

# THE ADVANTAGES OF BUILDING SIMULATION FOR BUILDING DESIGN ENGINEERS

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## ABSTRACT

Building dynamic simulation has been available to building design engineers for some time. However steady state methods are still being used and these methods do not provide the information required for making informed decisions on the best design options. An existing high specification building designed using steady state methods is used to compare the HVAC plant sizes installed to the plant sizes that would have been required if building simulation methods had been used. The value of the peak loads and their time of occurrence found from dynamic simulation are also compared to the steady state loads. Analysis of the results shows the inadequacies in the steady state methods. This information will show the advantages of using building simulation to those building design engineers that are not already using it.

## INTRODUCTION

Building simulation has been available to building design engineers for some time. To determine the methods used for building design in Ireland a survey questionnaire was circulated to all the Royal Institute of Architects in Ireland (RIAI) members and all Chartered Institution of Building Services Engineers (CIBSE) members in Ireland. The results of the survey [1] showed that to assess the impact of changing a building's form, siting, orientation, window design or insulation 63% of architects surveyed are using no method and 22% are using common sense or intuition. Of the engineers surveyed all except one are using computer calculation methods based on CIBSE steady state heat transfer methods to design buildings.

Russevelty [2] found from interviews with architects and building services engineers in the UK that the two main inhibitions to modelling were cost and doubts about usefulness.

This paper reports on an analysis of an existing building that has been designed using CIBSE steady state methods. Cooling energy loads were calculated for a range of different zones in the building using a computer program based on the CIBSE admittance

method and a computer program using dynamic simulation.

Analysis of the results shows the inadequacies of the steady state methods and the usefulness of the information provided by dynamic simulation. The reduced impact that buildings designed using simulation have on the environment is also identified.

## STEADY STATE METHODS

The steady state method used to design the building analysed is based on the CIBSE admittance method [3]. This method uses idealised (sinusoidal) weather and thermal response factors (admittance, decrement factor and surface factor) that are based on a 24-hour frequency. Levermore [4] has pointed out that it would be difficult to defend the CIBSE admittance method, as it is a simplification to ease manual calculations.

The admittance method was originally intended to calculate peak internal temperatures in buildings to ensure that it would not become uncomfortably hot during sunny periods. However Jones [5] has found that dynamic simulation gives temperatures that are generally 6°C lower than those obtained using the CIBSE admittance procedure – 30 °C against 36°C when calculations were undertaken on the sample office contained in the CIBSE guide section A8.

The admittance method is also used for the estimation of air conditioning plant capacity to maintain constant air temperatures in buildings. Building services engineers must ensure that the air conditioning systems that they specify for a building will adequately cater for the cooling load encountered and maintain design comfort conditions in the building. They usually add design margins to the load calculations to avoid the embarrassment and cost of having to replace the installed plant after the building has been handed over if the selected plant proves inadequate. Building services engineer realise that the steady state method is a simplified method and that margins are necessary to compensate for this. Experience has shown that using this approach the air conditioning plant will not be under-sized. Building services engineers do not normally check

the plant sizes that they have designed unless occupants complain of over or under heating. This would apply if the heating or cooling plant was undersized and thus the possibility of identifying over-sizing in most cases does not arise. Dynamic simulation programs are now available that allow building services engineers the possibility of checking their steady state air conditioning loads against dynamic simulation results. However due to the conservative nature of the construction industry building services engineers continue to use the method that they are most familiar with. To encourage more use of dynamic simulation and thus achieve better designed buildings the building services engineers should be made aware of the potential for over-sizing services using steady state methods.

### BUILDING DESIGN INFORMATION

Use of the steady state methods does not provide the building designer with the information required for making informed decisions on the best design options. For informed decisions to be made accurate information is required on the magnitude and duration of internal peak temperatures during the occupied period. This information is required for the building designer to decide if natural ventilation will work or if air conditioning is required. Accurate information is also required for the magnitude and time of occurrence of the peak heating and cooling loads and their variation over the heating and cooling season. The main influence on these loads (e.g. infiltration, or solar or casual gains from equipment lights and people) should also be determined accurately. It is only when the main influence on the peak load can be identified that the correct design solution can be found to reduce the peak loads. If this information is not available to the building designer this means that opportunities are being missed to design buildings better in terms of environmental quality and energy consumption.

An existing high specification building, which was designed using steady state methods, has been examined. The Heating Ventilation and Air Conditioning (HVAC) plant sizes installed are compared to the plant sizes that would have been required if dynamic simulation methods had been used to design the building.

The information obtained using simulation has determined when and why the peak loads occur in the different zones in the building. Analysis of the results shows the inadequacies in the steady state methods. The results also identifies the improvements that would have been achieved in terms of energy consumption, comfort conditions, and the reduced impact that the building would have had on the

environment had building simulation been used. This information will show the advantages of using building simulation to those building design engineers that are not already using it.

