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Paper: **Natural Ventilation Analysed Using Dynamic Simulation Software**

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Summary

The possibility of using natural ventilation for commercial buildings is increasingly being considered. To assist natural ventilation in these buildings atriums are often suggested for the building's design as well as mechanical systems providing low air change rates. To ensure that natural ventilation will meet today's comfort expectations the proposed design needs to be evaluated using dynamic simulation software. This paper is based on a study carried out on a Call Centre using a dynamic thermal simulation program that runs in conjunction with a dynamic airflow simulation program to provide a range of design information. As environmental conditions in naturally ventilated buildings are strongly influenced by the interaction of the temperatures and velocities of the air in the building these conditions must be calculated taking into consideration their dynamic interaction. The programs used take into account these dynamic interactions and provide design information in terms of temperature profiles, dynamic airflow rates between zones, Fanger's comfort analysis etc. Naturally ventilated building design is one approach to reducing the impact that buildings have on the environment. The information provided by simulation software can be used to check if this type of design can be successful.

Key Words: Call Centres Natural Ventilation, Fanger's Comfort Analysis, Dynamic Simulation

Introduction

In the battle for market share many organisations have placed Call Centres firmly at the forefront of their strategies to improve customer service while reducing costs. Analysts estimate that 1% of the UK's working population is employed in Call Centres and this figure could double by 2001. This will require the construction of at least another 400 Call Centres during the next two years.

This rapid growth in the UK and Ireland is also mirrored in many other parts of Europe and the US.

Greater demands from customers combined with the new capabilities offered by powerful technology are all combining to create unparalleled change. These external forces, together with a management focus on how work gets done, are making many organisations re-think how to reduce costs, how best to deliver value to their customers and how to provide the right working conditions for their workers.

Call Centres are constantly evolving and adapting to market demand and the management of these Centres are keen to encourage a team based approach. There is also a very strong requirement for the management of the Centres to maintain and develop quality staff. Personnel training costs are substantial and staff retention is emerging as an important competitive advantage. In most Call Centres staff turnover is very high and the average working life of a telephonist in a Centre is 18 months.

Call Centre technologies are evolving rapidly and sophisticated call routing and retrieval systems can now match calls with customer records and send callers to appropriate operators skilled in those particular products. But while technologies are expanding rapidly much less attention is being paid to the physical design of Call Centres and the role the building and the way the internal spaces are planned can play in maximising the productivity and satisfaction levels of the Call Centre staff.

Typical Call Centre

A typical Call Centre has been analysed in this paper to determine how the physical design of the building affects the environmental conditions in the internal spaces. The building has a 12m wide floor-plate on either side of a full height atrium. Due to the nature of the work the open plan office areas in Call Centres are subjected to a high occupancy load. The occupancy load is taken as 140 people on each floor in this building. Full occupancy is taken to occur between 0800-1800, Monday -Friday. During the night-time shift from 18.00-20.00, the occupancy in all areas is reduced to 50%. Each person is assumed to contribute 95W sensible and 45W latent gain to the space. Sensible loads were assumed to be 80% convective in nature, with the remainder radiant.

The heat gain in the space due to lighting is taken as 15 watts/m^2. During the night-time shift, i.e. 18.00-8.00 it is assumed that the lighting load would be reduced by 50% in all areas. This assumption is based on the fact that effective lighting controls and layouts are installed which take account of the low occupancy in the building during these times. The lighting gain is assumed to be 70% radiant in nature and 30% convective. The equipment gain in the occupied spaces due to the computers is taken as 200 watts per computer with each person having one computer. These gains due to computers are assumed to be reduced to 50% of their full rating during the night-time shift, 18.00-8.00, due to a similar reduction in occupancy. For ease of comparison the occupancy and casual gains described above during normal occupancy equate to people 11.8W/m^2, lights 15W/m^2 and computers 25W/m^2. Typically the solar gain that the spaces experience with Brise Soleil and clear float glass is 6.24W/m^2.

Ventilation Strategy

In order to avoid the occupants having to carry out stressful work in a sealed building the design of the building using natural ventilation air was analysed. Due to the high incidental gains in the building a mechanical system providing low air change rates and using ambient air was introduced to assist the natural ventilation strategy.

