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Alternative window wall ratio of glasses with different solar heat gain coefficient and solar transmittance and their effect on total energy consumption in alternative directions

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Abstract

Energy simulation model of the building of Eskişehir Technical University Industrial Engineering Department Academic and Administrative Staff rooms were created in this study carried in the scope of energy efficiency and performance of buildings. In the aforementioned energy simulation mode, in line with the International Measurement, Verification and Energy Needs Standards and Protocol (IPMVP) "energy consumption verification"; heating energy, indoor-outdoor environment and climate data were defined, energy consumption verification was carried out and a realistic model was achieved. Using the realistic model achieved, alternative directions were applied to alternative window wall ratios thereby calculating "reference energy consumptions" in "reference building models". Energy consumptions, calculated by applying alternative glass types to reference models, were then compared with reference energy consumptions

Keywords: energy efficiency, building orientation, window wall ratio, energy simulation, energy verification / calibration

1. Introduction

Increasing energy consumption rapidly distorts the natural ecological balance and sustainability. Sustainability affects the restricted energy resources and is important economically in terms of energy consumption of users' buildings. In addition, factors such as climate change and population concentrating in urban areas increase the attention to resistivity (Shamsuddin, 2020). "Energy efficiency" gains importance in the interface of sustainability and developing urban resistance. When considered on basis of sectors, energy consumed in buildings is defined as 37% for residential homes, 35% for commercial buildings and 27% for industrial buildings (URL 1). In this context, active and passive design criteria are noteworthy for designers, engineers and operators in construction sector. Because active design criteria are systems integrated in buildings, they indirectly lower energy cost. On the other hand, passive design criteria must be considered before constructing a building because they directly affect the operating costs. Passive design criteria are mainly as follows:

- Chosen location,
- Orientation,
- Building form,
- Physical characteristics of the building envelope,
- Solar control systems,
- Natural ventilation design,
- Physical characteristics of the window glasses. (Uslusoy Ş. S. & Altin M., 2014, URL 2).

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Looking at the energy consumption in offices, energy consumptions for heating-cooling and lighting account for 53% of total energy consumption (Figure 1) (URL 3). "Building envelope and orientation" constitute the surface that transfers the heat between indoor and outdoor environments, directly and indirectly receiving solar radiation and balances the wind infiltration (Danielski, I., et al., 2012, p. 24). These are among the principal criteria that need to be designed and/or agreed upon at the design state as these directly affect the total energy consumption (Chiras, D., p. 19).

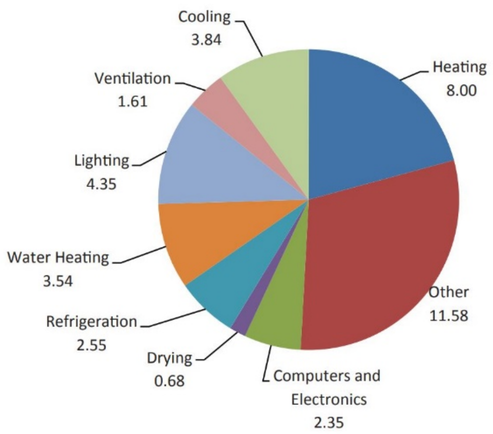


Figure 1 Total primary energy use in buildings (URL 3)

In a study conducted by Boyer et al, one of the leading applications for energy efficiency of buildings, Boyer et al discussed that buildings' energy simulations could be applied to different targets using "multiple model" approach and following logical steps were necessary in relation to design and research aspects. This way savings of energy consumption would be possible noting the figures calculated using energy simulation programs during the building design phase.

Yaşar Y. and Kalfa S. M. have compared eight different glass types' heating and cooling energy consumptions using a calculation model in Design Builder programme in absence of a realistic model for Blocks F and C of TOKI Housing Project in Trabzon.

Yang Q. et al have studied in 3 difference cities the effects of 3 different HVAC, 2 different glass types, 4 main directions and 9 window wall ratios on heating/cooling and total energy consumption. Kheiri, F. has studied optimum window wall ratios in four main directions in relation to illumination energy and HVAC in four cities of various countries.

Rizki A. Mangkuto R. A. et al's study, the space observed is an office room, having internal dimensions of L 5.4 m, W 3.5 m, H 2.7 m. Reflectance values of the ceiling and the floor were respectively 0.85 and 0.20. The window was assumed to consist of a single glazing with typical visible transmittance of 0.88. No shadings, furniture, and other accessories were associated with the space. The WWR was varied from 30% to 80% in an interval of 10%. They concluded that, three optimum solutions are found, all of which belong to four Pareto frontiers. The most optimum solution with the least mean distance to the utopia points is the combination of WWR 30%, Wall reflectance of 0.8, and south orientation.

In this study, the aim is to assess energy consumption changes of alternative glass types in different directions and increasing window wall ratios. This way, for the Eskişehir Technical University, Engineering Faculty, Industrial Engineering Department, Academic and Administrative Staff Building Block's:

- Energy simulation model was prepared;
- Consumption verification was made;
- Alternative window wall ratios were turned to alternative directions; and
- Heating-cooling energy consumption values were calculated to analyse.

