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Developments in Evaporative Cooling of Buildings in Maritime Climates

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Introduction

Concern with environmental emissions has focused attention on traditional forms of energy use in buildings, with a view to reducing and making more rational use of energy consumption. One area of concern is the traditional, refrigeration based, commercial air conditioning system, which has high levels of electrical power consumption in fans and refrigeration compressors. There is also concern among building owners and design teams, supported by the PROBE series of post occupancy studies, conducted by the CIBSE, that many buildings, with traditional forms of air conditioning, under perform in terms of occupant satisfaction, ease of operation and control, maintenance costs and successful commissioning.

In parallel with this there is the growing belief that more sustainable forms of building cooling, such as chilled ceilings, can often prove to be more successful in use, in the temperate North European climatic conditions, particularly in buildings with lower occupancy densities and where a high performance envelope is employed. Such envelopes are often designed in conjunction with high levels of heat attenuation in the building structure and fabric. In such circumstances general sensible cooling loads can be reduced to approximately $60W/m^2$. The traditional, refrigeration based, air conditioning systems were developed in North America and, arguably, are more suited to a continental land mass climate with discrete seasonal changes, high external loads, and high levels of external humidity in summer. Such systems typically require cooling water at between 5 and 8˚C and are more appropriately used where tight control of humidity is essential (such as in some industrial applications) or where high occupancy levels or local conditions give rise to high cooling loads. Chilled ceiling systems, however, require cooling water at 14 to 18°C while displacement ventilation systems typically supply air at 19 or 20°C to the space and hence can also use higher temperature cooling water. Such elevated cooling water temperatures provide an opportunity to use evaporation techniques to generate the cooling water for large portions of the year, even in maritime climates. Figure 1 shows a schematic diagram of a simplified evaporative cooling system.

