ENERGY PERFORMANCE AND COMFORT LEVEL IN HIGH RISE AND HIGHLY GLAZED OFFICE BUILDINGS

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ABSTRACT

Thermal and visual comfort in buildings play a significant role on occupants' performance but on the other hand achieving energy savings and high comfort levels can be a quite difficult task especially in high rise buildings with highly glazed façades. Many studies suggest that the energy needed to keep the interior conditions at required comfort levels in buildings depends on several factors such as physical and optical properties of building elements, indoor and outdoor climate and behaviour of the occupants, etc. Moreover depending on the different orientation of building facade, the impact of these parameters might vary. The buildings are usually designed without paying much attention to this fact. The needs of each building zone might differ greatly and in order to achieve better indoor environment, different actions might be needed to taken considering the individual characteristics of each zone. In the proposed research the possibilities of evaluating building energy and comfort performance simultaneously taking into account the impact of facade orientation with use of whole building energy simulation tools are investigated through a case study.

INTRODUCTION

Buildings account for nearly 40% of total primary energy use in a country and consequently they contribute a great deal to greenhouse emissions and global warming. Energy performance of buildings is a highly discussed subject among researchers, policy makers and appliers nowadays. Many actions to reduce building energy use are recommended and new strategies are developed.

Most of the energy consumed in buildings is used for creating a thermally and visually comfortable built-environment for its occupants. Comfort is linked with occupants' work productivity and particularly in commercial buildings where the salary costs makes the biggest part of the life cycle costs; it has a big influence (Wyo 1996). Moreover, comfort affects occupant's health, too. It is known that saving energy and achieving comfort can be in conflict especially in high rise buildings with highly glazed façades. However, as it is mentioned in ISO 7730:2005 (CEN 2005) providing adequate comfort to users should be the main aim of the building design process. For instance, when energy saving strategies are proposed, it is necessary to make sure that occupants are provided with enough comfort.

Many studies suggest that energy needed to keep the interior conditions at required comfort levels in buildings depends on several factors such as physical and optical properties of building elements, indoor and outdoor climate and behaviour of the occupants, etc. Moreover depending on the different orientation of building facade, the impact of these parameters might vary As a result of the inter-dependent interactions between building elements and systems and the large number of parameters that impacts the building performance, it can be a rather difficult task to design a building that can demonstrate a high performance in terms of comfort and energy. However, a suitable design procedure, performed by means of properly selected analysis methods and tools, can lead to improved results.

Computer simulation has gained a high popularity in the last decade to evaluate the energy efficiency of buildings. There are quite a big number of tools in use nowadays and their capabilities vary in a wide range. Some tools focuses on only certain issues inherited in building energy problems while others provide a more general view. The core tools in the building energy field are the whole building energy simulation programs that can provide users with building performance indicators such as energy demand and use, temperature…etc (Crawley at all.). These tools can carry out not only energy efficiency calculations but also comfort calculations

The aim of the work is to develop a simple integrated approach to support the energy efficient decision making process of building design by evaluating building energy use and occupants' comfort simultaneously for enhanced energy

efficiency and comfort solutions. A parametric study has been adopted and the method has been applied to a case study. The calculations were carried out by EnergyPlus whole building simulation tool.

METHOD

This work is an extension of a research done by the author in the scope of the European Union CITYNET Research and Training Network Project (Bayraktar at all.).In the current research the potential of evaluating building energy and comfort performance simultaneously with use of a whole building energy simulation tools was investigated through a case study.

A parametric study was carried out. The impact of thermal and optical parameters of glazing systems (Solar Heat Gain Coefficient:SHGC and Visible Transmittance: Tvis values), window-to-wall ratio of the building facade (75 % and a reduced 55 %) and shading effect of external shading devices were selected as independent variables of the study. It is known that space uniformity due to orientation of building façade plays a significant role on occupants comfort but on the other hand buildings are usually designed without so much considering this fact. The needs of each building zone differ greatly and for achieving better indoor environment different actions might be needed to taken depending on the individual characteristics of each zone. In the proposed research, this aspect was also taken into account. Moreover, all the cases are tested in presence and absence of a daylighting and glare control. 6o alternative simulation scenarios were formed overall. The amount of energy needed to keep the interior conditions at required levels along with the level of thermal and visual comfort occur at each time step was calculated simultaneously for different scenarios. This way, the mutual of effect of different combination of selected parameters was reflected on the results.

EnergyPlus is selected as simulation tool. It is a next generation dynamic building energy simulation program. It includes innovative simulation capabilities such as time steps of less than an hour, modular systems simulation modules that are integrated with a heat balance-based zone simulation (Crawley at all.)