Ambient air is supplied mechanically through the floor plenum and through windows and high level vents. With this arrangement it is important that the dynamic distribution and patterns of airflow in the building are identified. In order to do this a nodal representation of the airflow network has been created for the building. Each external node refers to a climatic pressure coefficient set, which assigns a pressure coefficient to the node for a given wind direction; this pressure coefficient is then used to derive the wind pressure on the node as a result of prevailing wind speed (after correction for node height and surrounding terrain effects on the wind speed profile).

Using the airflow network allows the effects of internal buoyancy and external wind pressures to be accounted for effectively. The mechanical system is also accounted for in the network.

Hoppers have been included in the external skin of the building. The architect decided the dimensions of the hopper vents to fit in with the elevation of the building. However part of the simulation study requested by the architect was to ensure that the dimensions of the hopper vents were adequate.The high level vents (hoppers) in the open plan areas will be opened and closed as space temperature dictates. The daytime control temperature for these hoppers is as follows:

Control Temperature	% Opening
20-22°C	10%
22-24°C	25%
>24°C	50%

To allow the hoppers pre-cool the slab, their control during the night is as follows:

Control Temperature	% Opening
15-17°C	10%
17-19°C	25%
>19°C	50%

All open-plan areas can be naturally ventilated via operable windows. To simulate occupant behaviour the windows in the zones will be opened and closed as the space temperature dictates. The table below sets out probable occupant window opening with space temperatures experienced:

Control Temperature	% Opening
22-24°C	25%
>24°C	50%

This probable occupant window-opening regime is used to take account of the effect that will occur if windows are opened. Obviously it can not be determined accurately when occupants will open windows. However this approach takes account of probable occupant interaction with their environment. Different window opening regimes can be tested as well as the regime suggested above and design information obtained. In this simulation study it was not possible to take account of occupants operating desk fans or adjusting their clothing. However including probable window opening regimes takes some account of occupants' natural inclination to adapt their surroundings to achieve the comfort conditions they require.

The controllable areas of the louvers in the atrium roof-light are opened and closed as control zone temperature dictates. The control regime for the louvers operates in parallel with the control of the hoppers.

Control Temperature	% Opening
20-22°C	25%
22-24°C	66%
>24°C	100%

A constant low air change rate is being supplied by the mechanical system into all spaces via the floor plenum, and extracted at high level through the atrium roof-light. This low air change rate satisfies fresh air requirements for the occupants.

Daylighting Strategy

To make more pleasant conditions in the building as much daylight as possible was designed for the building. Due to the risk of high solar gains coinciding with high incidental gains in the building a brise soleil arrangement was evaluated. Clear float glass and solar reflecting glass were also analysed. With antisun glazing the solar load contribution in the zone falls from 13% to

7% of the overall load. Therefore the addition of the antisun glazing only marginally improves the internal conditions due to the small contribution of the solar load.

The use of antisun glass would have also reduced the amount of daylight entering the building. The architect was determined if possible to use clear glass in the building to ensure that the occupants could relate to outside and not feel enclosed in an artificially lit building. A Radiance simulation was also carried out to ensure that the pleasant daylight conditions provided in the spaces would not cause glare on the computer screens for the occupants.

Building model

The building model comprises 52 zones. A perspective view of the model is shown in figure 1. The layout of the building allows some zones to have unobstructed airflow paths to the atrium whereas in other zones the airflow path is obstructed. The obstructions to the airflow paths are caused by the location of the management offices. A revised floor layout could possibly reposition the management offices and allow more effective use of the ventilation strategy. The second floor zoning arrangement is shown in figure 2.

Simulation can be used to identify typical and peak zones in a building. The zones with the peak conditions were those zones with the higher gains due to computers. This highlights the need to use accurate values for gains from computer equipment. The casual gain per computer of 200W was provided to the simulation team. A more realistic gain of 150 W could be used. With the advent of flat screen computers this heat gain will be further reduced to 87 Watts per computer.