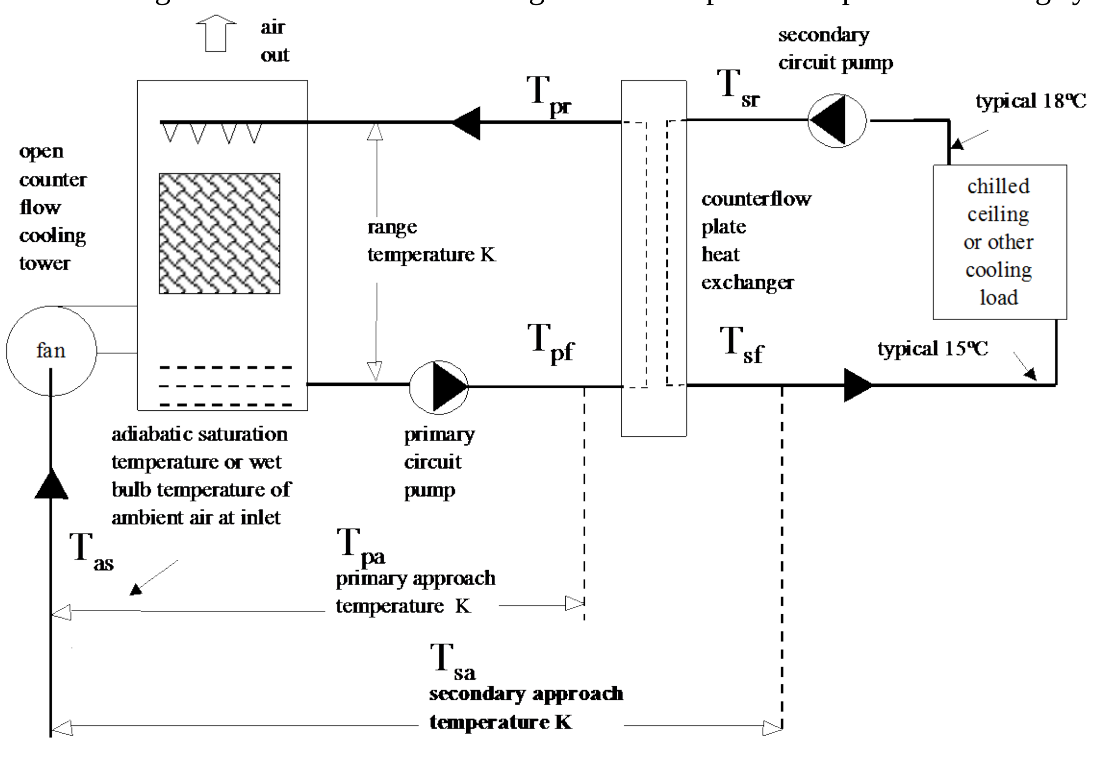

Figure 1. Simplified schematic of an indirect evaporative cooling system (IDEC)

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While water side evaporative cooling arrangements have been used occasionally, with air-water systems, particularly in more arid climates, the use of the technique falls far short of its potential. This is particularly the case in West European temperate climates where many opportunities to benefit from evaporative cooling techniques are often overlooked This situation is frequently attributed to a lack of in-depth knowledge of the performance, design optimization and degree of availability of evaporative cooling, particularly in temperate and maritime conditions. To address this issue an experimental research programme was established in 1998 in the Department of Building Services Engineering at DIT, Bolton Street, in conjunction with the Department of Mechanical Engineering, at UCD, Belfield. The programme is supported financially by the CIBSE, Enterprise Ireland and the DIT. Many other local companies have also donated equipment and services, to the project.

Evaporative Cooling and Chilled Ceilings

While the evaporative cooling technique can be exploited with any water based building cooling system, such as the commonly used fan coil system, the technique is particularly advantageous when a chilled ceiling system is used due to the higher cooling water temperatures which are employed and the higher levels of availability which result. A traditional all air, air conditioning cooling system is shown in Figure 2. The system uses chilled water at 5 to 8˚C to cool air to 12˚C, which then cools the room by creating a convection air current in the space. In contrast the chilled ceiling panel system, shown in Figure 3 cools the room partly by radiant heat exchange between the hotter room surfaces and the ceiling, which is maintained typically at a surface temperature of 17˚C. The ceiling panels are supplied with water, typically at 15˚C and return to the cooling system at 18˚C thereby extracting heat from the room. The ceiling cooling water circulates through a heat exchanger as shown in Figure 1. The heat exchanger is connected to an open cooling tower, which cools the primary circuit water by evaporation. It is advisable to separate the open tower water from the chilled ceiling panel water by means of a heat exchanger, even though this introduces a further stage of heat transfer, and results in a small reduction in cooling availability.