Description of Case Study Building and Simulation Scenarios

The building that is selected as case study is an existing office building located in Istanbul, in a district which is dominated by high-rise commercial buildings. It is one of the demonstration cases of European Union CITYNET Research and Training Network Project. The building has a rather standard construction with lightweight concrete floor slabs and double glazed curtain walls. It has 27 floors with an open floor plan. Office rooms are distributed along the external walls. The net internal floor area of each floor is 1190 m2 where 920 m2 of this is office working area and 270 m2 is the common circulation areas and service rooms. Window-to-wall ratio of the each floor is 75%. The building is occupied from 09:00a.m to 18:00p.m and has a common HVAC system operated during occupancy.

For the analysis a typical floor of the building was taken as a representing floor (20th floor, 83.00m elevation) and a baseline simulation model was created. Due to non-uniformity of space conditions, the baseline case was dived into 5 major zones: north, south, east, west and core (Figure 1). Calculations are carried out at different thermal zones of the building
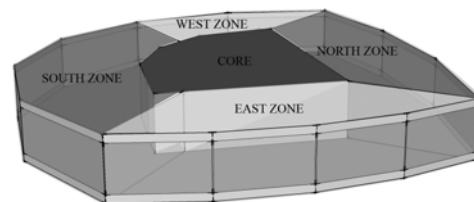

Figure 1. Simulation model of baseline case

A fractional occupancy and lighting schedule was estimated. For energy demand calculations, heating and cooling systems was modelled as how it is actually operated. Dual set point control with a dead band was used. Heating and cooling was made available throughout the year whenever needed. The heating set point is 22 C during office hours and 13 C during unoccupancy and cooling setpoint is 24 C during office hours. Heating and cooling system is off during weekends. The minimum supply air rate for each zone is assumed 10 l/(s/person). Building is assumed to be airtight and the infiltration rate was taken as 0.5 ach. Equipment loads are assumed 9 W/m2. The occupant density is 17 m^2/person.

In order to analyze the building's annual energy performance, the ASHRAE IWEC data was downloaded from official Energyplus website and was used as input.

Independent Parameters

In parametric study, a range of parameters including optical properties of glazing systems (SHGC and Tvis values), window-to-wall ratios (WWR), shading effect of external shading devices and daylighting and glare control application are investigated.

Table 1. Thermal And Optical Properties of Investigated Glazing Alternatives

Glazing Name	Construction	U Value (W/m2K)	SHGC	Tvis
GL1 (Existing Glazing)	IMF 170 8mm + Air 16mm + (4mm+ 1,52mm + 4mm)	1.40	0.51	0.68
GL2	ECABS-2 Colored 6mm + Argon 13mm + Clear Glass 6mm	1.5	0.15	0.11
GL3	Low-E Tint 6mm + Argon 13mm + Clear 6mm	1.5	0.37	0.44
GL4	Low-E Clear 3mm +Air 6mm + Clear 3mm + Air 6mm + Low-E Clear 3mm	1.53	0.46	0.66
GL5	Low-E Clear 3mm + Argon 13mm + Clear 3mm	1.52	0.60	0.76

5 different glazing alternatives were considered. Glazings were obtained from ASHRAE data sets catalogue in EnergyPlus. Thermal and optical properties of the selected glass types are given in Table 1.

Selected glazings were combined with 2 different shading devices. Existing building has fixed overhangs at each floor level only on the southern and western façade to provide shading. The new shading device that is proposed as an alternative, is a motorised semi-transparent external roller blind with a low solar transmittance (TS=0,1) and low solar reflectance (RS=0,2) It was assumed to be controlled automatically to decrease Maximum Allowable Discomfort Glare below 22 all around the year. Devices can be seen in Figure 2.
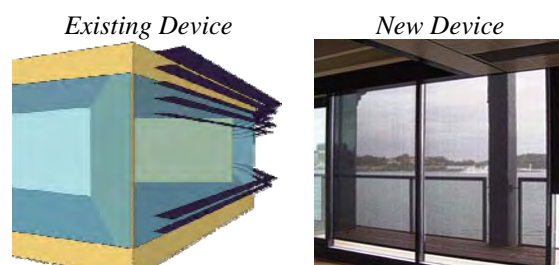
Existing Device   *New Device*

Figure 2. Studied Shading Devices

Above mentioned cases were combined with 2 different window-to-wall ratios. Existing building has a WWR of 75%. As an alternative, 55% of WWWR was adopted. Only the bottom part of the external wall was raised 80 cm to comply with the regulations (Figure 3).

