RATING THE ENERGY EFFICIENCY OF AIR CONDITIONED BUILDINGS

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BRE, working with a group of industry and property representatives, have developed a simple method for assessing the likely energy efficiency of air conditioned and mechanically ventilated buildings. For new buildings, the method uses information available at the early design stages. It therefore provides designers with a tool to assess the implications of various plant and envelope options from the beginning. It can be used as a label or target for energy efficiency and, as such, as a means of assessing buildings in both voluntary systems such as BREEAM or perhaps in Building Regulations. Using the index in reverse could provide designers with a means of targeting the size of plant and therefore plant room space.

The resulting Energy Performance Index has been tested against energy use data from existing buildings, initially for air conditioned and mechanically ventilated office buildings, and works well despite its simplicity. The method applies equally to existing buildings and new building designs. It can be applied to several building sectors, such as offices, hotels and department stores to indicate likely efficiency relative to suitable benchmarks, like the Energy Efficiency Office's Energy Consumption Guide 19 for Offices.

INTRODUCTION

It is helpful to have a working definition of energy efficiency. A useful working definition is as follows: The most energy efficient building is one which provides the specified indoor environment for least use of primary energy.

A simple and low cost method for assessing the energy efficiency of buildings can be used as the basis of goal based performance requirements and specifications, as the basis of a performance label or as an early stage design tool encouraging integration of services and envelope requirements. This paper proposes a method which is in principle suitable for each of this range of applications. The method has been developed by BRE with a wide range of industry and property interests through a series of consensus forming workshops. While the performance of the method is yet to be fully assessed over the full range of building types, early results are very promising.

BASIS OF THE ENERGY PERFORMANCE INDEX METHOD

The new method relies on 2 basic assertions:

- The wide range of decisions and assumptions made during the building design and specification process, including orientation, plan form, levels of fabric and internal heat gain, plant and system efficiencies, any oversizing allowances, etc, are ultimately reflected in the plant capacities installed.

- The provisions made to manage the plant and the internal environment influence the number of hours per year that these plant operate and their seasonal efficiencies.

The installed plant capacities and running hours, modified by plant management factors related to the means provided to control, monitor and report their operation can themselves then form the basis for assessment.

THE INDEX FOR AIR CONDITIONED OFFICE BUILDINGS

The index is derived from an estimate of likely annual energy consumption. The refrigeration plant of a notional 'base case' system is considered to operate for 1000 hours per year (full load equivalent) and the fans and pumps for 3700 hours per year (approximately equivalent to all year operation, 13 hours/day, 5.5 days/week). The energy consumed by this 'base case' system would approximate to:

$$Q_{ac} = (E_r \times 1000) + (E_d \times 3700)$$

Where: Q_{ac} = Annual energy consumption (kWh)
E_r = The rated energy input to the refrigeration plant (kW)
E_d = The rated energy input to the fans and pumps (kW)

Plant efficiencies conceptually enter into this calculation, but in the end are reflected in equivalent full load hours run. Considering the provisions made to manage the operation of plant to reflect directly on the equivalent full load hours of use, the energy consumed by the system would approximate to:

$$Q_{ac} = A\ (E_r \times F_r) + (E_d \times F_d \times 3.7)$$

Where: A is a constant
F_r and F_d are plant management factors which reflect the provision to control and monitor the refrigeration plant and the fans and pumps respectively

To compare designs which may include various options for energy supply on an equal basis, related to their potential to produce CO_2 emissions, the rated energy inputs to the air conditioning plant are expressed in terms of installed capacity per square meter of conditioned area, and in terms of primary energy:

$$Q_{ac(Primary)} = A\ (P_r \times F_r + P_d \times F_d \times 3.7)$$

Where: P_r = The installed refrigeration power demand in W/m^2 of treated area, expressed in primary energy units.
P_d = The installed power demand of the air and water distribution system (fans and pumps) in W/m^2 of treated area, expressed in primary energy units

An Index which increases as the likely energy use decreases is then produced simply by dividing a suitable large number by the likely energy use:

Equation (1).

$$INDEX = \frac{AC}{(P_r \times F_r + P_d \times F_d \times 3.7)}$$

For convenience, the value of 'AC' can be chosen so that an index of 100 is achieved when the likely primary energy use equals a particular 'target' value, for example representing a minimum acceptable level of performance.

