Instead it safely returns the condensed water as vapour back into the environment.

![Figure 4: DICER system with chilled water coil.](image)

In the arrangement of the embodiment using a VC the efficiency of the VC system is enhanced by passing the relatively cool exhaust air that leaves the PPHE, over the air cooled condenser. The condenser operation then approaches that of one that is water cooled.

The two other DICER embodiments that are available use either chilled water in place of the VC evaporator coil (Figure 4) or a liquid desiccant system (not shown) to reduce the wet bulb temperature of the exhaust air. In both these embodiments the water condensed from the air stream is evaporated in the exhaust air passages and disposed as vapour into the outdoor environment. The chilled water embodiment assumes there is a supply from elsewhere.

**Heating mode:** The same equipment used for the cooling mode embodiments can be used for heating the ventilation/supply air. The auxiliary VC system, set to reverse cycle mode, provides pre-heating of the exhaust air so that the evaporator becomes a condenser in the exhaust air stream and the condenser becomes an evaporator in the outside air.

As shown in Figure 5, The COP of the DICER system in heating mode increases to about 4.5 when the outdoor temperature is 0°C whereas the conventional VC system’s COP deteriorates to 1. Typically when ambient temperature is between 5°C and 7°C damaging frost begins to form on the evaporator coil of a conventional VC system. In order to combat the frost formation the control system initiates a defrost mode causing hot gas to pass through the evaporator. During this period there are transient energy and performance losses due to the switching into and out of the defrost mode. To overcome the defrost complication and maintain suitable air temperatures in the building, inefficient electrical resistive heating is widely used, resulting in the low COP of 1.

However the exhaust air that is discharged from the DICER system, after indirectly heating the ventilation/supply air, is relatively warm compared to outside air and is passed over the evaporator coil. This enables the VC to operate without frosting at lower than freezing temperatures. Avoiding frosting at lower than freezing outdoor temperature depends on the dryness and temperature of the exhaust air as it exits the PPHE.

The DICER embodiment that uses a chilled water coil for summer cooling may be piped to switch to hot water in the winter either in the same coil or a different coil (if preferred so as to prevent corrosion in the system and mixing of different water treatments). The storage of hot water can enable the use of solar energy either in total or for part of the heating energy needed. Liquid desiccant may also be used in heating mode by making use of its temperature rise when in contact with moist exhaust air. There is an advantage compared to hot water in storing concentrated desiccant for heating (as for cooling) as it does not require insulation. The hot water heating embodiment assumes there is a sustainable source of hot water from an efficient generator and/or solar system.

**Operation of the auxiliary VC system:**

The coils of an auxiliary VC operating within a DICER system always operate in relatively stable conditions compared to the coils of conventional air cooled VC systems. This is because one of the coils is positioned directly in the exhaust air stream at approximately the stable room temperature whilst the other is in the same stream, after the PPHE. This positioning of these coils results in a relatively small differential temperature between the coils with consequent high COP’s for both heating and cooling modes.

Despite the relatively high COP of the auxiliary VC its use should be minimized and the use of the even more energy efficient PPHE should be maximized by a suitable control system.
Another benefit of the stable coil temperatures of the auxiliary VC unit is that exhaust gas defrosting is rarely required except in extremely cold external conditions.

**COEFFICIENT OF PERFORMANCE COMPARISONS**

Coefficient of performance (COP) is defined as the ratio of thermal energy (kW) output to the electrical energy (kW) input to the system. Sometimes the COP is expressed as energy efficiency ratio (EER) which is the ratio of BTU (thermal energy in British Thermal Units) output to electrical energy input (kW).

In this paper, performance comparisons are expressed in terms of coefficients of performance and the COP’s of the ICER and DICER systems are compared with the COP’s of conventional vapour compression systems. Comparative data is graphed in Figure 5. The graphs for both ICER and DICER systems are from actual field trials carried out in the early 1990's and therefore the performance of typical (air cooled) vapour compression systems of that era have been graphed for comparison. Note that, since that time, improvements in energy efficiency of systems have occurred. These improvements have been driven by the U. S. law and regulated by the U. S. Department of Energy (DOE) [17]. However the similar types of improvements that apply to the conventional VC systems are also possible with the ICER and DICER systems, so the relativity of the comparisons is still valid in 2006.

In summary, the COP’s of both ICER and DICER systems improve as outdoor temperature move away from the ideal temperatures of around 22 to 24 °C. In contrast the COP’s of conventional vapour compression systems deteriorate as conditions become more extreme, either hot or cold.