All the cases were tested in presence and absence of a daylighting control and 60 cases were created overall
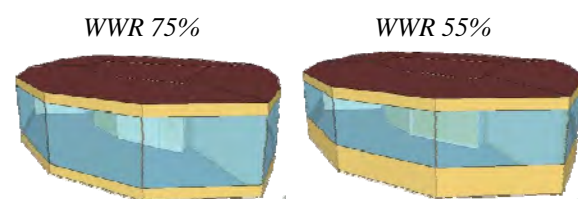
WWR 75%   *WWR 55%*

Figure 3. Studied Window to Wall Ratios

Thermal Comfort Analysis

For thermal comfort calculations, Fanger comfort model was chosen as calculation methodology in EnergyPlus. The Predicted Mean Vote (PMV) and the Predicted Percentage of People Dissatisfied (PPD) indexes were used to evaluate the thermal comfort. The PPD index provides information on thermal discomfort (thermal dissatisfaction) by predicting the percentage of people likely to feel too hot or too cold in a given environment (CEN 2005).

Fanger's PMV model is based on thermoregulation and heat balance theories. In the Fangers model, taking into account the average temperature comfortable for human skin and optimal sweat exhausting rate, PMV index shows the thermal sensational index produced by a combination of environmental parameters (physical variables such as air temperature, radiant temperatures, relative humility and air velocity and personal variables such as activity and clothing) and other factors have no significant effects on the state of thermal comfort. The formulas of Fanger's PMV and PPD that are adopted in EnergyPlus are, respectively (EnergyPlus 2009),

$$PMV = 3,115(0,303 e^{-0,114M} + 0,028)L \qquad (1)$$

$$PPD = 100 - 95 e^{(-0,03353\,PMV^4 + 0,2179\,PMV^2)} \qquad (2)$$

In the present work, the only parameter taken as independent variable and considered changing for comfort analysis is Mean Radiant Temperature. MRT was calculated for an average point in the middle of each zone to represent general comfort conditions. This way, the impact the simulation alternatives were reflected on MRT and consequently on occupants' comfort. All the other above mentioned parameters else than MRT were assumed to be same in all simulation cases. The Occupant clothing insulation was assumed 0.6clo from May to October, and 0.8clo for the rest of the year. Occupant activity level was taken 130 W/person for sitting and reading. Relative air velocity of 0.1 m/s was assumed for all cases.

The PMV-PPD indices are included in the ISO standard 7730 and also in the European standard, EN 15251. EN 15251 indicates four categories of state of comfort for mechanical heated and cooled buildings as shown in Table 2(CEN 2007). In this study, the case study building was tested again category II and III. The total number of hours during occupancy that can provide PPD levels according to selected categories were calculated for each scenario

Table 2. Recommended Categories For Design Of Mechanically Heated And Cooled Buildings

Category	PPD %	Predicted Mean Vote
I(high level of expectation),	< 6	-0,2 < PMV < + 0,2
II(normal level of expectation),	<10	-0,5 < PMV < + 0,5
III(moderate level of expectation),	<15	-0,7 < PMV < + 0,7
IV(acceptable only for a limited part of the year).	>15	PMV < - 0,7; or + 0,7 < PMV

Visual Comfort Analysis
The visual comfort is represented by the level of glare that occupants are exposed to and the illuminance level at working plane
The discomfort glare index (DGI) was chosen as performance indicator. EnergyPlus calculates the discomfort glare at a reference point due to luminance contrast between a window and the interior surfaces surrounding the window is given by Hopkinson (EnergyPlus 2009), according to the equation below

$$G = (L_w^{1.6}\Omega^{0.8})/(L_b + 0.07\,\omega^{0.5}L_w)\qquad(3)$$

where
G = discomfort glare constant
Lw = average luminance of the window as seen from the reference point
Ω = solid angle subtended by window, modified to take direction of occupant view into account
Lb = luminance of the background area surrounding the window

As reference point, a point corresponds to the middle of each zone were chosen. The height of the reference point was taken 1.2meters. Occupants assumed to be looking at the window and facing a true north, east south and west for each zone respectively. Recommended Values of Maximum Allowable Discomfort Glare Index for an office building was taken as 22. The total number of hours during occupancy that DGI is less than 22 calculated for each scenario.

It is important to limit the glare to avoid errors, fatigue and accidents as it is emphasized in EN 12464 Standard. In order to do that, new shading device was automated to be on whenever the DGI exceeds set value of 22.

The design power of artificial lighting system was assumed 12 W/m2. The lighting system was assumed to be switched on during the working hours and the design level was assumed to be modified according to a modifying schedule. For the cases that daylighting feature was introduced, the artificial light provided at the workplace was changed continuously in parallel with the control set point that would provide 500 lux illuminance at the desk level. This way, adequate level of illuminance required for visual comfort was achieved in every case. Therefore, only the impact of glare was investigated.

