INTEGRATING ENERGY EFFICIENCY INTO BUILDING DESIGN USING A SIMPLIFIED THERMAL ASSESSMENT METHOD

Simon Tucker
School of Computing and Technology, University of East London, UK
s.s.tucker@uel.ac.uk

Abstract: New buildings and building refurbishments should be designed such that the best use is made of solar energy, and that fossil fuel based energy is not wasted. Because the thermal processes in a building are quite complex, the use of thermal assessment methods such as dynamic thermal simulation are generally recommended as part of the design process. These methods are intended to show building designers the effects of their building proposals on energy use, but are often too slow and difficult to use and do not really 'fit' into typical design practice. Therefore the job of energy assessment might be given to an engineer, but usually no assessment is done at all, or else the engineer is employed only to 'rubber stamp' the completed design. The method outlined in this paper is intended to give the building designer access to all the information in such a way that at early design stages the thermal characteristics of the building design can be quickly explored, in a parallel way to which designers explore issues of function and use, aesthetics, structure and cost. It is proposed that through use of such a method, considerations of energy and environment can be integrated into each project from the very start of the design process.

1. Introduction

Rising temperatures and climate change is related to the release of CO2 into the atmosphere resulting from conventional energy use. In the UK domestic buildings alone use 30% of the UK energy total, with 62% of that proportion used for space heating (Shorrock and Utley, 2003). Existing thermal assessment methods range from complex computer based methods to simple manual methods, and these are all intended in one way or another to allow the building designer to reduce energy consumption of the building.
The complex methods can be accurate and give much detailed information on heat flows, internal temperatures and energy predicted for heating and cooling, and can be used to model any type of building anywhere in the world. They are however difficult to operate and considerable time is needed before meaningful results can be obtained. Therefore they tend not be used in design, or are only used as an afterthought.

Simple methods on the other hand are generally quick and easy to use but are often lacking in accuracy and/or are very limited in the types and locations of buildings that can be assessed. These might be used more often, but are not of much use at helping with the detailed design of thermal operation of the building.

The method reported here successfully combines many of the advantages of both the complex and simple methods.

2. Philosophy of the Method

2.1 Testing the parameters

The method is intended to allow the user to quickly explore the effect on thermal behaviour of altering the following parameters;

- opaque fabric areas and orientations
- glazed areas and orientations
- opaque fabric construction details
- glazing types
- infiltration rates
- ventilation rates and times
- heating patterns and set points
- conditional operation of devices such as shutters, sunspaces, windows etc
- location (hourly weather files used)

The efficiency of the heating and cooling plant is also important but has not been considered at this stage. The following information is given as output;

- Annual space heating energy use
- Estimation of overheating (number of days during the year on which internal temperature exceeds 27C)
- Information as to the relative contribution of the different parts and systems of the building towards that energy use

The above parameters together describe the building and its thermal behaviour, and the user is enabled to explore which parameters (or which combinations of parameters) have the greatest effect on thermal behaviour. The key is the speed with which this exploration can be done – within 10 minutes for example the designer can explore the effects of window size and orientation on level of solar gains and heating energy use, or on the effect of changing the thermal mass of the building, or the potential for using night cooling in conjunction with the thermal mass in order to reduce daytime internal temperatures.

These types of studies are precisely those that designers need to do at an early stage, in order to gain an understanding of the thermal characteristics of the proposed building, particularly because these early design decisions will largely determine the thermal performance of the resulting building (Ellis and Mathews, 2001). It is claimed here that a very fast method that focuses on thorough testing of all the relevant variables will allow a picture to be built up in the mind of the designer. It would take several hours at least to carry out just one of the above studies using a dynamic thermal simulation, and the level of information required about the building would be difficult to obtain at this early design stage. Balcomb (1992) claims that a tool must be easy to use and produce results within 10 minutes if it is to be useful in building design. The speed of the method described here, and the reduced level of information required, means that it can be used at the start of the design process when decisions will be made about form, materials, orientation and so forth.

2.2 Design practice

Larger architectural and engineering practices can more afford the time and money to employ specialists to carry out thermal simulation work which could then inform the rest of the design team. Whether they usefully use the results of simulation to improve building performance is a question that it outside the scope of this paper. In fact the whole question of how simulation results should be used to inform the development of the design is a relatively under researched area. But if a practice has only one or two architects then spending hours on computer simulations is rarely an option and smaller practices are also less likely to be able to pay a consultant to do the work. In one study in the Netherlands it was found that architects made nearly all of the design decisions affecting energy use very early on in the design process, and also that they almost never used thermal simulation but instead preferred to rely on checklists and experience (De Wilde at al, 2001). Many buildings also are not really 'designed' but are only informed by economy of construction and in developed countries at least would only have to meet the minimum standards demanded by the regulations. But in order to decrease CO2 emissions due to the heating of buildings, an effort should be made to minimise energy use as part of the design of the building.

