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Designing opaque building façade components for cooling energy conservation

Ş. Filiz AKŞİT
Istanbul Technical University Faculty of Architecture, Istanbul TURKEY

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Abstract
The objective of this paper is the presentation of an approach towards the design the texture of the opaque façade of buildings with the aim of cooling energy conservation. This study is based on the development and assessment of different alternatives for the opaque façade on the design stage of a building which are compared with respect to their heat gain during the period of the year when cooling may be required to achieve comfort conditions in dependence of their orientation, and includes a way of selecting the alternative with the lowest heat gain. The application was realized in order to show that in particular in regions with high cooling energy expenses the development of different alternatives for opaque façades at the architectural design stage of a building can provide designs with reduced heat gain. The method developed in this study was applied to Istanbul region.

Keywords: *Cooling energy conservation, energy consumption, texture of the opaque component*

Introduction

The façade of a building is an aspect of the architectural idea behind a building which is perceived at first, and which, therefore, plays an important part in the architectural design. The façade of a building is the result of a balanced interaction of various aspects such as harmony between building and environment, equipment with all the properties required for the particular function, dynamic of the façade (recesses and projections), ratio of opaque to transparent components, material, colour, etc. The façade of a building may be constructed from more than one material. Depending on the properties of the opaque component, the texture of the façade may be completely smooth or rough, have recesses or projections. The façade texture which is established as a result is at the same time one of the most effective tools to impart a distinguishing feature to an architectural design. With innovations introduced by new technology also the façade is changing and may acquire a different character. The building sector which develops in line with technology provides the opportunity for more flexibility in architectural designs. The architect put these possibilities to good use both in the functional and the aesthetic design of different façade textures. The texture of the façade in architectural designs is important with respect to technological, economical, socio-cultural aspects, harmonization with the environment, aesthetic impression etc, but also with respect to energy conservation. With the aid of different façade textures it is possible to reduce heat gain and consequently to reduce the requirement for cooling energy.

During the period of the year which requires cooling, the main instrument of protection against direct irradiation from the sun is the use of shading elements on the façade. It is, however, also possible to reduce heat gain with the introduction of simple changes in the façade texture without having to employ shading elements. It is obvious that with changes in the shaded and irradiated areas of a building façade, which occur constantly with the movement of the sun during the day, the façade texture assumes an important role in the control of the amount of heat gain. When calculating the heat gain during cooling period, the heat gain for different textures will be different because of the constant changes in shaded and irradiated areas. Façade textures which reduce the requirement of artificial cooling systems to a minimum during the cooling period, which – in other words – ensure energy conservation, should be the alternative of choice. These would be façade textures with the lowest heat gain.

Reduction of heat gain with the aid of the building façade is of particular importance in regions with a long cooling period and high cost of cooling energy. In temperate and hot regions of Turkey the cost of cooling energy is 4-5 times higher than the cost incurred for heating. For this reason, the expenses for cooling energy need to be reduced in particular in temperate and hot regions of the country. Minimization of cooling energy costs during the period of the year requiring cooling is possible with the aid of the façade texture. In this study the cooling period is defined as the period which requires the use of mechanical cooling systems in order to achieve climatic comfort conditions. It is a simple fact that a reduction in the load of mechanical cooling systems reduces the expenses for cooling energy (Koçlar Oral, 2002).

The parameters affecting heat gains related to opaque components of the building façade are,

- optical properties,
- U value and
- texture of the opaque component.

Optical properties are absorbtivity and reflectivity. The U value (overall heat transfer coefficient) of the opaque component is one of the most important termophysical properties affecting thermal performance of a building façade and it is easy to control by designers.

Depending on the texture of the opaque component, shaded and irradiated façade areas change with the position of the sun during the day. The heating effect of solar radiation can be minimized by reducing the irradiated façade area. A texture of the opaque component which provides as large a shaded area as possible should be preferred for temperate and hot regions during the cooling period. This paper, therefore, aims at examining the effect of the texture of the opaque component on heat gains through the building façade by means of the proposed method.

Methodology
One of the most important parameters affecting cooling energy consumption, in other words heat gains, is the building façade. In order to minimize heat gains through the building façade it is necessary to:

- determine appropriate values for the heat transfer coefficient of opaque and transparent façade components,
- reduce opaque and transparent surface areas where the heat gain is high, and
- prevent the heating effect of solar radiation by providing shaded areas at the opaque component and transparent parts of the building façade.

The study was carried out to determine the effect of the texture of the opaque component on energy consumption for cooling. The methodology of the study comprises the following main steps (Akşit, 2002) :

1. Determination of the opaque component alternatives
The most appropriate opaque façade components and elements have to be defined by way of developing various alternatives used in the construction sector for opaque component elements with respect to their heat transfer coefficients. In this step optical properties and the orientation of opaque components are also determined for opaque component alternatives.
When determining alternatives for the façade texture, it was taken care to select cost reducing alternatives which can easily be employed by the construction industry. To facilitate easy construction of recesses and projections, concrete was selected as opaque component material. For the recesses and projections 5 cm and multiples of it have been applied horizontally and vertically in a systematic way. In order to allow for comparison, the ratio of recesses and projections of all façade textures was selected as:

- $A_{recess} / A_{façade} = 0.75$
- $A_{projection} / A_{façade} = 0.25$

The façade texture alternatives examined in this study are given in Figure 1. Alternative 1 is a flat surface without any recesses or projections. It was used as reference for the efficiency of the other alternatives.

