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Research into Evaporative Cooling of Buildings in Maritime Climates

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The Research Programme

In part 1 on this article, last month, the evaporative cooling of buildings was described and the reasons for the current interest in the technique outlined. This month, the results of the evaporative cooling research programme are discussed and the potential of this alternative method of building cooling, in Irish climatic conditions, reviewed.

The temperature of the water exiting from the cooling tower and hence the temperature of the water supplied to the ceiling is limited by two factors – the wet bulb temperature of the ambient air and the secondary approach condition of the tower and heat exchanger (or the temperature difference between the water supplied to the building cooling system and the ambient wet bulb temperature). The secondary approach temperature (SAT) is an important feature of the evaporative cooling process as it has a major influence on the level of annual cooling availability, particularly in Dublin, as shown in Figure 1, which indicates the impact on annual availability of reducing the SAT from a more conventional 8K to the 3K outlined in this work. Availability of cooling water at 16˚C, for example, increases from 50% at 8K SAT to 88% at 3K SAT, while availability of cooling water at 10˚C rises from only 10% at 8K to 50% at 2K. Hence as the secondary approach temperature is reduced cooling availability increases considerably, however the electrical energy consumption of the process also increases. Hence the optimization of the approach condition is a key aspect of the current research programme.

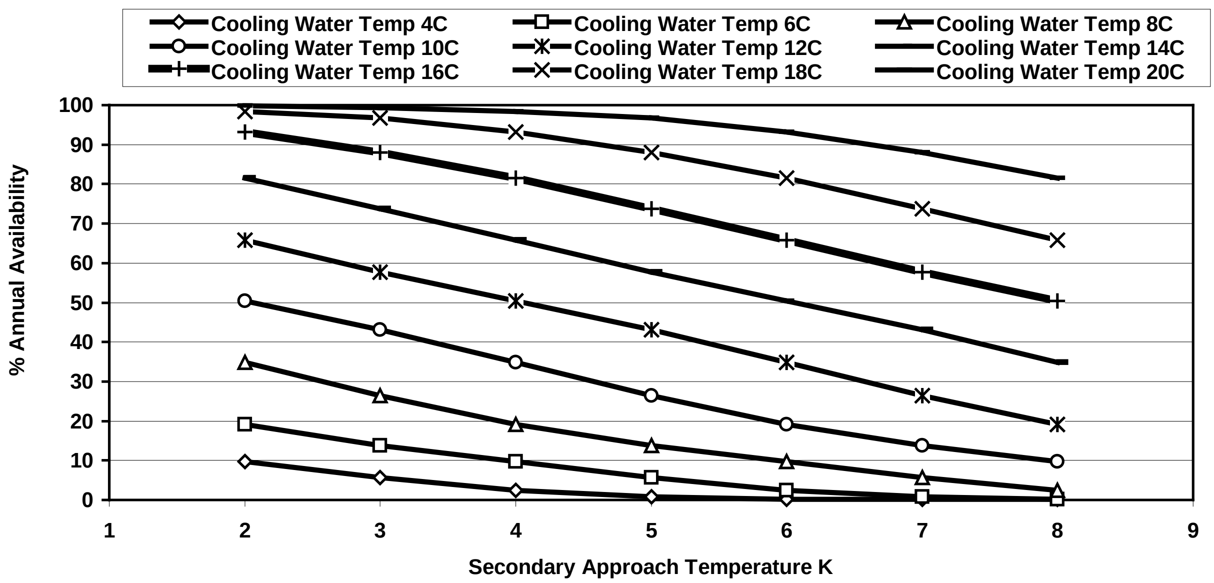

Figure 1 Impact of SAT on percentage annual availability of cooling water in Dublin.

Some results from the research work are summarised in Table 1 below. Test were conducted on the experimental rig at varying load and ambient wet bulb temperatures. The tests indicate that a 3K secondary approach condition is feasible with a 20 kW cooling load (column 6). It is also noted that the approach condition seems to fall slightly as the ambient wet bulb temperature rises. This aspect favours the evaporative cooling of buildings as availability is improved in summer when ambient wet bulb temperatures and cooling loads are higher.

