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The Components Of Heating And Cooling Energy Loads In UK Offices, With A Detailed Study Of The Solar Component

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Potential Relevant Topics:

HVAC
Implementation of the Directive on Energy Performance in Buildings
Policies and Programmes (Local, National or International)
Measurement & Verification

Keywords:

Simulation, Offices, Measurement, Energy Use, Heating/Cooling Load Profiles, Solar Shading, Overheating, Physical Characteristics.

Abstract:

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The AuditAC[1] project is producing information which will enable the energy efficiency of Air Conditioning Systems to be improved through Audits and Inspections. Part of the basic information the project will produce is guidance on the type of loads imposed on the AC systems by the building and occupancy characteristics.

The driver for this is Article Nine of the European Directive on the Energy Performance of Buildings which requires “regular inspection” of all systems above 12kW rated output. Part of the inspection is also to determine if the required cooling loads can be reduced or met by alternative solutions such as solar shading devices and more effective glazing systems.

Following on from 2 previous papers presented on the energy use of Air Conditioning systems at IEECB 2004[2,3], this paper presents an initial overview of the relative importance, amplitude and time-varying nature of the components of the heating and cooling load found in a UK Office. These components have been obtained using the modelling methodology outlined in another IEECB ’06 conference paper[4] and are semi-empirical in nature.

The load components presented are the ‘internal gains’, ‘ventilation and infiltration’, ‘fabric’ and solar components, and have been derived from the modelling of one Office from the original Welsh School of Architecture “AC Energy Use in Offices: Field Monitoring Study”. Information of this nature will be invaluable in assessing which actions might initially be the most effective in reducing the energy consumption of heating and cooling systems in UK Offices by measures such as solar shading and glazing treatments, as it shows how much of the total heating and cooling load we might expect to meet through such actions.

The paper then goes on to examine the nature of the Solar Component in UK Offices.

The methodology used in the two analyses will be used to inform the AuditAC study and, as a result, the guidance to be provided for countries other than the UK.

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Breakdown of the Heating and Cooling Loads on UK Office A/C Systems

This section of the paper shows how the loads imposed on the heating and cooling systems vary in a particular UK Office building. The aim is to establish the main sources of the loads, and their relative importance, with the ultimate aim to be able to advise designers of buildings and A/C systems on the issues which will affect the heating and cooling loads in the building and hence the energy needed to maintain comfort conditions.

Modelling Issues

Based on Bleil de Souza[4], we have already seen that two different modelling tools can reasonably accurately describe the internal temperatures achieved within a real building, with all the uncertainties associated with the operation of a real building. This finding implies that the same models would therefore also be able to predict where the loads in the building come from, and this section of the paper deals with these load predictions.

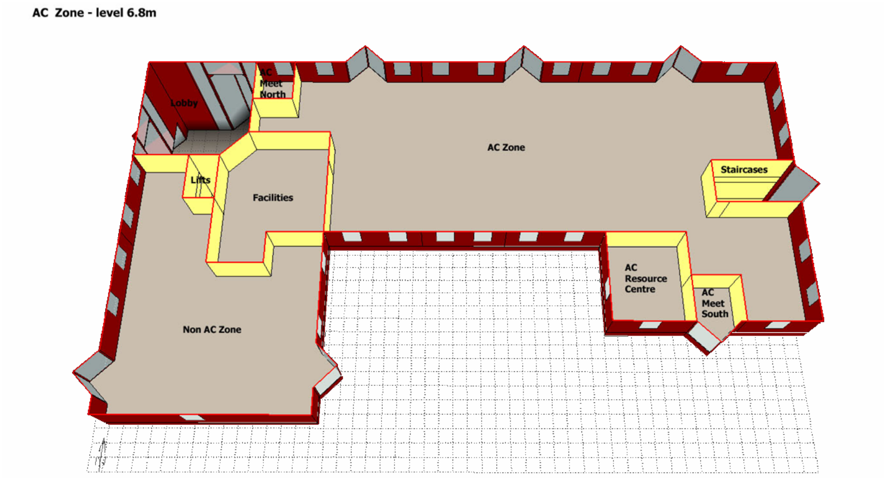


Figure 1. ECOTECT model of example building

The following tables and graphs show for one UK Office building, depicted in Figure 1, how the overall loads on the building heating and cooling systems are 'built-up' in terms of the 'internal gains', 'ventilation and infiltration', 'fabric' and solar components. The 'baseline' modelling input figures for this building are the 'average' values for all the building components and parameters as shown in Table 1.

Table 1. Average and range of input values for the modelling parameters

Group		Minimum	Average	Maximum
Air changes				
	Ventilation Rates	8 l/s person	16 l/s person	36 l/s person
	Infiltration Rates	0.15 ach	0.35 ach	1.25 ach
Internal Gains				
	Activity levels	115 W/person	130 W/person	140 W/person
	Lighting levels	-	9.79 W/m^2	11.5 W/m^2
	Small power Rates	9.26 W/m^2	21.38 W/m^2	37.02 W/m^2
Materials				
	Glass transmittance	0.228	0.565	0.901
	Glass conductivity	0.604 W/mK	1.294 W/mK	1.984 W/mK
	Wall insulation conductivity	0.025 W/mK	0.039 W/mK	0.053 W/mK
	Ceiling insulation conductivity	0.025 W/mK	0.039 W/mK	0.053 W/mK

The heating and cooling set-points in the building are 21°C and 24°C respectively, and the cooling load calculations occur only for the occupied periods which are from 08:00 to 18:00, Monday to Friday. The cooling loads presented are the sum of the 'purchased air' loads as predicted at 15 minute intervals by the EnergyPlus software tool. The loads shown are those that would be imposed on any heating or cooling system which may be installed, and do not therefore include any issues to do with system design, system efficiencies, etc. The loads were also produced in response to the measured weather data for 2001 for the location.

Modelling Results – Average Parameter Values

Figure 2 graphically presents the breakdown of the predicted overall monthly loads on the heating and cooling system in this Office building based on inputting the average values for the main parameters in the building as shown in Table 1. A negative figure indicates a heat loss from the space, i.e. a load on the heating plant. The energy balance requirements to meet the heating and cooling setpoints are also shown on this graph as the white portion of each stacked bar.

It should be noted that all the predicted loads are also based on ideal control and unlimited capacity in the heating or cooling systems. The results presented are for the sensible cooling loads only, as there is no humidity control available on the A/C system in this building.