Natural Ventilation Strategy Analysed Using Dynamic Simulation

As environmental conditions in naturally ventilated buildings are strongly influenced by the interaction of the temperatures and velocities of the air in the building these conditions must be calculated taking into consideration their dynamic interaction. A dynamic thermal simulation program that runs in conjunction with a dynamic airflow simulation program was used to provide a range of design information. The dynamic simulation program used in the study was ESP. For more details on this program see Clarke [1]. The multi-zone airflow simulation program Macroflo is fully integrated within the ESP program and provides the dynamic bulk airflow results for air entering the building and for airflow between zones for the overall energy analysis. For example for airflow through open internal doorways the method used is based on Cockroft [2]. For the method of transferring the results from the dynamic airflow simulation to the dynamic thermal simulation program see McLean [3]. In this simulation study computational fluid dynamics (CFD) has not been used. Although available the use of CFD significantly increases simulation run times. The use of dynamic bulk airflow simulation however is a significant improvement from using fixed standard air change rates, which do not take account of wind speed or direction or differences between temperatures inside and outside the building. The dynamic multi-zone airflow simulation program uses the same time-step as the dynamic thermal simulation model. The term "dynamic" as referred to this air-flow simulation is used to describe the possibility of the airflow changing quantity and direction at each time step. These programs provide design information in terms of temperature profiles, dynamic airflow rates between zones, Fanger's comfort analysis etc. For Fanger's comfort analysis an approximation is used in that the air velocity in the space is based on the bulk airflow results and the airflow parameter is set based on this. The temperature profiles can be used to analyse the conditions during worst case days. The dynamic airflow rates are useful in displaying the amount of air moving between zones in the building and the direction of the airflow through the building. Fanger's comfort analysis is necessary to ensure that comfort standards are examined in more detail.

The initial thermal and airflow simulation of the building revealed a number of interesting issues, which are set out below:

Simulation Results

The building was simulated using weather data for a representative year obtained from the local meteorological station. The weather data included hourly values of dry bulb temperature, wet bulb temperature, direct solar radiation, diffuse solar radiation, wind speed and wind direction. The simulation period chosen was the summer months of July and August.

Table 1 shows the result of Fanger's comfort analysis on the simulation results. This represents individual comfort levels based on air temperature, mean radiant temperature, air movement, humidity, clothing and activity level. From the results in this table it can be seen that the percentage of time that conditions are warm/unpleasant varies quite considerably in the representative zones in the building i.e. from 0.2% to 19.6% with the highest occurrence of unsatisfactory conditions taking place on the second floor. Obviously a zone with unsatisfactory conditions (i.e. warm/unpleasant) for 19.6% of the time would not be acceptable either to the design team or to the client. This information allows the design team to identify the unacceptable zones and investigate possible changes to design parameters to determine if conditions can be improved. Zones 5 and 11 on the second floor suffer the highest instances of unpleasant conditions. This is due to the fact that these zones are predominantly on the negative side of the building (NE) and thus the air enters these zones either from other open-plan areas or from the atrium. The air entering from other open-plan areas has increased in temperature due to the heat from the incidental gains and the atrium air is at a higher temperature than the ambient air. Thus the air at the higher temperatures is less effective in maintaining satisfactory conditions in the space. This design information could possibly be used to reduce the occupancy and incidental gains in the zones that have unacceptably high percentages of warm/unpleasant conditions.

The effectiveness of the brise soleil arrangement can be seen in figure 3 as during times of peak conditions the windows are completely shaded. This design information shows the design team that all design steps have been taken to eliminate direct solar radiation entering the building during peak times.

Figure 4 displays the amount of air moving between zones in the building and the direction of the airflow through the second floor of the building. This information is useful in determining the causes of high temperatures in any zone in the building e.g. adverse airflow may be occurring. The term adverse airflow is used to describe situations when the air enters zones either from other open-plan areas or from the atrium as opposed to the desired situation in which air would enter the zones from outside.

Figure 5, shows the effect of opening the windows on the internal temperature conditions. The results are shown for zones on ground, first and second floors.

Figure 6 shows the solar load in a typical zone with clear float and solar reflective glazing. It can be seen from the graph that the difference in solar load contribution to the zone from using clear float glass and solar reflecting glass is quite small and will not contribute significantly to the conditions in the building. This information would allow the design team to decide with confidence to use the clear float glass and help achieve the daylighting strategy of providing more pleasant conditions in the building.

