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INDIRECT EVAPORATIVE COOLING OF LOW ENERGY BUILDING

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With the growth of living standards, there is an increasing demand for the cooling of living space. Rational energy use demands the use of alternative ways of cooling because the energy consumption of compressor cooling is high. In this article a new cheap and efficient paperboard compact heat exchanger and indirect evaporative cooling are presented. Indirect evaporative cooling is the most suitable way of cooling for low energy buildings especially if combined with heat recovery ventilation system. Operation simulation of an indirect evaporative cooler installed in a low energy house is also shown.

1 INTRODUCTION

Energy efficient buildings are nowadays constructed so that because of their shape, thermal insulation, windows quality, active and passive solar energy use, they need less energy for heating in the heating period, but they offer greater living comfort. Enlarged building tightness causes the decrease in fresh air inflow and the problem of poor indoor air quality. Because of that ventilation of the building is necessary and installation of a system for heat recovery. The decrease in fresh air inflow actually causes the problem of poor indoor air quality. The concentration of pollutants (CO_2, odours, smoke, volatile organic compounds) increases, and so human comfort drops significantly.

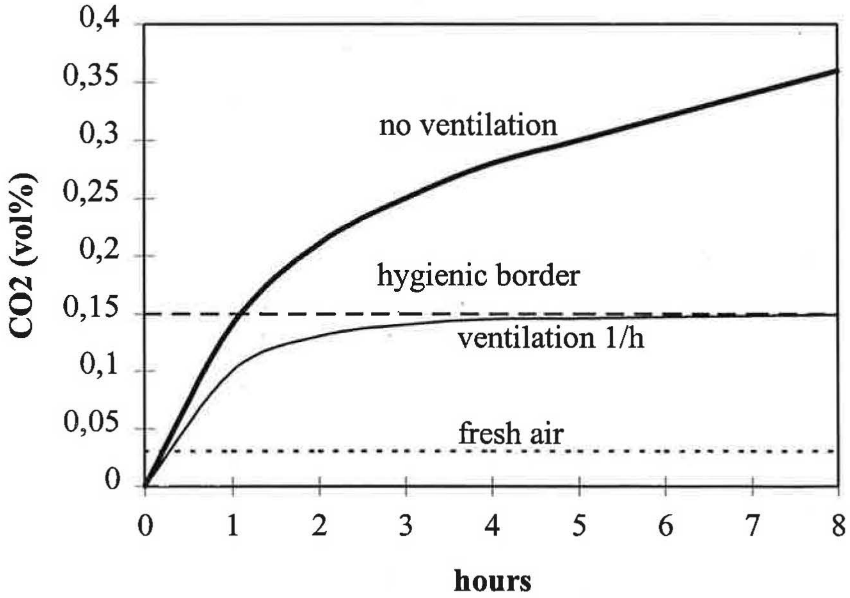

FIGURE 1: Concentration of CO_2 in the room depending on ventilation

For complete human comfort, air has to be cooled in the summer period. Compressor cooling devices, which are the most widely used for space cooling in the developed countries, are energy consuming and so they are not appropriate for an energy efficient building.

For energy efficient buildings indirect evaporative cooling is the most suitable because it is an environmentally friendly and energy efficient cooling method that only uses water as the working fluid. Compressor cooling device requires almost six times the electrical demand of the evaporative cooler.

Another advantage of indirect evaporative cooling is that the heat recovery ventilation system could be adapted, with small supplements, into a device which also enables cooling of hot outside air, and hence climatization of the living spaces. Such system so operates trough all year.

And finally indirect evaporative cooling provides superior indoor air quality over compressor cooling systems since 100% outdoor air is used [2].

2 INDIRECT EVAPORATIVE COOLING

Evaporative cooling is one of the oldest cooling methods known. We distinguish between direct and indirect evaporative cooling. In not arid regions, for living space cooling, indirect evaporative cooling is more appropriate [4]. By indirect evaporative cooling, air is cooled so that it is passed over the area that is evaporatively cooled on the other side. Fresh cooled air does not come into direct contact with water, and so the moisture content of the air is not increased. Such a cooler, and the corresponding psychrometric chart are schematically shown on Figure 2.