RESULTS
The proposed method was applied to the case study building and 60 cases were tested. The changes in energy demand values together with the changes in comfort were illustrated in the figures given in this section.

First of all, energy demand for cooling and heating and lighting energy consumption were calculated hourly for a year for each zone and summed up to evaluate the conditions representing one floor. Similar approach was adapted for comfort calculations. Results were calculated for each single zone hourly at selected points and averaged to represent the conditions in this particular floor.

In the second part of the work, performance of each case was given at hourly steps for each zone and the differences caused by orientation were evaluated.

Annual Average Results
Figure 4 and Figure 5 summarize the results of space heating, cooling and lighting load calculations for all cases. Case 11 represents the actual building. From the figures, it is clear that each glazing demonstrates a different annual energy performance due to its different thermal and optical properties. The decrease of WWR from 0.75 to 0.55 has resulted in a decrease between 13 to18 percent in cooling loads in all cases except the ones with Glazing 2. There was only a 7% of decrease was observed with glazing 2 cases due to the low solar heat gain coefficient. The change in WWR was also reflected on heating loads. An average of 3 % of increase was predicted in all cases except cases with glazing 2, where heating
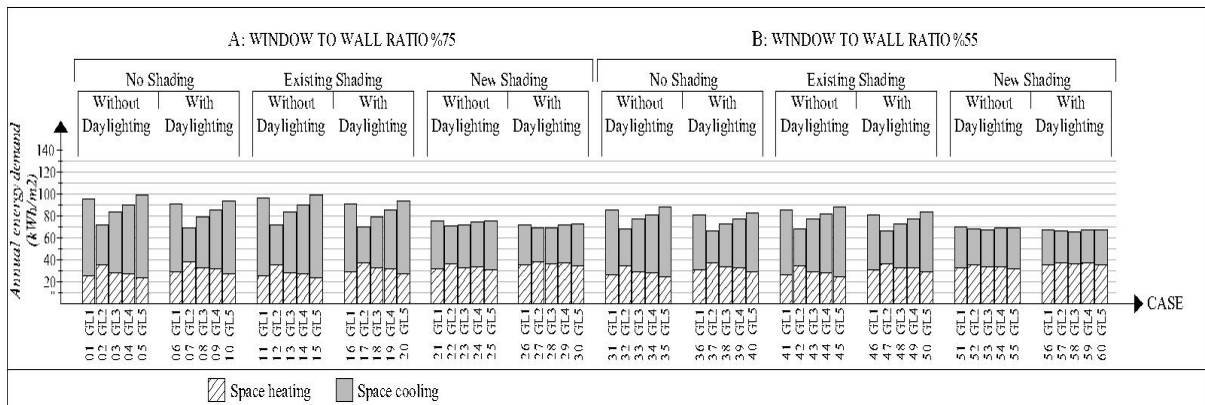
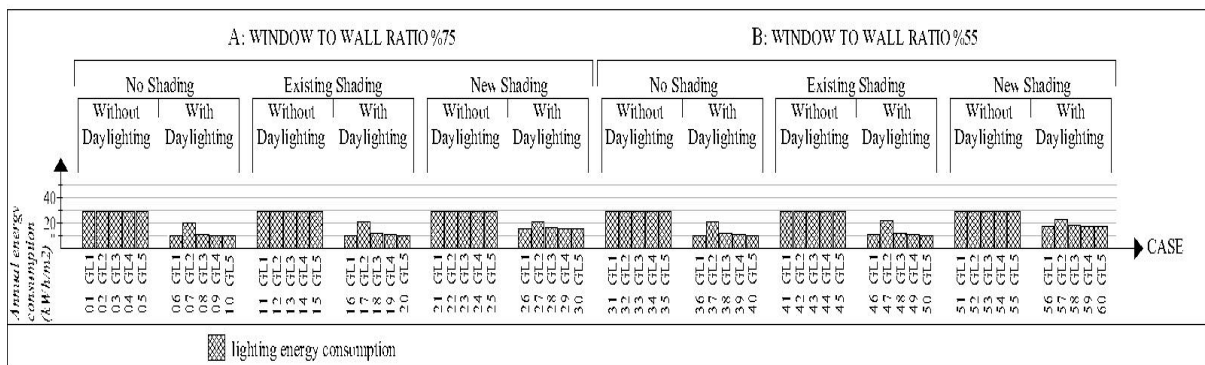Figure 4. Annual Space Heating and Cooling Results

Figure 5. Annual Lighting Energy Consumption Results

load was dropped around 2% instead. The impact of WWR on heating demand was found to be quite small.