2. Methodology

Attaining more realistic values is necessary due to uncertainty of calculations of energy simulations in buildings. To achieve that, energy consumption verification must be carried out in line with the protocols (such as M&V and IMPVP) foreseen by the Department of Energy (DOE) (Güçyeter B., 2010).

For the purposes of raising consciousness and awareness for effective architectural energy design of office buildings and probing the window wall ratio of building structure of office buildings in terms of heating energy performance following principles must be clearly defined:

- Examination of building energy performances in line with the International Measuring Performance and Verification Protocol and standards (IMPVP, Article 3.4.4. D),
- Measuring the energy consumptions of sample building in terms of in detail (one year; 8760 hours),
- Equalizing the energy calculated by energy simulation program and energy consumed within the limit values defined in line with these standards, and creating a realistic model,
- Turning the realistic model of the building to cardinal and intercardinal directions based on various window wall ratios, thereby recalculating and assessing the energy consumption,

Building energy consumptions were measured as per ASHRAE 2002, CIBSE (Section A) and M&V and the simulation model was created in line with ASHRAE 2005, IMPVP and M&V protocols. It was ensured that the indoor environment temperature values and energy consumption values were within the limit values defined in line with the IMPVP. Limit conditions are assessed in terms of 8760-hour measurement data by:

- The Stability Coefficient (sensitivity percentage / R) and
- Square Root Average Error Margin (RMSE)

When indoor temperatures are brought to limit conditions, the same operation must be repeated for calculated-measured energy consumption as well. The energy model that satisfies all of the above is referred to as the "Realistic Model" (Ke M. et al, 2013).

3. Location and current situation of the Sample Building

Eskişehir Technical University, Engineering Faculty, Industrial Engineering Department Academic and Administrative Staff Building Block is located on the latitude of 39.81 and longitude of 30.53. With an orientation of 38.69º north-south, the building was completed in 2000 (Figure 2). Two-storey reinforced concrete building has 10 rooms on ground floor and 9 rooms on first floor and the first-floor projects by 90 cm compared to the ground floor (department head's room is of the size of 2 rooms) (Figure 3-4). Aerated concrete blocks were used to fill the outside walls and the façade of ground floor was cladded with glazed bricks. The building's heating requirement is met by a heat centre that works on natural gas. Heat conductivity values of the construction elements used on the building envelope are given in Table 1.

Table 1 Building Envelope Element's U values

Building Envelope Element	U (W/m^2K)
Ground Floor Wall	0.875
1st Floor Wall	0.96
Reinforced Concrete Wall	3.05
Ground Floor Pavement	2.34
1st Floor Pavement (contact inside)	3.29
1st Floor Pavement (contact outside)	3.23
Roof floor	3.54
Windows and Joinery	2.80

Figure 2 ESTU Industrial Engineering Department

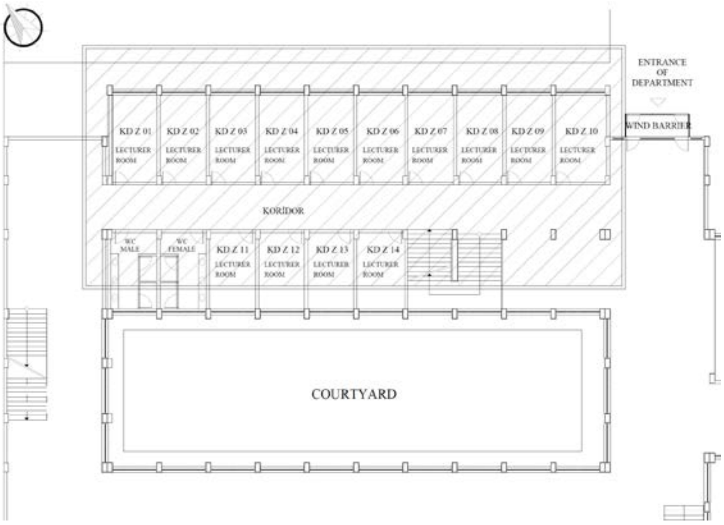


Figure 3 ESTU Industrial Engineering Department Ground Floor Plan

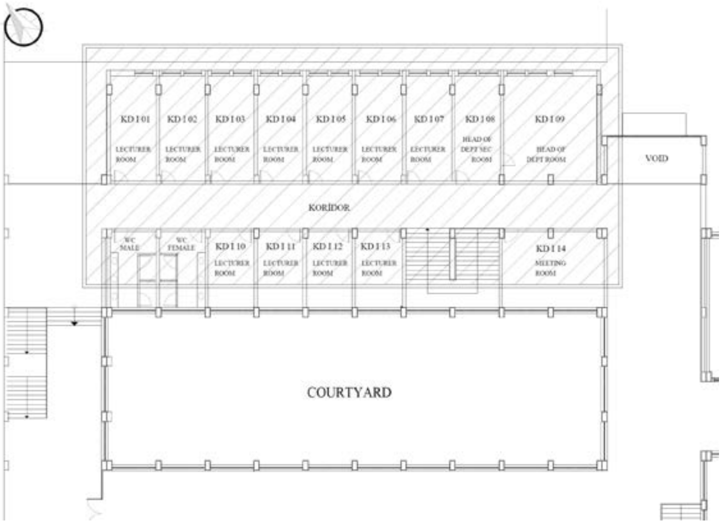


Figure 4 ESTU Industrial Engineering Department First Floor Plan

3.1. Taking the Measurements of the Sample Building to Enter into the Model

"Dynamic Calculation Model" is used to attain more realistic results in energy consumption calculations with energy simulation programmes. Synchronously collected data are used in dynamic calculation model to reveal the performance of the building envelope in particular. Indoor and outdoor environment data that affect the sample building's energy consumption, and the amount of energy consumed in heating system are measured.