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1	2	3	4	5	6
Nominal Load	**Wet bulb temperature (WBT)**	**Primary flow temperature from tower**	**Secondary flow temperature from heat exchanger**	**Primary approach to WBT**	**Secondary approach to WBT (SAT)**
kW	°C	°C	°C	K	K
24	6.4	8.7	10.7	2.3	4.3
24	11.1	12.8	14.6	1.7	3.5
20	**9.2**	**10.6**	**12.1**	**1.4**	**2.9**
20	**10.2**	**11.3**	**12.9**	**1.1**	**2.7**
20	**12.5**	**13.5**	**15.1**	**1.0**	**2.6**
20	**16.5**	**17.4**	**19.0**	**0.9**	**2.5**
15	9.3	10.6	11.7	1.3	2.4
15	10.6	11.6	12.8	1.0	2.2

Table 1. Summary of experimental test results from prototype cooling tower test rig

Variation in Availability Levels

As the cooling water temperature generated by evaporation varies constantly in response to the wet bulb temperature of the ambient air, the annual percentage availability needs to be examined in terms of the monthly variation through out the year. Statistically, for example, cooling water at 18˚C can be generated in Dublin for 8440 hours per annum, or 97% of the year. Table 2 shows the breakdown of this availability across all months. From this table it can be seen that availability of water at 18˚C is reduced to 80% in July, 90% in August and 91% in September. However buildings which are lightly occupied during these months, such as in education, may be cooled throughout the year using evaporative cooling. Traditional buildings which are heavily occupied during the summer months would generally require supplementary refrigeration based cooling, at least in selected areas. However supplementary refrigeration based cooling may be avoided, altogether in some buildings, with evaporative cooling systems, in temperate climates where a high level of heat attenuation is incorporated by exposing the thermal inertia of the building structure. This could be achieved in conjunction with a more flexible and adaptive approach to comfort conditions such that higher internal comfort conditions are accepted in high summer.

	Cooling water temperature ˚C													
Month	-2	0	2	4	6	8	10	12	14	16	18	20	22	**Month**
Jan	0	1	3	8	24	46	74	91	98	100	100	100	100	**Jan**
Feb	0	0	0	7	26	49	79	99	100	100	100	100	100	**Feb**
March	0	0	0	8	25	52	85	97	100	100	100	100	100	**March**
April	0	0	2	8	21	49	79	84	97	100	100	100	100	**April**
May	0	0	0	0	1	7	23	59	90	100	100	100	100	**May**
June	0	0	0	0	0	1	3	25	71	92	99	100	100	**June**
July	0	0	0	0	0	0	1	4	18	52	80	95	100	**July**
Aug	0	0	0	0	0	0	0	2	14	52	90	99	100	**Aug**
Sept	0	0	0	0	1	3	12	24	44	74	91	99	100	**Sept**
Oct	0	0	0	0	1	9	24	43	66	89	99	100	100	**Oct**
Nov	0	0	3	14	27	43	61	76	88	99	100	100	100	**Nov**
Dec	0	1	3	24	40	60	79	92	100	100	100	100	100	**Dec**
Annual %	0	0	1	6	14	26	43	58	74	88	97	99	100	

Table 2. Annual availability potential of cooling water in Dublin at 3 K SAT (percentages)

While the ambient wet bulb temperature is more stable than the ambient dry bulb temperature, the daily variation in the wet bulb temperature produces similar variations in the cooling water temperature generated and was therefore, also, considered in the research programme. The daily variation, in cooling water temperature, over the course of the working day, is relatively small, at typically, 2˚C. For example Figure shows the diurnal variation in conditions as measured for the 6th of September 2000. On this day the cooling water temperature generated varied from 14.5 to 16˚C, with a typical value of 15˚C and with a return temperature of 18˚C. Such temperatures are very suitable for use with chilled ceilings. The close tracking between the secondary flow temperature and the ambient wet bulb temperature is also evident. In general chilled ceiling systems can tolerate a variation in cooling water temperature of this magnitude, as they have a high degree of self regulation, with cooling output being maintained when the cooling water temperature and room temperature rise by similar amounts, For example, a cooling water temperature supplied to a chilled ceiling at 16˚C and returning at 18˚C, with a room temperature of 23˚C produces approximately the same cooling output as a supply of 18˚C returning at 20˚C with a room temperature of 25˚C. Another feature of these tests is that the ambient wet bulb temperature is significantly more stable that the ambient dry bulb temperature (which varies from 16 to 19˚C). This indicates that wet cooling is preferable to dry cooling, even on those occasions when the dry bulb temperature is sufficiently low to produce the required cooling water temperature.

