Section: Improving operational effectiveness and reducing environmental impact

Title:

Indoor swimming pools and leisure centres
A model to improve operational effectiveness and reduce environmental impact

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Abstract:

Swimming pools consume disproportionately large amounts of energy compared to dry buildings. Despite the large contribution they make towards the operating costs in local authority property portfolios, they are generally little understood. Water evaporation requires the supply of latent heat of vaporisation. This energy, contained in the water vapour, is lost from the building through ventilation. This form of energy loss far exceeds dry building losses through ventilation and conduction. A holistic formula for evaporation has been incorporated into a model of a pool hall to analyse the annual energy costs, and to identify the means to reduce them. The model has been used to improve understanding of key performance variables, and to evaluate investment in various measures to improve energy efficiency. The simulation also helps with training in pool operations and in design. The results for a typical leisure centre are presented. Savings of over 20% are normally possible.

1 Background

There are several thousand indoor swimming pools in the UK. Many are operated by or on behalf of local authorities, many by hotels and leisure businesses as well as a fair number which are private domestic units. They generally consume vast amounts of energy, much of it wasted. There appears to be a widespread lack of understanding of why so much energy is consumed and how best to reduce it. Operators are naturally reluctant to make adjustments to heating and ventilation systems for fear of harming their businesses and the health, safety and comfort of their clients. This steady-state model was developed to provide operators with a clearer understanding of how pools work, and the scale of the potential savings.

Indoor swimming pools do not behave like normal dry buildings. They are more like boilers, the evaporation of water playing as key role in energy use. The energy required to evaporate water (the “Latent Heat of Vaporisation”) is about 540 times more than that needed to raise the temperature of water by one degree Celsius (the “Sensible Heat”), and very much more than that required to heat air. It is not surprising therefore to find that the energy involved in this process dwarfs the conventional heat loss through the building fabric and in dry building ventilation.

The problem with indoor pools is that they need to be heated to about 30°C to provide a comfortable bathing environment. Even small deviations from this temperature lead to discomfort and complaints. Unfortunately the level of evaporation at this temperature is quite high, so that most of the heat which is used to heat the pool water ends up in the hot wet energy-rich air above it. In the absence of ventilation, this air would become “saturated” with water, so that condensation would occur if it came into contact with any surface at a lower temperature. Ventilation systems are therefore installed in order to dilute the water vapour in the air to below that concentration which is critical to condensation on exposed surfaces. The net effect is that the ventilation drives out the energy which has been used to maintain the water at 30°C. In addition the cold inlet air has to be heated to maintain an air temperature near to the water temperature. Clearly the less the ventilation, the less is the energy loss, but the higher is the risk of condensation, with its consequent risk of damage to the building fabric.

