MODELLING COOLING DEMANDS IN UK OFFICE BUILDINGS: THE IMPACT OF USING 3 DIFFERENT STRATEGIES TO ASSESS INTERNAL GAINS

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ABSTRACT

This paper demonstrates how variations in the estimation of internal gains due to usage affect the cooling demands of speculative office buildings. The imprecise information available on these gains at the design stage has a large effect on the predicted energy demands of these buildings, which are being built to much higher energy performance criteria.

This means in practice that designers of speculative office buildings are going to struggle to meet operational energy consumption targets unless they fully understand the implications of the choice of the internal gain strategy they use to account for the potential internal loads due to occupancy.

The study compares and contrasts 3 different strategies suggested by the literature to assign these internal gains to offices and is applied in a UK case study office building. The focus of the analysis is the impact of the magnitude of these gains in the cooling demand to be met by the building services not the cooling energy consumption of these services.

KEYWORDS

Internal Gains in offices, Cooling demands, Modelling new buildings

INTRODUCTION

In new buildings or speculative buildings the usage is unknown by definition, either from the desire of the owner to have flexibility or by the fact that it is decided in a post-design stage and it is likely to change regularly.

However, as is already known, in office buildings the occupancy is a major component of the cooling demand to be met by the services because of the extensive use of electric equipment, artificial lighting and the increase in the amounts of people inside office areas, in order to maximize the use of the space allocated for work.

In a new era of building performance regulations, asset and operational ratings, and energy certificates (which focus mainly on the building envelope and HVAC systems), designers are required to estimate usage patterns to meet increasingly stringent energy performance targets when these patterns are actually unknown. This work is intended to provide some initial guidance in this matter, and to provoke further debate on how best to model and design for the effects of this major component in the holistic design of buildings.

This paper starts by considering variations in the magnitude of the internal gain profiles as there is enough information available to simulate different scenarios and evaluate the impact of them in the cooling demands.

An overview of internal gains in UK office environments (Knight and Dunn 2002) show the results from a survey of 30 UK office buildings and compare those values with a range of values derived from different sources such as CIBSE, Government Good Practice Guides, BSRIA rules of thumb, etc. These sources generally show these values in W/m^2 and W/person, with minimums, maximums and averages plotted separately for people, lighting and equipment. A more detailed approach is also discussed with specific values assigned to lighting and equipment based on their number and type.

Another study (MacDonald 2002), focusing on uncertainties in building simulation, suggests the problem might be assessed through a sensitivity analysis and therefore compiles values from guidance and regulations, mainly ASHRAE and CIBSE, to set up potential ranges for testing. Particular attention is given to equipment loads (mainly based on EEO 1995 and DETR 1996) and which percentage of nameplate power rating should be used.

However, most simulations will still be based on internal gain values provided by ASHRAE and CIBSE recommendations, which generally provide unitary loads for people, lighting and equipment. Values for people, provided per person, are based on metabolic rates, and in CIBSE 1999 are also considered based on the internal dry bulb temperature. Values for lighting are provided by type of luminaire and type of bulb and values for equipment are provided by equipment type. As the latter is seen as one of the most important loads in office buildings a discussion about worst case power demand, % of worst case nameplate ratio, peak and average power and diversity factors is provided in a separate section in both sources.

Sometimes this information is also provided in W/m^2 for lighting and equipment, but with the advice that it be used only in extreme cases when little information about the building is known. A preferable approach when the number of people is known might be to follow recommendations about the amount of equipment per person (CIBSE 1999), or to follow recommendations about using a load factor for equipment based on different sizes of workstations found in various types of offices. It is important to note that CIBSE presents the information with a strong emphasis on the equipment loads, whereas ASHRAE (ASHRAE 2001) emphasises the loads due to artificial lighting. This is mainly because US offices tend to have deeper floor plans than UK offices, thus they need to rely more on artificial lighting.

It can be clearly seen that, in spite of the different sources there seems to be a consensus about the fact that the most ‘reliable’ way to deal with internal gains when simulating building performance is by assigning loads due to people, lighting and equipment using information about quantity and type that has come from a survey. However, opinions diverge when information about types and quantities is unknown. Some sources would suggest a simplified approach to assign uniformly distributed overall loads in W/m2 to the floor plates being considered. Others would suggest dealing with loads based on likely density of people per area of floor plate being calculated.

