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COMPARISON OF HEAT RECOVERY SYSTEMS IN PUBLIC INDOOR SWIMMING POOLS

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Abstract—The heating of swimming pools can be expensive in terms of energy costs and energy-saving measures which are much more effective than the simple recovery of the exhausted air are recommended. A new open-cycle absorption system is presented here, operating by chemical dehumidification on the exhausted air. It allows important energy savings of the same order as the motor-driven heat pump systems, although its technology is in principle simpler and cheaper. Copyright © 1996 Elsevier Science Ltd

Keywords—Swimming pools; heat recovery; open cycle; absorption.

INTRODUCTION

The winter heating of an indoor swimming pool is one of the few air-conditioning applications when sensible heating must be provided, but a latent load withdrawn is at the same time. The operation is usually conducted through a suitable introduction of fresh air, whose humidity ratio is lower than the ratio to be kept in the ambient. The energy cost is far from being negligible, first of all for the obvious reason that the fresh air is normally much colder than the exhaust. Moreover, the requested flow rate is generally much higher than the simple ventilation for air change.

However, another energy cost may be not recognised: the room air is exhausted at a high enthalpy content, not only for the sensible but also for the latent fraction. Simple heat exchangers are not able to recover the latent part, which will be supplied to the fresh air by the evaporation from the pool with a corresponding energy cost. One could conceive employing a total heat wheel between fresh and exhausted air. Such exchangers give back the withdrawn humidity to the fresh air: thus they make ventilation useless as far as the withdrawal of latent load is concerned.

Recent evaluations, even if more conservative than the traditional procedures, assign more than 75% of the total swimming pool loads to pool evaporation and to ventilation [1–3].

Increasing the relative humidity (r.h.) is surely a possible measure to reduce evaporation: it is probably an intervention to be suggested whenever a suitable design of the building envelope and of the air distribution system allows it. However, in many existing plant it is not advisable, since a r.h. higher than 50% would generate frequent and harmful water condensation on part of the perimeter walls.

Only the heat pump allows adequate utilisation of the latent heat of the exhausted air, which acts as a cold source for the heat pump evaporator, that of course operates with a wet battery at temperatures lower than the ambient air dew point. To obtain a good performance, the plant will also include a heat exchanger between the exhausted air and the fresh air before the heat pump. The heat pumps can be driven by an electric motor or even by an i.c. engine with heat recovery [4–7]. The latter is an application well investigated, but used less than one would imagine, considering only the energy profit, probably because of the high capital costs with the charges of noise and vibration control.

Another possibility of exploiting the water content in the air which is not yet tested is at hand: chemical dehumidification.

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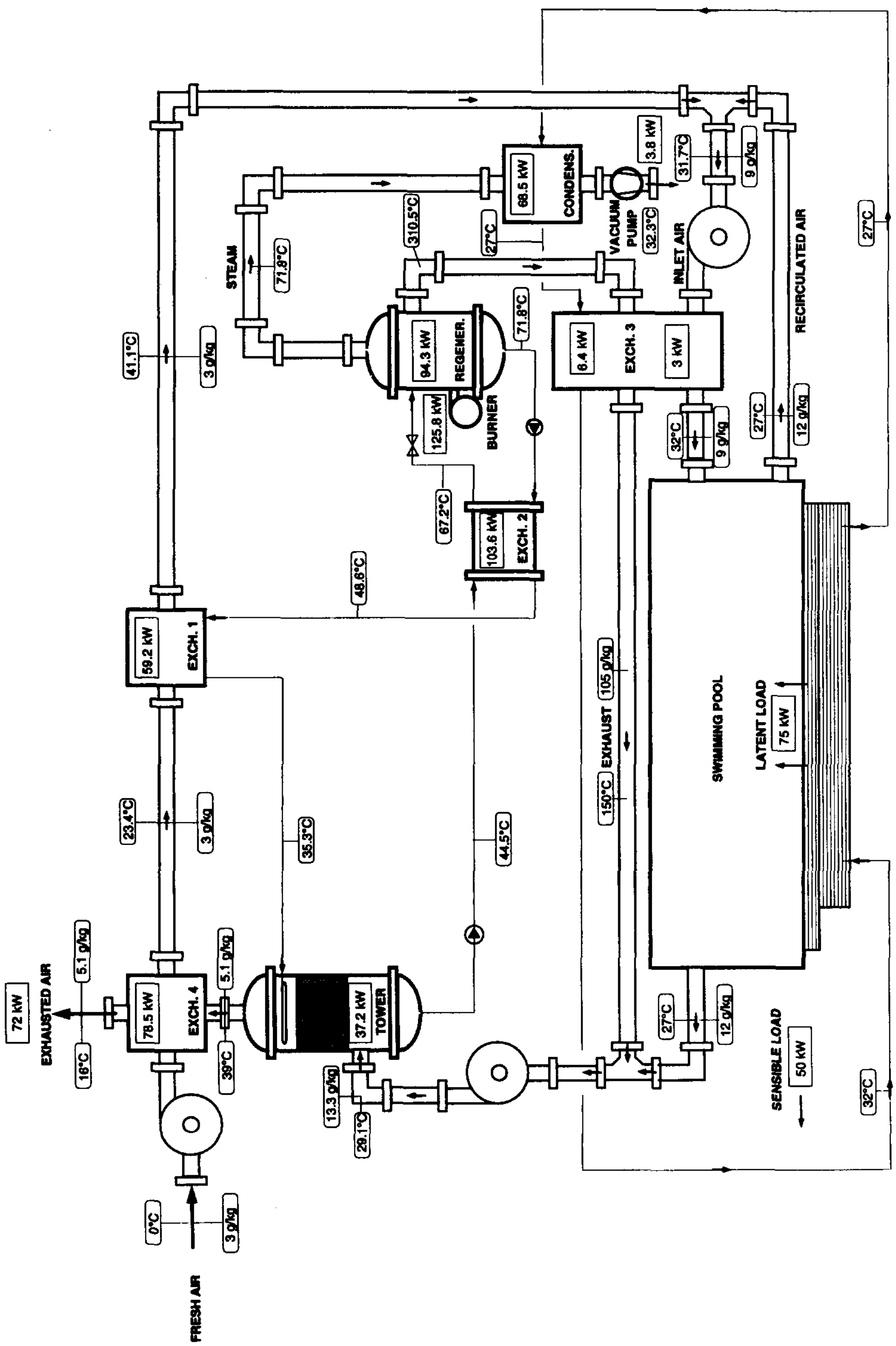

