OPTIMUM BUILDING ENVELOPE DESIGN FOR VISUAL, THERMAL AND ACOUSTICAL COMFORT CONDITIONS IN THE OFFICES

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ABSTRACT

The aim of this paper is to explain the results of a research project run in Yıldız Technical University which focuses on the optimum building envelope design for visual, thermal and acoustical comfort conditions in the offices placed in Istanbul city center. In this project, the building envelope alternatives are examined in terms of light, heat and sound considering the materials used mostly in Turkey. The applied method is assessment of the various building envelopes from the point of the view of the natural light, heat and sound, comparison of the outcomes and determination of the optimum building alternatives.

KEYWORDS

Building envelope, office, light, heat, sound.

1. INTRODUCTION

Building envelope should provide the visual, thermal and acoustic comfort in accordance with the function of the room. The material characteristics of the translucent -window- and opaque components-wall- of the building envelope and the ratio of these components are effective in order to create comfort conditions in an interior. Windows are the weakest elements in terms of sound and heat, but they are inevitable for natural lighting. The perfection of the design is highly related to the consideration of all parameters together such as light, heat, sound etc.

A research project supported by Yıldız Technical University Research Foundation is designed to determine optimum building envelope-façade- alternatives for visual, thermal and acoustical comfort in the offices situated in Istanbul city centre. This paper presents the results of the project.

2. METHOD AND ASSUMPTIONS

The aim of this study is to evaluate various building envelopes constructed with materials widely used in Turkey in terms of visual, thermal and acoustical comfort conditions for the offices placed in Istanbul. Research method is, determination of basic assumptions, comparison of results and determination of appropriate building envelopes. The rooms are assumed on the ground floor of an office building placed in the city centre on a traffic road. Three different room dimensions, window types, and four different wall constructions are chosen as to illustrate of the offices. Each room has single facade oriented to the cardinal directions with one window on it. Calculations are made for obstructed and unobstructed office buildings.

The general properties of building envelope components (window and wall) are presented in Table 1 and the assumptions of this study are as follows:

- The width of road and the height of buildings are 19.5 m and 24 m respectively (obstruction angle is 50–)
- The road traffic noise levels are 55, 65, 75 and 85 L_{Aeq}.
- The height (H) and length (D) of the rooms are 2.6 m and 5 m respectively. Rooms' width (A) are 3 m, 5 m and 10 m (named with R1, R2 and R3; Figure 1).
- The rooms have single facade oriented to four directions as North, East, South and West.
- The height and sill of the windows are 1.5 m and 0.85 m.
- Working plane height is 0.85 m.
- The windows are three types (W_1: triple glass; W_2: separated frame double glass; W_3: double glass). The window widths vary according to the transparency ratio (window/wall ratio), as 20% and 50 %.
- The opaque components are four types (called as O_1, O_2, O_3, O_4).
- The materials of the floor, wall and ceiling are chosen as carpet, plaster and acoustical mineral wool. Light reflectance of the ceiling, wall and floor are 0.80, 0.60 and 0.20 respectively.

Table 1.
Properties of building envelope components
(U: Heat transmittance coefficient; t: light transmittance; m: mass per unit area)

Win. type	Mater.	Thickness / U / t / m/
W1	Triple glass	Σ 125 mm (4[12]4[100]5) / 1.9 w/m^{2}K/ 0.66 / 32,5 kg/m^2/
W2	Separeted frame Double glass	Σ 108 mm (4[100]4) / 2.5 w/m^{2}K/ 0.76 / 20 kg/m^2/
W3	Double glass	Σ 20 mm (4[12]4) / 2.8 w/m^{2}K/ 0.76 / 20 kg/m^2/

Wall type	Material and thickness (mm)		Σ Thic. / U / m/
O1	Internal plaster	20	300 mm / 0.33 w/m^{2}K/ / 175 kg/m^2/
	Lightweight concrete block	200	
	Insulation panel	50	
	External plaster	30	
O2	Internal plaster	20	280 mm / 0.48 w/m^{2}K/ / 284 kg/m^2/
	Hollow brick	190	
	Insulation panel.	40	
	External plaster	30	

Wall type	Material and thickness (mm)		Σ Thic. / U / m/
O3	Internal plaster	20	300 mm / 0.57 w/m^{2}K/ / 575 kg/m^2/
	Prefabricated concrete panel	200	
	Insulation panel	50	
	External plaster	30	
O4	Internal plaster	20	170 mm / 0.71 w/m^{2}K/ / 270 kg/m^2/
	Concrete panel	40	
	Insulation panel.	40	
	Concrete panel	40	
	External plaster	30	

3. VISUAL COMFORT EVALUATION OF FACADE ALTERNATIVES

From the view point of the visual comfort, only daylight illuminances on the working plane are calculated for different facade features according to the assumptions of the study by using the Aydınlı average sky model adapted to the statistical meteorological data of Istanbul. Illuminance distributions determined are compared with the required minimum illuminance value (500 lm/m^2) for the offices. Calculations are realised for 21 December and 21 June, at 9.00. In the evaluation of the distributions, illuminance on the tables is taken as the basic criterion. The ratio of the table number illuminated sufficiently to the total number of the tables in the room is taken into consideration. Furnished office plans are shown in Figure 1.