The lighting energy use was calculated 28.9 kWh/m2 for the all the cases where there was no daylighting control. Lighting energy use was not changed with WWR because design power of the artificial lighting system was same. When the daylighting control strategy applied, it was seen that lighting energy use was decreased around 65% in cases where there is no shading device or existing shading was on, and 45% in cases with new shading device. The lighting energy saving was less with the cases with a new shading, because the new device reduced the entrance of daylighting but still was efficient enough to provide enough daylighting. When the daylighting performance of two WWR was compared, it was seen that, there is an insignificant difference. Both WWR are able to maintain enough daylighting illuminance levels due to large glazed area.

When the new and existing of shading devices were compared, it was seen that the existing shading has little influence on total energy demand. It helps reducing cooling loads only %1. On the other hand, newly proposed shading systems introduced 17% improvement on annual energy demand and %65 on cooling energy demand.

Therefore, the existing shading found to be ineffective.

Least cooling, heating, lighting and total annual energy demand are obtained with case 57, case 15, case 10 and case 60, respectively.

Figure 6 illustrates the percentage of occupied hours that discomfort glare index less than 22. The occupied hours for the building are 9 a.m. to 7 p.m. Monday–Friday, corresponding to 2600 working hours. These results are derived from predicted glare calculated at each reference point in the middle of each zone. Here only the average of all zones is shown. Daylighting control of artificial lighting system has no effect on glare so the results of the both cases were given altogether.

The change in WWT had no significant affect on glare, because only the bottom part of the external wall raised 80 cm and still the wall stayed below eye level. The results show that in case of no shading device or existing device, approximately 18 % of the working hours, occupants won't be exposed to glare but rest of the time will be uncomfortable for all glazing except glazing 2. Glazing 2 has very low visible transmittance value and can eliminate glare problem better than other glazings. It was observed that existing shading has too little impact on glare. As expected, the new shading device improved the visual comfort a great
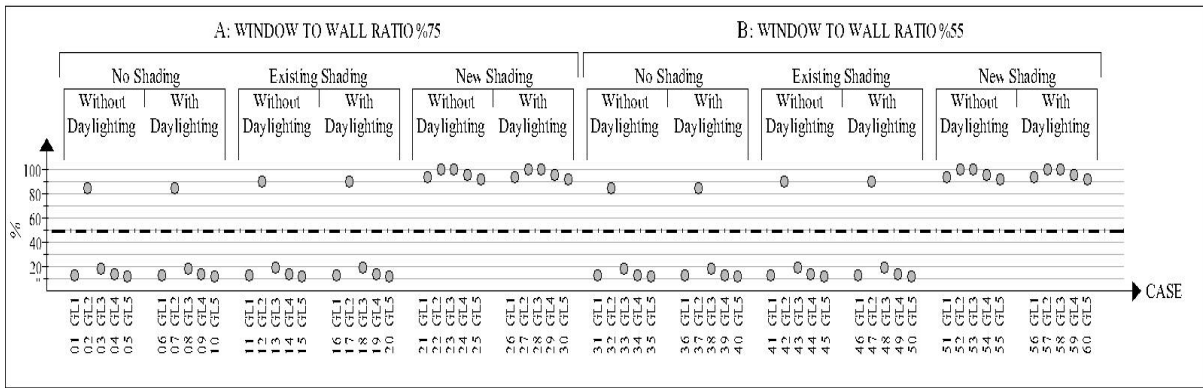
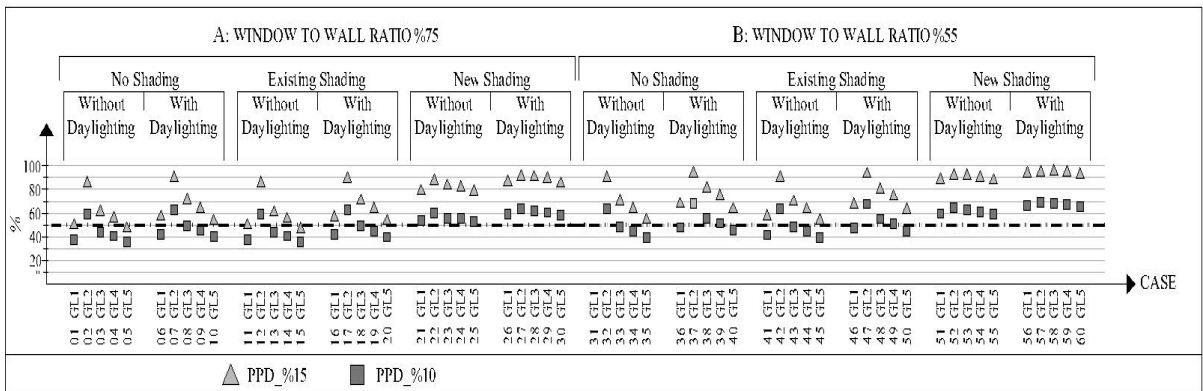Figure 6. Percentage of hours that Discomfort glare index less than 22

Figure 7. Percentage of hours that PPD index is less than 10% and 15%

deal and more than 80 % of the time glare was eliminated. The combination of new shading device with Glazing 2 and Glazing 3 introduced %100 comfortable office hours from glare point of view.