Fig. 1. Sorption dehumidification heating system for a swimming pool.

Table 1. Thermal efficiency of the different heat exchangers in the proposed systems

Type	Thermal efficiency
Gas–liquid heat exchangers	70%
Liquid–liquid heat exchangers	80%
Gas–gas heat exchangers	60%
Condenser	70%

PLANT DESCRIPTION

If an air flow goes through a packed tower where a liquid desiccant trickles down at a suitable concentration, the air will come out dehumidified. The enthalpy variation due to the loss of latent heat will be partly in the air at the outlet of the tower with a higher fraction of sensible heat and partly in the desiccant, which will increase its temperature during the process. The desiccant regeneration can be operated by heating, e.g. by a gas burner, this can give rise to an effective heat recovery system on the exhausted air driven by gas burning. As will be illustrated, an open-cycle heat pump is thus obtained [8–10].

Let us consider the plant scheme in Fig. 1. The swimming pool ambient is conditioned by air supplied at 32°C; it is made up of recirculated air, that allows a homogeneous distribution and load fulfilment at a low thermal level, and of a suitable amount of fresh air for ventilation. Of course an equal flow rate is exhausted.

The exhausted air is treated after mixing with the exhaust of the regenerator burner, whose enthalpy content (both sensible and latent) is still appreciable, in a packed tower fed by a liquid

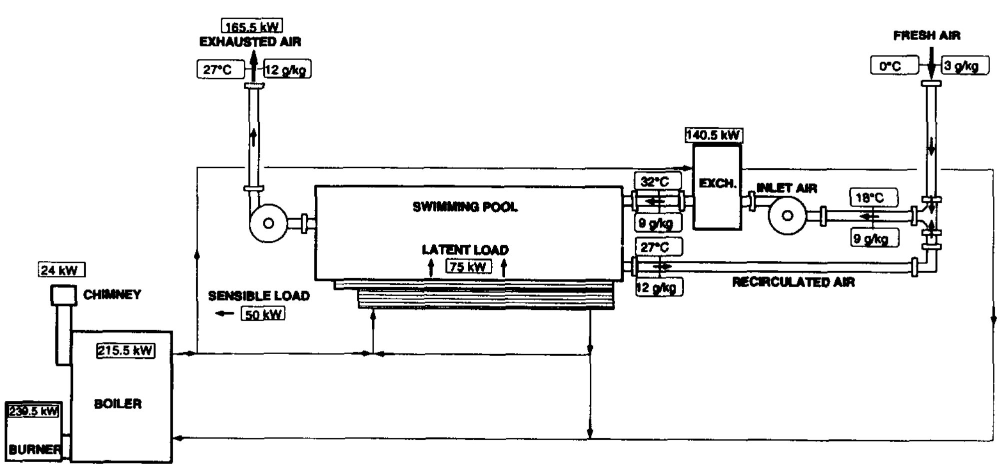

Fig. 2. Heating system for a swimming pool with simple ventilation.

