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DEVELOPMENT OF A SIMPLE MODEL FOR PREDICTING THE ENERGY CONSUMPTION OF HOUSES IN HOT MARITIME CLIMATES

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ABSTRACT

The paper describes the development of a simple computer model for predicting the annual amount of energy used in air conditioned houses. A steady state energy balance is carried out using mean monthly solar and other weather data, with typical incidental heat gain data based on family size and power ratings of appliances. Fabric and ventilation gains are predicted using house element areas, 'U' values and assumed infiltration rates. Computed cooling loads are converted to energy consumptions using air conditioning system coefficients of performance derived from measured energy consumptions and manufacturers' data. A limited validation of the model has been carried out using six houses about which the energy consumptions were known. Comparisons of predicted and measured energy were favourable.

INTRODUCTION

Much research has been carried out in Europe and the United States on predicting the energy use for controlling the internal environment in buildings. This has been necessary since over recent years costs have risen and ways of reducing them have had to be found. In order to assess the savings attributable to different conservation measures, it has been necessary to develop models for predicting energy use and assessing the value of different design options.

In Europe the energy consumption for heating domestic buildings has been of particular concern, but in the Middle Eastern countries, it is air conditioning which causes problems of increasing electricity use.

The problem of high energy consumption has become a major concern of local authorities as well as the people who experience a shortage of supplies and the possibility of price rises.

As part of a recently completed Ph.D. thesis, a simple model was developed for predicting the energy consumption of air conditioned houses. The model is based on data obtained from a range of six houses in the Dammam region of Saudi Arabia.

METHOD

The approach to the problem was to construct a simple steady state heat balance equation which could be used to determine the cooling load of a typical house. The electricity consumption of the air conditioning system could then be determined if the coefficient of performance (COP) was known. A comparison between this predicted energy use and that actually used could then be made. The method was applied to six different houses each having one of two types of cooling system; either a 'split' system or a 'window' system. The houses were surveyed and their electrical energy consumptions obtained to provide the input data for the model and a basis for the energy use comparison. Unlike models used to predict heating energy consumption, the effect of latent gains was taken into account. The model utilised mean monthly weather data and predicted energy used was on a month by month basis.

The basic equation describing the mean rate of total heat extraction (Q_T) from the building can be written:

$$Q_T = Q_F + Q_V + Q_I + Q_L \quad \text{kW}$$

where Q_F is the gain through the fabric, Q_V the gain due to ventilation, Q_I the incidental internal gain and Q_L the latent gain due to condensation of moisture.

A brief description of each of the components of Q_T follows, but it is not possible, within the length of this paper, to fully describe all the detail:

Q_F, the fabric gain, was determined from the expression,
$Q_F = A * U * (TS_a - T_i) / 1000$ kW for each building element.

Element areas (A) and thermal transmittance values (U) were derived from the house surveys and drawings. TS_a, the mean daily sol-air temperature, was determined for walls and roofs using the method described in the CIBSE Guide (Ref 1) for each orientation using the appropriate mean solar radiation and air temperature (T_o) data applicable to Dammam. The mean internal temperature, T_i, was obtained from the house surveys using a thermo-hygrograph.

The ventilation gain, Q_V, was derived using the expression

$$Q_V = 0.33N * V * (T_o - T_i) / 1000 \text{ kW}$$

An air change rate (N), of 1/h, was assumed to apply to all the houses. Actual data was not available since no measurements were taken. A figure of 1 ac/h is, however, commonly used in Europe for this type of study. Values greater than this would not commonly be assumed in situations where the cost of energy is considered important and 1 ac/h is generally sufficient to control odours. The volumes of the houses, V, were obtained from the survey measurements or drawings when available.

Incidental heat gains Q_I comprised two components, solar gain through windows (Q_{SOL}) and internal gain from lighting, people, domestic appliances and electronic equipment (Q_{INT}).