Data including outdoor environment temperature, relative humidity, direction and speed of wind and pressure readings were obtained from TUMAS system of the General Directorate of Meteorology (Metar-type station) and a climate data file was created. As for the indoor environment, indoor temperature, relative humidity and net heating energy were measured using datalogger and calorimeter. Dataloggers were placed at 150 cm height on the inner wall surface, ensuring that they're not exposed to solar radiation, in two rooms at each end and one room in the middle on ground and 1st floors (measurement interval was 15 minutes). On the other hand, calorimeter was connected to the heating pipe at the entrance of the building block. Calorimeter consisted of two probes measuring incoming and outgoing temperatures, a flowmeter and data recording device (measurement interval was 1 minute).

3.2. Creating the Model of Operation Buildings in Energy Simulation Programme

Simulation model of the Eskişehir Technical University, Engineering Faculty, Industrial Engineering Department Academic and Administrative Staff (Lecturer) rooms building were modelled in Design Builder programme in line with the standards set forth above, noting the architectural characteristics of the building (Figure 5).

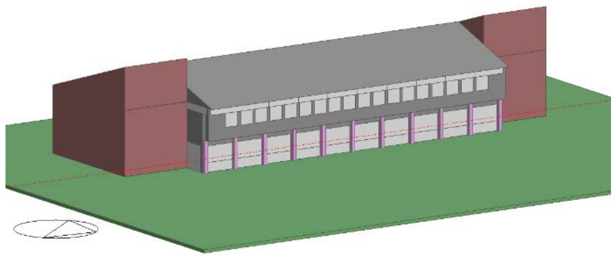


Figure 5 ESTU Industrial Engineering Department Building Simulation Model

3.3. Energy Performance Simulation Accuracy of Measured Buildings

In this comparison, coefficient of determination (Coefficient of Determination/R), coefficient of variation (Coefficient of Variation / RMSE) and average error (MBE) are used. Coefficient of determination (R) [%].

$$R^2 = \left(1 - \frac{\sum_{i=1}^{n} (y_{pred,i} - y_{data,i})^2}{\sum_{i=1}^{n} (y_{data} - y_{data,i})^2}\right) \times 100 \quad (1)$$

Coefficient of variation (CV / RMSE) [%];

$$CV = \frac{\sqrt{\frac{\sum_{i=1}^{n} (y_{pred,i} - y_{data,i})^2}{n-p}}}{y_{data}} \times 100 \quad (2)$$

And average error (MBE) [%];

$$MBE = \frac{\frac{\sum_{i=1}^{n} (y_{pred,i} - y_{data,i})}{n-p}}{\bar{y}_{data}} \times 100 \quad (3)$$

Where;

$y_{pred,i}$...; Value at which the calculated data equals to measured data,
$y_{data,i}$...; Value at which measured data equals to the calculated data,
y_{data}.....; Average value of measured data,
n......; Number of data included in assessment,
p......; Number of regressions used within the model.

Acceptable limit values of simulation data results in creating a realistic model are given in Table 2.

Table 2 International Performance Measurement and Verification Protocol's (IPMVP) Verification limit values

	ASHRAE G14 (2014)		IPMVP (2020)		M&V (2008)	
	MBE	RMSE	MBE	RMSE	MBE	RMSE
Hourly	±10%	25%	-	10-20%	±10%	30%
Monthly	±5%	15%	±20%	-	±5%	15%

Coefficient of determination, coefficient of variation and average error values for indoor temperature data of the Industrial Engineering Department Staff rooms are given in Table 3.

Table 3 Measured and calculated indoor temperature limit values (8760-hour) of Industrial Engineering Department Lecturer Rooms

	Coefficient of Determination (R)	Coefficient of Variation (RMSE (CV))	Average Error (MBE)
KD Z 01	0.89	16.78	0.62
KD Z 04	0.91	16.60	0.53
KD Z 10	0.94	15.43	0.21
KD I 01	0.96	16.19	1.09
KD I 05	0.95	15.20	0.37
KD I 09	0.94	15.48	0.33
AVERAGE	0.93	15.95	0.53

3.4. Calculation of reference energy consumptions based on alternative direction and window wall rations in the realistic model

In the realistic model that was created, window wall ratios were assessed in respective order in 8 different window wall ratios in the range of 10%-80% (Figure 6) without intervening the system and only considering the surface area of the windows. Only the heating and cooling energies were considering in calculating the reference energy consumptions, and electric energy consumption was not included in calculations.