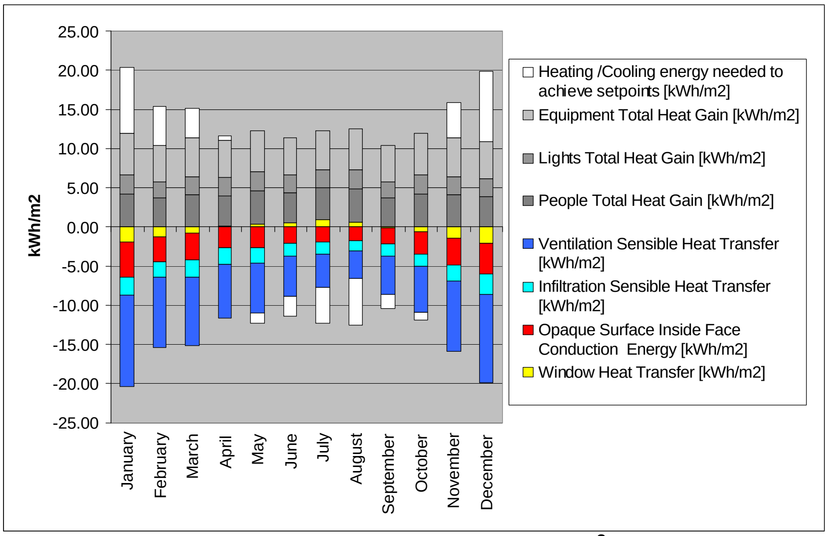


Figure 2. Average monthly heating and cooling load in kWh/m^2 broken down by component.

It can be seen that the overall load on the building changes from a requirement for heating in April to a requirement for cooling in May. The overall load reverts back to a heating load in November. The total cooling requirement over the Summer period is 17.0 kWh/m^2.

In terms of magnitude, the largest average energy **gains** to the modelled space are clearly the people and equipment loads which are roughly the same size. The other major load is the Lighting which is approximately half the size of each of these two previous loads. The only other energy gain to the space occurs through the window heat transfer component during approximately 4 months of the year in the Summer. This energy gain is on average very small in comparison to the other gains.

The average monthly energy **losses** to the modelled space are dominated by the ventilation component which is generally greater in magnitude than all the other losses combined. The other energy losses are, in order of decreasing magnitude, due to losses through the fabric (opaque surface inside face conduction), infiltration and window heat transfer components.

In terms of **variation**, it is seen that the internal gains (people, lights and equipment components) do not show much variation over the year, reflecting the 'hot-desking' nature of the occupancy in this space, and also highlighting potentially poor lighting control over the Summer period. The load components that show the largest variation over the year are the ventilation, infiltration and fabric components. The window heat transfer component, which includes solar gains, shows the lowest variation. This component is examined in more detail later.

Modelling Results – Sensitivity Analysis
A full analysis of the effect of varying each of the modelling parameters individually across their likely range in this building has been undertaken, with all the other parameters kept at their average value during the analysis. Table 1 shows the ranges of values for each parameter.

Table 2 shows the effect that each variation had as a percentage of the predicted overall kWh/m^2 load for each month.

Table 2. Percentage variation of predicted overall monthly load from varying individual parameters

Parameter varied:	Ventilation	Infiltration	Occupant Activity Level	Lighting	Small Power	Solar Transmittance	Window Conductivity	Opaque fabric conductivity	Ceiling conductivity
January	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**	**-8.55**
Min	-68%	-14%	5%	N/A	32%	1%	0%	-2%	-3%
Max	172%	52%	-3%	-4%	-40%	-1%	0%	2%	3%
February	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**	**-5.10**
Min	-85%	-18%	7%	N/A	47%	4%	-1%	-3%	-4%
Max	220%	67%	-5%	-5%	-55%	-4%	0%	2%	4%
March	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**	**-3.78**
Min	-100%	-24%	10%	N/A	66%	9%	-1%	-3%	-5%
Max	283%	91%	-7%	-7%	-69%	-8%	0%	3%	4%
April	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**	**-0.71**
Min	-310%	-96%	45%	N/A	301%	68%	-3%	-12%	-14%
Max	1124%	385%	-30%	-30%	-236%	-58%	1%	10%	12%
May	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**	**1.22**
Min	179%	39%	-24%	N/A	-134%	-34%	1%	5%	4%
Max	-457%	-150%	16%	14%	172%	29%	0%	-4%	-4%
June	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**	**2.49**
Min	90%	23%	-13%	N/A	-50%	-19%	1%	3%	1%
Max	-111%	-52%	9%	9%	110%	21%	0%	-2%	0%
July	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**	**4.56**
Min	43%	15%	-9%	N/A	-46%	-15%	1%	2%	1%
Max	-65%	-39%	6%	7%	70%	16%	0%	-1%	0%
August	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**	**6.02**
Min	27%	10%	-7%	N/A	-40%	-10%	0%	1%	1%
Max	-42%	-27%	5%	6%	57%	10%	0%	-1%	-1%
September	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**	**1.70**
Min	114%	28%	-16%	N/A	-69%	-16%	1%	4%	4%
Max	-178%	-69%	12%	11%	138%	17%	0%	-3%	-3%
October	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**	**1.02**
Min	198%	37%	-27%	N/A	-138%	-17%	1%	5%	8%
Max	-445%	-130%	18%	16%	210%	14%	0%	-4%	-7%
November	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**	**-4.55**
Min	-89%	-21%	9%	N/A	58%	4%	0%	-3%	-5%
Max	248%	78%	-6%	-7%	-58%	-3%	0%	3%	5%
December	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**	**-8.98**
Min	-63%	-14%	4%	N/A	28%	1%	0%	-2%	-3%
Max	157%	49%	-3%	-3%	-35%	-1%	0%	2%	3%

The figures shown in bold in Table 2 are the normalised overall heating or cooling energy needs for that month to reach the thermostat setpoints. A negative figure indicates that the space needs heating by the amount of energy shown. A positive figure indicates a need for cooling.

A positive % figure in the table indicates the percentage by which the monthly overall load figure increases as a result of the indicated change made in the parameter. A negative % figure indicates that the monthly overall load figure is reduced by that %. A negative figure greater than 100%, such as that for the maximum ventilation rate in May, indicates that the overall load is changed from, in this example, a cooling load to a heating load.