The solar data available consisted of daily and monthly mean global, direct and diffuse radiation provided by the meteorological station at the King Fahad University Research Institute of Petroleum and Minerals.

This data was manipulated to obtain the radiation on vertical surfaces for different orientations. The method used was that suggested by Markus and Morris (Ref 2). This information, in conjunction with the measured window areas and glazing characteristics, was used to determine the solar gains (Q_{SOL}).

Gains from people were estimated using information on the heat output per person (Ref 3), combined with occupation patterns obtained from the house surveys. For each house, a record was made of the number and types of domestic appliances and other electricity consuming equipment. Information on equipment loadings was obtained from the electricity company (Ref 4) and, by estimating the hours of operation, the energy consumption was calculated.

In an air conditioned house, the refrigeration system controls the humidity by extracting moisture from the air. In order to maintain constant internal conditions, the moisture losses must equal the gains from the various sources. Moisture gains arise from the respiration of people (MP), ventilation (MV) and the activities of bathing (MB), clothes washing (MW) and food preparation and cooking (MC). For each of these sources, information was obtained on the moisture output (Ref 5) which, for the people, was modified to take into account the occupation pattern derived from the survey. The moisture added by ventilation was determined as the product of ventilation air mass flow (1 ac/h) and the difference between internal and external moisture content obtained from thermo-hygrograph and weather records respectively. The sum of moisture inputs, equal to that extracted, was then factored by the latent heat (2450 kJ/kg) to give the heat extracted by the system. All the gains, Q_F, Q_V, Q_I and Q_L, were then converted to energy values, kWh, by multiplying by the number of hours in the month.

A computer programme was written to determine Q_T, the monthly total heat extracted. Checks were built into the programme to ensure that if the total latent heat gain was negative, it was set to zero.

