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Effects of Optimizing the Shading Device Orientation to Energy Consumption in Office Buildings

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Abstract

The passive strategies are promoted by the European Energy Performance of Buildings Directive (EPBD) 2002/91/CE and the EPBD Recast (Directive 2010/31/UE) to decrease energy demands of the construction sectors. As the buildings are using 35% of the total energy and causing roughly 25% of the global CO2 emissions, and the existing building stock represents a considerable big ratio compared to new buildings; this study approaches on existing buildings focusing on shading devices.
This study obtains optimum effects of the shading devices to decrease energy consumption on a hypothetical building which has the usual features for office types in Turkey. 4 offices (8 thermal zones) are planned as getting the benefit of daylight from different façades. The main goal of this study is to give an advice about using shading devices for existing buildings in order to reduce energy demands.
Within this study, OpenStudio simulation tool is used with Radiance and EnergyPlus plug-in software; in order to investigate the differences between the usages of shading devices in an office building. The alternatives will be simulated with an unshaded building for having a base for comparison. The electric, heating and cooling energy consumptions will be calculated by EnergyPlus and Radiance will be giving the daylight autonomy. Therefore we will be able to see the effects of daylight according to shading device usage.
As a result; the percentage of decreasing the energy demands with the optimum shading for each orientation will be determined by comparing the base building and the other alternatives.

Keywords -energy consumption; shading devices; energy efficiency; OpenStudio

1. Introduction

The passive strategies are promoted by the European Energy Performance of Buildings Directive (EPBD) 2002/91/CE and the EPBD Recast (Directive 2010/31/UE) in order to decrease energy demands of the construction sectors [1]. As the buildings are using 35% of the total energy and causing roughly 25% of the global CO2 emissions and the 60% of the energy used for the heating, cooling and hot water needs are supplied from fossil fuels in most of the countries. So it is obvious that we should work on these loads to decrease buildings' energy consumptions [2]. Since the existing building stock considerably represents a big ratio compared to new buildings; this study approaches on existing buildings focusing on shading devices.

Shading devices play a key role for the energy saving potentials of the large glazing designs. Either the new and existing buildings have large glazing façades to get the daylight benefit; the large glazing façades can cause the increase of heating and cooling loads in buildings [3,4,5]

Exterior shading devices are applied to decrease the cooling loads of buildings in hot climate zones. However, blocking effects of direct sunlight into the building is causes the increase in heating loads [3,6].

This study focuses on the effects of shading device alternatives to decide the optimum shading design to decrease energy consumption of a hypothetical standard office building in Turkey. 4 offices (8 thermal zones) are planned for getting the benefit of daylight from different façades. The main goal of this study is to give an advice for the shading device application in existing buildings in order to reduce energy demands. OpenStudio simulation tool is used with Radiance and EnergyPlus plug-in software products; in order to investigate the differences between the shading device alternatives for an office building.

As a result; the percentage of decreasing the energy demands with the optimum shading for each orientation will be determined by comparing the base building and the other alternatives. Alzoubi (2010) also have studied on the optimum shading device positions to decrease the energy consumptions by the heat gain from daylight [7]. Since the shading device orientation alternatives on different facades of a common office building scheme are investigated for İzmir, Turkey by using OpenStudio; this study differentiates from the other studies about the effect of shading devices on the energy consumptions.

As external shading devices can be added easily years after from the construction of a building in order to reduce energy consumption in existing office buildings, the next studies can be held on investigating the real case buildings by using a simulation tool to reach the expected accurate values for shading device implementations. Consequently, this study is the first step to improve the existing building stock with the light of an investigation on a hypothetical office building simulation results.

2. Shading Device Alternatives' Simulations

The energy performance of the buildings should be calculated by the methodologies based on the national and regional conditions, including; 'in addition to thermal characteristics, other factors that play an increasingly important role such as heating and air-conditioning installations, application of energy from renewable sources, passive heating and cooling elements, shading, indoor air-quality, adequate natural light and design of the building' [1].

The building simulation tools are the software products that can simulate the dynamic interaction between the interior heat, light, air and humidity variables of the building. These software products are used to estimate the energy consumptions depending on the climate, occupants and air conditioning systems and the energy performance of the buildings. Since producing a physical model is mostly not feasible as it is complicated and costs high, the building simulation is applied to analyze and understand the building energy performance in detail.