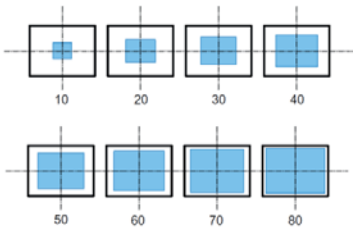


Figure 6 Window wall ratios used in the realistic model

3.5. Calculating total energy consumption values of alternative glass types applied to alternative direction and window wall ratios

Spectral data measured in manufacturer's laboratory setting in accordance with:

- Solar heat gain coefficient (SHGC) and solar transmittance (ST) EN 410 standards; and
- Solar Transmittance to EN 673 and EN 12898 standards;

were defined to 8 different base/basic model to determine the impacts of alternative glass types to heating/cooling energy consumption (Table 4). Total energy consumptions of new alternative models created (defining 5 different glass types to 64 models) were calculated.

Solar heat gain coefficient (%), solar transmittance (%) and Heat Transfer Coefficient (W/m²K) of alternative glass types applied to alternative direction and window wall ratios are shown in Chart 3.1 (URL 4).

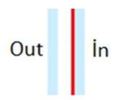
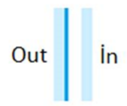
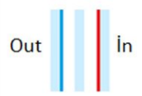
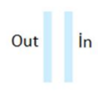
In alternative glass types:

- Type A glass is defined as glass that has low-e coated (ecotherm) double glaze that provides heat control in its inner glass;
- Type B glass is defined as double glaze glass coated with low-e (ecosol) that provides solar control;
- Type C glass is defined as triple glaze glass that has solar control on outer glass (ecosol) and low-e coating (ecotherm) that provides heat control on inner glass;
- Type D glass is defined as triple glaze glass that has low-e coating (ecotherm) that provides heat control on both inner and outer glasses;
- Type E Glass is defined as double glaze that has low-e coating (cool plus) that provides heat control on outer glass only; and

Current double glaze glass that does not have coating.

"Alternative heating-cooling energy consumptions" were calculated after making these definitions for each glass type.

Table 4 Characteristics of glass types used in the model (▬ Low-e coating providing heat control, ▬ Low-e coating providing solar radiation control, ▬ Low-e coating providing solar radiation and heat control, ▬ Glass) (URL 4).

Glass Type	Thickness	Material	Glass Characteristics/properties	Solar Heat Gain Coefficient (%)	Solar Transmittance (%)	Heat Transfer Coefficient (W/m²K)	
A	4mm	Outer Glass	Plain Glass	60	78	1,3	
	12mm	Air Gap	Argon				
	4mm	Inner Glass	Low-e Coating (ecotherm) (heat control)				
B	4mm	Outer Glass	Low-e Coating (ecosol) (solar control)	43	71	1,3	
	12mm	Air Gap	Argon				
	4mm	Inner Glass	Plain Glass				
C	4mm	Outer Glass	Low-e Coating (ecosol) (solar control)	32	63	0,7	
	12mm	Air Gap	Argon				
	4mm	Inner Glass	Plain Glass				
	12mm	Air Gap	Argon				
	4mm	Inner Glass	Low-e Coating (ecotherm) (heat control)				
D	4mm	Outer Glass	Low-e Coating (ecotherm) (heat control)	48	69	0,7	
	12mm	Air Gap	Argon				
	4mm	Inner Glass	Plain Glass				
	12mm	Air Gap	Argon				
	4mm	Inner Glass	Low-e (ecotherm) (heat control)				
E	4mm	Outer Glass	Low-e Coating (cool plus) (solar and heat control)	33	49	1,1	
	12mm	Air Gap	Argon				
	4mm	Inner Glass	Plain Glass				
M (Current Glass)	4mm	Outer Glass	Plain Glass	68	80	2,9	
	12mm	Air Gap	Argon				
	4mm	Inner Glass	Plain Glass				

3.6. Findings

- Calculating the reference total energy consumption Based on Alternative Directions and Window wall Rations it is evident that:
  - Energy consumption increases linearly with increasing window wall ratio in all directions:
    - 13% increase in north direction (92.076-104.018kW/year),
    - 17.7% increase in north-east direction (91.985-108.270kW/year),
    - 16.5% increase in north-west direction (91.904-107.026kW/year),
    - 20.1% increase in east direction (91.132-109.466kW/year),
    - 16.6% increase in west direction (90.698-105.733 kW/year),
    - 0.8% increase in south direction (87.747-88.972kW/year),
    - 12.1% increase in south-east direction (89.589-100.407 kW/year),
    - 8.6% increase in south-west direction (89.094-96.730kW/year),
  - Energy consumption decreases in the following order: east, north-east, north-west, west, north, south-east, south-west and south.
- Energy Saving Rates Based on Alternative Directions and Window Wall Ratios

Energy saving rates obtained by comparing calculated energy consumptions with the reference energy consumptions are given in the Figure 7-14.

