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An Study about the Performance Assessment of Indirect Evaporative Cooling (IEC)

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Abstract* – *Indirect evaporative cooling (IEC) is an interesting passive cooling technique in which the extracted air is cooled by means of adiabatic humidification. By passing over an air/air heat exchanger this air cools down the supply air. A clear interaction can be observed between the relative humidity of the extracted air and the thermal comfort realized in the building.

In this work, the effects of air stream direction in the channels of indirect evaporative cooler (IEC) on system performance have been investigated. In addition, the dependence of system performance on outdoor air temperature and relative humidity has been studied to determine the allowable conditions for proper operation of the system, with respect to thermal comfort criteria.

In an indirect evaporative cooling (IEC) installation the extracted air is cooled by means of adiabatic humidification. By passing over an air/air heat exchanger this air cools down the supply air. A clear interaction can be observed between the relative humidity of the extracted air and the thermal comfort realized in the building. To be able to predict the performances of this technique well, a good knowledge of the indoor relative humidity is thus important.

This paper presents the results of measurements carried out in the summer of 2006 in a nonresidential building which makes use of indirect evaporative cooling. An evaluation of the indoor summer comfort is made and the interaction between the thermal performance and the indoor humidity is investigated. Furthermore, using the multizone building simulation program TRNSYS, simulations were performed to evaluate the parameters influencing the room moisture balance.

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INTRODUCTION

Indirect evaporative cooling is an interesting passive cooling method in which a clear interaction can be observed between the indoor humidity and the thermal performance of the technique. In the installation the return air passes over the wet side of an air/air heat exchanger (Figure 1). By adiabatic humidification the air stream is cooled. At the same time fresh air flows over the other side of the heat exchanger and is cooled down (Figure 2). The technique differs from direct evaporative cooling in which the supply air stream is directly humidified. By humidifying the return air the dry bulb temperature of the supply air can be lowered without increasing its humidity ratio. In this way a more comfortable indoor climate can be obtained.

Typically, an IEC installation can operate at different stages. When the outdoor air is cold enough in summer, the air flow rate is increased and the air is used for free cooling. As soon as the outdoor air temperature is too high, the fresh air is adiabatically cooled by moistening the heat exchanger. If the desired indoor temperature is not yet reached, active cooling may contribute to lower the temperature of the supply air. In winter the heat exchanger can be used for heat recovery thus preheating the outdoor air. Because of its moderate climate the Belgian climate is suitable for the use of this technique on condition that the building cooling loads are also moderate.

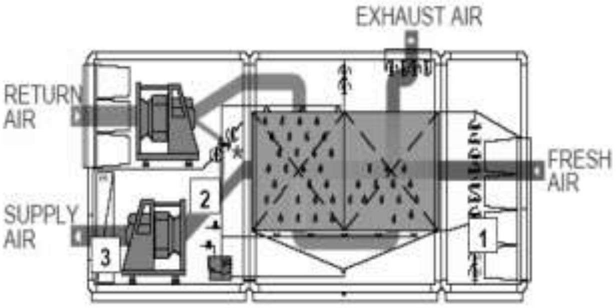

Figure 1 Indirect evaporative cooling.

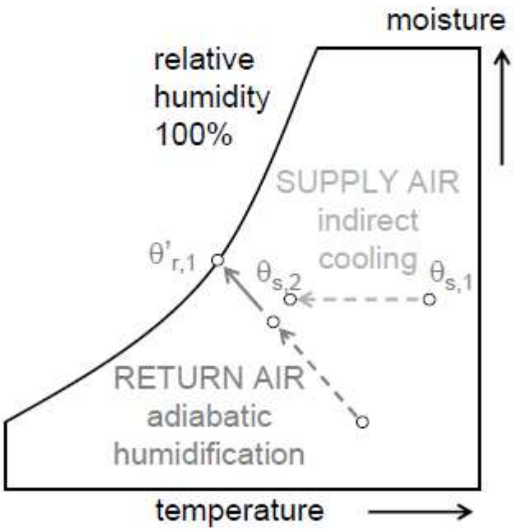

Figure 2 Physical state of airstreams in IEC.