Figure 7 shows a summary of thermal comfort evaluation results obtained with existing WWR. The percentage of working hours that the PPD is less than 15 and 10 percent were taken as comfort indicator (Corgnati at all. 2009) and depicted in the figures. Results indicate that the cases which combine glazings with no shading and existing shading conditions (except glazing 2), the building cannot enter EN 15251 Comfort category [5] II or III more than half of the working time. Glazing 2 provides better comfort levels. As can be clearly seen from the figure X, Introduction of new shading device significantly improved the thermal comfort and building satisfies more almost 55% of the time category II, and 85 % of the time category III. Moreover, the figure also shows that daylighting control contribute to thermal comfort. Results are improved around 20 %. Combination of daylighting control with new shading device offers the highest comfort conditions for this particular case study building. Similar results were obtained with WWR 55. Case 57 stays 69 % of the working time in category II and case 57 and case 58 stays 96 % of the time in category III. When the overall energy, visual and comfort performances were considered all together it was found that Glazing 3

combined with newly proposed shading device in presence of daylighting control demonstrated the best performance among all.

Hourly comfort results for each zone
Glazing 2, glazing 3 and glazing 5 were selected from the glass list for further analysis. Glazing 2 has a low SHGC and Tvis values (0.15 and 0.11 respectively) where glazing 3 has moderate values (0.37 and 0.44 respectively) and glazing 5 has high values (0.6 and 0.76 respectively).

In Figure 8, Hourly Discomfort Glare Index occurs on 21st march, 21st June, 23rd September and 21st December for each zone with selected 3 glazing alternatives combined with no shading and new shading device is illustrated. Considered comfort zone is highlighted in the figure.

When the performance of glazings absence of a shading device was compared, it was seen that less glare occurs with glazing 2 due to its low visible transmittance value. However glazing 2 requires more use of artificial lighting to provide required illuminance levels on the working plane. Vice versa is true for glazing 5.

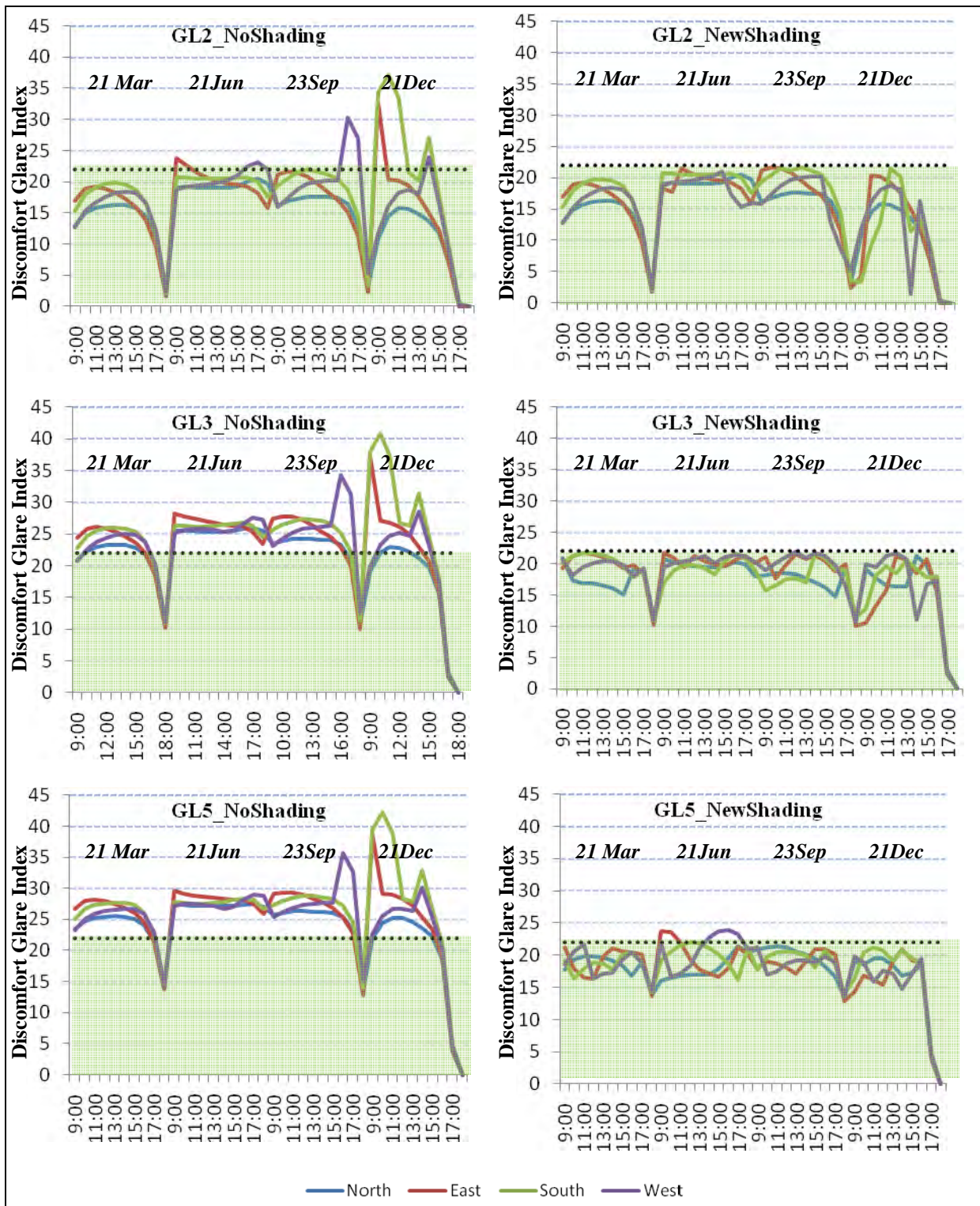Different levels of glare occur at different hours of the day and time of the year. For this