Calculated reference energy consumption is compared to energy consumption of alternative glass type, when the window wall ratio get %10 from %80 energy saving ratios for A, B, C, D and E types of glass respectively,

- North; %1.4-%10.4, %1.2-%10.2, %1.7-%14.2, %1.8-%14.5 and %1.3-%11.3,
- Northeast; %1.4-%10.9, 1.2-%12.3, %1.7-%16.4, %1.8-%15.8 and %1.3-%13.6,
- East; %1.3-%10.8, %1.2-%12.9, %1.6-%17.2, %1.8-%16 and %1.3-%14.6,
- Southeast; %1.1-%10.4, %0.7-%10.6, %1.1-%13.9, %1.4-%14.9 and %1.4-%14.9,
- South; %0.9-%9, %0.1-%5.1, %0.4-%7.9, %0.9-%11.1 and %0.1-%4.8,
- Southwest; %1.1-%10, %0.5-%9.1, %0.8-%12.2, %1.2-%13.9 and %0.5-%9.2,
- West; %1.3-%10.4, %1-%13, %1.4-%15.7, %1.6-%15.1 and %1.1-%13,
- North; %1.4-%10.6, %1.2-%11.6, %1.7-%15.7, %1.8-%15.3 and %1.3-%12.9

are determined.

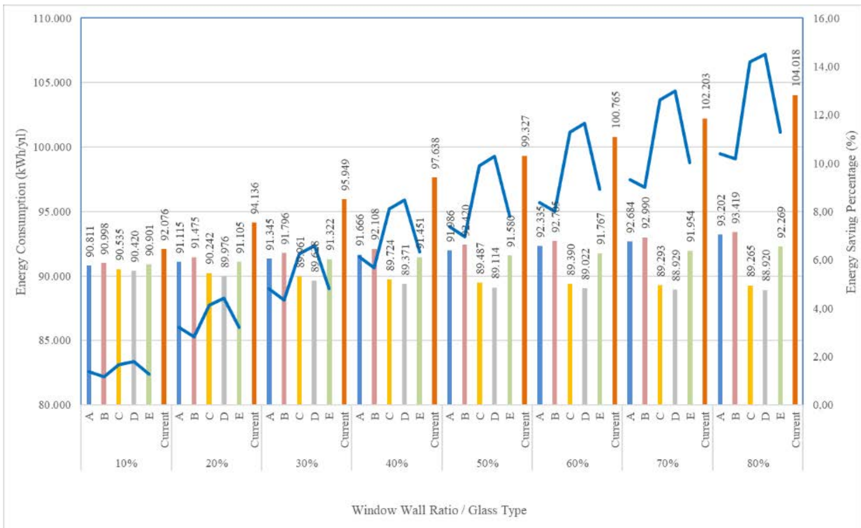


Figure 7 Energy saving rates, calculated energy consumptions and reference energy consumptions for North

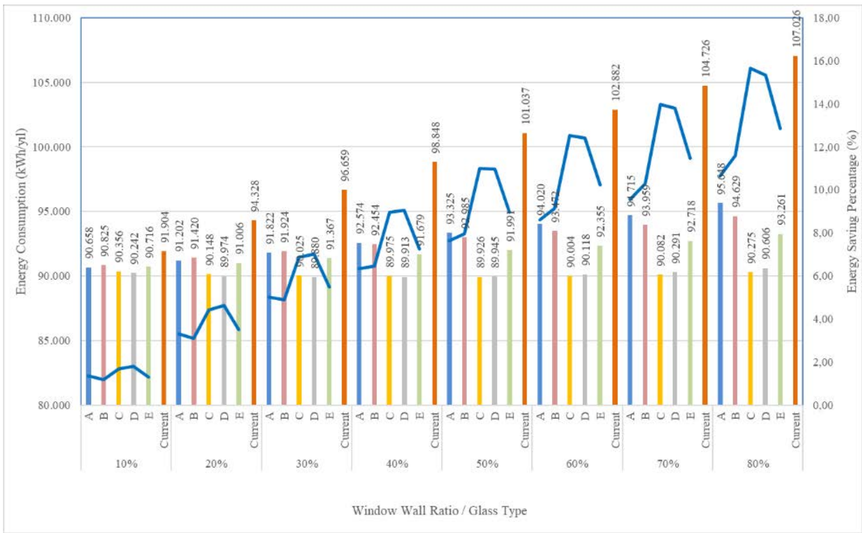


Figure 8 Energy saving rates, calculated energy consumptions and reference energy consumptions for Northwest