This paper focuses on the interaction between the thermal performance and the indoor moisture balance. The first part discusses the measured performance of an existing installation and uses the results to establish a correlation between the indoor humidity and the cooling performance. In the second part this correlation is used to perform dynamic simulations evaluating various parameters influencing the thermal performance of indirect evaporative cooling.

The cooling energy demand worldwide has increased tremendously in recent decades. This has created serious concern for which, in some countries, further utilities and hence additional supply had to be taken into account, thus increasing the average cost of electricity. Of course, this increase of energy consumption has environmental side-effects related to the increased CO_2 emissions and to the ozone-depleting ChloroFluro Carbons (CFCs) used in air conditioners. The Kyoto protocol binds the developed countries to reduce the collective emissions of six key greenhouse gases - among which CO_2- at least by 5 % by 2008-2012. This protocol encourages the governments, amongst others, to improve energy efficiency and to promote renewable energy. Therefore, counterbalancing the energy and environmental effects of air conditioning is a strong requirement for the future. Lately, research has been oriented towards low-energy techniques, one of which is evaporative cooling technique.

The main advantages of such systems are its simplicity, high cooling, low operational and maintenance costs, saving of fossil fuels and related emissions. Evaporative cooling is evaporation of other fluids in the presence of a draught, with a consequent cooling of the air. Evaporative cooling is especially well suited where the air is hot and humidity is low. However, in higher humidity areas there are many proven cost effective applications for evaporative cooling that makes it the right choice, for example, industrial plants, commercial kitchens, laundries, greenhouses, spot cooling (such as loading docks, warehouses, factories, construction sites, athletic events, workshops, garages) and indoor farming (poultry ranches, diary etc).

Evaporative cooling occurs when the vapor pressure of water is higher than the corresponding partial vapor pressure in the adjacent air. Such systems have a great potential to provide thermal comfort in places where the wet bulb temperature is low. Evaporative cooling equipment can be of the direct evaporative cooling (DEC) type or indirect evaporative cooling (IEC) type. In a DEC, water is vaporized in the airstreams and the heat and mass transfer between air and water cause the air dry bulb temperature to decrease and its humidity to increase, while the enthalpy is kept constant. However the minimum air temperature is the wet bulb temperature (WBT).

In an IEC, the primary air stream which is used to provide the cooling load of a building, is separated from a wetted surface by a flat plate or tube wall as shown in Fig.3. The secondary air stream flows over the wetted surface and exhausts to ambient air. The liquid water is evaporated to the secondary air stream and extracts heat from the primary air stream through the flat plate or tube wall.

Thus, the moisture content of air which flows through the primary channel remains constant. Finally, the primary cool air is used for cooling and ventilation.

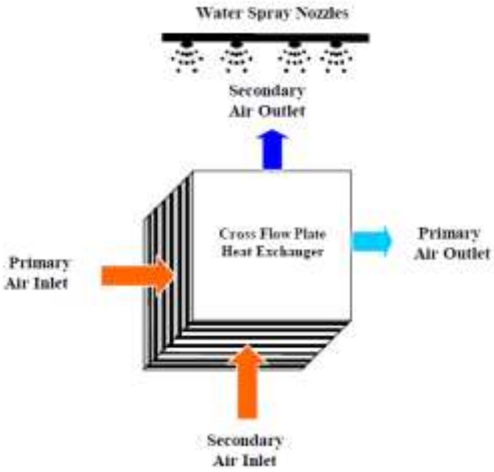

Figure 3. Schematic diagram of indirect evaporative cooler.