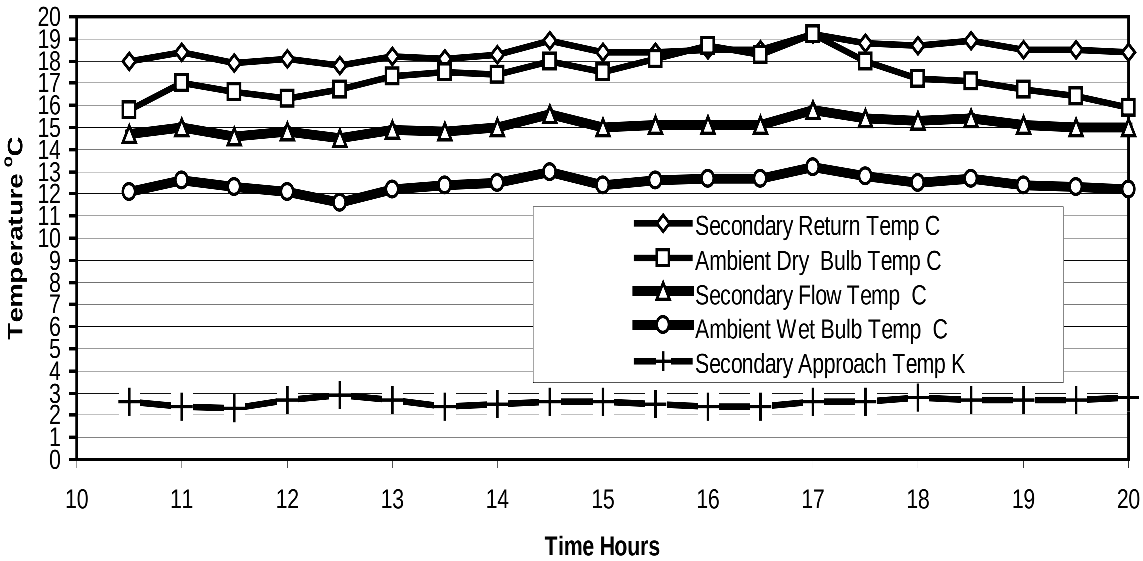

Figure 2. Conditions measured in the evaporative cooling test rig on the 6th September 2000 at a constant 20kW cooling load

Health and Safety Concerns

With chilled ceilings it is important that cooling water temperatures are not allowed to fall below the room air dew point temperature, in order to avoid condensation occurring on the cool ceiling surfaces. Because the ceiling surface temperature is always above the supply water temperature condensation is unlikely to occur until cooling water temperature falls below the dew point. Tests in a CIBSE research programme on chilled ceilings have shown that supply water temperature can be up to 2 K below room air dew point before ceiling condensation begins to occur. Nevertheless, the general advice is that supply water temperature should not fall below room air dew point. A mixing circuit can be incorporated in the system to maintain supply water temperature above a minimum set point.

An interesting feature of cooling towers used in this application is that as the maximum secondary cooling water temperature is 21°C, cooling tower primary water will not exceed 20°C when operating in summer. Hence the possibilities for the growth of legionella are minimal compared with conventional refrigeration condenser water cooling towers in which water temperatures are normally in the higher growth range of 27 to 33°C. The optimum temperature for growth of the bacterium is 37°C. Hence the risk of Legionnaires' disease is minimal (nevertheless, a water treatment system should be employed). This fact is important in promoting greater confidence in the use of cooling towers for evaporative cooling, particularly in commercial buildings.