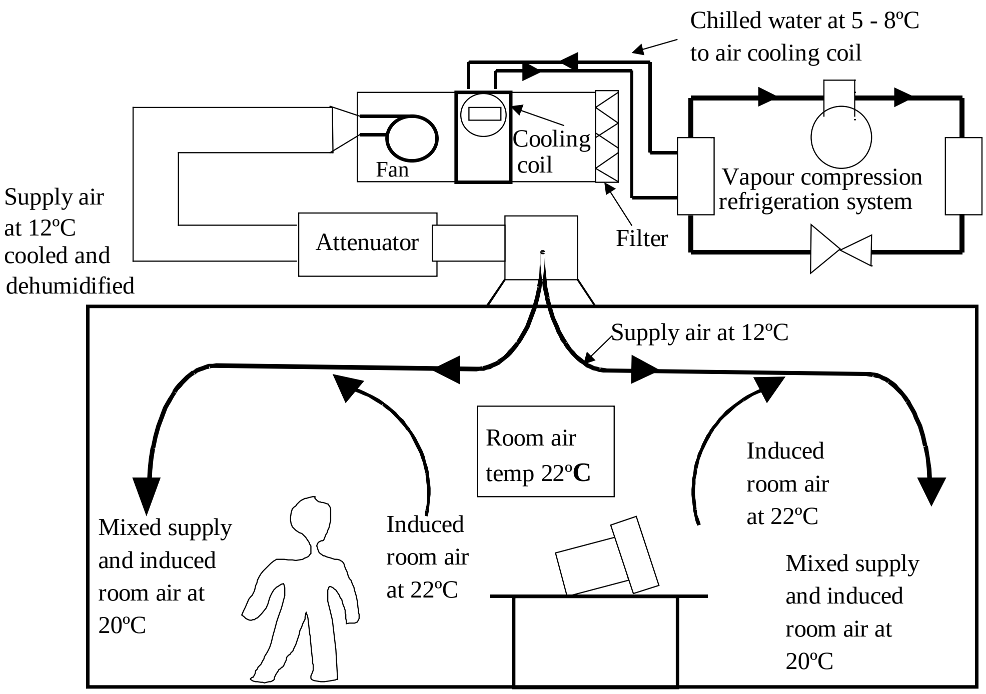

Figure 2. Traditional (all air) air conditioning cooling system

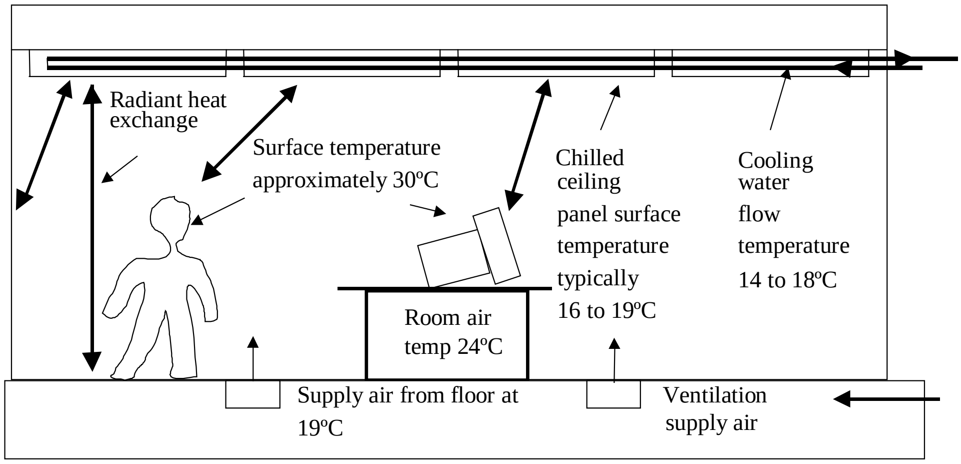

Figure 3. Principle of radiant cooling by chilled ceilings

The Annual Cooling Load Profile of Buildings

Another important factor, which supports the case for evaporative cooling is the change which has occurred in the annual cooling load profile of many commercial buildings, as a result of the introduction of the high performance building envelope. The use of high levels of fabric insulation, high performance glazing, more effective solar shading and, in particular, greatly improved standards of air tightness, has brought about a change in the traditional cooling load profile of commercial buildings. The summer peak external heat gain has been reduced, while simultaneously the ability of the envelope to dissipate internal heat gains, in the colder months been largely removed. This development has resulted not only in a reduction in the peak heating and cooling load, but also in a longer cooling season and shorter heating season in many recently constructed commercial buildings. The trend towards deeper plan layouts has served to further reinforce this change.

Buildings with long cooling seasons or year round cooling requirements are particularly suited to evaporative cooling as the cooling load extends into periods of the year with good evaporative cooling potential, due to the lower ambient wet bulb temperatures experienced in the non summer months. Wet bulb temperatures at or below 12°C, for example, are typically available in Dublin for 7,100 hours per annum or 81% of a typical year. Similar conditions are available in London for 6,300 hours per annum, or 72% of a typical year. Higher wet bulb temperatures, which generate higher cooling water temperatures, offer even greater levels of availability.

The Evaporative Cooling Process

When the issue of evaporative cooling arises, it is sometimes argued that as the ability to generate cooling water by evaporation depends on the ambient relative humidity and, as the relative humidity in the temperate maritime areas of North Western Europe is generally high, such locations are not suited to evaporative cooling techniques. While it is true that the relative humidity in temperate maritime areas is generally high (in Dublin, for example, the relative humidity is virtually always above 65%, and is above 75% for seven months of the year), the key governing parameter of the evaporative cooling process is not the relative humidity but the ambient wet bulb temperature. As the wet bulb temperature is, generally, relatively low in temperate climates (for example, it is less than 11˚C in Dublin for nine months of the year) the ability to generate cooling water at temperatures suitable for modern building cooling systems is often considerable.