Various investigations have studied the relative merits of IECs. Maclaine-Cross and Banks developed- by analogy from published solutions for dry bulb temperature in dry surface heat exchangers- an analytical solution to the indirect evaporative cooling processes based on the following assumptions: moisture contents of air, in equilibrium with water, a linear function of the water surface temperature; the evaporating water maintains stationary and continuous at the same temperature. Due to high values of water surface tension, the wall surface of cooling air passages cannot be completely wetted with spray water and this leads to a reduced mass transfer area for film evaporation. In order to improve the model accuracy, a wettability factor was utilized to describe the effect of incomplete wetting conditions. Kettleborough and Hsieh used a simple wettability factor to describe the effect of incomplete wetting.

HISTORICAL BACKGROUND

Appearance of evaporative cooling occurred at around 2500 B.C., during which the ancient Egyptians made use of water- containing porous clay jars for purpose of air cooling. This mechanism was also applied into ancient Egypt buildings and further spread across the Middle East regions where the climates are always at hot and arid state. Numerous similar built-ups such as porous water pots, water ponds, pools, and thin water chutes appeared in that time being and many of those were combined into the building constructions in order to create the buildings' cooling effects.

The modern evaporative cooling devices were originated from USA. In early 1900s, air washers were invented at New England and Southern Coastline and used for cleaning and cooling air in textile mills and factories. During that period, several air cooling devices including the direct and indirect coolers were also found in Southwest (Arizona and California) region. In late 1930s, many houses and business spaces at Southwest were equipped with individually made water dripping air coolers which, when entering into early 1950s, were developed into the massively producing products and obtained wide range of market places including USA, Canada, and Australia.

Owing to the distinguished advantage of the Indirect Evaporative Cooling over the direct one, i.e., no moisture added into the air thus enabling hygiene air quality, this type of air treatment has gained growing attention and fast development over the past few decades.

MEASURED PERFORMANCE OF IEC

Estimations were completed in the cafeteria of an occasion focus placed at the Belgian Coast (Oostende) in the middle of the year of 2006. Temperature and relative moistness were measured in the establishment at all phases of the procedure and also in the cafeteria. Likewise the position of the valves, pumps and fans were enrolled. The cross stream heat exchanger in the establishment has an aggregate width of 900mm, a length of 1950mm and is made out of polypropylene. Both the supply and return fan can work in two stages with a most extreme air stream rate of 7100m³/h.

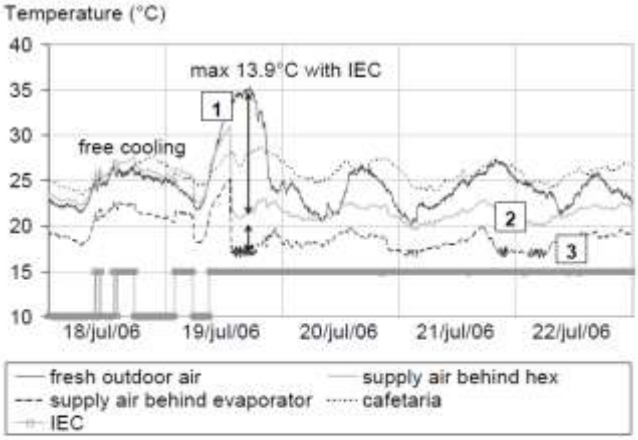

Figure 4 Measurements of IEC in Oostende (18/07/06 - 22/07/06)

Thermal summer comfort **-** Figure 4 presents the measured temperatures from 18 until 22 July 2006. Measurements were carried out every five minutes. The periods in which the IEC is working are indicated in figure 4 shows where the temperatures of the airstreams are measured.

During the first two days the temperature of the supply air downstream from the heat exchanger section did not differ much from that of the outdoor air. The heat exchanger was clearly bypassed to allow free cooling. The temperature measured behind the evaporator was always lower than before, showing active cooling has been working during the whole measured period. The outdoor temperature varied from 20°C to 35°C during the measuring period. The average temperature measured in the cafeteria was 26°C. Making use of evaporative cooling, a maximum temperature drop of 13.9°C was noticed on 19/07 when the outdoor temperature reached 34.8°C. On average a cooling of 3.3°C could be achieved with this method within the measuring period. At night free cooling was used for some hours to cool down the cafeteria.