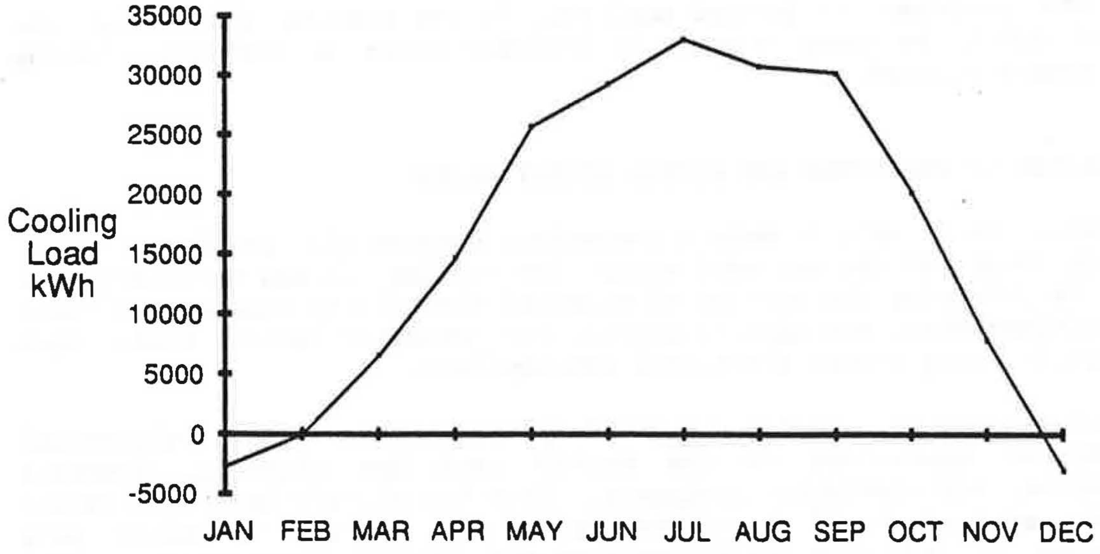

FIGURE 1. Monthly cooling requirements

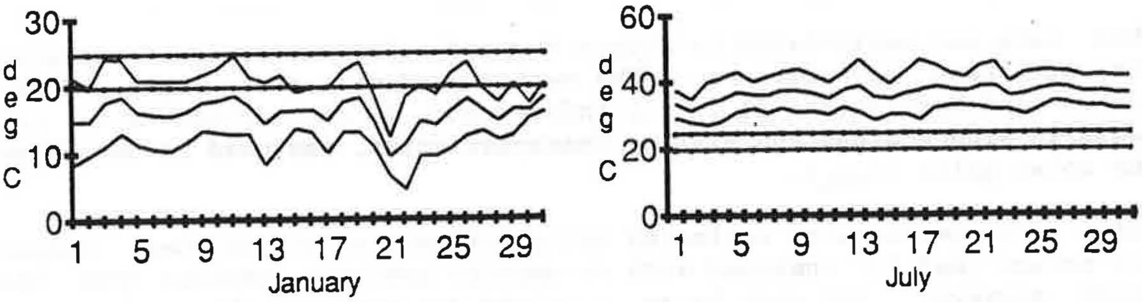

FIGURE 2. Examples of maximum, minimum and mean external temperatures in relation to comfort limits 20-25°C

This situation could arise if the outside moisture content was low enough to produce a negative ventilation moisture gain large enough to offset the positive gains. Also, if the sum of Q_F, Q_V and Q_I was zero or negative, no mechanical cooling was needed, in which case moisture gains were set to zero.

The monthly loads are shown for one of the houses in Fig 1. It can be seen that cooling loads are negative for some parts of the year, i.e. some heating would be required.

For the six houses studied, the model predicted a negative cooling load during the months of January, February and December. This result was further investigated by plotting outside air daily maximum, minimum and mean temperatures for each of these months for comparison with comfort conditions. Fig 2 shows examples of these plots for the months of January and July. For the months in question, external temperatures are generally lower than required for comfort, providing some confirmation that heating may be needed during these months.

Results from the house surveys showed that over 90% of the occupants perceived the 'summer' as the period May to October and about 55% indicated the period April to November.

For the purposes of further analysis, it was assumed that only the months April to November would be included where a definite cooling requirement existed.

COMPARISON OF PREDICTED AND ACTUAL ENERGY VALUES

In order to be able to make a comparison between the predicted house cooling loads and the measured energy for cooling, it was necessary, not only to determine the portion of measured electricity consumption used for refrigeration, but also to convert the predicted cooling loads into air conditioning system electrical consumptions.

It was assumed that each house would operate with a 'base' electrical consumption equivalent to the energy used for lighting, domestic appliances and electronic equipment. This had already been determined in the assessment of incidental gains and it was therefore only necessary to subtract the figure from the metered consumptions. The remaining energy was assumed to be for air conditioning.