Identifying that there are clearly 3 different strategies to approach the estimation of the internal gains for modeling purposes, the present study tests the following situations:

- Reference scenario: in which the actual types and quantities of people, lighting and equipment surveyed in the case study building are used as a basis, and only variations in the unitary loads assigned to each of these quantities is considered
- Speculative scenario 1: representing the case study building as a speculative office with an unknown usage and loads assigned to the floor plates being considered based on number of people per surface area
- Speculative scenario 2: also representing the case study building as a speculative office with an unknown usage but in which loads are assigned to the floor plates being considered by being uniformly distributed over the surface area.

It is believed that by comparing the surveyed with the 2 speculative scenarios proposed a debate about possible strategies to better deal with the unknown usage can be raised as this is a common situation faced by designers in practice.

METHODOLOGY

Internal gains

The three different criteria used to assign the internal gains are discussed in this section:

Reference scenario:

Loads are assigned based on a survey report which describes the number of people occupying each room and the number and type of office equipment found in each room. As there is no data about types of bulbs and number of fixtures available from the survey for this Case Study building, a fixed value of 15 W/m^2 is going to be used for lighting loads, according to the survey report suggestion.

Average, minimum and maximum values for each person and equipment type (Ref/Avg, Ref/Min and Ref/Max), for the reference scenario are tested based on data from the following sources: ASHRAE 2001, CIBSE 1999, Knight and Dunn 2003 and MacDonald 2002 described in Table 1. It is important to note that the minimum and maximum data for laptops, laser printers and fax were estimated from MacDonald’s recommendations therefore they end up being higher than values provided by Knight and Dunn 2003 which are extracted directly from the literature.

Table 1 – Values assigned for the reference scenario

Reference Scenario				
		Avg (survey)	Min (survey)	Max (survey)
People (W/person)		130	115	140
Lighting (W/m2)		15	15	15
Equipment (W):				
	PC	130.9	50	185
	Laptop	38.5	50	185
	Laser printer	30	35	145
	Fax	9.5	15	35
	Photocopier	212.2	120	1080
	Plotter	180	135	225
	Deskfan	42	33	51

Speculative scenario 1:

Loads due to people are assigned based on average, minimum and maximum values of m^2/person for each room, and values for equipment are set based on this occupancy density. Values for lighting are specified based on people’s density using Knight and Dunn 2003 for the first 3 simulations in this group. The rest of the simulations in this group use lighting loads based on W/m^2 as the guidance tends not to provide density based loads for this parameter.

Average, minimum and maximum values for people, lighting and equipment taken from Knight and Dunn 2003 are used to produce the runs Spec_1/Avg/S, Spec_1/Min/S and Spec_1/Max/S, in which 'S' denotes survey. These are then compared with the runs Spec_1/Min/G and Spec_1/Max/G, which use the minimum and maximum values for people, lighting and equipment taken from the ASHRAE (ASHRAE 2001) and CIBSE (CIBSE 1999) guidelines, and in which 'G' denotes guidance.

Extremes in terms of density and loads are also considered together, i.e. minimum density with minimum load/person and maximum density with maximum load/ person.

Average, minimum and maximum values for this group of simulations are shown in Table 2.

Table 2 – Values assigned for speculative scenario 1

Speculative scenario 1						
	Average: 11.1m2/person (Survey)	Minimum: 22.8m2/person (Survey)	Maximum: 4.3m2/person (Survey)		Minimum: 40m2/person (Guidance)	Maximum: 8m2/person (Guidance)
People (W/person)	130	130	130	People (W/person)	130	130
Lighting (W/person)	133	43	288	Lighting (W/m2)	8	18
Equipment (W)	158	124	229	Equipment (W/workstation)	83.7	167.7

Speculative scenario 2:

Loads due to people, lighting and equipment are assigned based on average, minimum and maximum values of W/m^2 for each room. Again, the average, minimum and maximum values for people, lighting and equipment are taken from Knight and Dunn 2003 to give the runs Spec_2/Avg/S, Spec_2/Min/S and Spec_2/Max/S, in which 'S' denotes survey. These have been compared with minimum and maximum values from ASHRAE 2001 and CIBSE 1999 guidelines denoted Spec_2/Min/G and Spec_2/Max/G, in which 'G' denotes guidance.