Within this study, OpenStudio simulation tool is used with Radiance and EnergyPlus plug-in software products; in order to investigate the differences between the shading device application alternatives for an office building. The building has totally 1620 m2 (324m2x 5 floors) footprint area divided into offices with a 72m2 (6m x 12m), however the building is examined considering the thermal zones. Therefore each thermal zone has 36 m2 areas (6m x 6m) by dividing each office into 2 as shown in Fig. 2.

The façades of the thermal zones are oriented to North; North and West; North and East; South; South and West; South and East; West; East. The two main parameters of the study are the width of the shading device and the angle between the shading devices and the window. So the devices with 50 cm or 25 cm width are changing from vertical to horizontal with the degrees of 90, 75, 60, 45, 30 and 15, depending on the orientation of the façade (Fig. 1). The fenestration type and materials are decided to be the same for all simulation alternatives.

The building is simulated for 13 times with OpenStudio environment and in one of the simulations on the building is kept as unshaded to have a base for comparison (Fig. 1 Simulations (a)). The monthly and annual electric, heating and cooling energy consumptions are calculated by EnergyPlus in kWh or Gj unit and the daylight autonomy with illuminance maps are picked from Radiance interface. Therefore the effects of daylight depending on shading device usage could be seen.

As a result; the percentage of decrease in energy demands with the optimum shading for each orientation are determined by comparing the base building and the other alternatives in terms of end use percentages of lighting, heating and cooling.

simulation name	degree (shading-window)	Width (cm)
sim 1	90	50
sim 2	90	25
sim 3	75	50
sim 4	75	25
sim 5	60	50
sim 6	60	25
sim 7	45	50
sim 8	45	25
sim 9	30	50
sim 10	30	25
sim 11	15	50
sim 12	15	25
sim 13	0	0

(a)

name	direction
TZ-1	S-W
TZ-2	S
TZ-3	S-E
TZ-4	E
TZ-5	N-E
TZ-6	N
TZ-7	N-W
TZ-8	W

(b)

Fig. 1 Simulations (a) and zone directions (b)

3. Case Building Definition

The hypothetical office building is developed for this study by investigating the existing stock in İzmir, Turkey (latitude 38.50°, longitude 27.02°). The building has five storeys, each with a 3.20 m height, including a lobby on ground floor, corridor, staircase and office spaces. Normally each office space has 72 m2 floor areas (6m x 12m). However the study depends on the thermal zone arrangement, not space by space method; each office space is divided into 36 m2 (6m x 6m) thermal zones as shown in Fig. 2. Additionally every façade of each thermal zone has two 2m x 1.2m sized windows.

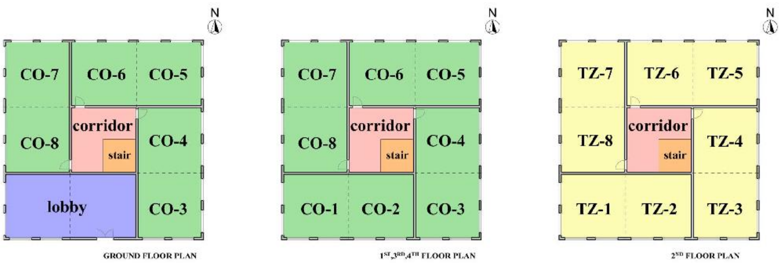

Fig. 2 Thermal zone location on floors (CO:code of office,TZ: thermal zone)

4. Shading Devices

Within this study, optimum shading devices are tried to be decided for different facades of varying thermal zones. According to the orientation of the exterior surface, shading devices are settled vertically for East and West façades, whereas they are settled horizontally for North and South façades (Fig. 1, Fig. 4) .

Since the main parameters are the width of the device and the angle between the device and window; it came out that the width of the shading can be 50 cm or 25 cm and the angle with window can be 90˚, 75˚, 60˚, 45˚, 30˚, 15̊. An example of a horizontal shading device settlement on the window and heights of the office zones can be followed in Fig. 3 Shading devices horizontal settlement figure on a section.

In order to reach more realistic energy consumption results; the illuminance maps and Radiance analysis are set in each space of the thermal zones in 2nd floor, as the mid-level of the building.