The results shown are for the initial design proposal. The simulation study quantified the temperatures in each occupied zone for each hour of the simulated period i.e. the months of July and August. The main causes of over heating have also been identified i.e. high casual gains from computers and the amount air moving between zones and the direction of airflow in the building. This information will allow the design team take the next step in the design process e.g. check with the client if the computers being purchased will have a lower heat gain than 200W or if flat-screen computers will be used, add an extract fan to the atrium to ensure that the airflow during warm periods is from outside across the open-plan areas and exits via the atrium.

Results based on Fanger's comfort equations are included in the paper. However the Fanger's comfort equation results will not necessarily agree with how people will react in actual buildings as the Fanger equations are based on climate chamber experiments where the people could not make any adjustments, which would improve their comfort situation. Nevertheless as Fanger points out [4] the predicted mean vote model just gives you some indication of where you should be. Brager and de Dear [5] found that *in naturally ventilated buildings indoor temperatures more closely match the diurnal and seasonal variations in outdoor temperatures. People recognise this, relax their expectations and not only become more tolerant of the more varied, dynamic and non-uniform indoor conditions, but often prefer having a closer connection with weather and seasonal change.* The effect of internal comfort conditions on productivity is difficult to quantify but people will feel more relaxed in a building that is not sealed and does not provide a closely controlled artificial environment.

Design Information

It is the interaction of the building with the local climate, the airflow through the building and the occupancy pattern and the use of computers that affect the environmental conditions in the building. Traditional design methods use an idealised weather profile, use assumed empirical airflow rates and use average values to represent the use of computers over 24 hours. It is only with the use of more realistic calculation methods that more accurate design information can be provided. This has now been recognised and the latest edition of the CIBSE guide A points out that admittance procedure is intended for application at an early stage in the design process [6]. It is important to be able to analyse temperatures for every hour of the calculated period and not just base decisions on one peak temperature occurrence. The availability of hourly temperature results allows the design team evaluate their design against the recommendation (for areas such as offices an inside dry resultant temperature of 25^0C is not exceeded for more than 5% of the annual occupied period) also contained in [6]. The results also show the variation that can occur in comfort conditions in the various zones in the building. A significant factor in this variation is the amount air moving between zones and the direction of airflow in the building. The amount of air and direction of airflow has been shown in Figure 3 above. Airflow results (quantity and direction) are available for each time step over the summer period. These results are used to analyse the amount of air movement through the occupied spaces when temperatures are high and provide more useful information than considering air temperature alone.

Conclusions

When the use of natural ventilation strategies is being considered for commercial buildings particularly those with high incidental gains it is important that the environmental conditions are evaluated over the summer months. Simulation results show the variation that can occur in comfort conditions in the various zones in the building. Displaying dynamic simulation results in graphical format and also showing Fanger's comfort results gives the design team more information and more confidence to make decisions on whether satisfactory working conditions will be achieved and staff will be satisfied in the new Call Centre environment. It should be noted however that although simulation can model parameters (wind speed and direction, variable occupancy profiles, etc.) that cannot be included in steady state or admittance methods there are still some assumptions in the simulation methods. As it is usually not possible to check the steady state or admittance methods using recognised validation data sets the effect of the omission of important parameters in these methods has not been determined. However continuing validation studies will help to improve the accuracy of simulation methods to produce relevant information for design teams. Simulation can produce a vast array of results and their accuracy is dependent on the experience of the user. Design teams need to bear this in mind. Properly used simulation can address the design parameters (thermal mass, natural ventilation, night cooling etc.) that architects are now proposing and provide useful information to make buildings more comfortable for their occupants and also reduce the impact that buildings have on the environment.