The data inputs for this group of simulation are shown in Table 3. This table is taken from Knight and Dunn 2003 who present composite ranges of values derived from a number of sources.

Table 3 – Values assigned for speculative scenario 2

Speculative scenario 2					
	Average (Survey)	Minimum (Survey)	Maximum (Survey)	Minimum (Guidance)	Maximum (Guidance)
People (W/m2)	14.6	5.7	30.4	20	20
Lighting (W/m2)	12.7	6.2	33.9	8	32
Equipment (W/m2)	17.5	5.7	34	7	45

Analysis

The modelling results are analysed for the overall office area and only the magnitude of the internal gains situated in those areas are going to be varied. Meeting rooms and other facilities are assigned values to be kept constant in all the simulations.

The results consider how a range of input conditions affect the average temperature for all the office areas as well as the calculated cooling demand, *not* the energy consumption for cooling. This calculation is undertaken across the year and for the Cooling Design Day (CDD). The results are displayed for the CDD and one of the summer months.

SIMULATION

The methodology was tested on a real UK office building situated in London. It is a 2 storey, load bearing sidelit building with 0.2 glazing ratio and 0.74 exposed wall / floor area ratio. The total conditioned floor area is 1366m^2 with a volume of 3879m^3.

The building was modelled in ECOTECT and exported to Energy Plus version 1.4. The zoning follows the internal partitioning, i.e. each room is a zone, and the HVAC schedule coincides with the occupancy period, from Monday to Friday 8:00 to 18:00.

The AC system was not modelled as the study will calculate only the cooling demand. An unlimited cooling capacity machine – Purchased Air – was assigned to each conditioned room to keep the room air temperature at a maximum specified setpoint of 24°C. The settings chosen for Purchased Air used the default values of the expanded compact system contained in Energy Plus except for the heating and cooling availability schedules, which were changed to match the occupancy.

The weather file used was GBR_London.Gatwick_IWEC from the website http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm and the design days were assigned based on information from Climate Design Data 2005 ASHRAE Handbook of Fundamentals contained inside Energy Plus.

Information from building materials come from a combination of survey and building regulations from the time the building was built. Information about ventilation and infiltration come from the same survey together with information about internal gains (used when the detailed analysis is carried out).

Using the data from Tables 1, 2 and 3 13 runs were undertaken in which only the internal gains situated in office areas are varied. The total area of offices is 994m^2 and the total conditioned volume to be analysed is 2734m^3.

The output variables plotted on an hourly basis were:

- Inside air temperatures
- Zone/sys sensible cooling energy

The simulations are for the whole year and the Design Days.

DISCUSSION OF INPUTS AND RESULTS ANALYSIS

Input - total internal gains

The range of total internal gains (in kWh) assigned to each simulation was summed for the working period for the cooling design day. The minimum and maximum values for each group of simulations are shown below and in Figure 1:

- Reference scenario (green bars):
  - minimum: 351kWh
  - maximum: 619kWh
- Speculative scenario 1 (red bars):
  - minimum: 130kWh
  - maximum: 1496kWh
- Speculative scenario 2 (blue bars):
  - minimum: 175kWh
  - maximum: 965kWh

Figure 1 also displays the average values and the max/min from the guidance for the speculative scenarios 1 and 2.

From these values it can be seen that the smallest range of modelled internal gains is provided by the reference scenario.

The highest range of internal gains is provided by the speculative scenario 1, for which the minimum value is 63% lower than the equivalent reference scenario and the maximum value is 142% higher than the equivalent reference scenario.

The range of internal gains provided by the speculative scenario 2 is between the other two approaches. The minimum value is 50% lower than the equivalent reference scenario and the maximum value is 56% higher than the equivalent reference scenario.

It is to be expected that the speculative scenario 1 would provide the widest range of variations in the results, because although the loads due to people are similar to those in the speculative scenario 2, the loads due to equipment are much higher due to the details of the method by which the equipment load is estimated, based on the number of people.