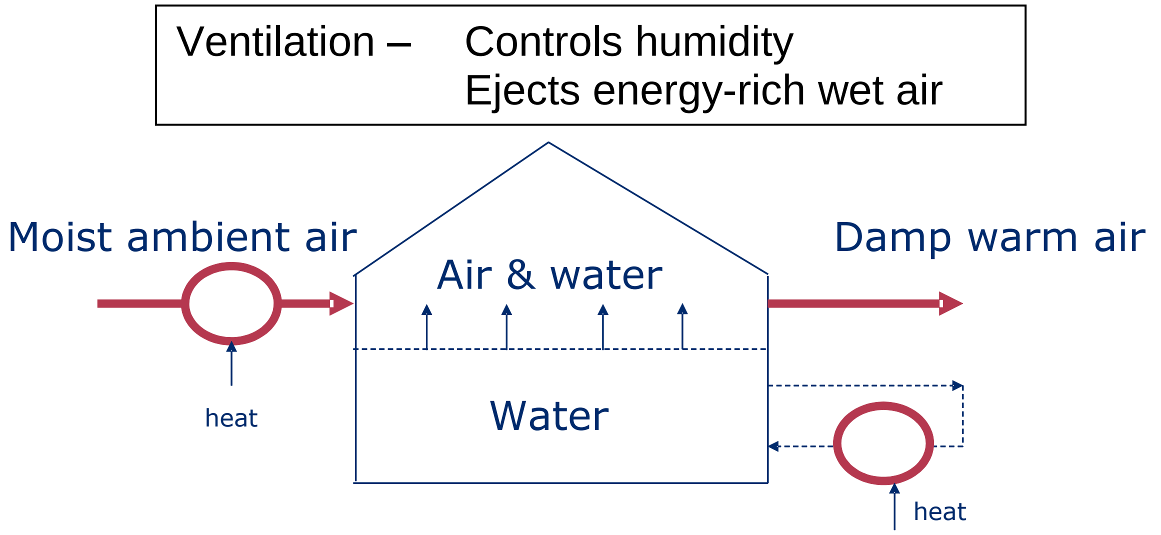
The level of activity in swimming pools affects the rate of evaporation since the surface area exposed to the air increases due to splashing, etc. Activity varies widely during the day, and ceases altogether overnight, which means that the level of ventilation needed to provide the desired dilution effect varies significantly. However, many pools, (including a large number of public pools, which were built during the 1960s and early 1970s when energy was relatively cheap), have single-speed ventilation systems. This means that for much of the time the amount of energy-rich air blown out of the building is far more than it needs to be, hence the waste.

A variety of measures can be taken to reduce energy consumption, including the use of pool covers which can be rolled out overnight, the use of variable-speed fan motors, de-humidification systems, heat recovery units, improved insulation, etc. However, the investment costs need to be justified, and some indication of the savings is crucial to securing the capital funding. The model provides a robust basis for estimating these savings. It has been developed from first principles and incorporates some experimental data from well-respected sources.

2 Methodology

The approach is based on assuming the pool building is similar to what is known in the field of Chemical Engineering as a "Two-Phase Continuous Stirred Tank Reactor", but with no reaction and with water and air as the two phases. Heated air (and some water vapour) enters the vessel and mixes evenly with the air and water vapour inside. Water is added to the vapour phase by evaporation from the liquid phase, and the air, together with the enhanced water vapour burden, is expelled.

FIGURE 1 Swimming pool schematic



Mass and heat balances over the building at any time, would enable the water vapour concentration in the pool air and the heat load to be calculated, provided the rate of evaporation could be determined.

A means of estimating the evaporation rate, and hence the rate of heat loss from the pool water, has been found which takes account of the activity within the pool in terms of the number of bathers. This method requires the values of several properties of wet air at different temperatures and water contents (relative humidity, saturation vapour pressure and enthalpy), and these properties have been built into the model. For any set of temperatures there is a unique combination of relative humidity and ventilation rate, and these are derived through iterative solution of the heat and mass balance equations.

2.1 Pool evaporation rate

The best model for estimating the rate of evaporation from a pool is the subject of some conjecture and is discussed at length by Charles C. Smith et.al., in a paper in the ASHRAE Transactions (1998)[1] They postulated two formulae (shown below) derived from measurements made at a large swimming pool, and claim them to be more accurate than the ASHRAE formula previously accepted[2].