### INADEQUACIES OF THE STEADY STATE METHOD

The steady state methods only provide information on the peak environmental conditions expected in the building and the associated maximum heating and cooling loads. The information that is now required to design low environmental impact buildings includes duration of high temperatures, effect of window opening on internal environmental conditions, mixed mode operation, use of natural ventilation and daylight. Steady state methods only provide information for one-hour summer and one-hour winter design conditions in buildings and thus do not assist the building designer to achieve low environmental impact design solutions.

Design is now being carried out that defines a maximum number of hours for which the internal temperature can be exceeded. For example the Scottish Office, Victoria Quay, Edinburgh has been designed with no area exceeding 26<sup>0</sup>C for more than 52 hours during the occupied period. The performance specification for the BRE Energy Efficient Office of the Future gives the summer internal criteria for the building not to exceed a dry resultant temperature of 28<sup>0</sup>C for more than 1% of the year and not to exceed 25<sup>0</sup>C for more than 5% of the year. To comply with these new comfort criterion the building designer needs to be able to accurately determine the plant sizes required and the environmental conditions expected during the occupied period.

Many of the new buildings being designed are non air-conditioned. In these buildings natural ventilation strategies often play an important role in achieving the desired conditions for occupants. To ensure that the proposed natural ventilation design strategy is effective for as much of the year as possible it is necessary to use dynamic airflow simulation in conjunction with dynamic thermal simulation. As steady state methods normally use fixed air change rates they are inadequate to design these new buildings.

### CASE STUDY BUILDING

The case study building is located in the International Financial Services Centre in Dublin. The building provides commercial office accommodation for the banking sector and was constructed in 1990. The building is extensively glazed with green tinted solar reflecting glass and includes a central atrium. The

windows in the building can be opened but they are not easy to do so. The building has been designed with full air conditioning. The air conditioning system has been designed using steady state methods and a variable air volume (VAV) system selected. The building services design engineers were concerned to ensure that the plant would cater for the anticipated and imagined load.

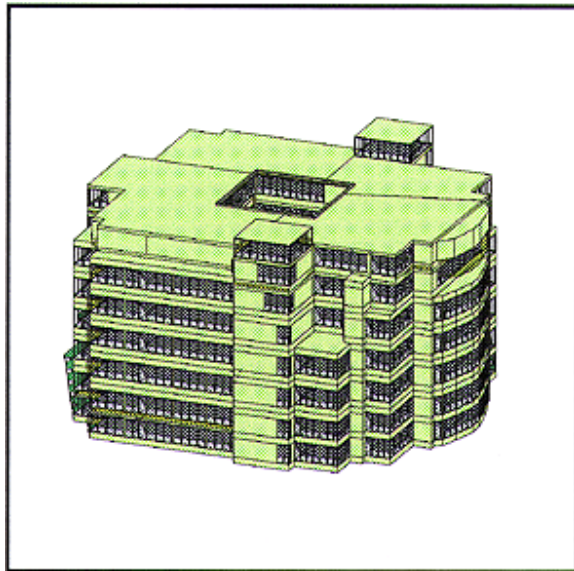


Figure 1 – Case Study Building.

A typical floor (level 4) of the building was selected and divided into 25 zones to correspond to the present layout of the floor. The main areas of interest were the open plan areas as they have the highest density of people and the highest level of incidental gains from lights and computers. A variable air volume air conditioning system was simulated to correspond to the system installed in the building.

### SIMULATION INFORMATION

The building was simulated over the summer months using a typical Dublin weather file which contained hourly values for dry bulb temperature, wet bulb temperature, direct solar radiation, diffuse solar radiation, wind speed and wind direction. The simulation results file includes internal air temperatures, dry resultant temperatures, airflow rates between zones and outside, heating and cooling loads etc. for each zone in the building. The analysis of the simulation results for the peak internal air temperatures and peak cooling loads and their causes is shown below.

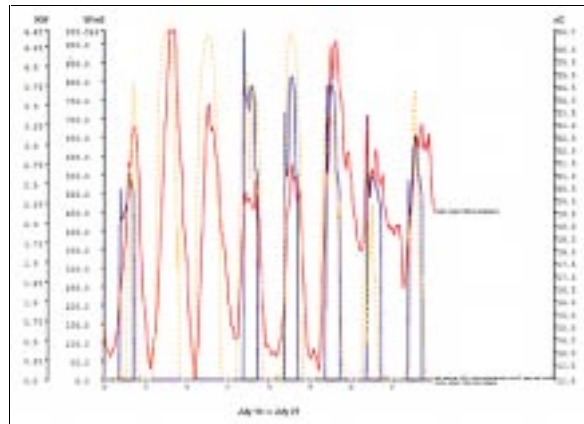


Figure 2 – Causes of Peak Conditions.