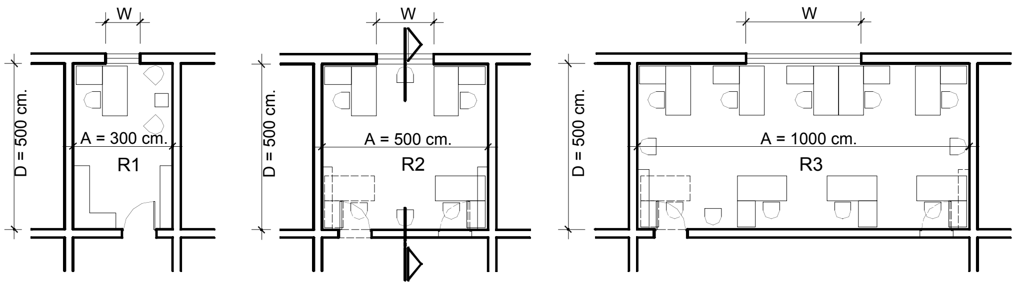

Figure 1. Plans of the furnished room.

According to the evaluation results of the calculations on the numbers of the table having necessary illuminance value depend on the transparency ratio and obstruction specifications. However, for all directions and days, the variations of the wall thickness and window glass transmittance do not affect the numbers of the tables sufficiently illuminated in the rooms. Therefore, the transparency ratio and obstruction specifications are taken as basic parameters for the evaluation of the illuminance distributions. Some examples of the sufficiently illuminated table ratios are given and appropriate results are shown by dark boxes in Table 2.

Table 2.
Examples of the sufficiently illuminated table ratios (%).
(RT: Room type; TR: Transparency ratio; UO: Unobstructed; O: Obstructed)

21 December – Hour 9:00								21 June – Hour 9:00							
North				East				North				East			
RT	**TR (%)**	**UO**	**O**	**RT**	**TR (%)**	**UO**	**O**	**RT**	**TR (%)**	**UO**	**O**	**RT**	**TR (%)**	**UO**	**O**
R1	20	-	-	**R1**	20	100	-	**R1**	20	100	100	**R1**	20	100	100
	50	100	-		50	100	-		50	100	100		50	100	100
R2	20	-	-	**R2**	20	100	-	**R2**	20	66	66	**R2**	20	66	66
	50	66	-		50	100	66		50	100	66		50	100	66
R3	20	38	-	**R3**	20	75	-	**R3**	20	63	38	**R3**	20	88	38
	50	63	-		50	100	63		50	100	63		50	100	63

The evaluation results of the illuminance distribution in terms of sufficiently illuminated table ratio for100% are summarised as below:

- 21 December, obstructed situation: There are no appropriate conditions on the working plane for the North, East and West. In the South, all of the tables have sufficient illuminance for only R1 room with 50% transparency ratio.
- 21 December, unobstructed situation: Necessary illuminance is provided on all of the tables (100%) for R1 room with 50% transparency ratio in the North and all offices having 50% transparency ratio in the East and South. Required illuminance is again provided R1 and R2 with 20% transparency ratio.
- 21 June, obstructed situation: Necessary conditions is realised only in the R1 room having 20% and 50% transparency ratios for all directions.
- 21 June, unobstructed situation: All rooms with 50% transparency ratio have appropriate conditions in terms of the sufficiently illuminated table ratio (100%) in all cardinal directions. However, only R1 room with 20% transparency ratio has good conditions for all directions.

4. THERMAL COMFORT EVALUATION OF FACADE ALTERNATIVES

Investigation of the envelope alternatives in terms of heat, covers checking the internal surface temperatures and interstitial condensation of the external wall constructions and calculation of the heating energy consumption of the rooms. Evaluation of the building envelope alternatives is realised according to the new heat insulation regulation of Turkey. This regulation aims to limit heating energy consumption and to control interstitial condensation of the external walls. It covers the upper limit values of annual heat loss through the buildings and condensation within walls. The appropriate rooms which annual heating energy consumption is below the upper limit value (Q=72.36 kwh/m^2) are shown by dark boxes in Table 3. As there are no differences between the results depending on various office volumes at the conditions considered in this study, as an example the results of the room type 1 (R1) is given.