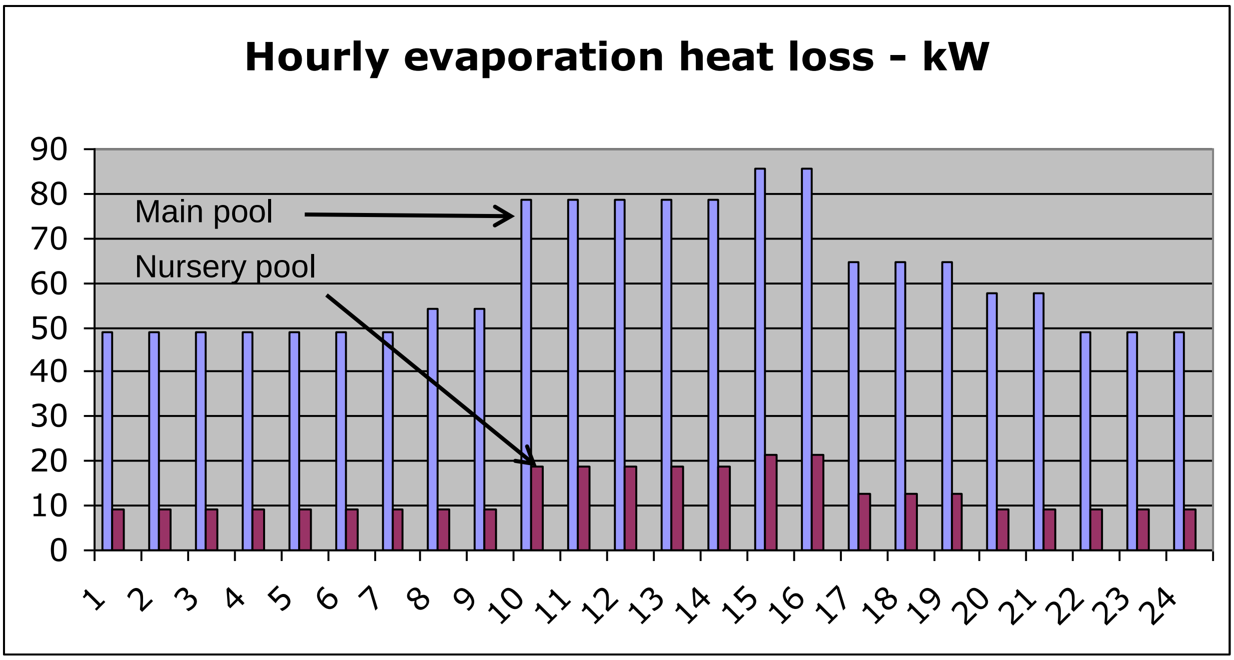
$$W = (69 + 0.35\,v)(p_w - p_a)/Y \qquad \text{.............(equation 1)}$$

$$ER = 1.04 + 0.046 \times C \qquad \text{.............(equation 2)}$$

where:
W is the rate of evaporation in pounds per hour per 1,000 square feet of surface area
v is the air velocity at the water surface in feet per minute
p_w is the saturation vapour pressure at the water temperature in mm Hg
p_a is the saturation vapour pressure at the dew point in mm Hg
Y is the latent heat at pool temperature in BTU/lb
ER is the evaporation ratio between an active pool and an inactive pool
C is the number of bathers per 1,000 square feet.

The important contribution made by Charles C. Smith et.al[1] was to provide a means of differentiating between an active pool and a static one. Until then the ASHRAE Handbook[2] had only provided a general expression for evaporation. Smith et.al predicted 26% less evaporation than the ASHRAE Handbook[2] during inactivity and 26% more with typical bathing intensity. Their equations (converted into metric units) were therefore used in the model to compute a profile of the evaporation from a pool over a 24 hour period. The results for a typical municipal pool are shown below.