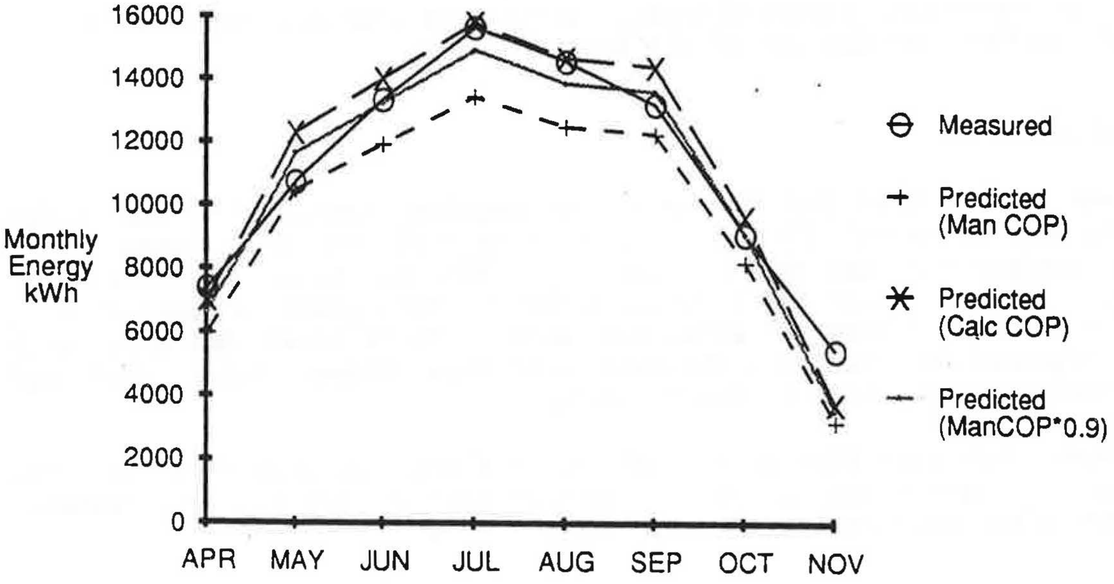

FIGURE 3. Comparative energy use

Conversion of the cooling loads to refrigeration system energy use required that they be divided by the Coefficient of Performance (C.O.P.) of the refrigeration unit.

A first approach was to obtain from manufacturers' catalogues the published COP figures for each type of unit surveyed, i.e. 'split' type and 'window' type (Refs 6 & 7). Typical values were 2.46 and 1.8 respectively and these figures were used to determine the consumption for each house for comparison with the electricity measurements. The predicted and measured energy consumption for the whole cooling season are shown in Table 1(a) for all the houses with the percentage accuracy. It would be expected that the predicted values would generally be lower than those measured since the COP's used were the manufacturers' figures which would normally be based on continuous running at a high load. In practice, COP's at the ends of the cooling season would be expected to be lower due to lower loads and intermittent operation. This would result in lower seasonal value than the manufacturers' figures. With the exception of House 5, all the predicted energies were lower than those measured.

Since seasonal COP's in practice would normally be lower than the manufacturers' figures, the 'predicted' COP's for each house were determined monthly by dividing the predicted cooling loads by the measured energy consumption. The means of all COP's determined in this way were then taken for the 'split' and 'window' unit houses giving values of 2.09 and 1.8 respectively. The value for the 'split unit' houses was, as expected, lower than the manufacturers' figure, but that for the 'window unit' houses was the same. This result was mainly due to the value for House 5 which was 2.19, whereas Houses 2 and 6 gave values of 1.66 and 1.61 respectively. If, however, the 'predicted' COP's of 2.09 and 1.8 are used to predict energy consumption, the comparison with the measured results gives improved accuracies as seen in Table 1(b). A further comparison was carried out using manufacturers' figures reduced by 10% (Table 1(c)).

Fig 3 shows the predicted energy consumption compared with that for April to November for one of the houses.

CONCLUSIONS

It can be concluded that the energy consumption, predicted by the Model using manufacturers' COP values, gives a good fit to the measured data. The indications are that manufacturers' figures should be reduced by about 10% to allow for seasonal effects. This gives a better fit, although House 5 gives an anomalous result. It is clear that more work is required to validate the model with more houses being used and refinements being made to the COP values.

Further work must also be carried out to assess the sensitivity of the model to variations in design features such as fabric, 'U' values, window sizes and ventilation control.

TABLE 1.

	ENERGY kWh	HOUSE 1	HOUSE 2	HOUSE 3	HOUSE 4	HOUSE 5	HOUSE 6
(a)	Measured	89922	140518	110693	61613	41629	67224
	Calculated	78361	130482	86807	56414	50184	59465
	Percentage	-12.8	- 7.1	-21.6	- 8.4	+20.6	-11.5
(b)	Calculated	91794	130482	101688	66085	50184	59465
	Percentage	+ 2.1	- 7.1	- 8.1	+ 7.3	+20.6	-11.5
(c)	Calculated	87068	144980	96452	62682	55760	66072
	Percentage	- 3.2	+ 3.2	-12.9	+ 1.7	+33.9	- 1.7

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