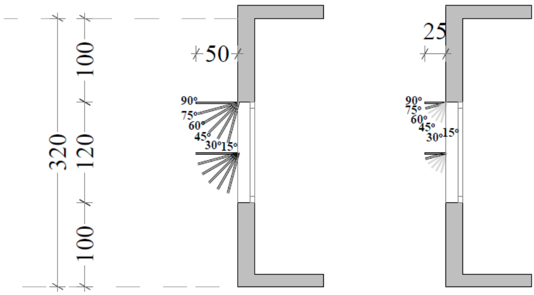

Fig. 1 Shading devices horizantal settlement figure on a section (with all angled alternatives)

5. OpenStudio-Simulation

OpenStudio, is an hourly dynamic simulation tool that is working with EnergyPlus Version 8.2.0-8397c2e30b and Radiance version 5.0.a in SketchUp modelling environment. Depending on ASHRAE, the climatic zone of İzmir is set as 3C: Warm – Marine with IP Units CDD50ºF ≤ 4500 and HDD65ºF ≤ 3600 and SI Units CDD10ºC ≤ 2500 and HDD18ºC ≤ 2000 [8].

As explained above, Radiance interface requires different thermal zones for each illuminance map, so that the building is divided into thermal zones according to each direction (Fig. 1). In order to make the energy demand and daylight illuminance calculations simpler; the maximum dimension of each thermal zone is set to 6 m.

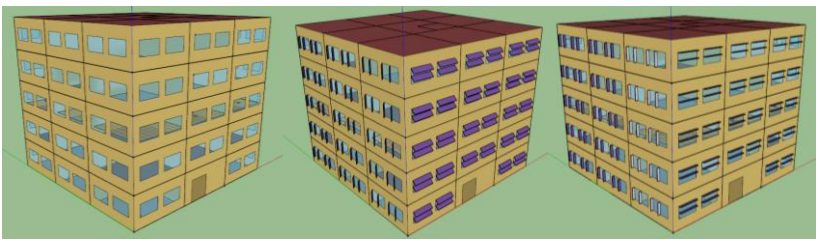

Fig. 4 OpenStudio modelling examples (a- without shading device; b-50cm,45̊; c-25cm, 90̊)

Construction Settings

Exterior Wall:

Reflectance: 0.08

U-Factor no Film: 0.648 W/m2-K

Roof:

Reflectance: 0.30

U-Factor no Film: 0.230 W/m2-K

Exterior Window:

Window dimensions: 1.2 m×2 m

Glass U-Factor: 3.122 W/m2-K

Glass SHGC: 0.252

Glass Visible Transmittance: 0.320

Other thermal zone setting (TZ-1, TZ-2,…, TZ-8):

Lighting: 9.5906 W/m2

People: 0.051129 person/ m^2

Sky diffuse modelling algorithm: Simple sky diffuse modelling

Illuminance set point: 500 lux

Illuminance map 5.4 m(L) x 5.4 m(W) x 0.8 m(H)

Daylight control and glare sensor height: 1 m

Heating thermostat set point: 21 ◦C (worktime) 15.6 ◦C (rest)

Cooling thermostat set point: 24 ◦C (worktime) 26.7 ◦C (rest)

6. Interpretation of the Simulations Results

OpenStudio simulation tool gives us the end use percentages of the energy consumptions as lighting, heating, cooling and others. Following this information, we can compare all energy consumption values with each other to find the most effective one. Therefore we reach the results giving the positive or negative effect of shading devices on energy consumptions.

Table 1. Simulation results parameters

Simulation code	Shading device width (cm)	Shading-window angle	thermal zone	
			code	direction
sim 1	50	90°	TZ-1	S-W
sim 3	50	75°	TZ-2	S
sim 1	50	90°	TZ-3	S-E
sim 9	50	30°	TZ-4	E
sim 7	50	45°	TZ-5	N-E
sim 1	50	90°	TZ-6	N
sim 11	50	15°	TZ-7	N-W
sim 9	50	30°	TZ-8	W

Since the loads are increasing during the heating period [9], it negatively affects the building energy efficiency. So that the energy efficiency is examined over lighting, cooling and heating loads one by one as explained below Table 2 and Table 3. 'Effectiveness value' refers to the lighting consumption difference between alternatives and base setting multiplied by the end use percentage.