**PERFORMANCE AND ENERGY SAVINGS WITH A DICER SYSTEM WITH REFERENCE TO THE PSYCHROMETRIC CHART**

The psychrometric chart Figure 6 graphs the processes occurring in a DICER system operating with 100% ventilation air at state point 1 and supplied to the rooms at state point 2. Note that the state numbers are also shown in Figure 4. The line 2-3 shows the room heat gains and state point 3 is the room condition. Line 3-4 shows duct heat gains and at state 4 the air enters the exhaust side of the heat exchanger before it is cooled and dehumidified in the cooling coil. The active cooling coil is only operating from the room condition to state point 5. After state point 5 the air enters the heat exchanger secondary passages where it contacts with water sprays and heat is exchanged between primary air and secondary air. At the exit there is sensible heating due to condenser heat rejection from state point 6 to 8 [19].

A DICER system will provide superior energy performance over a conventional vapour compression system in a situation requiring a large ratio of ventilation air to total air circulated within the building. Buildings such as healthcare and laboratory facilities require large amounts of ventilation air with zero recirculation air.

We have chosen a situation requiring 700 L/s of ventilation air with no recirculation to compare the performances of a DICER system with a conventional vapour compression system. Table 1 tabulates the cooling and heating loads for summer and winter design condition for some of the Australian cities that have sufficient humidity to require the DICER system rather that the ICER system. A weakness of a conventional vapour compression system is that in order to dehumidify air it must overcool it in the cooling coil. This requirement demands excessive energy. Table 1 records only the thermal load calculations (not the electrical input power) based on standard design conditions for these cities.
Figure 6: DICER Psychrometric Performance Chart.

The user of a system is more concerned with the net power consumed by the air-conditioning system. If we compare the DICER system cooling load for Sydney (13 kW) with the VC system cooling load for Sydney (22 kW) and take into account that the seasonal average COP for the DICER system may be 4 compared with a VC system’s COP of 2 our comparison becomes:

DICER system: \[ \frac{13}{4} = 3.25 \text{ kW} \]
VC system: \[ \frac{22}{2} = 11 \text{ kW} \]

We note that these are crude figures based on mid range COP’s taken from Figure 4. Since the time of the data of Figure 5, COP’s for both systems have (potentially) improved due to energy efficiency improvements in electric motors, fans, pumps, compressors and control systems.

Table 1: Energy Savings and Performance at 700 L/s air flow (100% outdoor air).

<table>
<thead>
<tr>
<th></th>
<th>DICER (kW)</th>
<th>VC (kW)</th>
<th>Cooling Energy Saved (kW)</th>
<th>Heating Energy Saved (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney</td>
<td>13.0</td>
<td>22.0</td>
<td>9</td>
<td>8.7</td>
</tr>
<tr>
<td>Brisbane</td>
<td>13.0</td>
<td>29.0</td>
<td>16</td>
<td>5.7</td>
</tr>
<tr>
<td>Darwin</td>
<td>13.0</td>
<td>40.0</td>
<td>27</td>
<td>1.8</td>
</tr>
</tbody>
</table>

A far better comparison would involve comparison between the two systems of seasonal/year round energy consumption. However, in the absence of seasonal trials, we believe that a reasonable aim in the research and development of the DICER system is a factor of three improvement in energy efficiency over the conventional vapour compression system.

Clearly, the energy savings benefits of DICER systems depend on the seasonal climatic profiles of different geographic locations. A DICER system has its greatest benefit at high temperature and low humidity when it essentially operates as an ICER system at comparatively, very high COP.

Some cities (Perth and Adelaide, Australia) have many hot days during their dry summer period. Not all people of these cities are satisfied with a system that fails to provide ideal indoor conditions on the few humid summer days that occur in these cities. In these cities, a system of the DICER principle will operate on the ICER principle (at high COP) throughout most of the summer except for a few humid days when the augmented vapour compression system is required.

So far in this paper we have considered summer operation where large benefit is obtained by indirect evaporation of water as the refrigerant.

The DICER system (also the ICER system) is not only effective during summer, but is also suitable for winter heat recovery. In this mode of operation the DICER system’s performance is similar to air to air heat exchangers without mixing between the supply and exhaust air.