Figure 8. Hourly Discomfort Glare Index on 21st march, 21st June, 23rd September and 21st December for Each Zone with Selected 3 Glazing Alternatives

particular example, glare causes much more problems in winter period in the morning and late afternoon hours due to low altitude of the sun.

In the summer period it is more likely to have more glare problems in the east zones, and it is followed by west, south, and north zones. However, in winter periods glare is likely to have high peaks in

south zone in morning hours, followed by east and west zones.

Since the requirements of each zones change rapidly with time and orientation it is clear that only a dynamic shading device that can adapt to changes can be suitable. When the new automatically controlled semi transparent shading
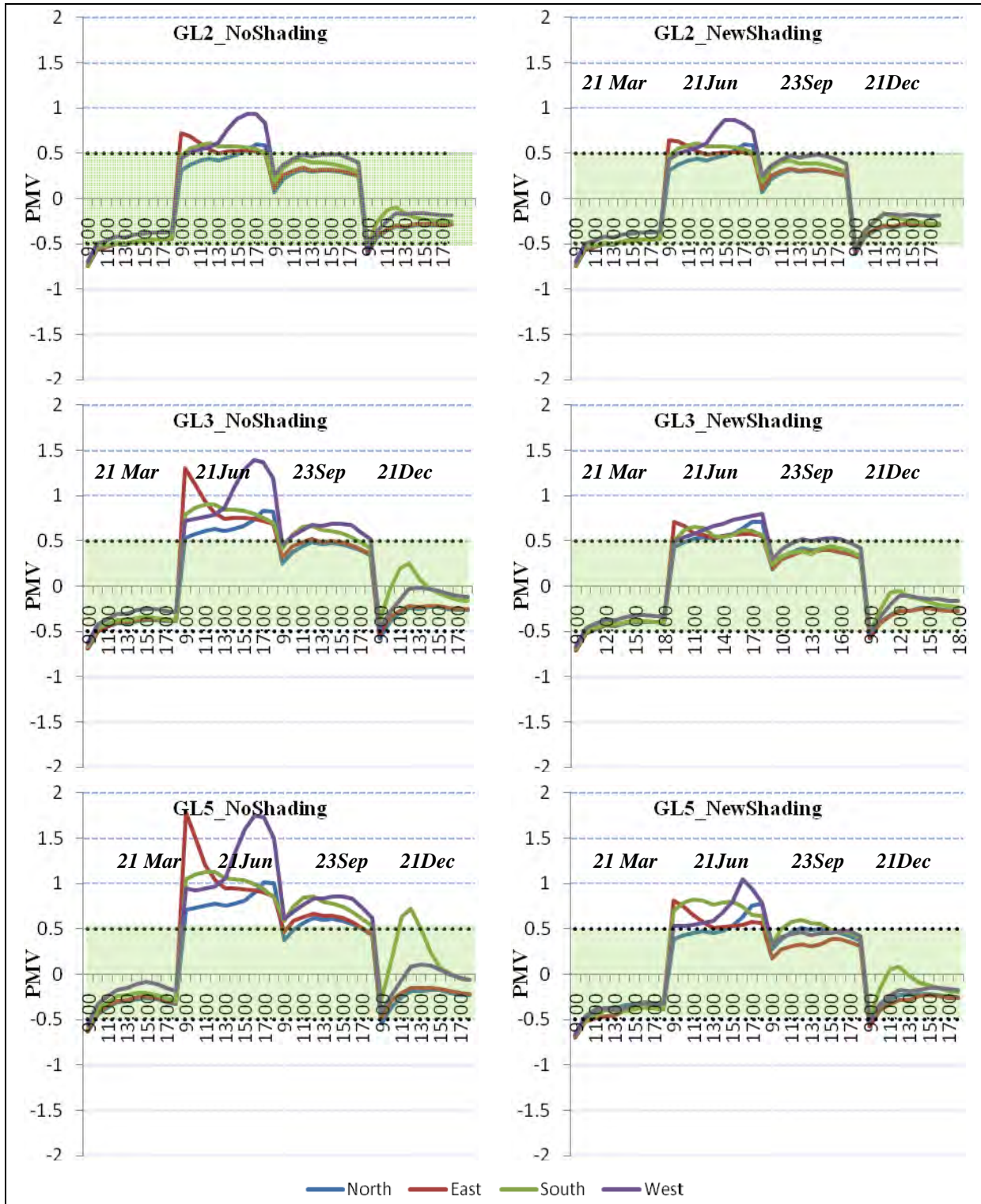
Figure 9.