The wet bulb temperature is a measure of the enthalpy or total heat contained in the ambient air. The total heat is composed of two components; the sensible heat, which is indicated by the dry bulb temperature, and the latent heat which is indicated by the moisture content of the air. The wet bulb temperature quantifies both of these components and governs the temperature to which water can be cooled by evaporation techniques. The temperature difference between the building cooling water and the ambient wet bulb temperature is known as the secondary approach temperature (SAT), see Figure 1. This is a key feature of the process as it governs the extent of cooling water availability. In the past it has been common to use a secondary approach temperature of 4 to 5 K. It has been established, however, in this research programme that SAT conditions as low as 3 K are viable with modern designs of cooling tower and plate heat exchanger. Hence it is possible to generate cooling water, for indirect supply to building cooling systems at a temperature of 3 K above the ambient wet bulb temperature. This is significant as it raises availability levels above those previously considered viable. As ambient wet bulb temperatures in Dublin vary from 0 to 18˚C, the range of possible cooling water temperatures is 3 to 21˚C.

Table 2 shows the frequency of wet bulb temperature occurrence in Dublin in the period 1966 to 1995 and the associated possible cooling water temperatures, based on a 3 K secondary approach condition. By using this table it is possible to estimate the annual extent of sensible cooling availability, with various design cooling water temperatures. A displacement ventilation system, for example, which supplies air to the space at 20˚C, will require cooling water at maximum 18˚C. Statistically cooling water at this temperature can be generated in Dublin for 8440 hours per annum, or 96% of the year. Chilled ceilings require cooling water at 14 to 18˚C and hence availability levels range from 74 to 96%. Fan coil systems require cooling water from 11 to 14˚C and hence have availability levels of 51 to 74%. It is clear therefore that high levels cooling water availability are possible with evaporative systems, and that such availability can be maximised with cooling systems which can use higher temperature cooling water, such as chilled ceilings, in buildings designed to minimise internal and external cooling loads.

External wet bulb temperature degree °C	Number of occurrences at the wet bulb temperature	Number of occurrences at & below the wet bulb temperature	Percentage of occurrences at & below the wet bulb temperature	Chilled water temperature possible at 3 degrees K Secondary approach	Average annual hours at & below the wet bulb temperature
-9	0	0	0.00	-6	0
0	5348	9779	3.72	3	326
6	**19672**	**94360**	**35.88**	**9**	**3145**
8	20285	135350	51.47	11	4512
10	20229	175951	66.91	13	5865
11	**19773**	**195724**	**74.43**	**14**	**6524**
12	**18383**	**214107**	**81.42**	**15**	**7137**
13	16412	230519	87.66	16	7684
14	13435	243954	92.77	17	8132
15	**9260**	**253214**	**96.29**	**18**	**8440**
16	5355	258569	98.33	19	8619
17	2712	261281	99.36	20	8709
18	**1196**	**262477**	**99.81**	**21**	**8749**
19	367	262844	99.95	22	8761
20	92	262936	99.99	23	8765

Table 1. Frequency of occurrence of hourly wet bulb temperature in Dublin in the period 1966-1995 (source: meteorological office)

While the research programme has focused initially on establishing a viable secondary approach condition, later work has addressed such issues as the variation in cooling water temperature with wet bulb condition and the important question of the energy efficiency of the process in comparison with the refrigeration based alternative. Health and safety concerns associated with wet cooling are also addressed. The results of this research will be discussed in Part 2 of this article, next month.

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Figure 4. General view of forced draft counter-flow cooling tower. Overall dimensions 0.914 x 1.207 x 3.436 high excluding air intake. (local marshalling terminals for data monitoring and control system shown at low level)