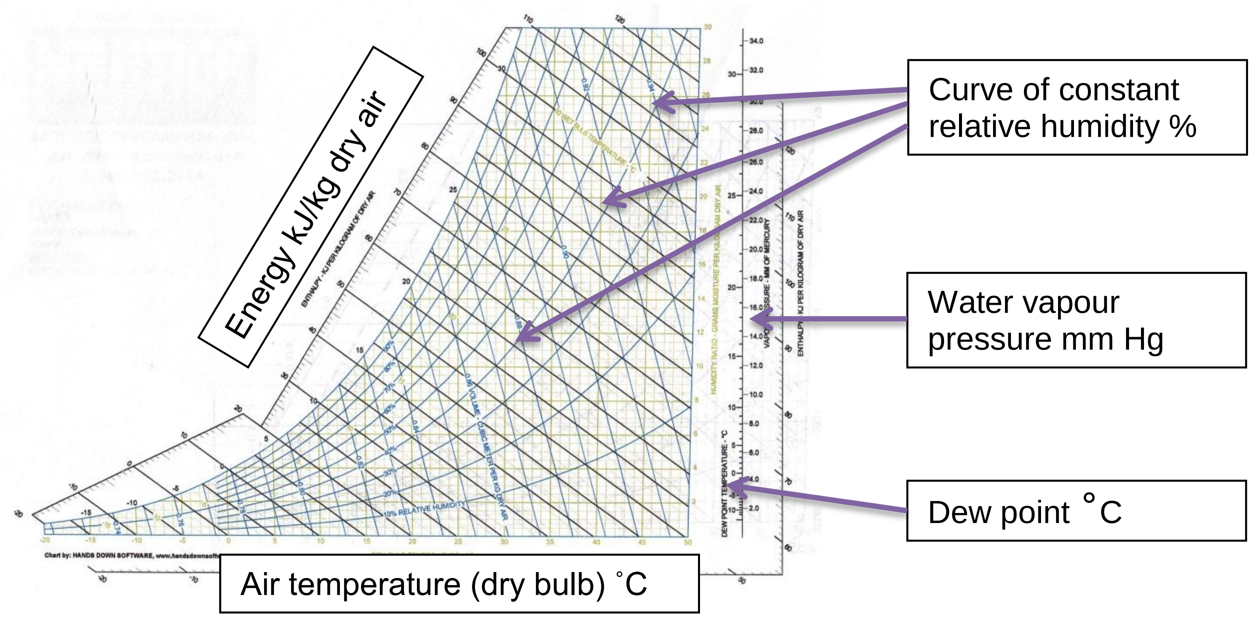
FIGURE 2 Typical pool evaporation heat losses during the day



2.2 Physical properties

The key variables in equation 1 are the saturation vapour pressures of water in the air immediately over the water surface. These physical properties, together with the enthalpy (or energy content) of the wet air, can be obtained from psychrometric charts publicly available. However, for modelling purposes a digital form is needed. Data were therefore extracted from a standard chart (using intervals of 5°C for air temperature and 10% for relative humidity) and an algorithm used to linearly interpolate between these within the model. A psychrometric chart showing how energy content, partial pressure and other physical properties of damp air vary with temperature, etc., is shown below:

FIGURE 3 Psychrometric chart showing properties of wet air



2.3 Heat and mass balances

The heat balance in broad terms is:

Air flow x inlet air enthalpy + heat supplied in air heater bank

+evaporation rate x latent heat

= air flow x outlet air enthalpy………(equation 3)

Similarly, the mass balance on the water in broad terms is:

Air flow x water content + evaporation rate

= air flow x outlet air water content...(equation 4)

The data used in these balances include the outside and inside air temperatures and the water temperature. A set of dry air flow rates is assumed, and for each of these, the total heat flowing into the building from outside in the air is calculated using the digitised chart data.

The heat lost from the pool by evaporation is derived from the equations 1 and 2 above for a range of assumed relative humidity values. The saturated vapour pressures and enthalpy are found using the digitised chart data. The number of bathers and the pool surface area are required in the computation.

The heat flowing out of the pool is calculated for each of the assumed dry air flow rates and relative humidity values by adding the heat inflow and evaporation heat. The heat supplied to the air heater is obtained from the difference for each case.

The mass balance for the water is also calculated for a range of ventilation rates and relative humidity values. Then the value of relative humidity which is common in both the heat and the mass balance at the same ventilation rate is found by iteration. The heat load at this relative humidity and ventilation rate is also calculated. A set of values of heat load and relative humidity are thus determined.

2.4 Daily activity profile and annual cost

Conditions vary over the day because the number of bathers fluctuates. In the early morning many pools are used by swimming clubs for training. This is often followed by a slack period, then pensioner groups, and school classes which come and go. During mealtimes only a few members of the public may be present, whilst activity may peak during early evening. The pool performance is therefore calculated at hourly intervals using observations made at several pools, and then an annual cost is derived for a given set of parameters.