References

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Zone	Comfortable Pleasant (% of simulated time)	Slightly Warm Acceptable (% of simulated time)	Warm Acceptable (% of simulated time)	Warm Unpleaseent (% of simulated time)
Second Floor				
2	5.8%	44.1%	48.1%	4.3%
5	0.0%	21.5%	67.5%	10.9%
6	2.8%	41.5%	47.9%	7.5%
9	0.6%	56.6%	42.1%	0.5%
11	0.1%	16.7%	63.5%	19.6%
Ground Floor				
28	8.2%	58.2%	31.5%	1.7%
31	1.8%	56.1%	40.8%	1.1%
33	7.7%	58.8%	30.9%	2.3%
36	0.5%	67.3%	31.3%	0.2%
37	3.6%	57.6%	36.2%	2.4%

Table 1: Fanger' s Comfort Analyse for stated Zones Over the July/August Simulated Period (8.00 –20.00)

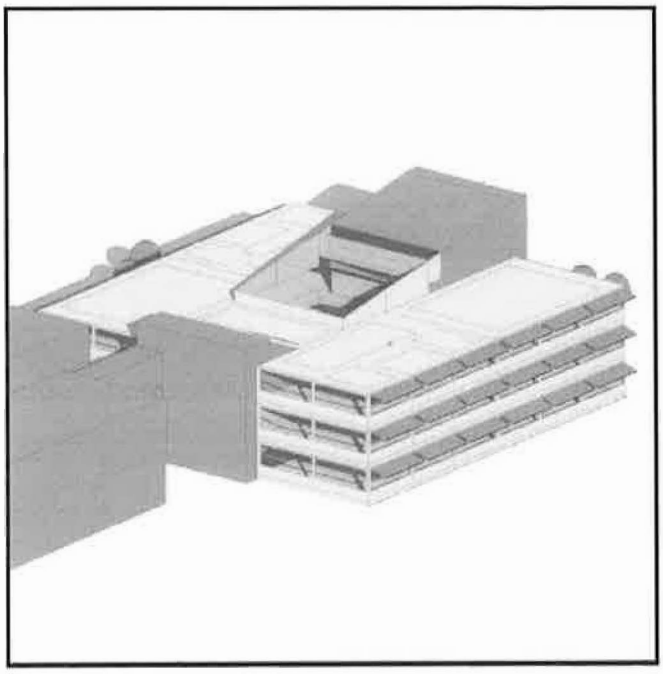

Figure 1: Perspective View of Model

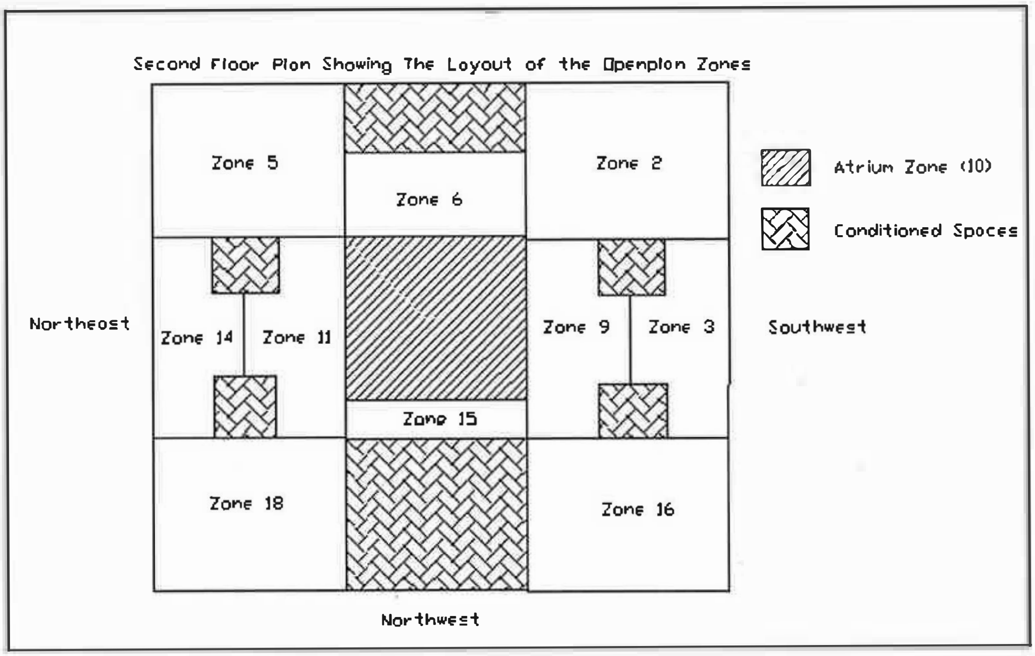

Figure 2 Second Floor Zoning Arrangement