The main observations from Table 2 are that, within the likely range to be found within this particular building, the parameter ranges that have the greatest effect on the loads within the space are the ventilation rate, the infiltration rate and the equipment loads (small power in the table). In some cases this range of variation is sufficient to change the overall requirement in the space from a heating to a cooling load or vice versa. This is particular true for the ventilation rate variation, the figures for which are shown graphically in Figure 3.

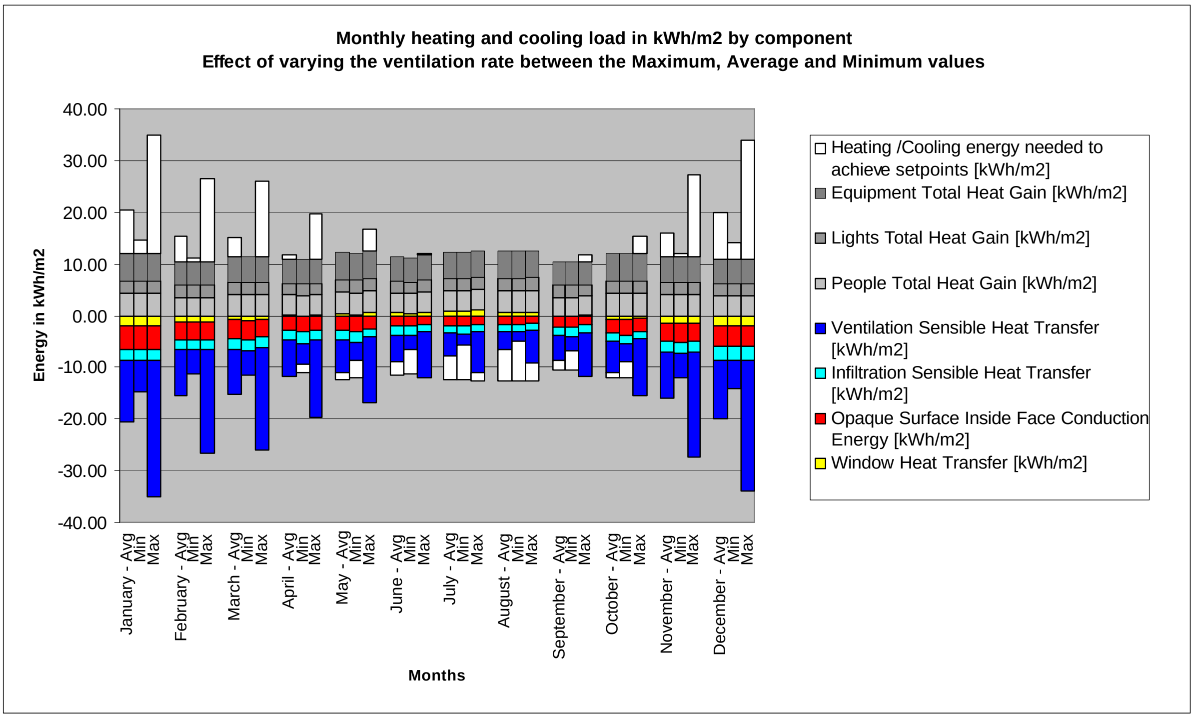


Figure 3. The effect on the monthly heating and cooling load, in kWh/m^2 per component, of varying the ventilation rate parameter between its Maximum, Average and Minimum values

The range of ventilation rates used are those that might be encountered in Offices according to CIBSE guidance[5]. In this case the Minimum ventilation rate was set at 8 litres/second per person (l/s/p), the Average ventilation rate at 16 l/s/p, and the Maximum ventilation rate at 36 l/s/p.

This figure holds a lot of information about the performance of the building under varying ventilation rates. For example, we can see from the range of white bars on the graph that, within this range of ventilation rates, cooling could be required between 2 to 7 months of the year depending on the ventilation rate chosen. The heating requirements could also be varied from 4 to 10 months per year.

Modelling Results – Solar Component

The overall window heat transfer component in this building is shown not to have a huge effect on the overall heating and cooling requirements, but we will examine it in more detail as this component may be more important in other buildings both in the UK and Internationally. Figure 4 shows how the window heat transfer component can be further divided into solar and non-solar components. This reveals how the two components interact over the year, and shows the relative importance of the window conductivity in assisting cooling in this building over the Summer period.