In order to investigate the causes of the peak conditions in a south-facing zone in the building the external air temperature, direct solar radiation and internal air temperature are plotted in figure 2 for the period that includes the peak. This identifies the causes of the peak i.e. the high direct solar radiation along with moderately high external temperatures on July 15 and 16 (the weekend) when the air conditioning system is not in operation. When the air conditioning system begins operation on July 17 the internal air temperature as would be expected is reduced. Although the direct solar radiation peaks again on July 18 the internal air temperature has remained within acceptable levels due to the air conditioning system.

In predicting the value and occurrence of the peak loads that will occur in buildings it is necessary to consider the sequence of several weather variables and their interaction with the building, and the operation or non-operation of the building services plant. This is more realistic than using an extreme value of one weather variable (outside air temperature), treating the weather data in an idealised way and omitting the type of building services system to be used.

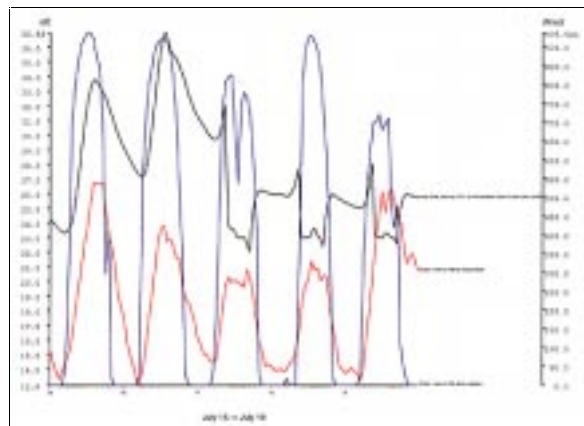


Figure 3 – Effect of Weather Variables.

This figure shows the weather variables (direct solar radiation and external air temperature) that have the most influence on the cooling load in the building when the plant is operating. The maximum load is similar on each day and the profile of the load follows the profile of the solar radiation due to the extensive glazing in the building.

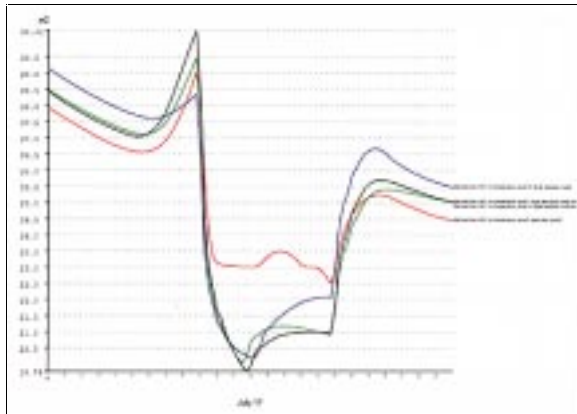


Figure 4 – Effect of Weekend Conditions.

These profiles from July 14- July 18 show the conditions before and after the extreme conditions that occur on July 15 and 16. This figure shows that the weekend heat up of the building is the main contributor to peak cooling load that occurs early on a Monday morning and reduces during the week despite increased direct solar radiation and external air temperature.

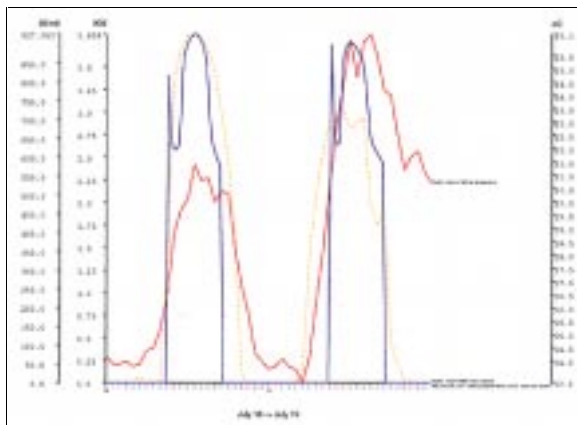


Figure 5 – Zone Cooling Loads.

Maximum internal air temperatures (and cooling loads) during the occupied times occur for the zones facing south, west, south-east and north-east at 9.15 on July 17. This is the Monday morning after the weekend of July 15 and 16, which had high values of solar radiation. Using the CIBSE load analysis maximum cooling loads would be predicted to occur at different times of the day for zones with different orientations. In the CIBSE calculations different values for the solar radiation occurring at different

times of the day would be used. This is just one factor why the cooling loads calculated using the admittance method and dynamic simulation will be different.