Table 3.
Appropriate rooms in terms of heating energy consumption
(RT: Room type; TR: Transparency ratio; O: Opaque component; W: Window)

North			Unobstructed				Obstructed				**South**			Unobstructed				Obstructed			
RT	TR	W.	O1	O2	O3	O4	O1	O2	O3	O4	RT	TR	W.	O1	O2	O3	O4	O1	O2	O3	O4
R1	%20	W1	63.88	68.27	70.94	74.97	65.67	70.44	73.13	77.23	R1	%20	W1	57.79	62.43	65.02	68.88	62.20	66.48	69.21	73.08
		W2	65.26	69.50	72.05	76.51	68.62	73.00	75.61	79.75			W2	57.23	61.22	63.59	67.30	63.11	67.26	69.86	73.85
		W3	67.40	71.64	74.15	78.58	70.78	75.21	77.89	81.84			W3	59.39	63.18	65.81	69.35	65.24	69.52	72.11	75.92
	%50	W1	72.55	75.28	76.95	79.12	77.66	86.47	82.22	84.51		%50	W1	60.13	62.57	64.22	66.17	68.38	70.94	72.61	74.67
		W2	77.20	79.57	81.24	83.81	83.82	86.39	88.17	90.56			W2	60.71	62.81	64.30	66.22	71.40	73.74	75.42	77.63
		W3	82.14	84.83	86.47	88.82	89.08	91.77	93.48	95.96			W3	65.04	67.43	68.75	70.92	76.30	78.75	80.27	82.54

Evaluation of the Table 3 is as follows:

- If the transparency ratio is 50% at the rooms faced to north, the annual heating energy requirement (Q value) of the rooms is bigger than upper limit value and all alternatives of the building envelope determined in this study aren't appropriate. However for the unobstructed rooms faced to south all alternatives of building envelope are appropriate.
- At all alternatives except unobstructed south faced rooms, if the transparency ratio is 50% Q value is bigger than the situation that transparency ratio 20%. At the unobstructed south faced rooms, because of transparency ratio 50% solar heat gains increase and heat loss reduces with high insulated window type W_1. So Q value of these south faced rooms is smaller than the rooms with transparency ratio 20%. This situation shows that if the transparency ratio 50% with high insulated window at the south facades, the insulation value of opaque components is getting unimportant.
- Checking of interstitial condensation and the temperature of inner surface of the wall constructions have been made when the internal air temperature is 20°C and relative humidity is 50% while external air temperature falls until –3°C and relative humidity is 80%. According to the studies on thermal comfort, if the difference between internal air temperature and internal surface temperatures of a room ranges from -3°C to +3°C, comfort is maintained in terms of radiant temperature. Evaluation of the different wall constructions has been realised as to these limitations.
- The difference between internal air temperature and internal surface temperatures is below 3°C with a lowest external temperature of –3°C. Consequently all of the wall constructions determined for this project are in comfort limitations in terms of internal surface temperatures.
- Condensation doesn't occur within the wall constructions 1,2 and 3 but occurs within wall type 4 at external air temperature –3°C. However, the amount of condensation water doesn't exceed the upper limit value (0.5 kg/m^2) given in the heat insulation regulation.

5. ACOUSTICAL COMFORT EVALUATION OF FACADE ALTERNATIVES

In terms of acoustical comfort, transmission loss (TL) and sound transmission class (STC) values of the envelopes are calculated and evaluated by using the required sound insulation values determined considering road noise level (between 55-85 L_{Aeq}) and acceptable level in the offices (NCB 35). Octave band sound transmission loss (TL) and sound transmission class (STC) values are taken from literature for three glass types and four masonry wall types. TL and STC values of the multi-element partitions -i.e. building envelope alternatives- constituted of the selected elements are calculated. Table 4 shows these values together with an example illustrating the required TL and STC values of an office building envelope for 65 L_{Aeq} road traffic noise. In the evaluation, the road with buildings on one side of the road (open area - unobstructed) and road with buildings on both sides of the road (with buildings-obstructed) are taken into consideration.