2.5 Understanding the performance

Because of the many variables which affect performance of a pool, a way was sought to summarise this in a single chart. For any specific pool of known water surface area the total heating cost can be derived as a function of the relative humidity, assuming this could be fixed by installing a suitable ventilation control system. This is done by performing multiple iterations over a range of ventilation rates. The solutions to the heat and mass balances provide a curve of the relative humidity and the annual cost for a given set of conditions (Figure 4). The use of pool covers, for example, is accommodated by reducing the evaporation rate by 95% during the overnight period. Also the impact of any heat recovery built into the air handling unit is accommodated in the heat balances.

3 Assumptions

3.1 Heat losses through the building fabric

For the purposes of the modelling exercise, the sensible heat losses through the walls and roof have been ignored. This is because they are likely to be small (5 to 10%) compared to the ventilation and evaporative heat losses.

3.2 Air velocity

The model assumes the surface air velocity to be zero. Many pools have ceiling mounted vents, but even those which have vents nearer to the pool surface are generally designed to minimise the surface velocity. This assumption is invalid in the case of open-air pools and pools where the doors are left open.

3.3 Perfect air mixing

The air near to the water is assumed to be at the same temperature and humidity as the air in the pool hall. This may not always be the case, and stratification is often suspected in pools with ceiling mounted inlet and outlet vents. However, adjusting the model to compensate for this would involve a degree of complexity which would not be justified.

3.4 Exit air composition

The outlet air stream is assumed to have the same concentration and temperature as the perfectly mixed air within the pool (as per the Continuous Stirred Tank Reactor model).

3.5 Physical properties

It is assumed that the contaminants (e.g. chlorine) in the water and air have no impact on the physical properties, as derived from the published psychrometric data for pure water and air mixtures.

3.6 Seasonality

The model takes into account the variability of the activity of a pool during the day, and assumes an annual average outside temperature and air humidity. The annual results are arrived at by multiplying the daily results by 365 rather than by applying a seasonal variation to the daily data. Seasonal effects can be examined by using appropriate data for different ambient conditions and pro-rating the results.

3.7 Energy Costs

Energy unit costs appropriate to each site can by input, together with the assumed boiler efficiency. The evaluation results shown below assume a fossil fuel price of 3p/kWh and a boiler efficiency of 80%.

3.8 Accuracy of data interpolation

The method of determining physical property data by interpolating between data points in a table is considered to be sufficiently accurate for the purposes of this model. An alternative approach is to revert to the original analytic formulae on which the charts are based.

4 Results

The main focus has been on using the model to understand pool ventilation and to inform pool operators how to save money. Some savings can be made by simple adjustments, such as switching ventilation to low-speed or off overnight during the summer. Other savings require capital investment or involve other additional costs. The model has therefore examined the impact of different scenarios in order to quantify these changes.

A typical municipal pool is 25m x 12m and has a nursery or teaching pool of about 6m x 10m. The centre is normally open from about 8am until 10pm, although club activities mean that on some days the pool is in use from about 6am.

Many pools have pool covers which are rolled out at the end of the day to reduce the evaporation overnight, but there are instances of covers remaining out of use, or not installed.

The majority of pools have a once-through ventilation system with inlet and exhaust fans running at constant speed 24/7. Some have a low-speed setting which can be switched from the control panel, whilst some have automatic switching using a timer, (though many of these are no longer serviceable). There has been some retro-fitting of air handling units with variable-speed fan drives, although in some cases these have not been linked into a closed control loop. Some of the forty year old installations originally incorporated heat-pump dehumidification and heat recovery by condensing the water vapour in the air, but most of these are no longer in service due to the cost of maintenance.

There are a number of suppliers of modular air handling units for retro-fitting, which incorporate variable speed fan control together with some degree of heat recovery from the exhaust air using a heat exchange section. Some also incorporate a dehumidification option. This enables the latent heat of vaporisation in the damp air to be recovered by condensing the water vapour on a cold coil. The energy recovered is used in a hot coil to heat the inlet air.