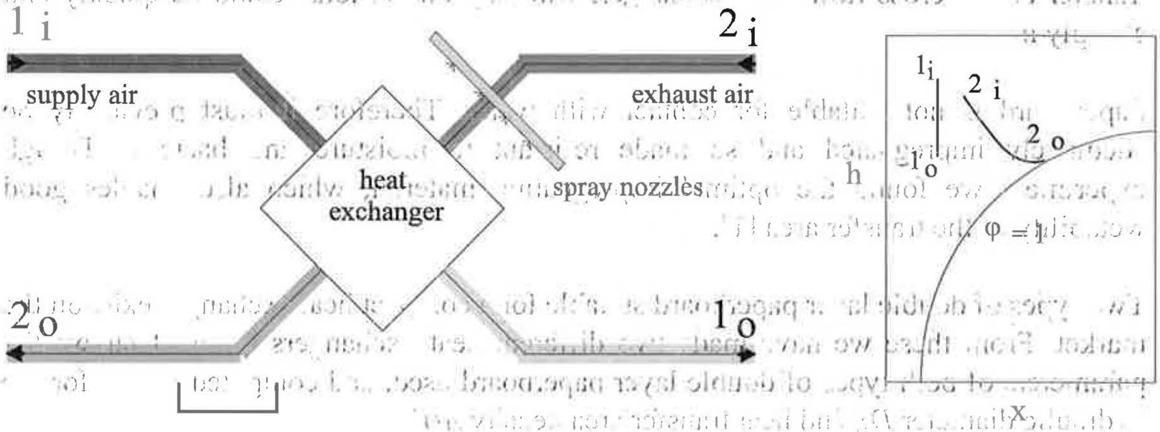

FIGURE 2: Operation of indirect evaporative cooler

On the secondary side of the heat exchanger there is a thin water film in addition to the air flow. The water is distributed by spray nozzles. Because of the difference between

water steam partial pressure on the water surface and in the air stream, water evaporation occurs. The air temperature drops, and the water film also cools.
The theoretical temperature of the water film and also the supply air equals the secondary air wet bulb temperature at the heat exchanger inlet. Compared to compressor cooling systems, increased air flow rates are used for indirect evaporative cooling to compensate for higher supply air temperatures [5].

Because of that indirect evaporative coolers are larger and more expensive. A more compact and, above all, cheaper heat exchanger design would dimensionally reduce the size of the device and make its price more acceptable for wider use. So we have focused our research especially on the development of cheap compact heat exchangers.

3 PAPERBOARD COMPACT HEAT EXCHANGER

Compact heat exchangers, with a high heat transfer area density, are most widely used for heat transfer between two air streams [7]. The heat transfer area is usually finned, and this gives the necessary compactness to the heat exchanger. The small distance between plates, and the high fin density, also mean small hydraulic radius (magnitude order of 10^{-3} m). Laminar flow of both fluids is thus assured. For manufacturing compact heat exchangers, aluminium sheet or foil is usually used. The second most widely used material is plastic.

In designing our heat exchanger we used material that is cheaper than known materials for heat exchangers, compact enough, and enables the simple and quick manufacturing of cross-flow heat exchangers of any dimensions. This material is double layer paperboard, which has an already designed transfer area and which costs only one fifth of the price of an aluminium heat exchanger [1]. By simple sticking and layering of the transfer area a cross-flow heat exchanger, with any dimensions, could be quickly and cheaply made.

Paperboard is not suitable for contact with water. Therefore it must previously be adequately impregnated and so made resistant to moisture and bacteria. Trough experiment we found the optimal impregnating material, which also enables good wetability of the transfer area [1].