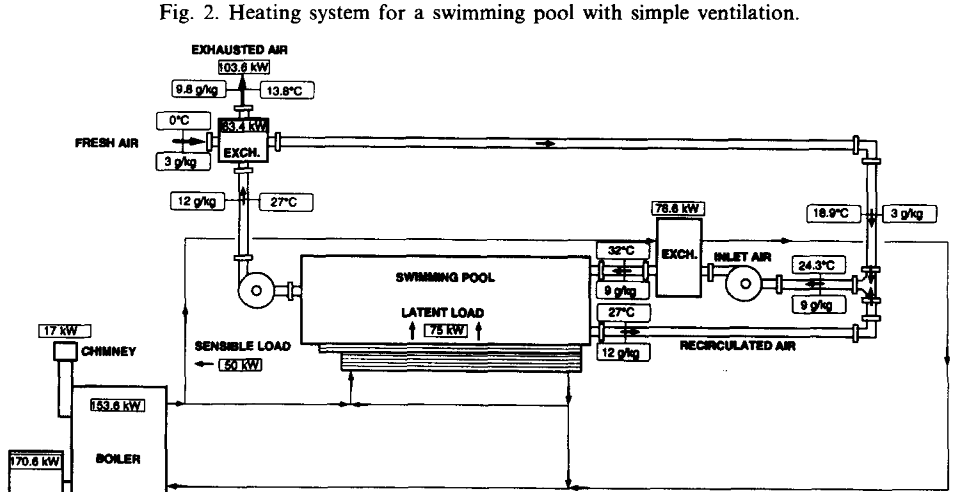

Fig. 3. Heating system for a swimming pool with heat recovery.

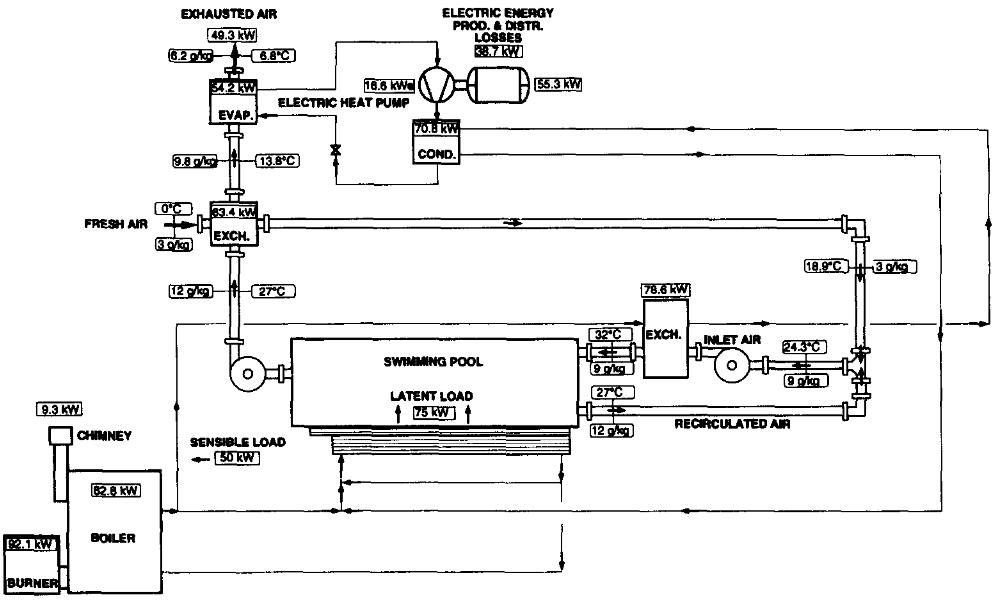

Fig. 4. Heating system for a swimming pool with an electric heat pump.