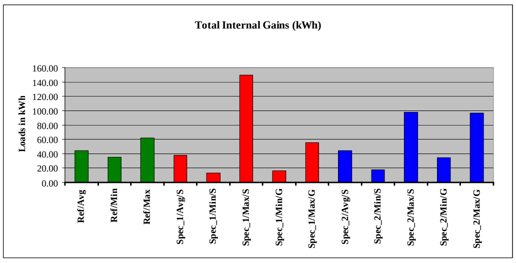

Figure 1 – Range of total internal gains for the 3 scenarios for the cooling design day (kWh)

Input – the components of internal gains

The proportion of each total internal gain due to each of the internal gain components is shown in Figure 2.

The main comments about each group of simulations are as follows:

- Reference scenario – As the lighting loads were kept constant, because the survey specified them simply based on W/m^2, their proportion of the overall internal gain decreases whenever values assigned to people and equipment increase. As a consequence, the minimum run has the highest contribution due to lighting, 43% and the lighting contribution in the average and maximum runs decreases to 34% and 24% respectively.

  Even with a fixed number of people and equipment, potential variations in the ranges of individual loads for each component will more strongly affect the contribution of the equipment in the overall internal gains than the contribution due to people. The percentage contribution due to equipment increases to 38% in the average run and 54% in the maximum run.

  As a result, equipment loads have a higher contribution in the overall gains of the maximum run and lighting loads have a higher contribution in the overall gains of the minimum run in this group of simulations.
- Speculative scenario 1 – In this group of simulations the lighting loads were assigned according to 2 different criteria in the survey and guidance information. The percentage contributions in the two subgroups of simulations for this approach will therefore be different.

  In the 3 simulations based on survey values, all the loads are related to a specific density of m2/person. In the maximum load run, the highest proportion of the load is due to lighting as these loads are higher than people and equipment ones. This situation is reversed for the minimum run where the lighting loads are lower than people and equipment ones. In the average run a more even distribution occurs because the loads for people, lighting and equipment are very similar.

However, in the 2 remaining simulations based on guidance values, the equipment and people loads are related to the specific m^2/person density but the lighting loads are assigned based on W/m^2 as the guidance didn't provide any density based values for such type of loads. In this case, the maximum run has the highest contribution due to equipment (39%) and the minimum run has the highest contribution due to lighting (48%).

Figure 2 shows that for speculative scenario 1 (prefixed 'Spec_1') the lighting loads are the highest proportion of the overall internal gains of the maximum run based on survey values and of the minimum run based on guidance values. It also shows that equipment loads have a high contribution to the overall internal gains for the maximum run based on guidance values whereas people loads make their greatest proportional contribution in the overall internal gains of the minimum run based on survey values.

- Speculative scenario 2 – In this group of simulations the percentage contribution of each of the internal gain components is almost even in the runs using survey values but very different in the ones using guidance values.

The maximum and minimum runs based on survey values have an almost even contribution from equipment, lighting and people, 35%, 34% and 31% respectively for the maximum run and 32%, 36% and 32% respectively for the minimum run.

However, the same cannot be said for the runs based on guidance values. In this case, the maximum run has the highest contribution clearly due to equipment (46%) and the minimum run has the highest contribution clearly due to people (57%).

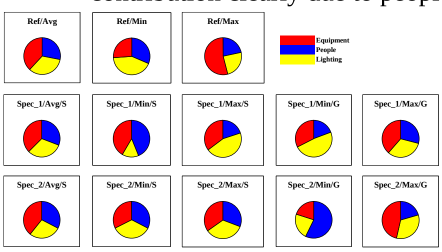

Figure 2 – Proportion of the total internal gain by component for each of the runs in the three approaches modelled.

What figure 2 clearly demonstrates is that using different criteria to assign internal gains will result in different percentage contributions from each of the internal gain components in the overall internal gain loads.

Temperature

This metric is used to assess the effect of the building and occupancy on the temperatures in the space after the occupancy period when the temperature is controlled to 24°C. The changes in air temperature are due to the effects of the radiant components of the occupancy period being stored in the fabric and re-radiating after occupancy hours.