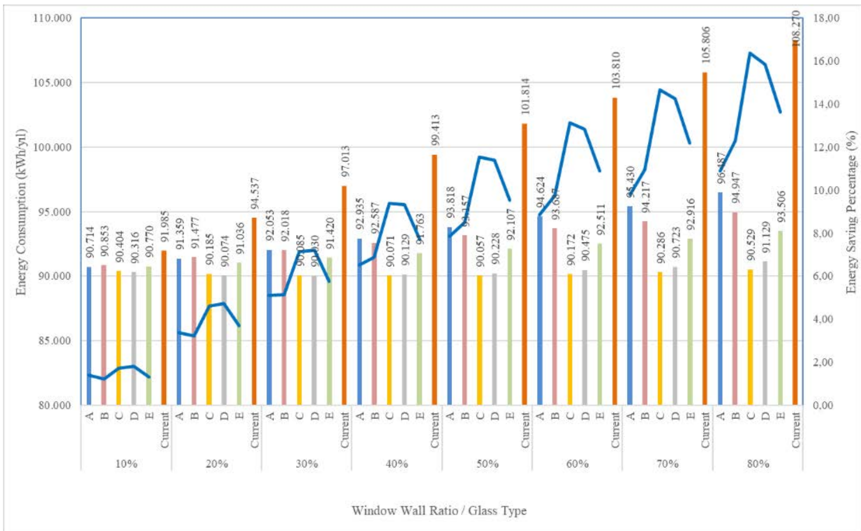


Figure 9 Energy saving rates, calculated energy consumptions and reference energy consumptions for Northeast

Figure 10 Energy saving rates, calculated energy consumptions and reference energy consumptions for East

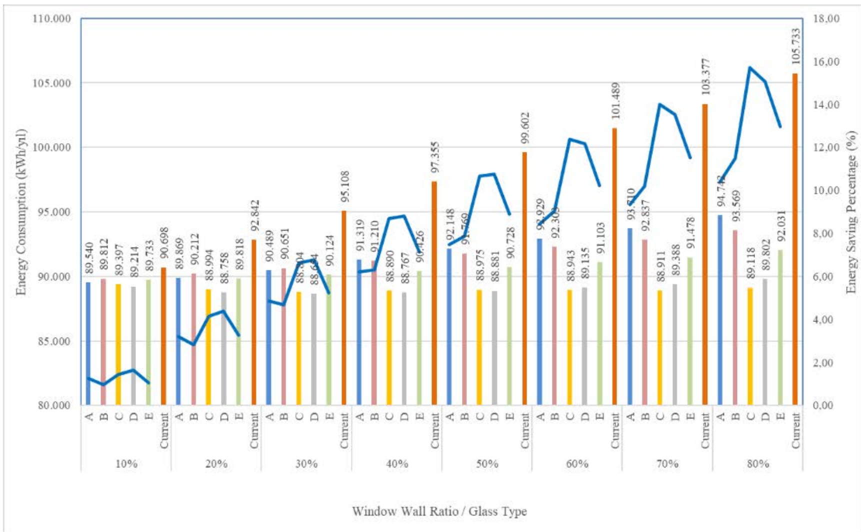


Figure 11 Energy saving rates, calculated energy consumptions and reference energy consumptions for West

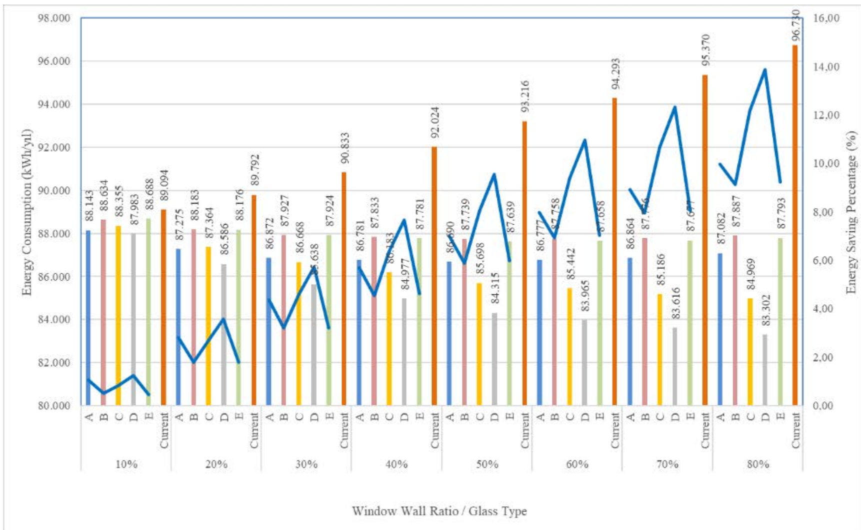


Figure 12 Energy saving rates, calculated energy consumptions and reference energy consumptions for Southwest

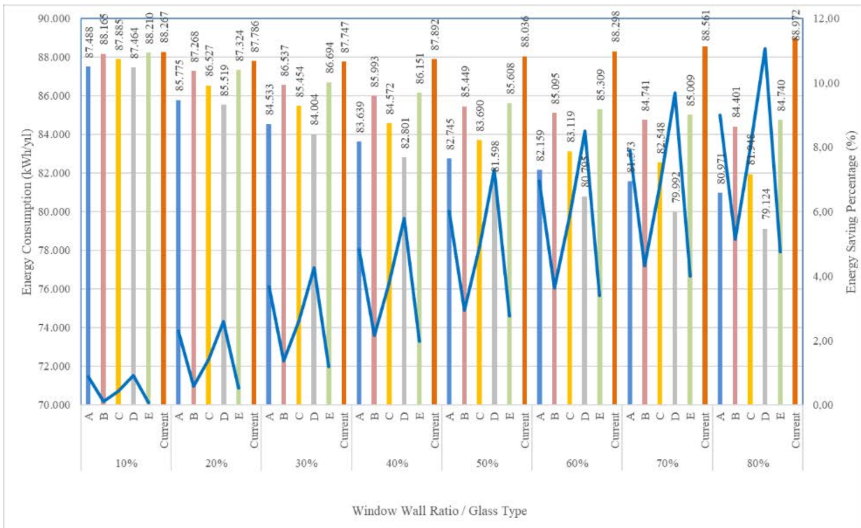


Figure 13 Energy saving rates, calculated energy consumptions and reference energy consumptions for South