The effectiveness for the DICER system in this case, is the same as defined for a rotary heat exchanger and the flow ratio \( F_R = 1 \) for balanced flow where mass flow rate for primary and secondary air is taken as equal [11].

\[
\varepsilon_D = F_R \frac{t_2 - t_1}{t_3 - t_1} \tag{1}
\]

In applications like this the dry effectiveness of the heat exchanger is taken to be 0.75. This effectiveness is not quite as high as the effectiveness for the evaporation mode of operation when the wetness of the exhaust stream plates promotes improved (more even) heat transfer. The pressure drop in the heat exchanger is also reduced as the exhaust air does not have to overcome the resistance of water droplets on its way out. Knowing the effectiveness and flow ratio, \( t_2 \) (which is the supply temperature to the rooms) may be estimated.

\[
t_2 = t_1 + \frac{\varepsilon_D \times (t_3 - t_1)}{F_R} \tag{2}
\]

The outdoor air is sensibly heated from 7.2°C (winter design condition for Sydney) to 15.5°C by exchanging heat from the room which is held at 21°C DBT and 30% RH. This is sensible heating process of the air along the constant humidity ratio line.
Das heating process for a DICER system with energy recovery (for Sydney winter design conditions) is shown in Figure 7. Depending on the heat loss of the building and internal heat generated, extra heating may or may not be required. Process 1 → 2 is the heat energy conserved and process 2 → 3 is the required extra heating if necessary. The dotted line shows that there is no need for humidification as long as the temperature is within the comfort zone as per the ASHRAE comfort standard 55 – 2004 [20].

Factor 10 Concepts and Design

The factor 10 concept emerged from concerned scientists searching for “a different way to protect the environment, an approach to sustainability that could be an integral part of the market and yield profits rather than generate costs. Violent and life-threatening reactions of the ecosphere to the stresses imposed by human activities are still growing in all parts of the world. Humanity continues to live in an increasingly dangerous and unsustainable environment. Essential environmental services are declining at an alarming pace. More people are exposed to polluted air and have less clean water available than ever before and fertile soil is eroding fast. Fresh water supplies are dwindling, bio-diversity is still rapidly declining, and so are forested areas.” [6]

In has been stated that not enough water, raw materials and space are available to support the current consumption of materials. More than 3 planets would be required to sustain the present way of life [5]. Thus it is realized by many scholars of this area, that if the human race is to sustain life on this planet we have to change our consumer behavior towards materials and energy.

Factor 10 is not an economic goal but rather a sustainability issue to achieve improvements in productivity by a factor 10 improvement for products that we consume in daily life [21]. This improvement requires improvements in the product, materials, performance, cost etc. In this paper the particular method of air conditioning can achieve a factor 10 design, where we have shown the performance to be 2-3 times higher than the conventional vapor compression system. The field trials so far have demonstrated that these types of air conditioner last about 3 times longer than the conventional vapor compression systems. Thus if the cost to the buyer is the same, we argue that this particular method of air conditioning has improvements at factor 10 level.

Having factor 10 design does not necessarily address the problems associated with this type of air conditioning system. Some of the problems are inherent with the current embodiments such as large size, expensive installation cost, and indeed, high initial equipment cost due to the low production volumes. Research, followed by product development, following sustainable design principles, initially targeting applications where the systems are most advantageous, such as those requiring high (especially 100%) ventilation air is almost certain to reap very significant improvements in sustainable air-conditioning.

Conclusion

The low running cost of indirect evaporative cooling is thoroughly investigated by many authors. Dry climates with high summer temperatures are ideal for indirect evaporative air-conditioning. We have described a system centered around a cross flow plastic plate heat exchanger that provides, not only effective heat recovery but internal evaporation of water, as a refrigerant, within the heat exchanger, thus eliminating the excessive energy required for conventional vapour compression refrigerated air-conditioning.

In addition we have explained how a conventional component, such as a relatively small vapour compression system may be included in the circuit of this system to extend its application to a wide range of climatic conditions (including conditions of greater humidity), in this way increasing its versatility in providing reduced energy consumption compared to conventional systems.

The application of this technology particularly applies to hospitals, schools, clean rooms, office buildings, clubs and large residences and is particularly advantageous where above average ventilation air is required.

Typical (seasonal) coefficients of performance for these systems vary with varying local climatic profiles, however, we believe that research on these systems should reasonably aim for a factor in the order of three in energy consumption.

Further research work and trialing should be done, by way of simulation and instrumented field installation in order to
assess the seasonal energy economy of these systems when operating in varying environments.

Early trialing at a custom building level has demonstrated that the simplicity of construction of these systems enables them to be designed for long life, once again, improving product life by a factor in the order of three.

Experience so far indicates that systems of this nature have the potential to be developed for high volume production, so that their initial cost becomes more competitive, whilst giving life cycle cost benefits to the user in the order of a factor of ten.

In addition, design following sustainable design principles should aim at a true Factor ten in terms of environmental impact.

REFERENCES
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