For simplicity, it is assumed that the influence of the plant management measures does not alter the ratio of hours run and that this remains about 3.7. However, the index formula has been found to be extremely insensitive to this assumption. Figure 1, based on 13 buildings, shows that the effect of varying this multiplier between 2.7 and 4.7, using representative values for plant sizes and control multiplying factors, produces a change in the index achieved of only 5%, once the formula is recalibrated to achieve an index of 100 at the defined minimum performance standard. This reflects the fact that the ratio is defined as a typical value under average conditions. The main sources of variability in individual cases are the plant management factors.

Plant management (monitoring and automatic control) measures

Monitoring equipment can be used to monitor the internal environment, the energy used by system components or their hours of operation. A monitoring system may also be designed to alert the building occupant or manager when plant and controls are not performing as intended, reducing the probability that energy is wasted.

Effective monitoring, alarm and automatic control measures can be considered to increase the expected efficiency of systems or, essentially, to prevent excessive hours of use, and reduce the probable energy consumption.

An essential feature of the Energy Performance Index calculation is thus to multiply the chiller and air and water distribution system capacities by factors dependent on the extent to which relevant plant management measures are provided.

Relevant measures, and multiplying factors which might be applied, are suggested in Tables 1 and 2 below. In each Table, either column A, B or C would be selected depending on the extent to which monitoring provisions are made - according to the following criteria:

A. A monitoring and reporting system which can fulfill the function of B (I), (ii) and (iii) below, and which can draw attention to out of range values

B. (I) Energy metering to major plant, and/or
   (ii) 'Hours run' metering to major plant, and/or
   (iii) Monitoring internal zone temperatures (and humidities)

C. No provision for metering or monitoring

The source of the measures was a checklist of energy efficiency features of design, encompassing fabric and plant details as well as plant management issues. The consensus workshops initially considered this checklist as a means in itself of assessing design. Later development however associated most of this design detail simply with the installed plant sizes, leaving only the plant management issues to be addressed separately.

The values of the factors listed under columns A, B and C were developed judgementally at the consensus workshops. It can be seen that the addition of realistic combinations of measures could move the average likely energy use of a design from 'typical' to 'good practice'.

1c. 'Mixed mode' operation in which sufficient opening windows in a narrow plan building are included to provide the required internal environmental conditions by changeover to natural ventilation when outdoor conditions allow. (It is suggested that this would only apply where the perimeter zone exceeds 80% of the treated floor area, and that when such windows are opened, the local zone(s) of air conditioning systems should be automatically inhibited from operation.)

2. Controls which limit plant operation to the hours of occupancy of the building, with the relaxations noted below in which operation outside the hours of occupancy forms a necessary part of the efficient use of the system:
   - To prevent condensation
   - For optimum start control
   - As part of a strategy to pre-cool the building overnight using outside air

3. Controls which include a deadband or interlock to prevent heating and cooling being supplied simultaneously to the same zone.

4. Refrigeration plant capacity controlled by:
   - The provision of modular plant with sequence control
   - Variable speed compressor
   - Other means by which plant input power is reduced in proportion to the demand to maintain efficiency at partial load conditions.

5. Ice thermal storage, partial or full:

   Partial: Chiller may operate continuously, charging store overnight and supplementing store during daytime occupancy.

   Full: Chiller operates only to recharge store overnight; full store capacity depleted during daytime occupancy.