3. Calibrated Heat Capacity Method (CHCM)

There are three parts to the method which are combined at present in a spreadsheet with a simple numerical interface. A brief description is given below. A thorough description of the method is given elsewhere (Tucker, 2004). The three calculations made and the methods used are as follows;

1. Hourly heat flows are determined using steady state heat loss equations modified for solar and internal gains
2. Hourly temperature prediction is achieved using an existing transient heat flow algorithm
3. The amount of heat required to heat the mass of the building is calculated from knowledge of the temperature of the building and of the effective heat capacity of the building.

Hourly steady state heat flows are calculated from equation (1)

$$Qss = Qf + Qv + Qsg + Qi \ldots\ldots\ldots\ldots\ (1)$$

where;

Qss = total steady state heat flow (W)

Qf = heat flow by conduction through the opaque fabric (W)

Qv = heat flow due to ventilation (W)

Qsg = heat flow through glazing due to solar radiation (W)

Qi = heat flow due to internal gains (W)

The above heat flows are easily calculated from knowledge of building U-values, ventilation rates, building element sizes and orientations and so on. The value of Qss gives the heat energy required to balance the losses and gains within the building during heated periods.

Hourly temperatures are obtained using transient heat flow equations which are derived from the concept of Newtonian cooling (see Mustoe and Barry, 1998, p634). Consider a mass at temperature t, in a surrounding fluid at temperature to. The following will apply over a time period $d\tau$;

Net heat flow from the mass to the surrounding fluid during $d\tau$ will be equal to the change in internal energy of the mass during $d\tau$

$$Qp - \alpha A(t - to) = \rho Vc \frac{dt}{d\tau} \ldots\ldots\ldots\ldots (2)$$

where;
$Qp =$ positive heat gains (W)
$\alpha =$ heat transfer coefficient from the surface of the mass to the surrounding fluid
$A =$ surface area of the mass
$\rho =$ density of mass (kg/m3)
$V =$ total volume of mass (m3)
$c =$ specific heat capacity of mass (J/kg K)

From equation (2), Eastop and Watson (1992, pp165-168) derive an expression which allows the hourly temperature of the buildings mass to be calculated. If this temperature is below the set point temperature of the building then the heating energy required to bring the building up to set point temperature is obtained from the steady state figure as described above. If the temperature is above set point then the heating demand will be zero.

The above calculations give the steady state energy demand but the energy used to heat the mass of the building when heating commences must be calculated. As the temperature of the building mass is known, it is a matter of calculating how much heat energy is required to heat the mass per unit rise in temperature. This is not a simple matter as this figure is nearly always different from the theoretical heat capacity of the building. The novel part of this method (apart from the combining of all these methods together) is in how the quantity of heat stored in the thermal mass is calculated.

The *effective thermal capacity* of the construction is always less than the actual thermal capacity because not all the depth of the materials is involved in the exchange of heat over diurnal cycles. For example, only 50mm of a 100mm concrete block wall with external insulation might be involved in absorbing and releasing heat as the air temperature in the room rises during the day and then falls overnight.

The CHCM relies on a useful number of constructions having previously been calibrated as to their effective heat capacity. Table 1 shows some examples of these. Each construction type is modelled in a number of different buildings within a dynamic thermal simulation program and its effective heat capacity measured. The buildings are of various sizes and forms and have different heat loss and heat gain characteristics. The ranges of values obtained are shown in figure 1 below and are a reflection of the way that effective heat capacity of a component varies depending on these heat loss and heat gain characteristics of the buildings. The mean effective heat capacity for a construction type is called here the *calibrated heat capacity* (CHC).

1	200mm sandstone, external insulation
2	100mm heavyweight concrete block, external insulation
3	105mm brick, external insulation
4	100mm solid timber with external insulation
5	13mm plasterboard on timber stud walls, insulation and brick outer skin

Table 1: Examples of constructions calibrated for effective heat capacity

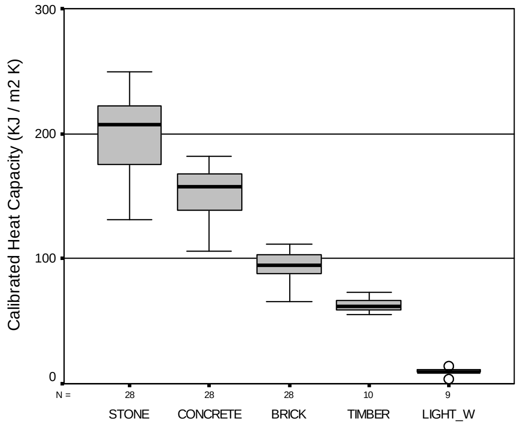

Figure 1. Box and whisker plots of Calibrated Heat Capacity for the 5 constructions of table 1.