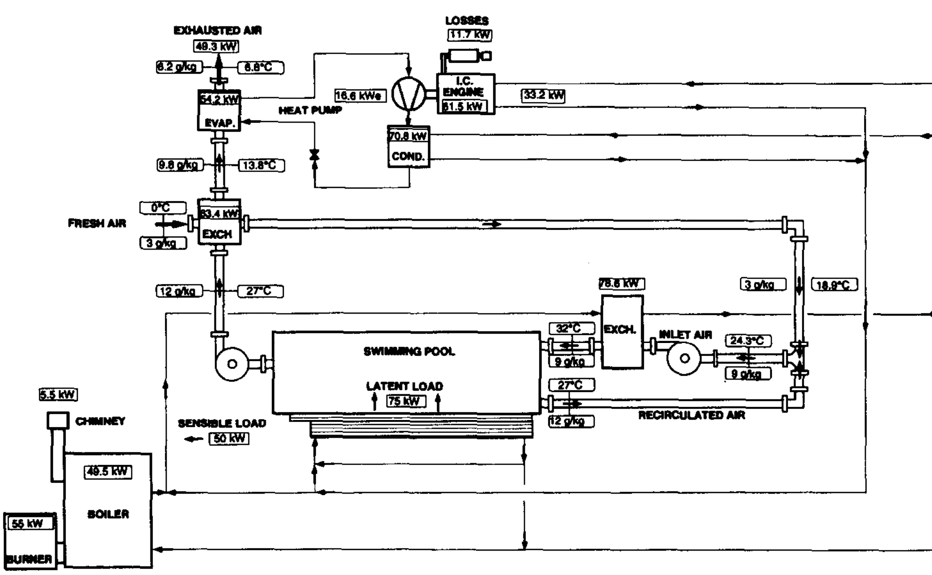

Fig. 5. Heating system for a swimming pool with an i.c. engine-driven heat pump.

desiccant, such as an aqueous solution of lithium bromide. The air comes out dehumidified and at a rather high temperature (say 40°C), so that it can preheat the fresh air in a heat exchanger (EXCH. 4).

The desiccant leaving the tower has augmented its water content and must be regenerated; therefore it is sent to a regenerator, i.e. a device heated by a gas burner where water vapour is separated and the solution is reconcentrated in salt. The solution comes out hot from the regenerator and an internal exchange with the solution to be regenerated is advisable (EXCH. 2). Moreover, further fresh air preheating is possible (EXCH. 1). The latter is an important heat

Table 2. Thermal power consumption of the different heating systems considered

System	Proposed system (Fig. 1)	Simple ventilation (Fig. 2)	Heat recovery (Fig. 3)	Electric heat pump (Fig. 4)	I.C. engine-driven heat pump (Fig. 5)
Power (kW)	125.8	239.5	170.6	147.4	116.5
Comparison	74%	140%	100%	87%	69%

exchanger, as it lowers the desiccant temperature to levels that permit an effective air dehumidification which could be prevented by too high a desiccant temperature.

The part of the plant already described could function, but with a rather poor energy profit, since the recovered energy from the air dehumidification must be given back to the regenerator with some penalty to be paid, when the same water is to be removed from the desiccant. However, the vapour liberated at the regenerator can be exploited by condensing it with a heating effect, for example in the pool water. Then most of the latent heat taken away from the exhausted air is recovered. The condenser can in this way almost completely satisfy the heating load of the pool.

The plant description is completed. The plant is able to satisfy wholly the swimming pool requirements, eventually with some small integrations (EXCH. 3).

PERFORMANCE PREDICTION AND COMPARISONS

Some assumptions regarding internal and external operative parameters are necessary to analyse the plant performance. A temperature of 27°C is considered for the ambient of the swimming pool with an equal temperature for the pool water (a recent experimental study on swimming pool comfort suggests that this condition is more comfortable for the user than the usual setting of an air temperature higher than the pool one [11]).

The inside r.h. is set at 50% (this value is imposed to prevent water condensation at the perimeter walls). The outside air is considered to be at 0°C with a humidity ratio of 3 g/kg. The sensible load (heat transmission through the building envelope) is 50 kW. The latent load (water evaporation from the pool surface) is 75 kW. A ventilation rate of about 10,000 m^3/h (2.777 m^3/s) is requested. For the outside and inside conditions already listed the energy loss of the ventilation is more than 90 kW.

For an air delivery at 32°C, the recirculated air flow rate is 20,000 m^3/h (5.555 m^3/s). The overall