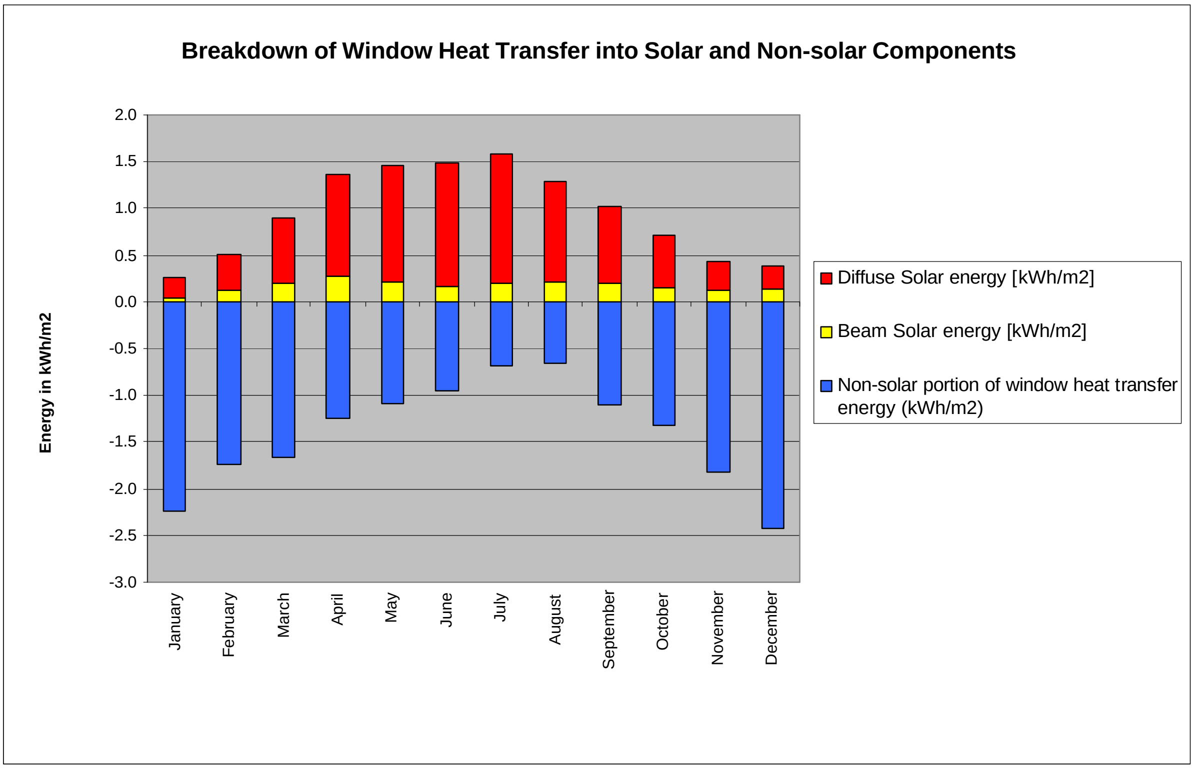


Figure 4. Breakdown of Window Heat Transfer into Solar and Non-Solar Components

The direct or beam solar gains are a relatively small component in the Air Conditioned zone modelled, as Figure 1 shows that there is not a great deal of glazing that would be in direct sunlight as the majority of the glazing is located on the North wall. The majority of the solar gains are therefore diffuse.

The second half of this paper discusses the area of solar gains in more detail, with particular attention to the effect that various solutions may have on daylighting levels. Artificial lighting gains, while only about half the equipment and people gains, are an important area for attention as daylight-linked control of these systems to a 500 lux level as recommended by CIBSE[6] for this type of space could reduce the heat gains from lighting by 80%[7].

Overall Breakdowns Conclusions

The overall conclusions for this building, based on the average values for each of the parameters, are:

- Over the entire year the building heat gains are dominated by equipment and people, with lights also being important. The building heat losses are dominated by the ventilation component, with fabric losses also being significant.
- As the gains from equipment and people have a large effect on the loads to be met by the systems, so the demands imposed will be heavily dictated by control of these factors. Assuming that we have no control over the occupancy then the area that would most benefit from attention in trying to reduce the cooling load would be the equipment load over the Summer.
- External conditions mean that on average the air change and opaque fabric components in this building always lose heat to the surroundings throughout the year.
- The window heat transfer components on average play little part in the overall energy balance in the building, i.e. solar gains appear to have little influence on overall energy requirements in this building.

- Good control of the ventilation and infiltration components, linked with heat recovery in the winter, would appear to provide opportunities for minimising or eliminating heating and cooling needs in this building.
- Fabric losses play an important part in the heating and cooling needs for the building, and a more detailed analysis could be undertaken to find the optimum insulation and thermal mass levels needed to obtain the correct balance between reducing the Winter heat load on the heating system, yet retaining the Summer heat loss which is beneficial in reducing the cooling load.

Solar Shading systems and Their Relative Effect on A/C Loads

This section of the paper considers how solar shading in a building affects the loads on the AC system. From the previous section it can be seen that internal lighting gains in the Office modelled are a significant load on the A/C system in the summer period. On the other hand, based on climate data for Cardiff and the specific configuration of the building, direct solar gains are much less significant. If, as is the case throughout the UK, daylight can be used to offset a major portion of the internal lighting loads, then the design of the solar shading is often as much about admitting the right amounts of daylight as it is about keeping out unwanted solar gains. Obviously in hotter and sunnier climates the relative influence of each will vary.

As most commercial buildings use manually operated vertical blinds and other internal shading devices to reduce direct solar gains and glare, the relationship between solar gain, overheating and daylight can be a complex one. This is due to occupant control and because the exact nature of their installation and the existence of pelmets and window vents have a significant effect on their thermal performance, something that is discussed in detail in the following sections. It is therefore important to consider the exact nature of installed shading systems and subject them to simulation methods that fully account for convective and radiative effects as well as conduction.

As auditors are unlikely to use complex numerical simulations of each building, to accurately judge the potential of changes to shading and glazing they will need to rely on some very general characteristics of each building they assess and the climate in which it sits. However, the true effects of solar gains on overheating in buildings depend not only on external characteristics such as window size and orientation, but also on the properties of the internal surfaces they strike – be they floors, walls or even blinds and curtains. These effects determine the ratio of instantaneous space gain to stored fabric gain, a characteristic fundamental to the response of each room.

The aim of this part of the paper is therefore to describe the methodology used to determine those internal building characteristics that most affect solar overheating. EnergyPlus[8] has been used to undertake a series of parametric analyses on the single office building shown in Figure 1 and the comparative results are presented. **Whilst in the case of this specific building the effects of solar gains are relatively small, the intention is that the methodology will be applied to a range of buildings using different hourly climate data sets from across Europe**.

The parametric study considered the relative influence of the following factors:

- window size and glazing type,
- external shading systems,
- internal shading systems and associated convection coefficients,
- levels of exposed internal thermal mass, and
- perimeter zoning within the simulation model.

The Basics of Internal Solar Shading Design

In many building regulations and simplified analysis methods, solar effects on buildings are characterised only by the exposed area of glazing and type of glass used. This is used to give a measure of solar gains entering the building, effectively a simple solar aperture value. However, the true effects of solar radiation on internal conditions within a space are much more complex. The following is an examination of the factors that affect the influence of solar radiation on internal energy loads.

Window Size and Glazing Type

In terms of analysis, window size and glazing type are almost the same thing. Large areas of glass with a low solar transmittance are effectively the same as a lesser area of glass with a proportionately higher solar transmittance. Thus the effective area of glazing is usually given by multiplying its physical area by its average solar transmittance.

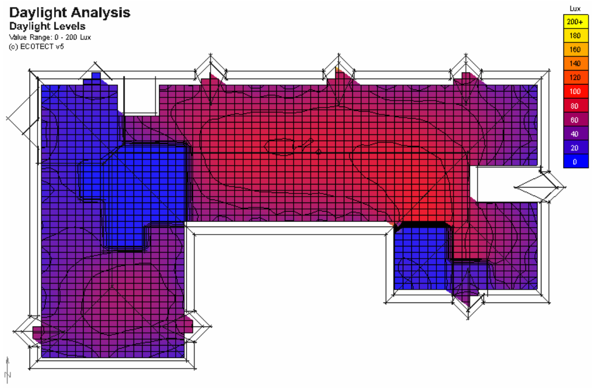
In these cases, solar transmittance is given as a solar heat gain coefficient (SHGC). This refers to the ratio of solar heat gain actually entering a space through a window compared to the total incident solar radiation falling on its outside surface. This includes both directly transmitted solar heat and the solar radiation actually absorbed by the glass, which is then re-radiated, conducted or convected into the space. This is an important point as some older tinted glasses claimed a very low solar transmittance by suspending metal particles as part of the pigment within the glass. When subject to solar radiation however, these would absorb a significant portion of the gains which would heat the glass up quite considerably. Whilst the direct sunlight travelling through the glass was relatively low, a large portion of the solar gain was still conducted to the inside surface of the glass and then radiated and convected into the space behind.