The information provided by dynamic simulation allows the building designer to understand what is happening in the building over a period of time and check out the reasons for the peak loads. With the admittance method the building designer only has one hourly value available and no trends with which to investigate the value.

### ZONE COOLING LOADS USING ADMITTANCE AND SIMULATION METHODS

Cooling energy loads calculated for some of the zones in the building using the CIBSE admittance method and dynamic simulation method are given in the table below.

Table 1–Comparison of Admittance Method and Simulation Cooling Loads.

Zone No.	Admittance Peak Cooling Load	Simulation Peak Cooling Load	% Difference
5	8499Watts @14.00	4450Watts @9.15	91%
9	5116Watts @16.00	3863Watts @9.15	32%
17	3050Watts @15.00	2375Watts @9.15	28%

Three zones were chosen for comparison that would show the effects of high glazing ratio facing south (zone 5), moderate glazing ratio facing west (zone 9) and no glazing but with high incidental gains (zone 17).

The two methods (admittance and dynamic simulation) for calculating peak cooling load and its time of occurrence for the three zones showed no correlation and gave wide variation in the results. From figure 5 above for the simulation results it can be seen that the peaks occur for all zones at 9.15 on July 17 as the air conditioning plant starts operation at 9.00 after the weekend shutdown. This weekend in the weather file had high solar gains on July 15 and 16 and had caused a build up of temperature in the building. The CIBSE results showed the peak loads to occur in the afternoon. The simulation method has the advantage that the causes (direct solar radiation, outside air temperature, incidental gains etc.) and their time of occurrence that create the peak cooling loads can be displayed and analysed to check their genuineness. The simulation method also takes into account dynamically how the building interacts with real climate data. On the other hand the CIBSE admittance method assumes idealised weather data and that the building structures response and the

occupants use of the building in terms of lights and equipment can be described only using sine waves with a 24-hour frequency. The ability to include the history of a building's performance over previous days and weeks to predict the impact of real weather patterns and modes of occupation is a fundamental difference between dynamic simulation and the admittance method. With simulation the long-term changes in weather data are taken in to consideration. This means that a lower level of thermal energy is stored in the building compared to the idealised (repeated) weather data. When a warm period occurs the building is able to limit temperature rise by absorbing thermal energy and releasing it again when the building cools.

The large percentage difference (up to 91%) in the results shows the extent of over-sizing that is possible with the admittance method. The consequences of over-sizing plant in terms of increased capital costs, increased operating energy requirements and increased CO<sub>2</sub> emissions to the environment should make the building services engineer seek a better method for designing buildings.

### IMPROVED DESIGN

In order to improve design more use must be made of a building's ability to modify the climate and less use of building services which consume a lot of energy. Passive designed buildings use less energy and for passive control of internal comfort levels the realistic representation of building and climate dynamics are essential if the optimisation of energy flows are to be clearly understood and exploited. Using dynamic simulation will provide the building designer with the required information to optimise energy use in the building.

### COMFORT

Traditionally building services engineers have concentrated on providing a constant air temperature (and relative humidity) in building design. The CIBSE guide gives recommended dry resultant temperatures for different types of buildings in table A1.3. The values given are predominately in the range 18 °C – 22 °C. However a BRESCU report [6] points out that opening windows forms a psychological safety valve which allows the comfort envelope to be relaxed and that in some buildings investigated the occupants felt fine at temperatures of 26°C and 27°C. The Comfort Group in the Pascool project [7] speculated on adaptive behaviour in the following way. When temperature variation in buildings has been eliminated by air conditioning the need for adaptive processes have been eliminated. However far from regarding this as desirable this

fails to exercise the inherent adaptive ability of the occupant. In order to restore the opportunity to adapt the occupants neutral zone will become narrower and if these are not met complaints will arise. Thus the perceived need to provide closely controlled will not provide comfort conditions in buildings.

With dynamic simulation adaptive comfort opportunities such as operable windows and wider temperature bands can be investigated.

### CONCLUSIONS

This information will show the advantages of using building simulation to those building design engineers that are not already using it. If dynamic simulation had been used in the case study building realistic loads would have meant better plant selection, lower capital costs, lower operating energy requirements and less impact on the environment. If adaptive comfort possibilities had been simulated then the occupants may have had a more comfortable building. The information obtained using dynamic simulation has determined when and why the peak loads occur in the different zones in the building. This information allows the designer the possibility of improving the design.

The extreme assumptions on climate implicit in the admittance procedure are not appropriate for the naturally controlled summer conditions that are now required in modern buildings.

The use of dynamic simulation allows more creativity by the building services engineer rather than just concentrating on peak loads to make the plant big enough.

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