Energy Efficiency Research

While it is generally believed, that the generation of cooling water by evaporative means, may result in significant reductions in building energy consumption in comparison with chilled water which has been generated, by means of conventional refrigeration systems, there is little published experimental research which would confirm and inform this view. Indeed some aspects of the evaporative cooling technique tend to increase rather than reduce energy consumption. In order to achieve high levels of cooling availability when ambient wet bulb temperatures are high it is necessary to increase the air volume flow rate of the cooling tower fan. Hence electrical energy consumption rises. However, advantage can be taken of a falling ambient condition in the non summer months to expand the approach temperature by reducing the cooling tower air volume flow rate and still maintain a constant cooling water supply temperature to the chilled ceiling. Hence the electrical energy consumption of the cooling tower fan can be progressively reduced in line with a falling ambient wet bulb condition, resulting in improved annual energy efficiency.

While the issue of cooling tower fan energy needs to be addressed the issue of primary circuit pump energy also needs to be investigated. This issue arises as the cooling water temperature difference, the range temperature, on the primary side needs to be low (typically 2K) when a low approach condition is sought. Therefore, the pump power, per unit of heat rejected is high. However, as advantage can be taken here, also, of low ambient wet bulb temperatures, the range temperature can be expanded, during off-peak periods, by reducing the primary circuit mass flow rate. This can be achieved either by using a variable speed primary pump or by changing over to a smaller pump.

A series of tests have been completed on the test rig to determine the energy efficiency of the process at various load and wet bulb temperature approach conditions. The energy efficiency of the process has been assessed in terms of the COP. This is defined as the ratio of the energy rejected in the cooling tower to the total electrical energy used in the cooling tower fan and primary circuit pump. In effect the COP is the quantity of heat rejected in kWhs per unit of electrical power input in kWhs. COP ratios ranging from a minimum of 5.4 to a maximum of 20.4 have been measured in these tests. These COP levels compare very well with standard refrigeration cooling systems in which the COP would normally range from 2.8 to a maximum of 7.0, depending on size, load and type of system used.

In conclusion, therefore, this research programme has shown that cooling water generated by evaporative means can be used to provide effective sensible (as distinct from latent) cooling of buildings, in maritime climates. While such cooling water can be used by any water based building sensible cooling system availability levels are highest when cooling is achieved by means of contemporary high temperature cooling systems such as chilled ceiling panels and chilled beams (cooling convectors placed at ceiling level). The extent of the availability of cooling water, generated in this manner, is so wide that it comes close to providing year round cooling for such systems, particularly where buildings have been designed to minimise external and internal cooling loads, incorporate heat attenuation in the structure and use an adaptive approach to comfort conditions. Such features help to reduce cooling loads and extend the period of the year for which evaporative cooling of the building is feasible, thereby simplifying system operation and offering considerable reductions in electrical energy consumption. The energy efficiency of the process is particularly good when lower ambient wet bulb temperatures are used to generate higher cooling water temperatures in the 15 to 18˚C region. This indicates that the technique is particularly suited to buildings with long cooling seasons (such as deep plan buildings with internal cooling loads) fitted with systems designed to take advantage of higher cooling water temperatures, such systems include chilled ceilings.

In addition to the research funds, which have supported this programme many local firms have generously donated purpose built equipment to the project. These firms are listed in Table 3, beneath.