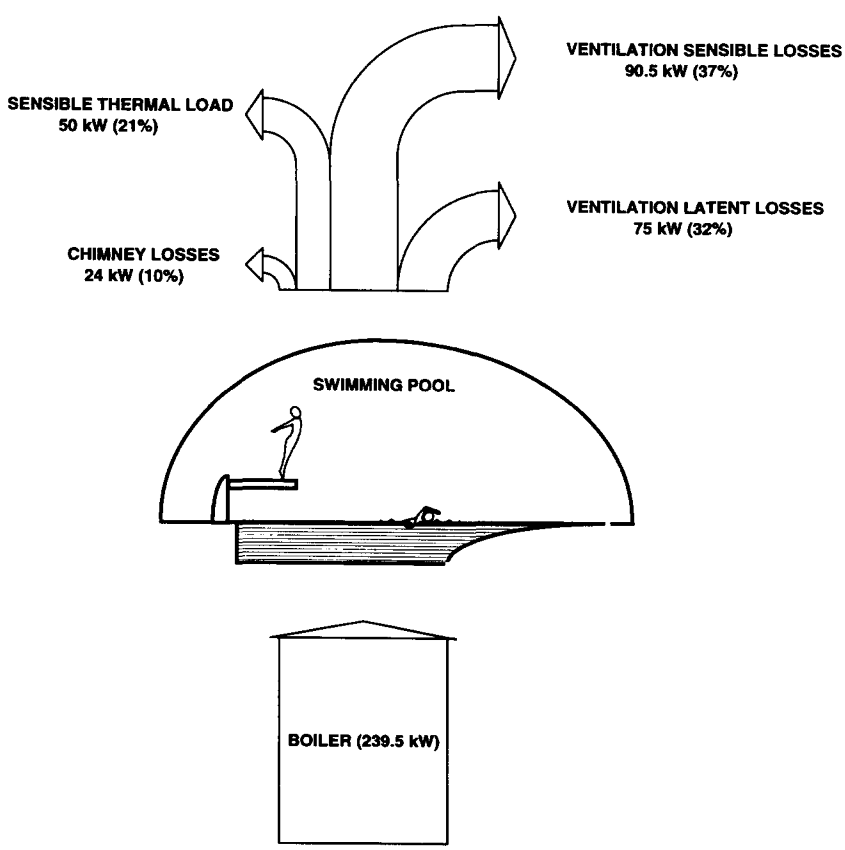

Fig. 6. Energy flow diagram for the heating system with simple ventilation.

load to be satisfied is about 215 kW, shared respectively between 140 kW to the air and 75 kW to the pool water.

In a previous paper [12], the working conditions for a chemical dehumidification plant were optimised, determining the concentration values of the desiccant (an aqueous lithium bromide solution, 58% salt) and the L/G ratio between desiccant and air rate in the packed tower ($L/G = 2/3$). The effect of the efficiencies of the various heat exchangers on the plant behaviour were evaluated there; the assumed efficiencies in the present analysis are listed in Table 1.

Figure 1 gives the main parameters of the plant for the conditions just mentioned. A comparison was made with other systems under the same conditions; the systems considered are the following:

(a) simple ventilation system (Fig. 2): it is the classical ventilation system where a fresh air supply compensates the latent load due to the pool evaporation without any recovery on the exhausted air. The heating load is satisfied by a boiler that, considering the low supply temperature, is a condensing one; its efficiency on the gross calorific value (GCV) is estimated at 90%;
(b) heat recovery system (Fig. 3): it is quite similar to the previous scheme with a regenerative heat exchanger between the fresh and the exhausted air. As partial latent heat recovery is possible in this heat exchanger, a rather high efficiency (related to the sensible component) was assumed, as high as 70%;
(c) electric heat pump system (Fig. 4): after the regenerative heat exchanger the evaporator of an electric heat pump employs the exhausted air as the cold source, whereas the condenser contributes to the pool water and supply air heating. An evaporation temperature of 3°C was assumed, together with a condensing temperature of 37°C; the heat pump COP was estimated at 40% of the corresponding Carnot value between the same temperatures. For a comparison with the other systems in terms of primary energy requirements, an efficiency of electric energy production and distribution of 30% (always with respect to the GCV) was assumed;