The indoor summer comfort was evaluated using the Adaptive Temperature Limits Indicator (ATG) which takes into account the thermal adaptation of occupants to the indoor climate. The method differs between alpha and beta-buildings. The evaluation of the beta-building is more severe, and assumes occupants cannot control the indoor climate e.g. by opening windows.

Furthermore, thermal comfort is divided into three levels. It is required that buildings meet the standard level B, corresponding to 80% thermal acceptability, to have a good indoor comfort.

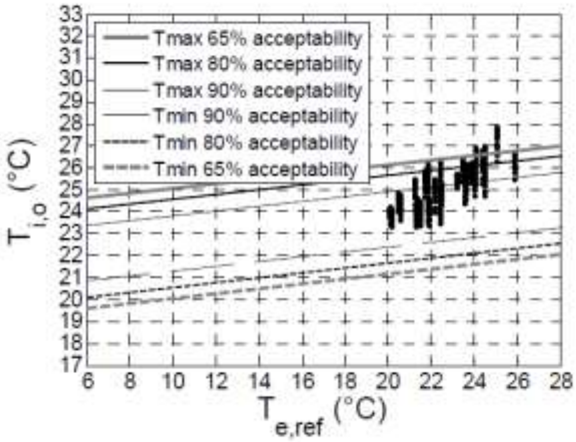

Figure 5 Thermal comfort in July using the Atg evaluation method (beta–building)

The evaluation of the indoor climate in July 2006 is given in figure 5. On the horizontal axis the running mean outdoor temperature Te,ref is presented, which is a weighted average of the outdoor temperature from the current day and that of the three preceding days. The vertical axis shows the indoor operative temperature Ti,o. In the graphs only the occupancy hours are taken into account (08-22h). During 79.3% of the occupancy hours in July the indoor climate was situated in class B or better. We can conclude that although active cooling was working most of the time, the cafeteria did not always meet the criterion for good thermal comfort.

FACTORS AFFECTING THE (IEC) PERFORMANCE

When all is said in done, indirect evaporative cooling execution is affected by the same factors that influence direct evaporative cooling. Use of heat exchanger however likewise influences the execution of the indirect evaporative cooling. This extra factor is the execution of the heat exchanger used in the Indirect Evaporative system. The greatest execution of diverse heat exchangers contrasts from one kind of heat exchanger to an alternate.

Heat exchangers have diverse greatest exhibitions for two fundamental reasons: one is the method of heat trade and alternate is the heat conductivity of heat exchangers material. The stream rate of air passing through the heat exchanger and air turbulence additionally influence the rate of heat transferred through the heat exchanger. The higher the air stream rate and air turbulence through the heat exchanger, the more productive the heat exchanger.

CONCLUSION

Indirect evaporative cooling is an interesting passive cooling technique in which the thermal performance depends mainly on the indoor humidity. Measurements carried out in July 2006 in a non-residential building show that by using this technique the supply temperature can be cooled up to 14°C during warm periods. Despite the fact that active cooling was present to further cool the supply air, an evaluation by the adaptive temperature limits indicator showed that a good indoor thermal comfort was not always satisfied during the whole measured period.

The evaluation of the measured data shows a linear correlation between the cooling amount of the supply air and the maximum cooling which is possible using IEC. Dynamic simulations based on this constant effectiveness affirm that the knowledge of the indoor moisture balance is important to predict the performance of indirect evaporative cooling in an accurate way.

Mathematical models for simulating IECs have been developed in this work. The results show the performance strongly depends on ambient air humidity and temperature. However, it is easy to prepare a good indoor thermal condition under lower humidity even at high ambient temperatures. It is found that that the IEC with proper configurations is capable of preparing a good indoor condition, even in high relative humidity (70%) and high ambient air temperature (50oC). Therefore, this system is a suitable technique to supply the cooling load in humid and tropical climates. Also, investigation of the effects of flow direction in dry and wet channels on performance showed that the performance countercurrent layout is more than other types and using it increases produced cooling load and decreases electricity consumption.

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