The model enables all of these options to be evaluated, and for rational choices to be made which are appropriate to each site.

4.1 Impact of relative humidity

FIGURE 4 Annual pool heating costs vs relative humidity

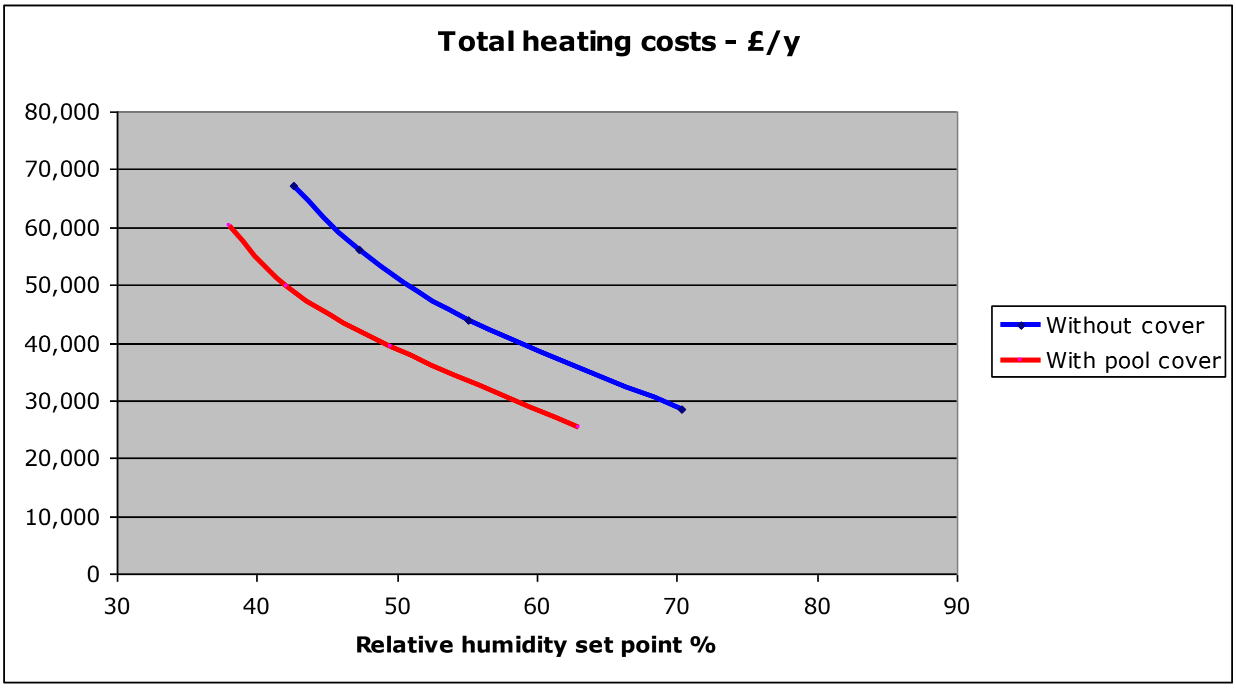


Figure 4 shows the effect of relative humidity on the overall cost of heating a typical municipal pool. This shows that significant savings on operating costs can be achieved by increasing the humidity level. This means increasing the risk of condensation and damage to the building fabric. Whilst many pools are set up to operate around a figure of 50% RH, there is no sound basis for this and each pool is different. The key factor is the exposure of the wet pool air to cold surfaces such as glazing, structural steel, and un-insulated roofing. The results show that by being able to increase the humidity level from 50% to 60%, for example, through better insulation, glazing and cladding, a saving of about £10,000 per year could be made.

4.2 Impact of pool covers

Figure 4 also shows a second, lower curve, representing the costs when a pool cover is used overnight. The difference between the two curves diminishes somewhat as relative humidity increases, but lies in the region of £10,000 per year. This gives about a two-year payback for a typical cover installation.