Two types of double layer paperboard suitable for a compact heat exchanger exist on the market. From these we have made two different heat exchangers. Table 1 shows the parameters of both types of double layer paperboard used, and computed values for the hydraulic diameter D_h and heat transfer area density A/V.

parameter	unit	paperboard type	
		wave B	wave C
b	mm	3,73	2,78
d_p	mm	0,15	0,15
d_r	mm	0,1	0,1
D_h	mm	2,81	2,16

A/V	m^2/m^3	659	835

TABLE 1: Heat transfer area geometry data

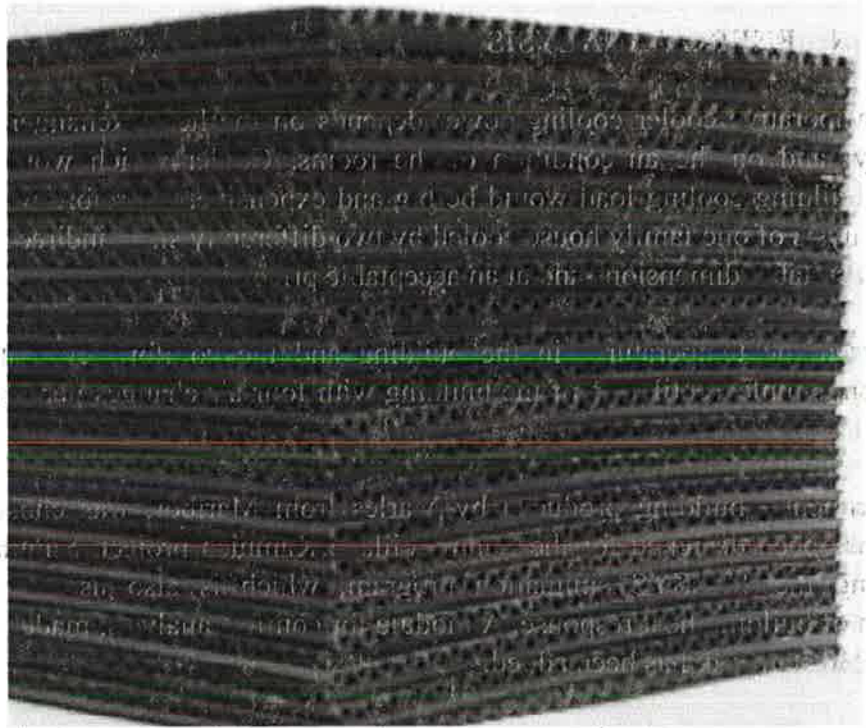

FIGURE 3: Cross-flow paperboard heat exchanger

The characteristics for both paperboard heat exchangers have been determined by measurements [1]. These characteristics enable determination of the heat transfer coefficient and pressure drop for a known air flow rate through the heat exchanger.

The measurements have shown adequate impregnation of the paperboard and very good wetability of the transfer area on the secondary side of the heat exchanger. Good wetability is very important for high efficiency of indirect evaporative cooler. Namely a poor wetability of the heat exchanger heat transfer area could reduce the overall efficiency for a few percents.

A mathematical model of heat and mass transfer in the indirect evaporative cooler has been developed for conditions study in the heat exchanger and for dimensioning. A computer program has also been made to enable calculation of the outlet parameters from the known inlet parameters of air and water for the chosen dimensions of the cross-flow heat exchanger. The computer program also allows for calculations of heat recovery. The mathematical model and computer program have been verified by measurements [1].

As the supply air temperatures are relatively high, for a corresponding cooling power high air flow rates are necessary. Because of that indirect evaporative cooler unit has to be large and thus expensive. The same is valid for air channels. To optimize the unit needed in an energy efficient one family house an energy analyse should always be made. An optimization should be made regarding comfort level.

4 BUILDING ENERGY ANALYSIS

Indirect evaporative cooler cooling-power depends on the heat exchanger dimensions (efficiency) and on the air-condition of the rooms. Cooler which would cover the complete building cooling load would be big and expensive. Therefore we have made energy analysis of one family house cooled by two differently sized indirect evaporative coolers, of suitable dimensions and at an acceptable price.

We analysed the temperatures in the building and the comfort level attained. For comparison, simple ventilation of the building with four air changes per hour was also analysed.

The experimental building produced by Marles from Maribor, was chosen [3]. The building has been designed for the Sunny Village Kamnica project. Simulations were made using the TRNSYS simulation program, which is also used for computer simulation of building heat response. A module for comfort analysis, made according to the ISO 7730 standard, has been added.