Table 4.
Multi element partition sound transmission loss (TL) and Sound transmission class (STC) values.
(TR: Trancparency ratio;Last line shows the required TL and STC values for 65 L_{Aeq} road traffic noise)

TR (%)	Window type	Opaque component type	TL (dB)						STC
			125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
20/50	W1	O1	26/28	34/35	43/44	49/50	53/54	46/48	46/47
		O2	36/35	39/36	48/46	53/52	56/55	52/48	49/48
		O3	37/36	41/38	51/49	55/54	57/56	5249	50/49
		O4	36/34	38/37	46/46	52/51	55/54	51/48	48/47
	W2	O1	26/26	33/33	42/42	47/47	50/50	48/43	44/42
		O2	33/30	38/35	46/45	51/49	54/52	48/44	47/44
		O3	33/29	39/37	49/47	52/50	55/52	49/44	48/46
		O4	32/29	37/35	45/44	50/48	54/52	48/44	46/45
	W3	O1, O2, O3, O4	28/24	28/26	32/28	42/38	44/40	38/34	35/32
Required sound insulation for $65L_{Aeq}$ (open area/with buildings)			22/26	25/29	26/30	29/33	29/33	25/29	28/33

Assessments and main results are as follows;

- For the conditions considered in this study, the variation of the glazing/wall ratio from %20 to %50 does not affect the appropriate building envelope. Moreover, there are no differences between the results depending on various office volumes.
- **For 55 L_{Aeq} road traffic noise**, all envelope alternatives are appropriate.
- **For 65 L_{Aeq} road traffic noise**, all envelope alternatives provide the required insulation, when there is no building on the other side of the road. When the road has buildings on both sides, alternatives except with W3 glazing, provide the acoustical requirements.
- **For 75 L_{Aeq} road traffic noise**, required insulation values can not be provided by the alternatives with glazing W3 as well as W1-O1 and W2-O1 multi-partition walls. In the case of buildings on the other side of the road, only the alternatives W1-O2, W1-O3, W1-O4 are suitable.
- **For 85 L_{Aeq} road traffic noise**, all building envelope alternatives are insufficient to fulfil the required conditions.

6. CONCLUSION

The integrated results held by the comfort evaluation of the light, heat and sound for the different facade alternatives investigated in the study are shown in Table 5.

TABLE 5.
Comfort evaluation results for the examined building envelopes.

Direction	21 December - Hour 9.00		21 June - Hour 9.00	
	Unobstructed	**Obstructed**	**Unobstructed**	**Obstructed**
North	All rooms are Uncomfortable	All rooms are uncomfortable	All rooms are Uncomfortable	All rooms are uncomfortable
East	TR=20%; 55/65 $L_{Aeq;}$ R3 is uncomfortable	All rooms are uncomfortable	TR=20%; 55/65/75 L_{Aeq}; R2 and R3 are uncomfortable.	TR=20%; 55/65 $L_{Aeq;}$ R2 and R3 are uncomfortable
	TR=50%; 55/65 L_{Aeq}; W3 and O4 are insufficient		TR=50%; 55/65 L_{Aeq}; W3 and O4 are insufficient	
	75/65 L_{Aeq}; W3 and O1are insufficient		TR=50%; 75L_{Aeq}; W3 and O1 are insufficient	TR=50%; 55/65/75 $L_{Aeq;}$ all rooms are uncomfortable
South	TR=50%; 55/65/75 L_{Aeq}; R3 is uncomfortable	All rooms are Uncomfortable	TR=20%; 55/65/75 L_{Aeq}; R2 and R3 are uncomfortable.	TR=20/50%; 55/65 $L_{Aeq;}$ R2 and R3 are uncomfortable
	75 L_{Aeq}; W1 and O1 are insufficient		TR=50%; 75L_{Aeq}; W3 and O1 are insufficient	TR=20/50%; 55/65/75 L_{Aeq}; all rooms are uncomfortable.
East	All rooms are uncomfortable	All rooms are Uncomfortable	TR=20%; 55/65 $L_{Aeq;}$ R2 and R3 are uncomfortable	All rooms are uncomfortable
			TR=50%; 55/65 L_{Aeq}; W3, O3 and O4 are insufficient	
			TR=20%; 75L_{Aeq}; R2 and R3 are uncomfortable.	
			TR=50%; 75L_{Aeq}; W3, O1 and O4 are insufficient	

For the obstructed buildings

- In winter and at all directions none of the facades are sufficient for none of the offices
- In summer in East and South at the office R1, the required conditions are held for 20% of transparency ratio and 55/65 L_{Aeq} outdoor noise.

For the unobstructed buildings;

- In winter none of the facade alternatives are appropriate for North and West. At East and South for the bigger ratios of transparency , inappropriate situations occur and generally window W3 and wall type O1 insufficient.
- In summer at other directions than North there are building envelope alternatives causing appropriate conditions, although in North none of them this is sufficient. On the other hand, sufficient conditions held in East and South are more than those in West. In general, window W3 and wall type O4 are in sufficient.

Although in different scientific works, the importance of the designing building envelopes as to the direction is emphasised, it is difficult to mentioned that in applications this is largely considered. By the work realised in this project it is once more demonstrated that in the determination of building envelope different details should be applied regarding to direction.

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