The results in Figure 3 show that for the Cooling Design Day (CDD) the average internal temperature is above the 24°C setpoint before and after the working period in all the runs.

It is clear that, as expected, after-hours the average internal temperature is very influenced by the previous working period, where higher internal gains result in higher internal temperatures and lower internal gains result in lower internal temperatures.

The average hourly temperatures outside the working period for the minimum and maximum runs of each simulation group in the cooling design day are shown below:

- Reference scenario:
  - minimum: 25.9 °C
  - maximum: 26.2°C
  - difference: 0.3°C
- Speculative scenario 1:
  - minimum: 25.4°C
  - maximum: 27.9°C
  - difference: 2.5°C
- Speculative scenario 2:
  - minimum: 25.5°C
  - maximum: 26.8°C
  - difference: 1.3°C

These figures reflect the ranges of energy being input to the space from each approach.

In speculative scenario 1, the minimum temperature is 0.5°C lower compared to the minimum value of the reference scenario, and the maximum value is 1.7°C higher compared to the maximum value of the reference scenario.

In speculative scenario 2, the minimum temperature is 0.4°C lower compared to the minimum value of the reference scenario, and the maximum value is 0.6°C higher if compared to the maximum value of the reference scenario.

Figure 3 also reveals that, for the CDD, the **outside** air temperature only goes above the setpoint 3 hours after the start of the working period, at the end of the morning, and it falls back below the setpoint 2.5 hours after the end of the working day. However, outside the working period, the outside air temperature is always below the average internal air temperature. This shows the potential for using free cooling to reduce the average internal air temperatures during part of the working day and for the whole unoccupied period, thus increasing the 'stored cooling' for the following day. The problem here occurs if reheat is required the following morning to bring the building up to temperature.

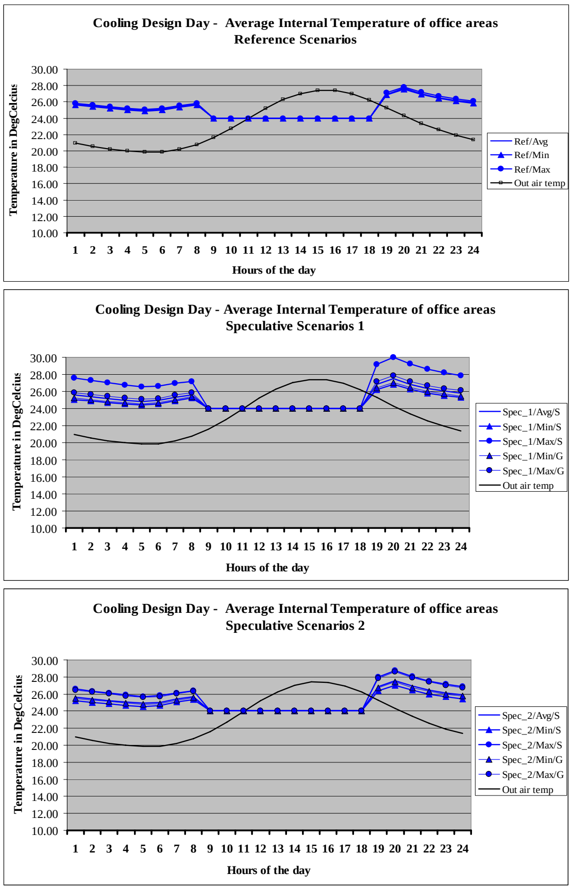

Figure 3 – Hourly average inside temperatures (°C) – Cooling Design Day (CDD)

Modelling these variations during the whole month of August (Figure 4) shows the same increase in the average internal temperature after working hours, but now the average internal temperature is below the 24°C setpoint before the working period.

The influence of the internal gains in the average internal temperatures outside the working period can clearly be seen in Figure 4. Maximum runs (all indicated in red) will result in higher temperature increases and minimum runs (all indicated in blue) will result in lower temperature increases.

Despite the space being cooled to 24°C, the importance of the internal gains on the cooling demand in this case study building can still be clearly seen in the ranges of temperature predicted between the lowest and highest gains. For the lowest gains it appears that the cooling might only be required for a limited number of days, whilst for the highest gains the cooling is clearly an important requirement.