Alternative 2 is an opaque façade with horizontal projections, and alternative 3 a façade with vertical projections. The alternatives 4 and 5 have been derived from the alternatives 2 and 3.

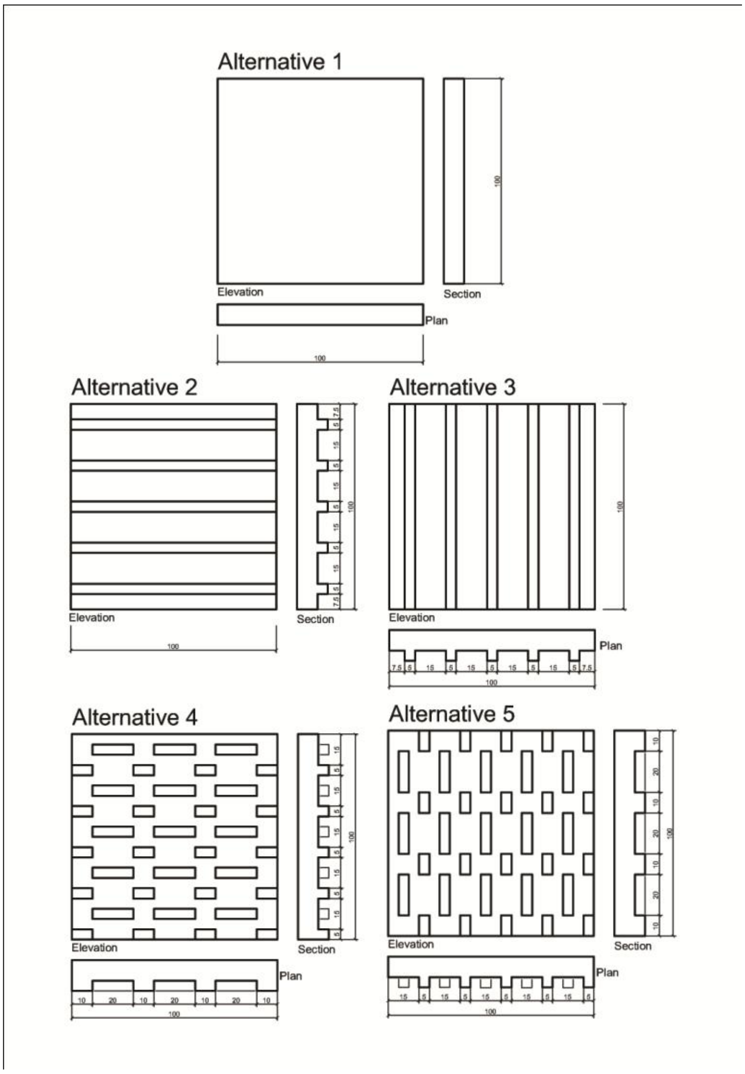

Figure 1. *Opaque component alternatives*

2. Determination of the U value of the opaque component alternatives

The overall heat transfer coefficient of the opaque façade component which consists of different sections can be calculated with the following formula.

$$U_o = \frac{U_1 . A_1 + U_2 . A_2 + ... + U_n . A_n}{A_1 + A_2 + ... + A_n} \qquad [1]$$

U_o : Overall heat transfer coefficient of the opaque component, $W/m^{2o}C$
$U_1,U_2...U_n$: Overall heat transfer coefficients of each different section created by the opaque component, $W/m^{2o}C$
$A_1,A_2...A_n$: Area of each different section created on the opaque component, m^2

The overall heat transfer coefficient of each different section of the opaque component (U_1, U_2 ... U_n) which are indicated in the equation above can be calculated with the following formula (ASHRAE, 1993).

$$U_1\ , U_2 ... U_n = \frac{1}{1/\alpha_i + d_1/\lambda_1 + d_2/\lambda_2 + ... + d_n/\lambda_n + 1/\alpha_d} \qquad [2]$$

α_i , α_d : Inner and outer surface heat transfer coefficients, W/m^{2o}C
d_1,d_2 ... d_n : Thickness of each layer, m
λ_1,λ_2 ... λ_n : Thermal conductivity of each layer, W/m^{o}C
1,2 ... n : Layer numbers

To select other variables related to the façade affecting cooling energy conservation, parameters such as orientation and optical properties of the opaque façade components have to be determined.

The overall heat transfer coefficient of the opaque component (U_o) is 0.45 W/m^{2o}C. This value is the minimum value of the overall heat transfer coefficient for an opaque component that can be considered in reference to building materials produced in Turkey.

It was assumed that the building façades are oriented west, southwest, south, southeast and east. The external surfaces of the façade elements are painted in a bright colour with an absorbtivity (a_o) of 0.40.