Unless the transmittance of a glass is given as a SHGC, care should be taken about claims of high performance. Table 2 gives some example SHGC values for a range of different window and glazing types.

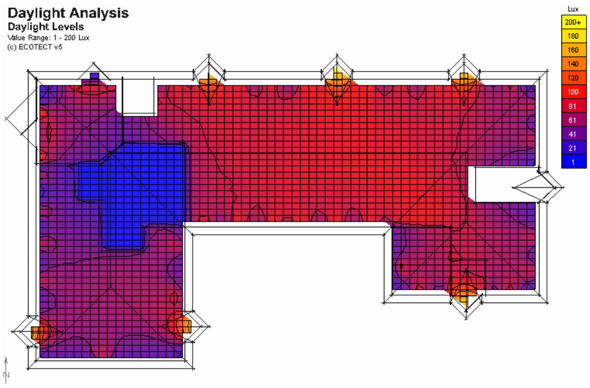
Table 2. Some example solar heat gain coefficients[9]

Glazing Type	SHGC
Single Glazed, Clear Float	0.86
Single Glazed, Bronze or Gray Tinted	0.73
Double Glazed, Clear Float	0.76
Double Glazed, Bronze or Gray Tint	0.62
Double Glazed, High Performance Tint	0.48
Double Glazed, High Solar Gain, Low-E	0.71
Double Glazed, Moderate Solar Gain, Low-E	0.53
Double Glazed, Low Solar Gain, Low-E	0.39
Triple Glazed, Moderate Solar Gain, Low-E	0.5
Triple Glazed, Low Solar Gain, Low-E	0.33

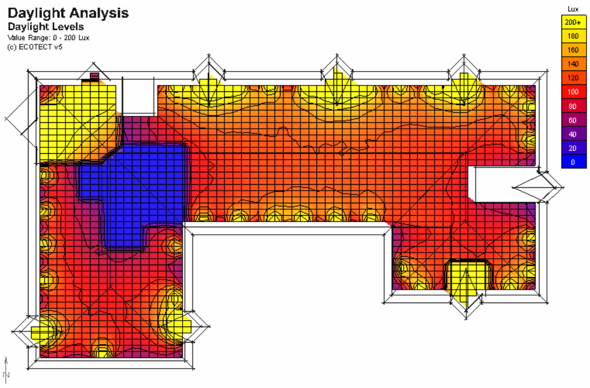
In many glasses, the SHGC is related to visible transmittance. This essentially means that any reduction in solar gain passing through the window with a low SHGC is accompanied by a similar reduction in the amount of visible light transmission, resulting in reduced internal daylight levels. There are some recent spectrally selective glasses in which this effect is less noticeable however, as shown in Figure 5, the effect of variation in the visible transmittance of glass on internal daylight levels is significant. These figures were obtained under an overcast sky of 4500 lux.



Visible transmittance: 0.25



Visible transmittance: 0.50



Visible transmittance: 0.75

Figure 5. The effect of glazing visible transmittance on internal daylight factors.

Varying the SHGC simulates the effect of using either different solar control glasses or applying a perforated metal mesh, a shade screen or other semi-transparent external shading systems. Figure 6 shows the results of a parametric analysis in which the SHGC of windows on the south, east and west façades was varied from 0.1 to 0.9 in steps of 0.2. The metric used for comparison was the total annual heating and cooling loads per square metre floor area.

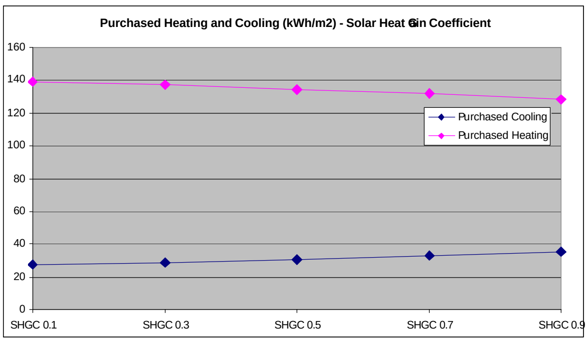


Figure 6. The effect of external shading devices on total annual heating and cooling loads per square metre floor area.

In the building studied here, increasing the SHGC increased the total annual cooling load whilst at the same time reducing the total annual heating load, with an overall annual variation of less than 2%.

External Shading and Solar Protection

If there is an opaque obstruction between the sun and a window, direct solar gain will be blocked – being either absorbed or reflected by the objects that form the obstruction. Diffuse radiation from the sky and reflected radiation from the ground and other external surfaces may still get through.

Of all the available options, external shading devices usually work best. This is because they prevent the gains from hitting the window in the first place. To reach internal blinds, louvres or curtains, the solar radiation must already have passed through the window. Whilst it is then blocked by the internal obstruction, it is still incident on that obstruction so the energy acts to increase its surface temperature. Under direct sun, temperatures in the air gap between a blind and the window may be up to 20°C higher than average internal air temperatures.

In many buildings a combination of external and internal shading systems are used. This is primarily to combat glare at times of low sun angle. Badly designed external shading can often result in people keeping the internal blinds closed throughout the day, requiring the electric lights to be turned on to make up for the reduction in light levels. The means a double load – more gains to the space through solar radiation on the blinds and more heat from the extra lights. This indicates again that, at higher latitudes where the sun is lower in the sky, good solar shading design is not just about solar protection but also preventing external glare and at the same time maximising internal daylight.

There are many different types of external shading device, each with their own performance profile reflecting the changing position of the sun both hourly over the day and seasonally over the year. Some systems, such as fixed horizontal shades, will have poor performance when the sun is at a low altitude but very good performance when it is high overhead. On south-facing facades this effect can be exploited to allow solar gains in winter whilst fully protecting in summer. Other external shading systems such as perforated metal mesh can be configured to be independent of solar position, providing the same level of protection throughout the year. Further still, systems such as shutters and rollers can be deployed dynamically by the occupants to accommodate hourly solar variation.