Building heat gains consist of solar gains and internal building gains which are defined by heat gains from human bodies and from lights. Possible window shading was ignored. The complete solar gains are obtained by simulation. The analysis which has been made thus represents extreme living conditions. In real living conditions architectural shading, window shading and vegetation could significantly reduce solar gains of the building and through this the maximum temperature of the building.

Figures 4 and 5 show analysis results for July. Data for only one week are shown because of the better readability of the graph in comparison to the whole month graph.

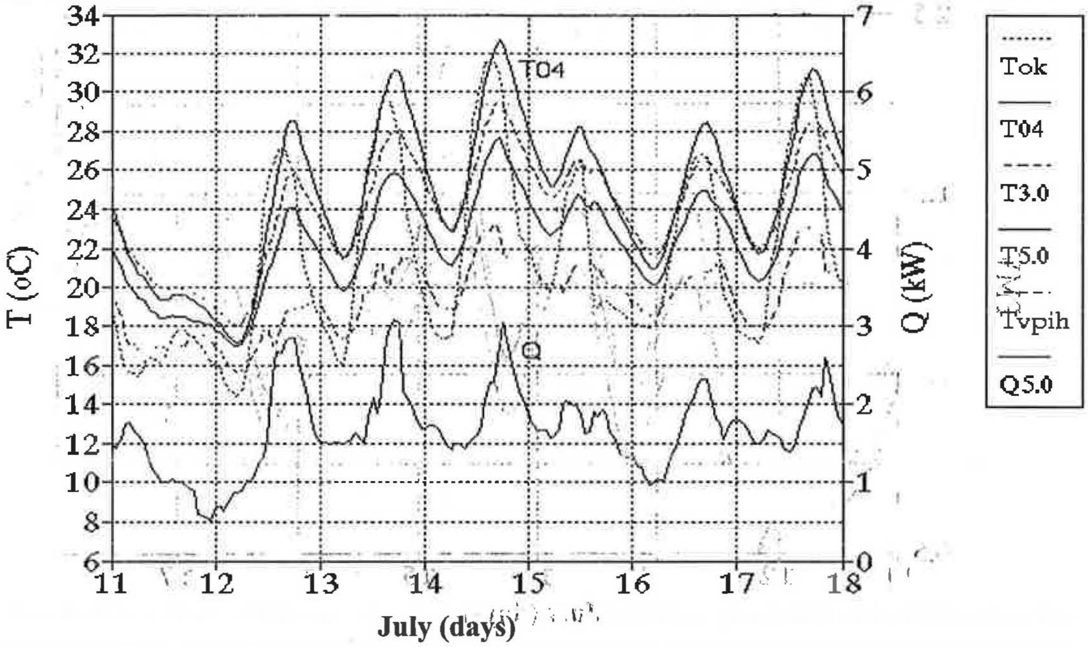

FIGURE 4: Temperature conditions in the building

The results of the analysis show that already a simple ventilation (T04) to some extend represents a way of cooling, even through this is practically insignificant. With indirect evaporative cooling (T3.0, T5.0) temperatures in the building could be dropped to 5 °C, comparing to a simple ventilation, depending on the cooling device used and it's cooling power.

The temperatures of the air supply (Tvpih) do not differ much between each other. So cooling power or room temperature could be regulated only by increasing air supply flow rate or air changes per hour. The wet bulb temperature of room air is equal to or even higher than the ambient temperature (T_{ok}) during the night, so it is more suitable to use ventilation instead of indirect evaporative cooling at that time. The room air could in this way be significantly cooled during the night.

The most important analysis is that of the comfort attained. Comfort is expressed by the PMV (predicted mean vote) index which represents human comfort expressed by numbers. PMV moves from +3 (hot) to -3 (cold). A comfort analysis was made for a person dressed in light working clothes and carrying out light household activity. Figure 5 shows the PMV index for July.