6. Air flow rate controlled by:
   - A form of variable motor speed control in which reduced speed results in reduced power consumption
   - Variable pitch fan blades
   - Variable fan inlet guide vanes

A PERFORMANCE STANDARD FOR AIR CONDITIONED OFFICE BUILDINGS

A performance goal could be used to calibrate the Index of 100. This could be a minimum standard if the procedure were to be incorporated into regulations, or it could be a best practice standard. Sufficient energy performance information for offices is provided for the UK in Energy Consumption Guide 19 (ECON 19) "Energy Efficiency in Offices" [Best Practice Programme, EEO, 1991] which details the performance of a range of office building types. This database is being extended and broadened to include other building types.

CORRELATION BETWEEN THE PERFORMANCE INDEX AND ENERGY USE

Figure 2 indicates the correlation between the Energy Performance Index values achieved by a sample of office buildings and their annual energy use relative to a particular goal. The buildings had been either completed or refurbished within the last five years. The necessary plant sizes, monitoring and control and energy consumption data were provided voluntarily to BRE. Despite the simplicity of the index calculation, which only seeks to assess the likely energy efficiency of the air conditioning plant, there is a remarkably good correlation with total annual energy consumption. Further data from additional exemplar buildings are being sought to develop further confidence in the method.

APPLICATION TO OTHER SECTORS

The Index method can be applied to other sectors, provided certain assumptions are made concerning the ratio of operating hours between the distribution system and the refrigeration plant. A different value of the factor 'AC' in Equation (1) would then recalibrate the formula to provide an Index of 100 at a new 'target' energy consumption.

CONCLUSIONS

1. A new Energy Index method has been proposed which may be used as an energy efficiency target or energy label.

2. Although essentially simple in nature and in application, the Energy Performance Index appears to be a useful comparator of the energy efficiency of air conditioned building design.

3. The possibilities of extending the Index to include other building services, such as heating and lighting, and to apply the method to other sectors, are being investigated.

4. A desire to achieve a certain value of the Index could form the basis of a design specification, and would encourage early discussion of the issues between architect and services designer. It could be used to identify either minimum acceptable practice, best practice, or both.

5. The Index achieved by a particular building design, or an existing building, could be an effective label describing its likely energy impact under 'standard' conditions of usage.

6. The method of calculating the Index is simple and could be used in reverse during design to indicate the plant capacities and plant management facilities needed to achieve certain values of the Index. This would help in assessing the servicing costs of particular design options, and in planning plant room space.

7. Being goal based, rather than prescribing the use of particular technologies or features of design, the Index provides the designer with great flexibility in developing optimum solutions to suit particular needs.