4.3 Impact of variable-speed fans

FIGURE 5 Impact on costs of daytime pool activity

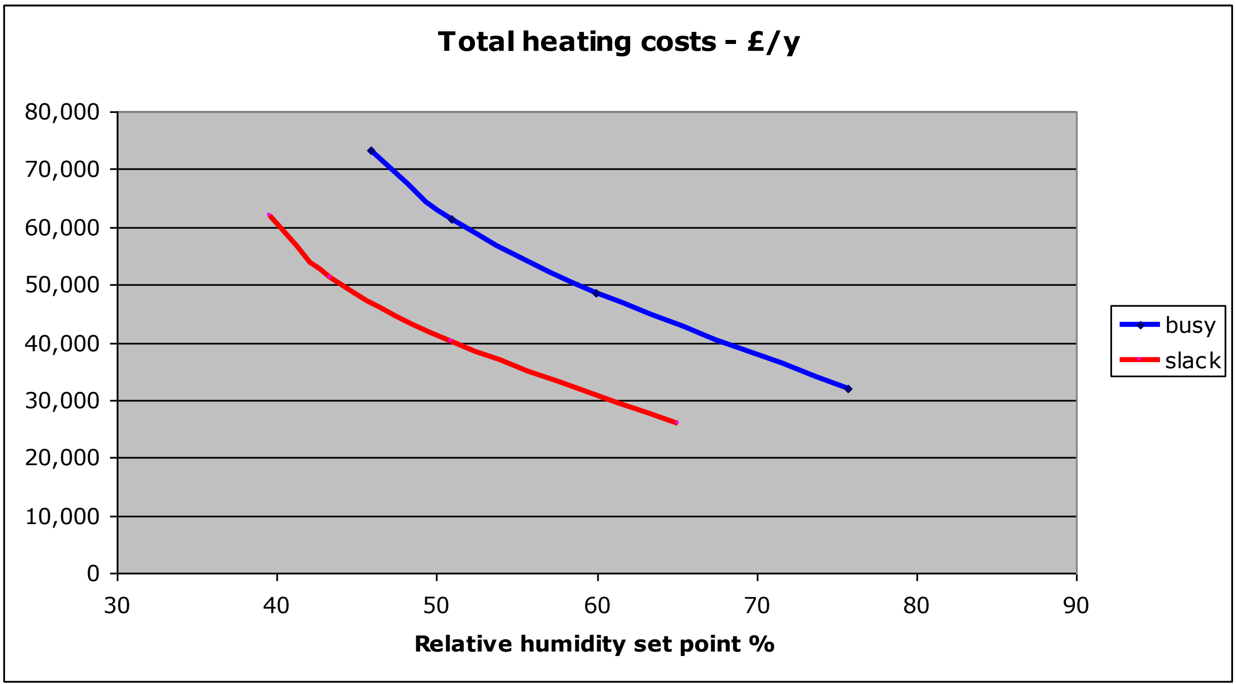


Figure 5 shows the same curve for high pool activity and for low pool activity levels. In a fixed speed system the design would probably have been based on the higher activity level, which in most cases means that the ventilation is too high for much of the time, and certainly overnight. Variable-speed fans, if correctly implemented with a control loop based on humidity measurements, would reduce the ventilation when appropriate, such as when activity in the pool falls away. The difference between the annual costs at high and at low activity levels during the day is about £20,000, plus the electricity cost savings associated with lower fan speeds. With fixed speed ventilation, half of this cost is wasted if the pool is slack for half the time it is open. Variable-speed fans automatically compensate for low evaporation levels when the pool cover is applied overnight, and allow the pool to be operated at an increased humidity level with less added risk (through better control).