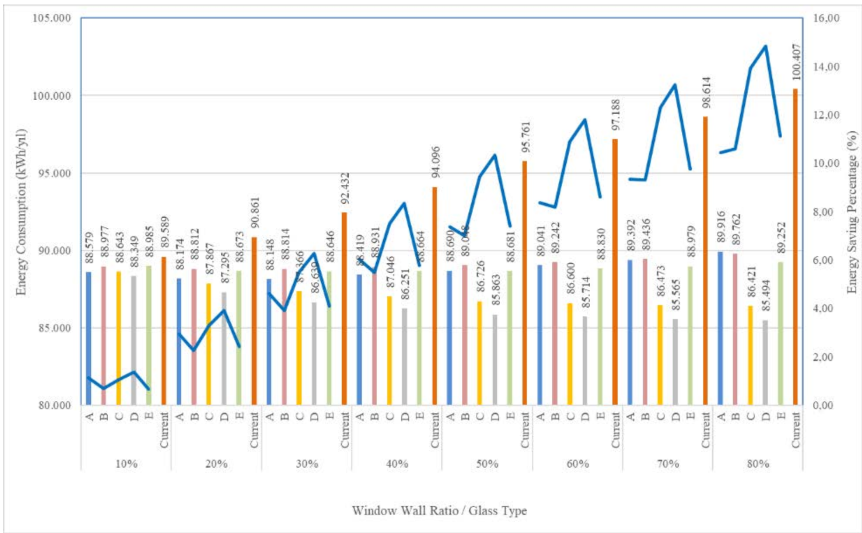


Figure 14 Energy saving rates, calculated energy consumptions and reference energy consumptions for Southeast

4. Conclusion

User comfort is very important in the context of sustainable environment and urban resilience. Therefore in this study, which was carried out for the purpose of drawing attention to energy efficiency in office buildings, which has major contribution to energy performance and efficiency of buildings, indoor and outdoor environment data were measured and heat energy verification was made to yield a “realistic model” to satisfy the norms of ASHRAE, CIBSE, M&V and IMPVP standards in Eskişehir Technical University, Engineering Faculty, Industrial Engineering Department Academic and Administrative Staff Building Block as the model building. Window wall ratios were set in the range of 10% to 80% on this realistic model and by turning the realistic model to cardinal and intercardinal directions, reference energy consumptions were calculated. Alternative glass types were defined in the realistic model created to calculate energy consumptions of alternative models. Consumptions obtained were compared with the reference energy consumptions. Based on the measurement and calculation analysis carried out:

In review of the measurements made it was identified that:

- In Eskişehir (continental) climate area, heating period (7 months) is longer than cooling period (2 months),
- In cooling period, the cooling load decreases because the outdoor temperature drops at nights,
- Fronts facing west and especially east very rapidly cool or heat,
- Window wall rations for total optimum energy consumption must be:
    - 30% in north direction,
    - 10% in all other directions

in new building designs that are similar to architectural characteristics of the sample building in Eskişehir.

When calculated Reference energy consumptions are compared with energy consumptions with the alternative glass types on the other hand; saving rations for window wall ratios in the range of 10% to 80% are given in Table 5 below.

Table 5 Energy saving ratios of alternative glass types based on alternative glass types and window wall ratios