If we formulate effectiveness value (1);

Effectiveness Value : E.V.
Lighting Consumption Alternatives : L.C.A.
Lighting Consumption Base : L.C.B.
End Use Percentage (%) : E.U.P.

$$E.V = (L.C.B - L.C.A.) \times E.U.P \qquad (1)$$

Table 2. Daylight and lighting consumption results

thermal zone	thermal zone	building	alternatives	base
direction	UDI	average daylight autonomy	Lighting Consumption [GJ]	
S-W	0.77	0.26	1.63	1.60
S	0.48	0.22	3.17	2.27
S-E	0.76	0.26	1.77	1.82
E	0.48	0.13	3.53	3.09
N-E	0.66	0.16	3.11	2.26
N	0.53	0.26	3.70	3.57
N-W	0.59	0.11	3.37	2.22
W	0.48	0.13	3.11	2.73

Table 1. Heating and cooling consumption results

thermal zone	alternatives	base	alternatives	base
direction	Heating Annual Value [GJ]		Cooling Annual Value [GJ]	
S-W	1.82	1.63	5.09	5.99
S	0.65	4.86	0.66	5.19
S-E	1.79	5.27	1.58	6.27
E	0.83	4.80	0.88	5.40
N-E	2.16	4.96	2.39	5.04
N	0.98	4.06	1.09	3.92
N-W	1.95	4.85	2.37	4.83
W	0.79	4.45	0.90	4.62

Table 4. End use percentage

thermal zone / direction	End use percentage %		
	lighting	heating	cooling
S-W	22.65	18.91	35.11
S	23.07	18.73	35.03
S-E	22.65	18.91	35.11
E	23.97	18.51	34.56
N-E	23.62	18.53	34.84
N	22.65	18.91	35.11
N-W	24.15	18.24	34.77
W	23.97	18.51	34.56

'Energy Efficiency Value' is formulated as the sum of Effectiveness values of lighting, heating and cooling loads defined below, that is (2) used to find total energy consumption situation by using Table 4 that's result is shown in Table 5. Energy Efficiency Results.

Total Energy Efficiency Value : T.E.E.V.

$$T.\ E.\ E.\ V. = E.V._{\text{lighting}} + E.V._{\text{heating}} + E.V._{\text{cooling}} \qquad (2)$$

Table 5. Energy Efficiency Results

direction	**lighting**	**heating**	**cooling**	**Total efficiency (%)**
S-W	-0.6795	-3,5928	31,599	27,33
S	-20.763	0,1873	11,5599	-0,92
S-E	1,1325	-3,9711	35,11	32,27
E	-10,5468	0,5553	20,736	10,74
N-E	-20,077	4,2619	2,7872	-13,03
N	-2,9445	2,0801	-4,9154	-5,78
N-W	-27,7725	7,6608	-0,6954	-20,81
W	-9,1086	2,0361	5,8752	-1,20

7. Conclusion

The scope of this study is; to examine the optimum shading devices for each orientation comprised by the differentiating angles and sizes according to the base building. The results show that different orientations of the facades need different angled settlements of shading devices, shown in Table 1 Simulation result parameters. As a result of the comparison between the size alternatives; a 50 cm sized shading device is better than a 25 cm shading device width. For the second parameter, angle between the window and shading device; the best solution giving lower energy consumption about South-West zone, South-East and North façades with 90°; East and West zones façade with 30°, South zone façade with 75°, North-East zone façade with 45°, North-West zone façade with 15°.

Lighting usage percentage includes almost 23 % of total end use energy, 18 % for heating and 35 % for cooling (Table 4). According to Table 5. Energy Efficiency Results; lighting energy consumptions are increasing with negatively the effect of shading devices; even the heating and cooling consumptions rise positively. If we examine just the effect of heating and cooling loads on the building, we can obtain positive efficiency for each thermal zone. On the other hand, depending on the final energy consumptions; just in South-West, South-East and East zones are positively affected by the lighting consumptions although some results about percentages are quite low such as -0,92 % for the South façade or -1.20 % for the West façade.

Generally implementations prove that same sized and angled shading devices are used for every façade orientation in Turkey. This study presents the optimum shading devices for each façade orientation with the suitable design decisions in terms of energy consumptions for İzmir-Turkey. As Bellia (2013) investigated external solar shading devices' effects on energy consumptions in the Italian climate, for the typical office buildings in Europe. That study results give the highest energy efficiency for a warm summer climate by the solar shading devices provide a global annual energy saving value as 8% for Milan (the coldest climate) and 20% (for Palermo, the warmest one) [10]. By that study; it is suggested that the usage of shading devices is better solutions for energy saving in global scale.

Consequently, all the information gained by this study, as mentioned above, can be used for the implementation of optimum shading devices on existing building façades in order to decrease energy consumptions for the 1st degree day climate zone of Turkey, represented by İzmir. So that this study can be applied for the other climate zones of Turkey in order to decrease the energy consumptions in national scale.

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