Thick masonry constructions have a wide range of high values of effective heat capacity whereas thinner lightweight constructions have a smaller range of relatively low values. Despite these ranges, when the CHC for a particular construction type is used in buildings of various heat gain characteristics, the predicted heating energy use is very close to that predicted by the dynamic thermal simulation program (figure 2).

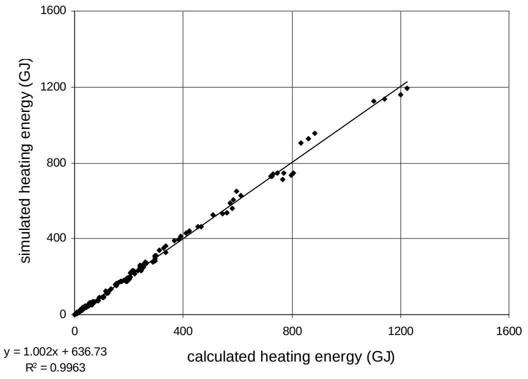

Figure 2. Comparison of simulated and calculated annual space heating energy

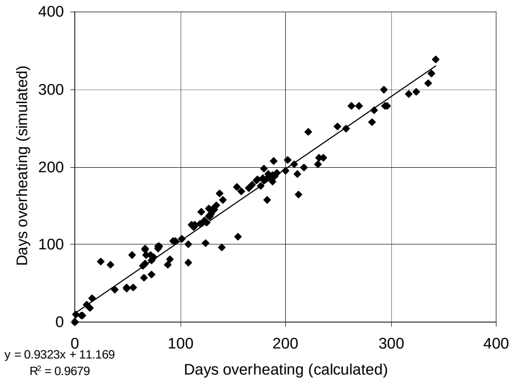

Figure 3. Comparison of simulated and calculated days of overheating during one year

Overheating prediction given by the transient heat flow algorithm is accurate enough to give a useful indication of degree of likely overheating (figure 3). It will be noted from equation 2 that the theoretical heat capacity is used for temperature prediction, and further work is required to determine whether another calibration exercise is required to determine ‘effective heat capacity for temperature prediction’. It may be that the calibrated heat capacity described here (which is calibrated only for heating energy calculations) is the same as that driving building temperature.

4. Further applications

The method is designed to test multiple building variables very quickly. To be useful in practice some more construction types would have to be calibrated to determine their effective heat capacities and development of a 2D or 3D graphical interface would make the method more user friendly.

Apart from applications in building design practice, it is thought that this method would be ideal for educational use. Architectural design students are usually under great pressure to produce creative design work and because usual methods of environmental analysis such as thermal simulation take so much time to learn to use productively, the student is forced right from the start to choose between doing ‘design’ oriented work, and becoming a specialist in environmental analysis. Because the majority of students will shy away from the perceived difficulties of the latter a division is created between ‘mainstream’ architecture and environmental architecture whereas really all designers need to be addressing environmental issues as an integral part of their work if CO2 emissions from buildings are to be reduced. If the student is taught the basic principles of building heat flows and energy use, and how these can be affected by the design and the parameters of the building, then it is likely that sound energy strategies can be integrated into the design of each building.

5. Conclusions

The method described here could help in the effort to reduce building related CO2 emissions. It is fast and accurate and is designed to enable integration of sound energy strategy into building design. It does this through enabling a rapid exploration of the building variables so that the designer can build up an understanding and a feeling for how those variables influence thermal behaviour.

6. References

Balcomb, J.D. ed., *Passive Solar Buildings*, The MIT press, Massachusetts, 1992

De Wilde, P., Van der Voorden, M., Brouwer, J., Augenbroe, G. and Kaan, H. (2001) *The Need For Computational Support In Energy-Efficient Design Projects In The Netherlands,* Seventh International IBPSA Conference Rio de Janeiro, Brazil August 13-15, 2001, pp 513-520

Eastop, T.D. and Watson, W.E., *Mechanical Services for Buildings,* Longman, Harlow, 1992

Ellis M.W. and Mathews, E.H., *A new simplified design tool for architects,* Building and Environment 6 (9), Elsevier, 2001, pp 1009-1021

Mustoe, L.R. and Barry, M.D.T., *Mathematics in Engineering and Science,* Wiley, Chichester, 1998

Shorrock, L.D., Utley, J.I., *Domestic energy fact file 2003*, BR 457, Building Research Establishment, Watford, 2003

Tucker, S., *A simplified method of building thermal assessment*, unpublished PhD, University of East London, 2004