To effectively examine these effects it is necessary to compare extreme examples of each case. Thus, in addition to the SHGC simulation described previously, the following two analyses have been performed:

- Variation in horizontal shading depth directly above windows on the south, east and west facades. In these cases a horizontal plane running the full length of each façade was generated at depths of 200mm, 500mm, 1000mm, 1500mm, 2000mm.
- To represent dynamically deployed shading systems such as shutters or rollers, calculations were performed such that the shading was engaged on each window when the incident solar radiation exceeded a given threshold value. Calculations were performed for thresholds varying from 100W/m² to 600W/m² in steps of 100W/m².

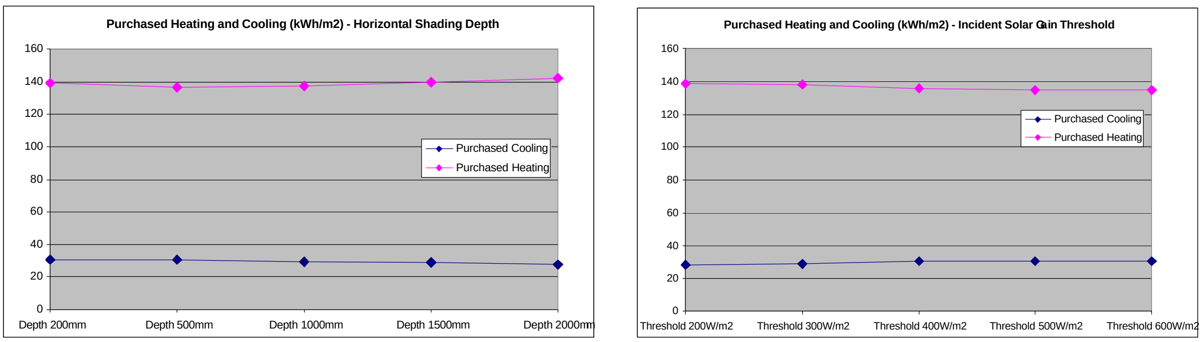


Figure 7. The effect of external shading devices on total annual heating and cooling loads per square metre floor area.

The results show that, whilst varying these parameters has an effect, annually it is less than 1.5%.

Internal Shading

Once solar gains have passed through a window and hit an internal blind, they are already effectively inside the space. Only if the blind surface is highly reflective and the solar rays redirected straight back out the window will this not result in some heat internal build-up. Thus, whilst the blinds may effectively block glare and daylight, the effects of conduction, convection and radiation will usually convey almost all the heat into the space.

If the area between the blind and the window is open at top and bottom, a convection current will likely result with warm air rising out the top drawing cool air in from the bottom. Such a system is a very efficient heat transfer mechanism which can be used to good effect in winter, but is rarely desirable in summer. This can be ameliorated to some extent using pelmets and full-length blinds, as well as controllable high level vents at the top of the window to duct the rising warm air to the outside.

The true thermal effect of an internal shading system therefore depends greatly on the detailed nature of the air flow it induces. However, a typical thermal analysis will only consider its opacity and any additional insulating characteristics it imparts to the window. To properly consider convection effects requires a detailed 3D model of the window-blind configuration and a complex computational fluid dynamics (CFD) solution.

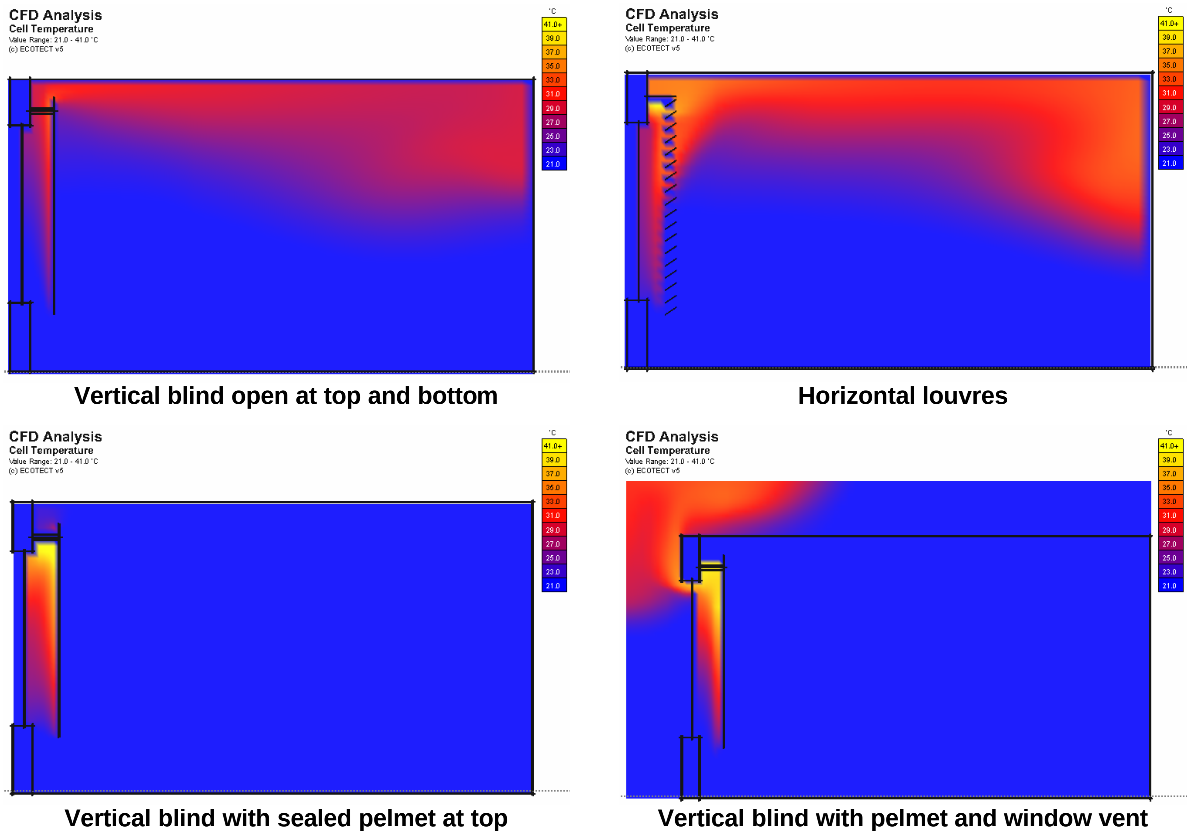


Figure 8. Example images from a computational fluid dynamics analysis of a range of internal shading systems showing internal temperatures distribution resulting from 660W/m² of incident solar gain on the window.