It is also important to note that the influence of the internal gains on the average internal air temperature can still be observed during the weekends. Variations in the average internal air temperature due to minimum and maximum internal gains tend to reduce from Friday evening towards Monday morning but they can still be clearly perceived. A detailed analysis of the inside face heat exchange is required to assess the contribution of the internal gains in the building fabric but is beyond the scope of this paper.

Cooling energy demand

Analysis of the month of August (Figure 5) shows the ranges of predicted total cooling demands over the month, and confirms what is expected, i.e. maximum internal gains result in maximum cooling demands and minimum internal gains result in minimum cooling demands. The total and the peak cooling energy demands in the month of August for each run are shown in Table 4. From this table we can see that the total minimum demand is only 3.8% of the total maximum demand.

This clearly shows that, depending on the internal gains chosen, the building designer could think his building might be able to avoid air conditioning or that it needs substantial amounts of air-conditioning. This is clearly not a helpful conclusion for the building designer or services engineer.

Figure 6 shows the hourly cooling demands for the CDD resulting from each method. These figures are consistent with the previous findings. The total and peak cooling demands for the working period over the cooling design day are:

- Reference scenario:
  - minimum: 391kWh and 45kW
  - maximum: 632kWh and 69kW
- Speculative scenario 1:
  - minimum: 237kWh and 29kW
  - maximum: 1268kWh and 135kW
- Speculative scenario 2:
  - minimum: 269kWh and 32kW
  - maximum: 883kWh and 95kW

From the values in Table 4 it can be seen that in the speculative scenario 1, the minimum total cooling demand in August is 74% lower than the minimum value of the reference scenario, and the maximum value is 163% higher than the maximum value of the reference scenario.

If we now compare the peak cooling demand on the CDD for the same runs then the figures are 36% and 96% respectively.

In speculative scenario 2, the minimum total cooling demand in August is 62% lower than the minimum value of the reference scenario, and the maximum value is 64% higher than the maximum value of the reference scenario.

If we now compare the peak cooling demand on the CDD for the same runs then the figures are 29% and 38% respectively.

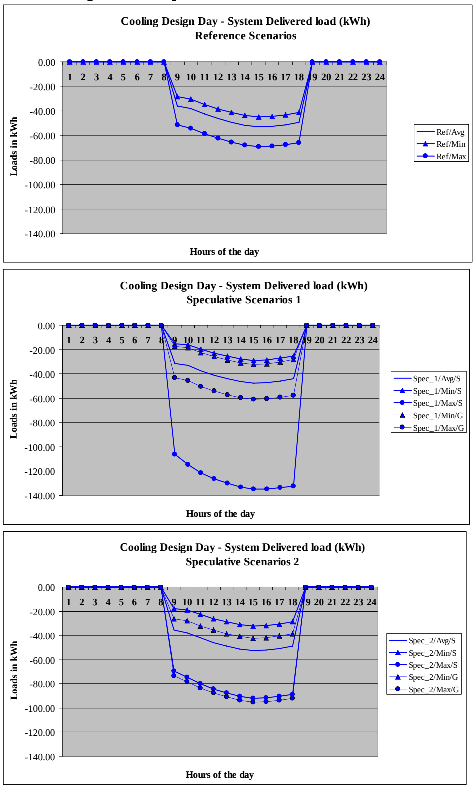

Figure 6– Hourly cooling demands (kWh) – Cooling Design Day (CDD)

What these figures show are that the predicted range of monthly cooling energy demands and peak cooling power required for the same building can vary dramatically just as a result of choosing different internal gain estimation procedures, and that even then they can be dramatically different from the surveyed occupancy.

CONCLUSIONS

The paper has shown that the realistic range of occupancy and usage profiles for an office building, factors completely outside the control of the building and services designers, can have dramatic effects on the overall building energy performance, in this case the cooling demand.

This has major implications for building designers when trying to design robust buildings which will have a low energy running cost with a range of occupancy types.