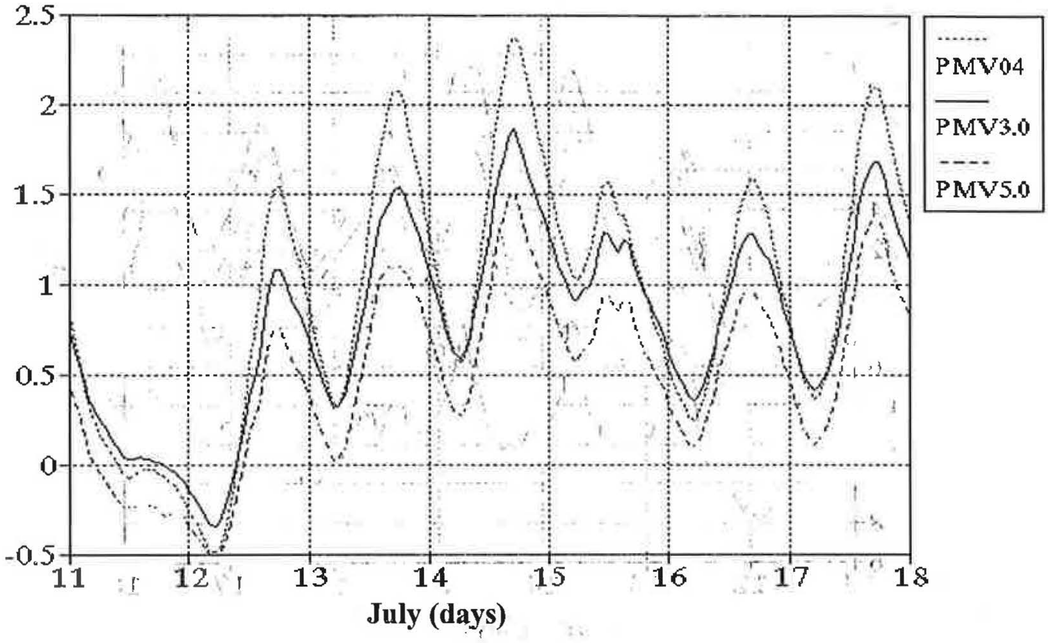

FIGURE 5: Human comfort reached in room

The difference in comfort level during the day is significant. Larger unit enables decent living conditions while the simple ventilation gives warm and thus unpleasant living conditions. In hot sunny summer days all units have to operate through all day to minimize daily peak temperature.

More interesting might be a comparison of average hours per day when air conditions reach the comfort zone. The comfort zone is defined according to standard [6] as a state of air with which more than 90% of people are satisfied and this corresponds to the values of PMV index at between -0,5 and +0,5. Table 2 also shows hours per day when the PMV index is between -1 and +1, which equals the range between slightly cold and slightly warm. The maximum value of the PMV index (PMV_{max}) reached in July is also shown.

device	air changes/hour	PMV	hours/day	PMV_{max}
ventilation	4	-0,5<PMV<+0,5	**10,5**	2,38
		-1<PMV<+1	16	
indirect evaporative cooler	3	-0,5<PMV<+0,5	**11,5**	1,86
		-1<PMV<+1	19.5	
	5	-0,5<PMV<+0,5	**17,5**	1,52
		-1<PMV<+1	23	

TABLE 2: Comparison of average number of comfort hours in the analysed building

5 CONCLUSIONS

Indirect evaporative cooling is gaining more and more importance worldwide. With development of heat exchangers indirect evaporative coolers are becoming smaller and smaller, their size being until now one of their main disadvantages. The energy crises, knowledge about the harmfulness of CFC's and new materials have also helped towards a new thrust in the development and use of indirect evaporative coolers. Worldwide there are nowadays over 20 million residences that use one of the evaporative cooling device to meet their cooling needs [5].

In individual buildings for our climatic conditions this device becomes economical if it is combined with a heat recovery unit. As the energy analysis of energy efficient building show, the supply temperatures range between 18 and 22 ^{o}C. These are high temperatures for climatisation. So for optimal comfort conditions, corresponding building shading has to be assured. Solar energy gains are thus reduced, and hence also the necessary size of the cooling device. The cooling device thus becomes acceptable both in size and in price.

Our research work on paperboard heat exchangers shows that paperboard is an appropriate material for heat exchangers. It is light weight and cheap. Used impregnation ensures a good wetability and thus efficient operation and a suitable working life.

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