device was introduced, graphs show that discomfort glare levels was reduced and a more uniform figures were obtained. Glazing 3 combined with new shading was able to demonstrate a more smooth performance.

Similarly, in Figure 9, Predicted Mean Vote occurs at hourly scale on 21st march, 21st June, 23rd

September and 21st December for each zone with selected 3 glazing alternatives combined with no shading and new shading device is illustrated. Considered comfort zone is highlighted in the figure. (-0.5<PMV<0.5)

Depending on the thermal and optical characteristics of the glazings different PMV

graphs were obtained. Figure 9 (on the left hand side column) shows, occupants are likely to feel warm during summer period. More severe problems may occur with Glazing 5. This is because, high surface temperatures of glazed areas cause high MRT values and subsequently cause thermal discomfort. Especially in the east zone in morning hours and in west zone in afternoon hours peaks were observed. When automatically controlled shading device was applied, results were improved to a great extent by helping eliminating high window surface temperatures

CONCLUSION

This study explored the potential of evaluating building energy and comfort performance simultaneously taking into account the impact of facade orientation. Moreover, capabilities of a whole building energy simulation tool were tested for such a work.

In the proposed method, optical parameters of glazing systems (SHGC and Tvis values), window-to-wall ratio of the building façade, shading effect of external shading devices and daylighintg control was investigated simultaneously through a case study. A total number of 60 cases were calculated.

The results of energy calculation demonstrate that thermal and optical properties of glazing systems were reflected on energy performance. When the glazings with high or medium SHGC and Tvis values are particularly considered, application of automatically controlled external shading device lowered down the need for cooling significantly but on the other hand it also increased the need for heating slightly. When the overall annual performance was considered, still the appropriate shading device contributed to energy performance a great deal. Application of daylighting control eliminated excessive and unnecessary use of artificial lighting and lowered down cooling loads and lighting energy use. It also slightly increased heating energy need due to less internal gain. However, it still resulted in better energy performance on total energy loads. Combination of shading and daylighting strategies contributed to energy performance significantly.

Furthermore, visual and thermal comfort for each case was predicted. It was seen that low SHGC and Tvis values resulted in less glare. However, the undesirable visual performance of other type of glazings was improved with a suitable shading system. From thermal comfort point, it was seen that, the existing building and its variations with different glazings with high and medium SHGC and Tvis values cannot provide required comfort. Application of again suitable shading also contributed to thermal comfort and improved

comfort categories. The joint impact of shading control and daylighting control introduced highest energy, visual and thermal performance.

Moreover, the simulated results showed that the comfort obtained in each zone differs greatly depending on the orientation and the time of the days and year.

Several conclusions can be concluded from this study. In such built-environments, evaluation of thermal and visual comfort simultaneously with energy consumption level is crucial. Combined effect of glazing and shading devices has the final influence both on energy and comfort issues and they need to considered together in the early design stage. The needs of each building zone can differ greatly and for achieving better indoor environment different actions might need to be taken depending on the individual characteristics of each zone. Automated shading devices can adapt to changing indoor and outdoor conditions and they can provide better solutions. Design and control strategy adjustments can enhance the performance of the building a great deal. Parametric study gives good results but it is quite labor intensive and takes considerable amount of time. Optimization techniques should be integrated to the method for future work.

ACKNOWLEDGEMENT

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