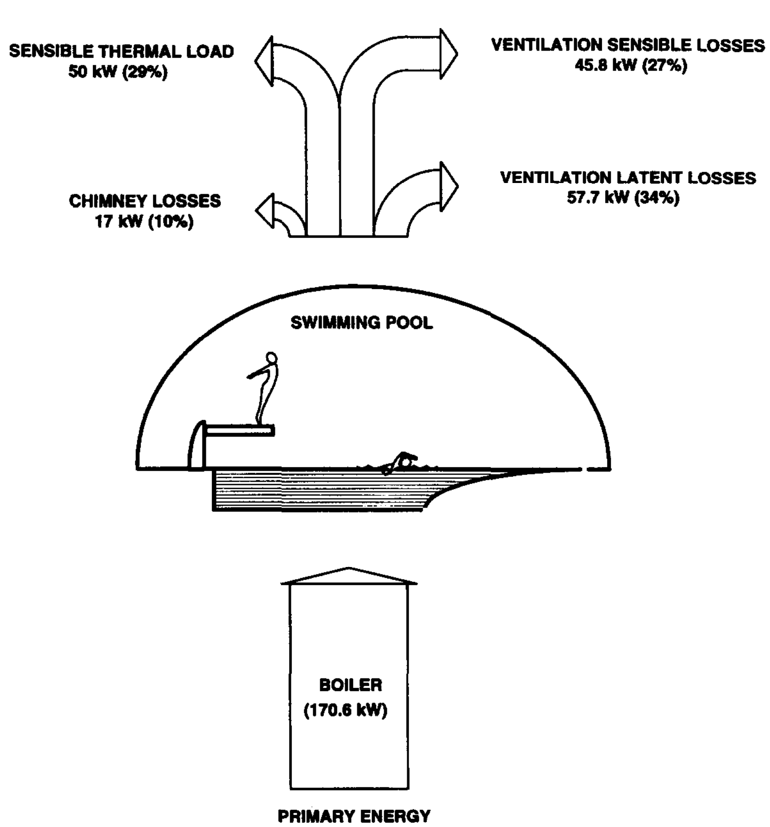

Fig. 7. Energy flow diagram for the heating system with heat recovery.

(d) i.c. engine-driven heat pump system (Fig. 5): it differs from the previous scheme by the utilisation of an i.c. engine-driven heat pump with heat recovery. A mechanical efficiency of 27% and a heat recovery of 54% for the motor (always with respect to the GCV) were assumed.

Table 2 gives a comparison between the various systems in terms of required thermal power of the fuel (GCV). As can easily be appreciated, taking as a reference plant the heat recovery system, for simple ventilation one needs a 40% higher energy supply, whereas the energy savings are, respectively, 13 (electric heat pump), 31 (i.c. engine-driven heat pump) and 26% (proposed system).

The systems considered, besides having different energy requirements, show a quite different distribution of them. The sensible losses of the pool room, the sensible and latent losses of the exhausted air and finally the losses of the exhaust to the chimney are common to the five examined systems (the latter except the electric heat pump one). The loss to the chimney does not appear directly in the proposed system, since the combustion products are treated together with the exhausted air in the packed tower, so that the related losses are accounted for under the item 'sensible and latent losses of the exhausted air'.

The energy flow for the simple ventilation system is reported in Fig. 6. A great deal of the lost energy is due to the exhausted air. The heat recovery system is able to reduce these losses; hence, the relative importance of the sensible losses from the swimming pool room is now higher, as illustrated in the energy flow diagram (Fig. 7).

The electric heat pump system utilises a large fraction of the enthalpy in the exhausted air. Therefore, the energy flow of Fig. 8 shows a percentage increase in the sensible losses of the swimming pool room; a new item is listed regarding the losses of production and distribution of the electric energy to drive the compressor. This item has a great relative importance. The losses

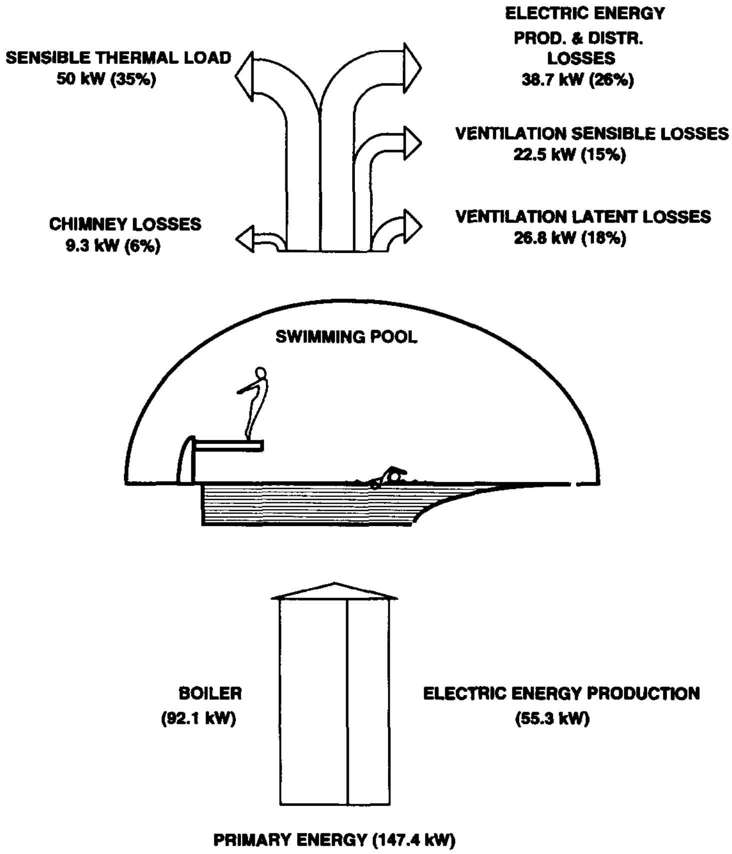

Fig. 8. Energy flow diagram for the heating system with an electric heat pump.