4.4 Impact of heat recovery and dehumidification

FIGURE 6 Impact of heat recovery

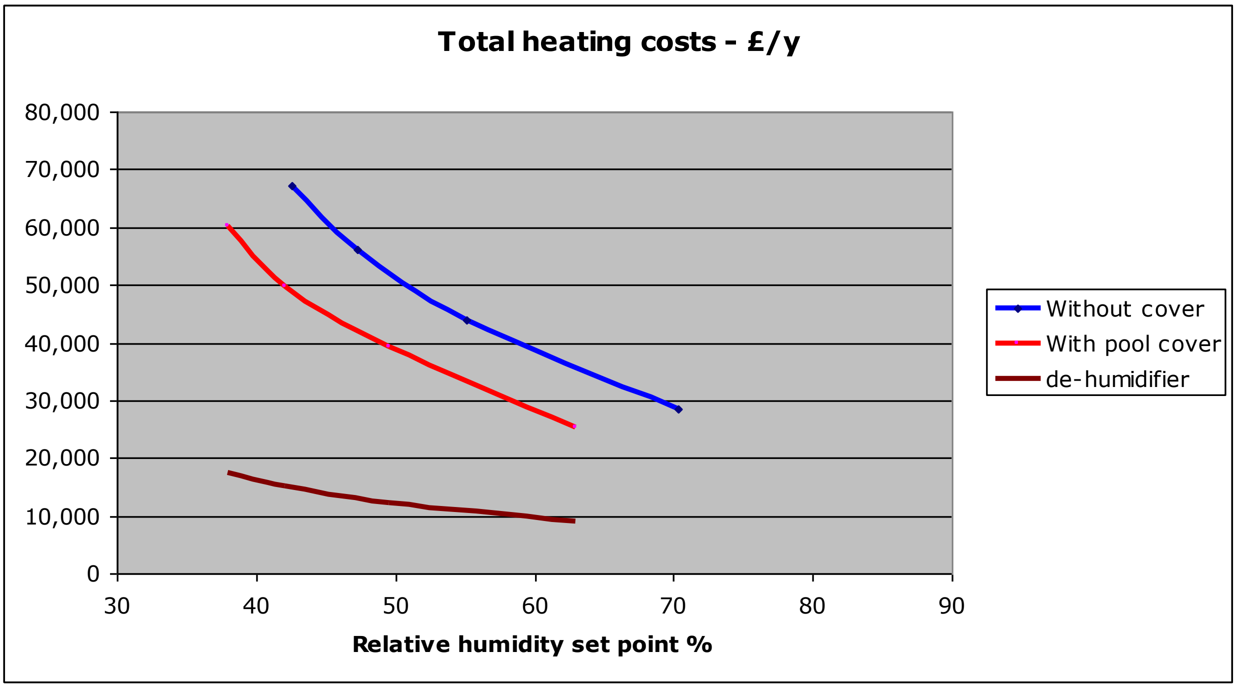


Figure 6 shows how the level of heat recovery affects running costs. The very high levels of heat recovery achieved by heat pump dehumidifiers appear at first sight to offer huge financial savings. However, these need to be balanced against the electricity consumed in their operation. Unfortunately with a coefficient of performance of about 3, and an energy unit cost ratio of about the same, the financial benefits are small if anything.

5 Conclusion

The swimming pool model has been derived from heat and mass balances over a building containing a large area of evaporating warmed water. The rate of evaporation has been calculated using formulae reported in the ASHRAE Transactions (1998)[1] which is based on measurements of water loss and heat use of an actual indoor pool, and which take into account the level of pool activity. The built-in physical property data are extracted from standard psychrometric charts and used by interpolating between data points. The scenarios examined have provided robust justifications for changes in pool operations designed to save energy. Other publications[3,4] have addressed this topic but are not reviewed here. The following table summarises in broad terms the justifications for changes to a typical 1960s pool:

TABLE 1 Examples of investment estimates

Action	Gas savings £/y	Electricity savings £/y	Investment £	Payback years
Pool cover	10,000		20,000	2.0
Ventilation control	12,000	5,000	30,000	1.8
Insulation	8,000		20,000	2.5
De-humidifier	20,000	(16,800)	20,000	6.3

Note that benefits are for independent investment measures and care should be taken when summing them.

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