The overall results show that for the Case Study building:

- Resulting variations in the predicted cooling demand can be substantial when using realistic occupancy scenarios.
- The range of variations in the magnitude of the internal gains in the reference scenario (the surveyed usage situation) is the lowest one because types and quantities of people, lighting and equipment are known. However, this methodology to vary the magnitudes of internal gains can only be applied in very specific situations.
- Speculative scenario 1 provided the largest range of variations in the magnitude of the internal gains and therefore could be presumed to represent the worst case situation for building and service designers.
- Speculative scenario 1 predicted a monthly cooling demand in August 74% lower than the minimum demand calculated for the reference scenario and 163% higher than the maximum one calculated for the reference scenario. This scenario also predicted peak cooling loads 36% lower and 96% higher than the reference scenario on the CDD. The effect that accommodating this range of potential cooling demands might have on the comfort and energy efficiency of a pre-installed cooling system is the next question to be answered, but is beyond the scope of this paper.
- The differences in magnitude of the internal gains influence the internal air temperatures outside the working period including the weekends, i.e. the internal gains continue to influence the building heat exchanges for many hours after occupancy.

The overall conclusion of the paper is that for the case study building assessed, the internal gains are a major influence on the cooling demands seen by the A/C system. If this building were a speculative building with no predetermined occupancy, then designing an energy efficient cooling system for this building would require the architect and engineer to work in harmony to minimise the effects of potentially large variations in this gain.

Of the two methods appropriate to be used when the usage is unknown, speculative scenario 1 would provide a 'safer' design for a cooling system in terms of the cooling demands capable of being encompassed, but speculative scenario 2 would probably provide a better sized cooling system for the majority of occupancy types. This finding is based on a previous study (Knight and Dunn 2002) which found that the 30 UK cooling systems studied were invariably sized to meet twice the load actually encountered.

This paper has only started to explore the implications of the internal gains on designing for energy efficiency in building cooling systems, but has shown that the area is important and worthy of further detailed attention.

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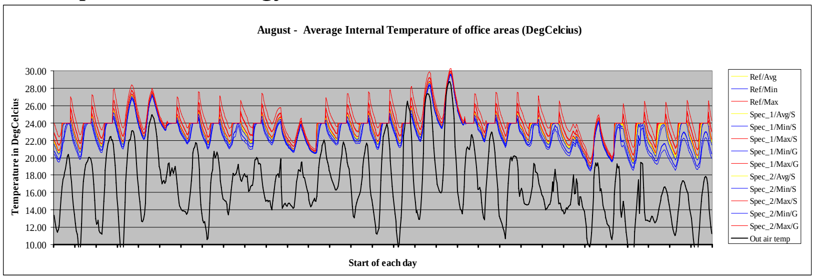

Figure 4 – Hourly average internal temperatures (°C) – month of August

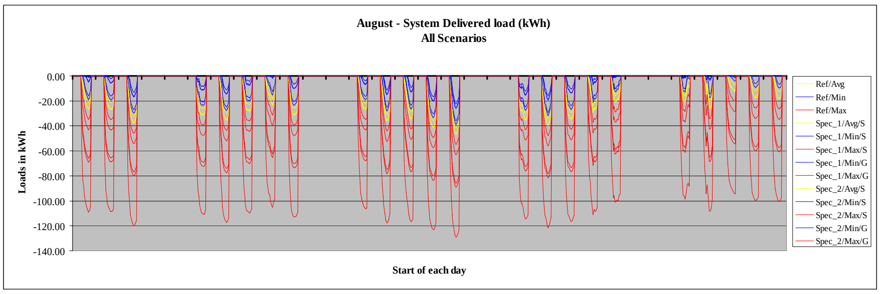

Figure 5 – Hourly cooling demands (kWh) – month of August

Table 4 – August cumulative cooling demand and peak cooling demand

	Ref/Avg	Ref/Min	Ref/Max	Spec_1/ Avg/S	Spec_1/ Min/S	Spec_1/ Max/S	Spec_1/ Min/G	Spec_1/ Max/G	Spec_2/ Avg/S	Spec_2/ Min/S	Spec_2/ Max/S	Spec_2/ Min/G	Spec_2/ Max/G
Total cooling demand (kWh)	5081	3372	8680	3973	881	22866	1225	6769	4986	1265	13455	2853	14264
Peak Cooling Demand (kW)	47	39	63	42	23	129	26	55	47	26	86	36	89