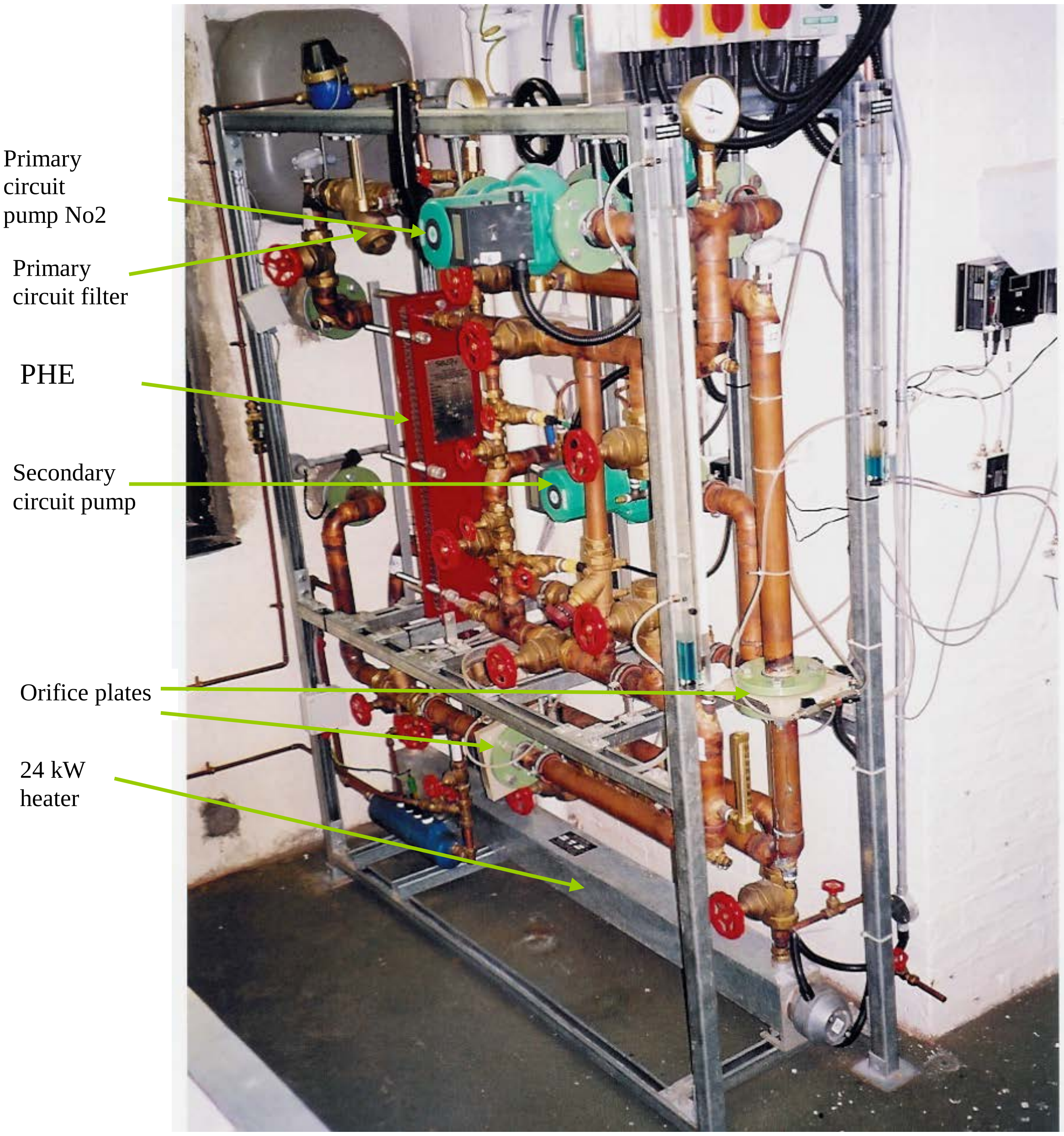

Figure 3. General view of laboratory element of the test rig, showing instrumentation, primary and secondary circuit pumps, plate heat exchanger and in-line 24 kW 3 phase electric heater (overall dimensions 2m wide x 0.5m deep x 2.0m high).

FIRM	EQUIPMENT DONATED
Jones Engineering Ltd (HA O Neil)	Schedule 80 PVC pipework installation from laboratory test rig to roof
L Lynch and Company Limited	Fabrication of laboratory test rig
Mc Cool Controls and Engineering Limited	Control panel, controls and data logging
Redbro Manufacturing (RMI) Limited	Air handling unit
RSL (Ireland) Limited with Baltimore Aircoil International N.V. SWEP Plate Heat Exchangers	Prototype counter-flow cooling tower Plate heat exchanger
Industrial Water Management Limited	Water monitoring and treatment system
Wilo Engineering Limited	Primary and secondary circuit pumps
Thermal Heat Exchangers (Irl) Limited	Air handling unit cooling coil

Table 3. Research programme industrial sponsors.