Figure 8 shows some example images of such a CFD solution for a range of different internal shading devices after 15 minutes of exposure to 660W/m² of incident solar gain. However, even with such detailed analysis, it is very difficult to calculate an accurate convection coefficient for each blind assembly as the systems are essentially dynamic feed-back loops, changing in efficacy as warmed air re-circulates back in through the bottom. Similarly, the efficacy changes based on the amount of incident solar radiation, the solar absorption and emissivity of each surface and the flow resistance of both top and bottom openings.

Auditors are unlikely to apply such solutions at the level of detail required and manufacturers are unlikely to provide detailed data on the full range of potential installation configurations.

In order to determine the relative sensitivity of the calculations to variations in convection coefficients, three different internal shading configurations were used: a flat blind open at top and bottom; a flat blind with a sealed pelmet at the top; and a set of horizontal louvers set at an angle of 45deg. The vented window option shown in Figure 8 was not tested as, to effectively balance pressures in the room, an additional inlet vent would have been required along with a relatively arbitrary specification of inlet air conditions.

Computational fluid dynamics calculations were performed on the three configurations in order to determine air flow rates and exit point air temperatures. From this an estimation of the convection transfer functions was made for each system under high (660W/m²) and low (100W/m²) incident solar radiation conditions. Figure 9 shows the effect of the three internal shading configurations on total heating and cooling energy when applied to the test building. Future work in this study will consider the effects of dynamic internal shading on both energy and daylight, including a detailed analysis of variations in louver angle, percentage blind coverage and window venting.

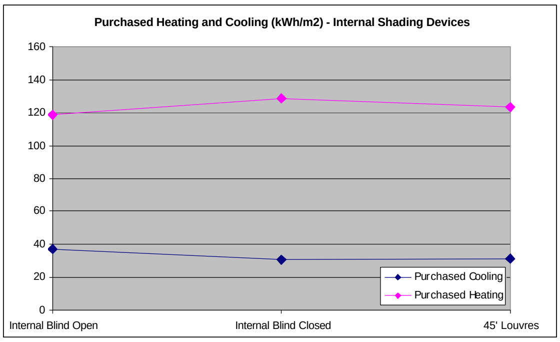


Figure 9. The effect of internal shading system on total annual heating and cooling loads per square metre floor area.

Even within a large conditioned zone, the results show that loads are sensitive to internal convection effects, with a total variance over the range of parameter values in the order of 5.3%.

Exposed internal mass

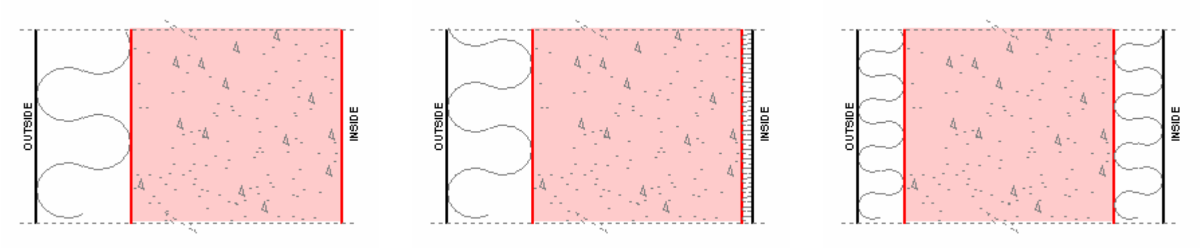
When solar radiation falls directly on the surface of a material, the incident energy acts to increase the surface temperature. As it does this, the temperature differential between the surface and the material immediately underneath also increases. This results in a flow of heat from the surface deeper into the material itself. The rate of this heat flow depends upon the conductivity of the material.

For most high thermal mass materials with high conductivity, this occurs faster than the surface heat can be lost by radiation or convection into the air layer immediately above it. This means that surface temperature rises remain relatively low with the heat energy quickly dispersed over a much greater mass of material. Inside a space, this means that both air and mean radiant temperatures remain relatively unaffected. However it also means the heat is stored within the fabric of the space for release later when internal temperatures fall.

For low thermal mass or low conductivity materials (i.e.: highly insulating), very little of the surface heat is conducted away internally. This means that the rise in temperature at the surface is much higher, leading to the majority of heat being lost immediately by radiation and convection. This has an almost immediate impact on both air and mean radiant temperatures within a space. This means that, with the appropriate choice of materials, the designer has significant control over the response of each space to internal and solar gains, suggesting the placement of carpets, tiling, wall-coverings and furniture all play an important thermal role that must be accounted for.

To determine the effects of internal exposed thermal mass, energy calculations were performed using three different material configurations. As EnergyPlus calculates the thermal response of each material based on the width, density, specific heat and conductivity of each of its component layers, the three different materials had to be constructed such that their overall thermal responses were equivalent in order that the comparison not be masked by differences in heat transfer coefficients. Additionally, the same material was applied to both the walls and the ceiling of all spaces in the building. The floor was assumed to be carpeted and not available as an exposed surface.

A standard concrete wall construction was used as the basis of each material, with compensating insulation layers on the inside and outside. The three levels of exposed mass were generated by varying the inside insulation layer and compensating with the outside layer, as illustrated in Figure 10. Analysis in EnergyPlus showed that U-values between the cases varied by less than 0.01 W/m²K.



Exposed Thermal Mass. *5mm Internal Insulation* *25mm Internal Insulation*

Figure 10. The component layers of the three materials used in the exposed internal thermal mass analysis.

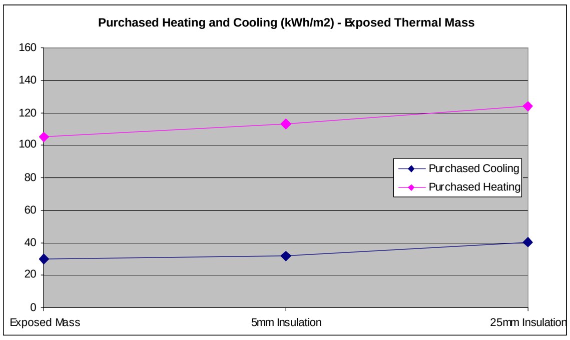


Figure 11. The effect of exposed internal thermal mass on total annual heating and cooling loads per square metre floor area.