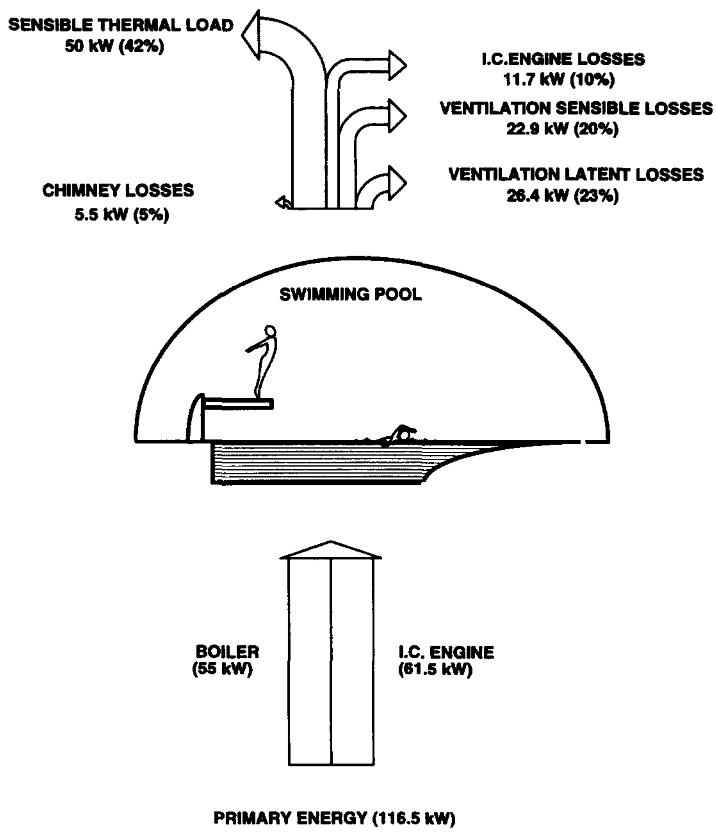

Fig. 9. Energy flow diagram for the heating system with an i.c. engine-driven heat pump.

related to the energy transformation to drive the compressor are, however, low for the i.c. engine-driven heat pump systems, thanks to the heat recovery on the engine (Fig. 9).

Finally, the chemical dehumidification system allows a sharp abatement of the latent losses on the exhaust (Fig. 10). The ventilation losses also include the losses of the combustion products exhaust; that is the reason why the item is greater (relatively and absolutely) than for the heat-pump equipped systems. Moreover, less sensible heat is recovered from the exhaust for the assumed efficiency of the air–air heat exchanger (60% instead of 70% for the heat recovery system of Fig. 3).

Practically, the proposed system and the i.c. motor-driven heat pump one are equivalent from the energy needs point of view.

A FURTHER COMPARISON

So far the comparison has been carried out under nominal working operations. The results could be modified for different outside or inside conditions. A special modification is worthy of examination, i.e. an inside r.h. variation from 50 to 70%, mantaining both air and pool water temperatures at the previous values. In fact the building envelope insulation of modern swimming pools can bear an even higher r.h. without risk of condensation. The comfort of the swimmers should be favourably influenced (a more moderate evaporation from wet skin out of the pool).

A higher r.h. greatly reduces the pool evaporation; therefore, the related loads are strongly lowered. In the example considered, an increase of the inside r.h. from 50 to 70% almost allows a halving of the evaporation loads (from 75 to 40 kW). At the same time the ventilation rate is reduced from 10,000 m^3/h (2.777 m^3/s) to only 3500, from the combined effect of the lower evaporation and of the higher difference between inside and outside humidity ratios; the resulting values are those imposed by standard air change needs.

The fresh air sensible load becomes only 32 kW instead of 90 kW. Figure 11 illustrates the overall needs of the systems considered as a function of the inside r.h.; the reduction is quite considerable