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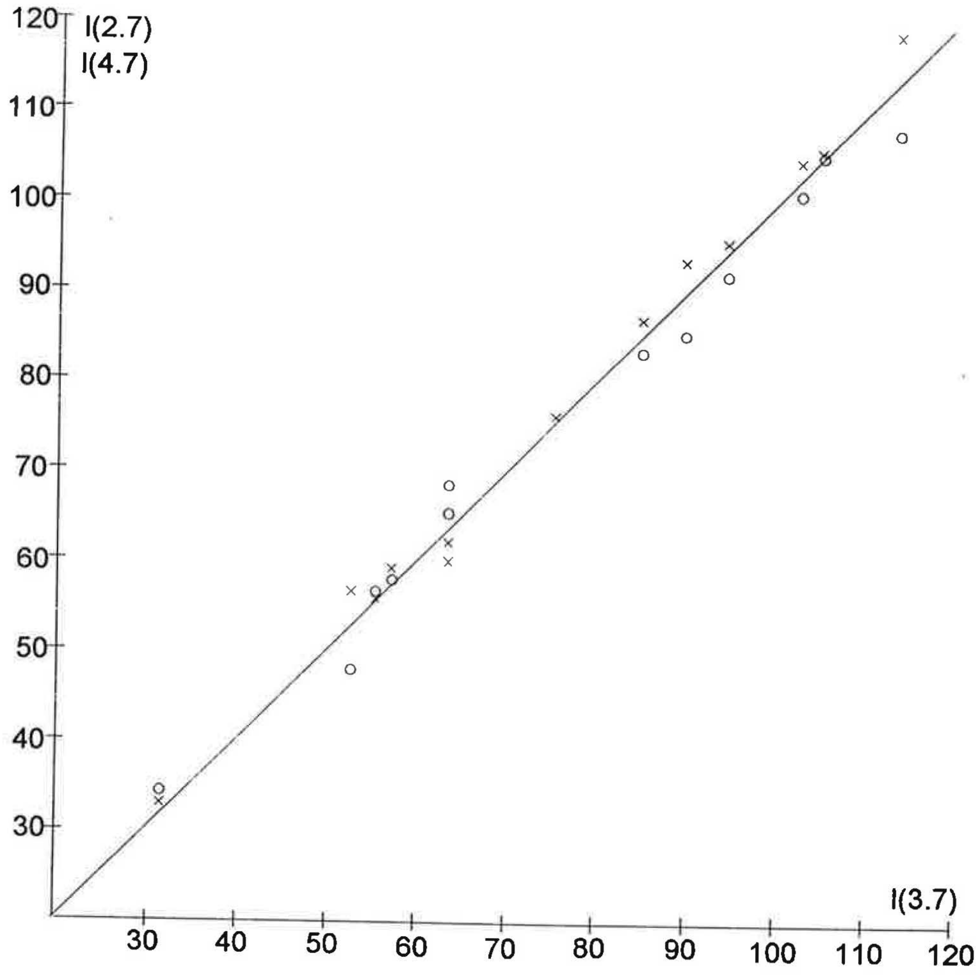

Figure 1. The effect of varying the ratio between distribution system and refrigeration plant operating hours on the calculated index (I).

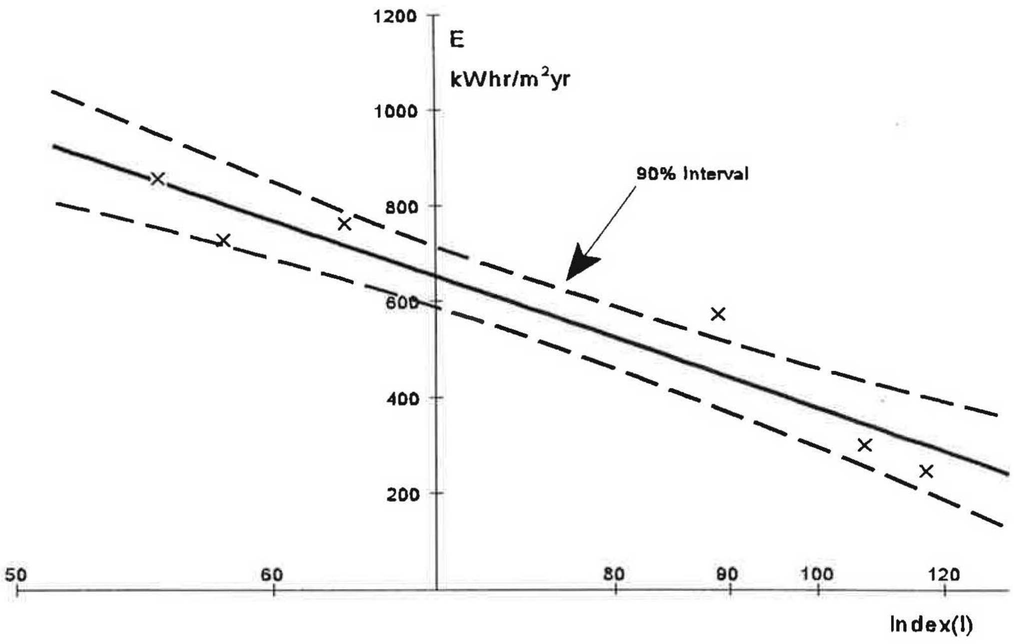

Figure 2. Relationship between the calculated index (I) and annual energy consumption

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