Even within a large conditioned zone, the results show that loads are sensitive to internal convection effects, with a total variance over the range of parameter values in the order of 5.3%.

Zones and zoning

Almost all thermal analysis algorithms calculate a single temperature for each zone – this being the average over the whole space. This is calculated by summing all the gains and losses across the zone. If one part of a zone is subject to high solar or radiation gains, it is likely to have a higher local temperature. However, this will only be indicated by a slightly increased zone average, the specific localised temperatures in different parts of the zone will not be calculated.

If a large space were subdivided into a number of smaller 'virtual' zones, it would be possible to quantify these localised variations. Each calculated temperature will still be the spatial average for each 'virtual' zone, suggesting that ideally they should be as small as possible. However, each thermal analysis engine treats the interface between 'virtual' zones differently. Some use fictitious surfaces and require the user to specify heat transfer and inter-zonal air flow values. EnergyPlus requires that the interface between zones be physical, created as a resistance-only material or a large open window. Either way, these 'virtual' inter-zonal boundaries will affect both the flow of heat around the zone and the mixing of the air volumes – introducing inaccuracies into the calculation. Thus by creating very small 'virtual' zones near a window, the thermal analysis may not properly account for air movement across the space – meaning that it is likely to overemphasise the thermal effect of the solar gains. If you use very large 'virtual' zones, the same averaging effects will tend to underemphasise the solar gains.

Unfortunately there is no simple answer for the optimum zone size. As a result, it is important to know the extent to which different relative 'virtual' zone sizes affect solar gains in office buildings.

To investigate the effects of zone size, five 'virtual' zone configurations were used based on the perimeter depth around the building. Depths of 2m, 4m, 6m and 8m were compared. The comparisons, as shown in Figure 12, consider total heating and cooling loads as well as peak and average zone temperatures. In order to see the full effect of zone depth, internal temperatures were calculated under free-running conditions with the HVAC switched off and no temperature control. Peak and average temperatures were derived from the standard operational period of the building (8:00am to 6:00pm, Mon-Fri).

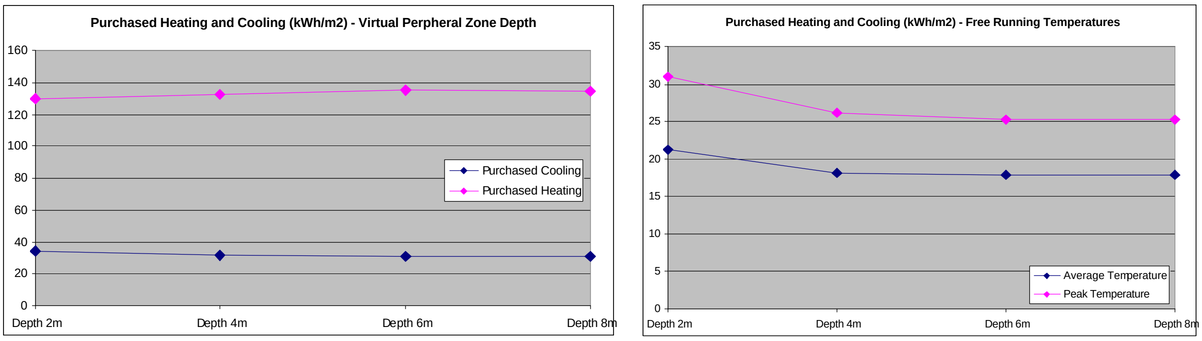


Figure 12. The effect of peripheral zone depth on total annual heating and cooling loads per square metre floor area as well as free running internal zone air temperatures.

Due to increased internal temperatures, the graphs show that small 'virtual' perimeter zones tend to underestimate heating requirements and overestimate cooling. Whilst the percentage overestimation effect on cooling is greater than the underestimation of heating, the demand for cooling is much less so the overall loads vary by approximately 2%.

Findings from the solar study

The results of this particular analysis are specific to a particular office building within the UK. However, it does illustrate the application of the analysis method and the types of results that can be derived from its application. Of more importance are the tabulated results from an analysis of a wide range of buildings and climate types, which is the next step in this study.

To summarise the results for this building, the relative effect of variations in each parameter is shown in Table 3 as a percentage of predicted overall kWh/m^2 load for the year (shown in bold). Table 4 shows the minimum and maximum values used for this comparison.

As comparisons were based on the sum of total annual heating and cooling loads, the values in the table represent variations in the combined heating and cooling load. A negative value is therefore a reduction in overall load whilst a positive represents an increase.

Table 3. Percentage variation of predicted total annual load from predicted 'average' load with variation of individual solar parameters

Parameter varied:	SHGC	Horizontal External Shading Depth	Dynamic External Shading	Internal Shading Convection	Internal Exposed Thermal Mass	'Virtual' Perimeter Zone Depth
Annual	**166.45**	**166.45**	**166.45**	**166.45**	**166.45**	**166.45**
Min	-0.7%	0.0%	0.0%	-2.1%	3.1%	4.0%
Max	1.1%	1.4%	-1.1%	3.2%	-2.6%	-0.9%

Table 4. A summary of the maximum and minimum values for parameters used in Table 3.

Value	Min	Max
SHGC	0.1	0.9
Horizontal External Shading Depth	200mm	2000mm
Dynamic External Shading	100W/m2	600W/m2
Internal Shading Convection	0.10	0.87
Internal Exposed Thermal Mass	No Surfaces	All Surfaces
'Virtual' Perimeter Zone Depth	2m	8m

Overall Conclusions

The paper has shown how loads on the heating and cooling systems in a UK Office building can be broken down by modelling into the main components making up that load, and what the relative importance of these components were in the building studied. The methodology used for this assessment will be applied across a range of European locations and building types as part of the AuditAC project.

The solar study has shown that it is possible to determine the relative influence of a wide range of solar parameters on total heating and cooling requirements. Once applied to many buildings, this will enable the derivation of trends that will enable a qualitative assessment of the physical characteristics that are most likely to affect solar overheating of a range of buildings in various climates. The assessment of characteristics will inform auditors working under Article 9 of the European Directive on the Energy Performance of Buildings as to the most appropriate preliminary advice to provide to minimise solar overheating in the specific building they are working on.

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