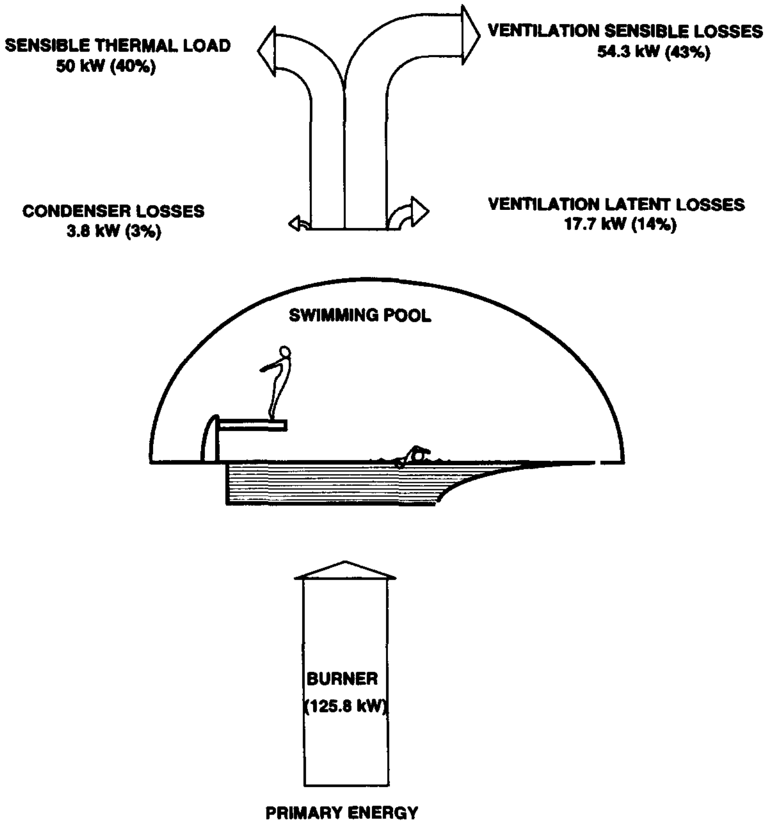

Fig. 10. Energy flow diagram for the sorption dehumidification heating system.

for the simple ventilation system. However, it is not at all negligible, even for the other systems. The relative savings are practically the same, except for the simple ventilation system whose performance is better than previously at 50% r.h.

It is worthwhile appreciating that a suitable modification of the inside conditions can influence the energy needs as much as a more sophisticated plant. For example, going from the heat recovery system to the i.c. engine-driven heat pump system, the energy saving is 50 kW, i.e. the same as when the heat recovery system operates at a r.h. of 70% instead of 50%.

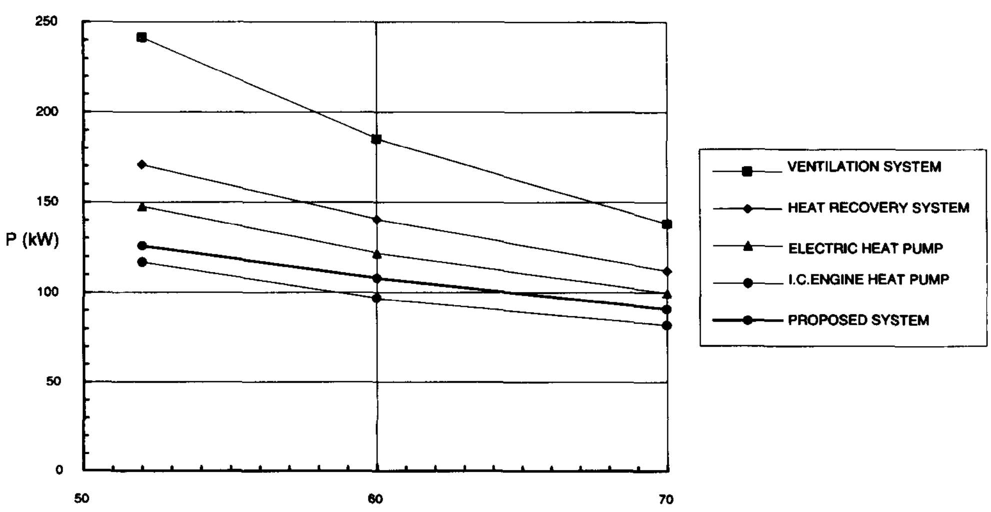

Fig. 11. Thermal power consumption of the different heating systems as a function of relative humidity in the swimming pool.

Really the same inside variation for the two most energy efficient systems allows a further energy reduction of about 30 kW. However, the absolute importance is lower and a greater simplicity of construction and maintenance could be considered more important than just the energy savings.

CONCLUSIONS

The heating of sports auditoria, including a public swimming pool, can be very energy expensive and energy-saving measures are welcome. Important advantages are possible with a careful choice of the inside conditions, together with a suitable design of the building envelope. Failing this possibility, the energy-saving measures can apply to a better utilisation of the energy fluxes; the heat pump is the best device to this end. The new open-cycle heat pump system proposed here allows a strong reduction of the energy needs, arriving, with a simple and presumably cheap technology, at savings similar to the i.c. engine-driven heat pumps, which are more expensive both in capital costs and maintenance.

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