		NORTH	NORTH-EAST	EAST	SOUTH-EAST	SOUTH	SOUTH-WEST	WEST	NORTH-WEST
%10	A	1.266	1.271	1.220	1.010	780	950	1.158	1.246
	B	1.078	1.132	1.054	612	102	460	886	1.078
	C	1.541	1.581	1.494	946	382	739	1.301	1.548
	D	1.656	1.668	1.612	1.240	804	1.111	1.484	1.662
	E	1.175	1.215	1.164	604	57	406	964	1.188
%20	A	3.022	3.178	3.217	2.687	2.011	2.518	2.973	3.127
	B	2.661	3.060	3.151	2.050	518	1.609	2.631	2.908
	C	3.895	4.352	4.423	2.995	1.259	2.428	3.848	4.180
	D	4.161	4.463	4.506	3.566	2.267	3.206	4.084	4.354
	E	3.032	3.501	3.603	2.189	463	1.616	3.024	3.322
%30	A	4.604	4.960	5.023	4.283	3.214	3.961	4.619	4.837
	B	4.153	4.995	5.316	3.618	1.210	2.905	4.457	4.735
	C	5.988	6.928	7.275	5.066	2.294	4.165	6.304	6.634
	D	6.322	6.983	7.176	5.793	3.743	5.194	6.454	6.779
	E	4.628	5.593	5.986	3.785	1.054	2.909	4.984	5.292
%40	A	5.972	6.478	6.555	5.677	4.252	5.243	6.036	6.275
	B	5.530	6.826	7.279	5.165	1.898	4.191	6.145	6.394
	C	7.914	9.342	9.899	7.050	3.320	5.841	8.465	8.873
	D	8.267	9.285	9.530	7.845	5.091	7.048	8.587	8.936
	E	6.187	7.650	8.249	5.432	1.741	4.243	6.929	7.169
%50	A	7.341	7.996	8.087	7.071	5.291	6.526	7.453	7.713
	B	6.907	8.657	9.243	6.712	2.587	5.477	7.832	8.053
	C	9.840	11.756	12.524	9.034	4.346	7.518	10.626	11.112
	D	10.213	11.586	11.885	9.898	6.438	8.901	10.721	11.093
	E	7.747	9.707	10.511	7.079	2.428	5.577	8.874	9.046
%60	A	8.430	9.186	9.273	8.147	6.139	7.516	8.560	8.862
	B	8.060	10.123	10.761	7.945	3.203	6.535	9.186	9.410
	C	11.375	13.638	14.522	10.588	5.179	8.850	12.546	12.878
	D	11.744	13.334	13.659	11.474	7.504	10.328	12.355	12.764
	E	8.998	11.298	12.232	8.358	2.990	6.635	10.386	10.527
%70	A	9.519	10.376	10.458	9.222	6.988	8.505	9.667	10.011
	B	9.213	11.589	12.280	9.178	3.820	7.594	10.539	10.767
	C	12.910	15.519	16.520	12.141	6.013	10.183	14.466	14.644
	D	13.274	15.083	15.432	13.050	8.569	11.754	13.989	14.436
	E	10.249	12.890	13.953	9.636	3.552	7.693	11.899	12.008
%80	A	10.816	11.783	11.846	10.491	8.000	9.648	10.991	11.378
	B	10.599	13.323	14.068	10.645	4.571	8.843	12.164	12.397
	C	14.753	17.741	18.869	13.985	7.024	11.761	16.615	16.751
	D	15.098	17.142	17.524	14.913	9.848	13.428	15.931	16.420
	E	11.748	14.764	15.981	11.155	4.231	8.937	13.702	13.765

Consequently, because the passive design parameters tend to differ for each building, it is fairly difficult to come up with a standard value for the window wall ratio. It is necessary to create individual models and carry out calculations by professional groups specialized in energy simulation program and energy consumption for each building. However, in continental climate it was established, the following would be beneficial:

- Materials to increase thermal resistance must be used throughout the building envelope,
- Thickness of the insulation material on the building facades facing north must be thicker and window and door frames with glass must have argon gas filling,
- On south facades however, glass types with lower Solar Transmittance must be used,
- Shading systems must be used on east and west facing facades to ensure positive results in terms of energy savings and energy conservation.

Moreover, the following must be ensured for optimum total energy savings for the buildings of the typology of the sample building in Eskişehir province according to glass type;

- Low-e coated triple glazing (Type D glass) with high thermal resistance, which provides heat control in both exterior and interior glass in the range of 10%-80% opacity window wall ratios in north, south, southeast and southwest directions,
- Window wall ratio in north-east as follows:
    - In the range of 10%-30%; triple glazing (D type glass) with low-e coating with high thermal resistance that provides heat control in both exterior and interior glass,

    - In the range of 40%-80%; Low-e coated triple glazing (C type glass) with a low Solar Heat Gain Coefficient providing solar control on the outer glass and high thermal resistance providing thermal control on the inner glass,
- Window Wall ratio in north-west as follows:
    - In the range of 10%-40%; triple glazing (D type glass) with low-e coating with high thermal resistance that provides heat control in both exterior and interior glass,
    - In the range of 50%-80%; Low-e coated triple glazing (C type glass) with a low Solar Heat Gain Coefficient providing solar control on the outer glass and high thermal resistance providing thermal control on the inner glass,
- Window wall ratio in east as follows
    - In the range of 10%-20%; triple glazing (D type glass) with low-e coating with high thermal resistance that provides heat control in both exterior and interior glass,
    - In the range of 30%-80%; Low-e coated triple glazing (C type glass) with a low Solar Heat Gain Coefficient providing solar control on the outer glass and high thermal resistance providing thermal control on the inner glass,
- Window wall ratio in west direction as follows:
    - In the range of 10%-50%; triple glazing (D type glass) with low-e coating with high thermal resistance that provides heat control in both exterior and interior glass,
    - In the range of 60%-80%; Low-e coated triple glazing (C type glass) with a low Solar Heat Gain Coefficient providing solar control on the outer glass and high thermal resistance providing thermal control on the inner glass,

are determined.

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Resume

Hakan Ünalan graduated Department of Architecture (Anadolu University, 1997), after he worked two different architectural offices and then started in Anadolu University as lecturer (1998). He received his Ph. D. (2016) and Assist. Prof. Dr in 2019 in Architectural Doctorate Program from Anadolu University. He currently works in Department of Architecture and Urban Planning, School for The Handicapped, Anadolu University.

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