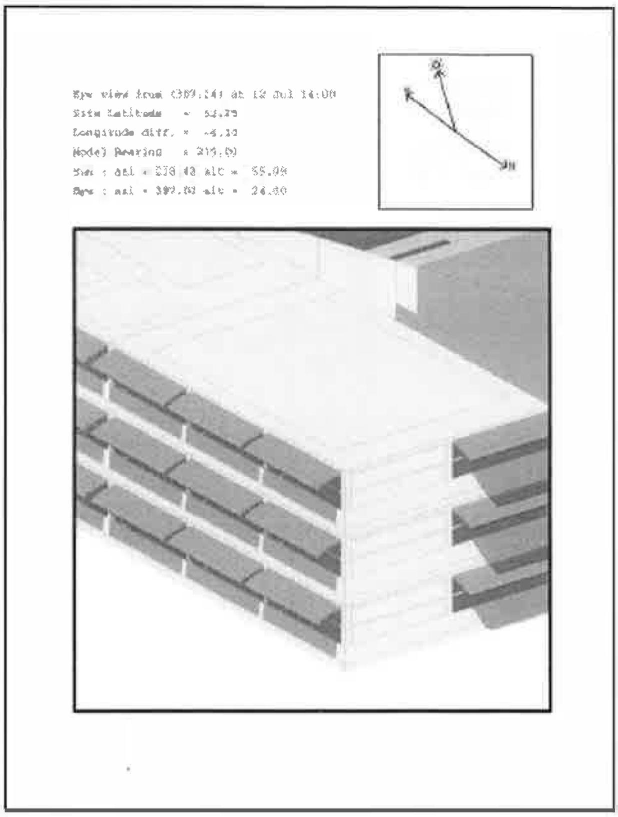

Figure 3: Suncast Image Illustrating the Effective Brise Soleil

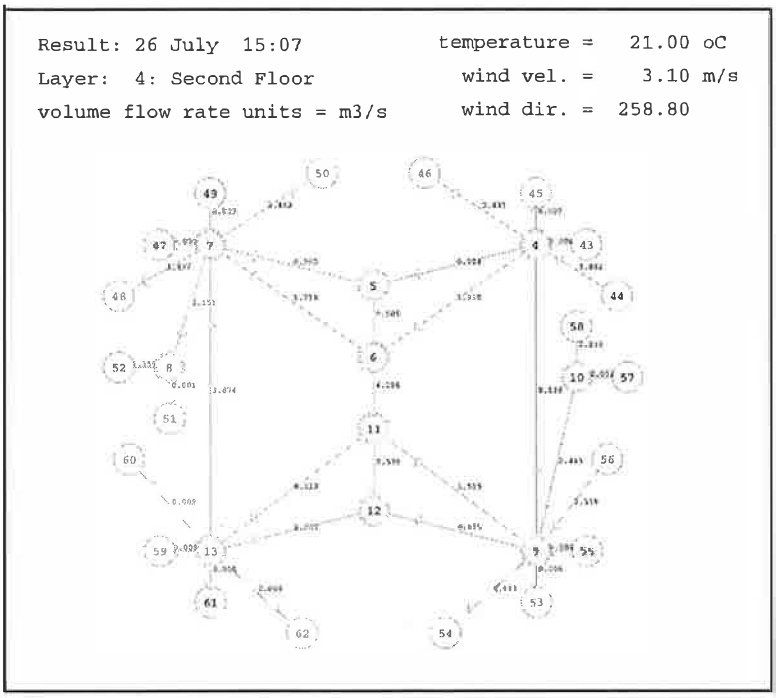

Figure 4: A Macroflo Results of the Airflow on Floor Two

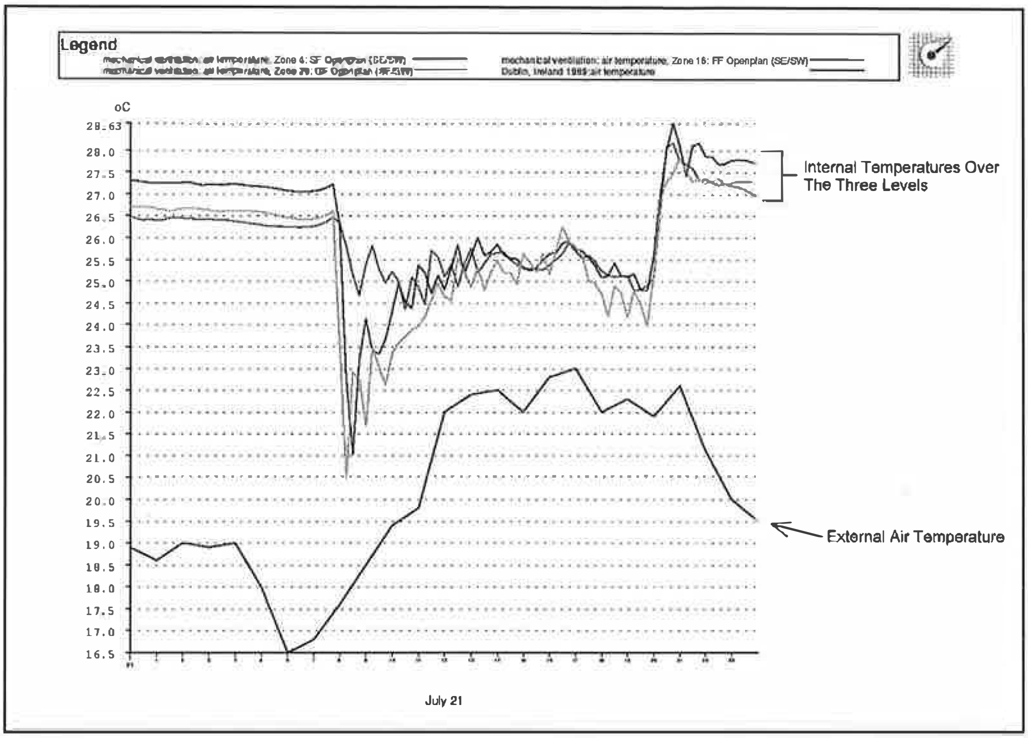

Figure 5: External and Internal Air Temperatures

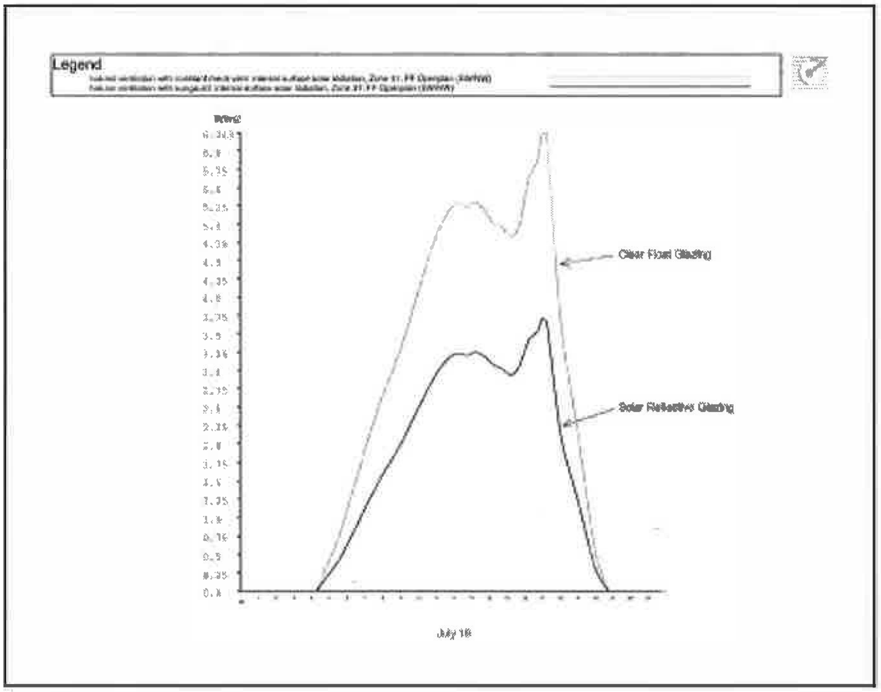

Figure 6: Internal Solar Loads with Clear Float and Antisun Glazing