3. Calculation of heat gains per unit area for texture alternatives of the opaque component

In order to calculate heat gains per unit area for alternatives of the texture of the opaque component, the following method was applied:

- Selection of the design day and evaluation of the meteorological data

To minimize demand for supplementary mechanical cooling energy, the optimum value of the overall heat transfer coefficient for opaque components should be determined in terms of the climatic conditions of the region during the cooling period. Instead of repeating the calculations for all days of the cooling period, it is more convenient to choose a representative design day which simplifies the calculation.

Values of climatic parameters such as solar radiation intensities and outdoor air temperatures are taken for the chosen design day.
Outdoor design conditions are determined for the design day, under real sky conditions.

July 21st was selected as the design day of the region`s cooling period. Outside air temperature and solar radiation data were obtained from the National Meteorological Institute. The calculations were made for "real sky" conditions.

- Determination of the indoor design conditions

Indoor design conditions can be derived from the comfort conditions. Indoor climatic parameters are air temperature, relative humidity, air velocity and inner surface temperatures, whose comfort values can be determined by means of comfort charts.

The permissible limit value of inner surface temperature for an opaque component is calculated as follows (Oral, Yılmaz, 2002):

$$t_{mrt} = t_i \pm \varepsilon \qquad [3]$$

t_{mrt} : Permissible limit value for mean radiant temperature of the opaque façade component for the design day of the cooling period, ^oC
t_i : Comfort value of indoor air temperature, ^oC
ε : Permissible limit value for difference between inner surface temperature and indoor air temperature, ^oC.

The comfort value of indoor air temperature is 25^{o}C (Berköz et al., 1995), (ASHRAE,1981), (Norman, Bryson, Cunnıngham, Thomas,1983). The permissible limit value for the difference between inner surface temperature of the building façade and comfort value of indoor air temperature is +3^{o}C during the cooling period. Permissible limit value for mean radiant temperature is 28^{o}C.

- Calculation of shaded and irradiated areas on the opaque component for each hour of the design day

Depending on the recesses and projections on the opaque component and their thickness, different shaded and irradiated areas will be formed.

In order to be able to calculate the shaded and irradiated areas with respect to the recesses and projections on the opaque component, a shading analysis must first be carried out. The shading analysis can be carried out by means of profile angles.

To calculate shaded areas, the profile angles (Ω) and the horizontal shadow angles (δ), are used (Figure 2). The profile angle is the angle between the perpendicular plane of the direction of the solar radiation and the horizontal plan. Profile angles can be calculated as follows on the basis of the sun altitude angle and the wall-solar azimuth angle (ASHRAE, 1993):

$$\Omega = \tan^{-1} (\tan \beta / \cos \gamma) \qquad [4]$$

Ω : Profile angle
β : Sun altitude angle
γ : Wall-solar azimuth angle
The horizontal shadow angle (δ) is the difference between the solar azimuth and wall azimuth.

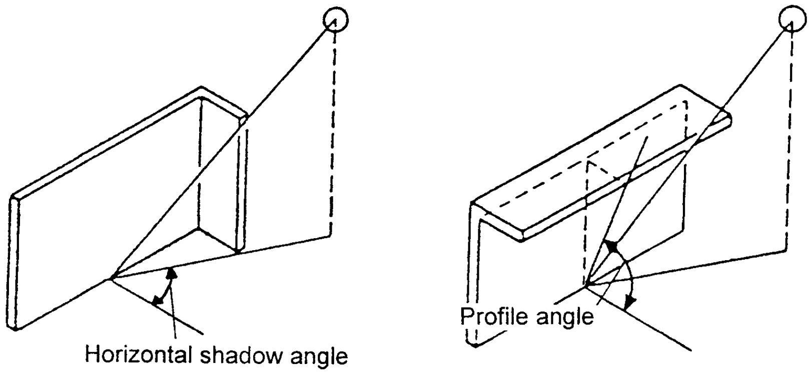

Figure 2. *Horizontal shadow angle (δ) and profile angle (Ω) (Pita,1989).*

With the aid of the profile angels and the horizontal shadow angles given in Table 1, the shaded and irradiated areas in the façades have been calculated for each hour of the design day (21st of July) and for each orientation. The programme Autocad was used to draw and calculate the shaded and irradiated areas on the façades. The drawings in Figure 3 indicate the shaded and irradiated areas for 11 am on the design day, with orientation to the south. Similar drawings have been made for each orientation and each hour of the day.

Table 1. *Profile angles (Ω) and horizontal shadow angles (δ) determined for*

	W		SW		S		SE		E	
Hour	Ω	δ	Ω	δ	Ω	δ	Ω	δ	Ω	δ
5							5,83	70	2,21	25
6							25,5	61	13,5	16
7							35,9	52	24,2	7
8					85,8	87	43,3	42	35	3
9					77,3	76	51,4	31	47,9	14
10					72,5	61	58	16	60,4	29
11			86,5	82	70,4	37	66,2	8	75	53
12	90	90	75,6	45	70	0	75,6	45	90	90
13	75	53	66,2	8	70,4	37	86,5	82		
14	60,4	29	58	16	72,5	61				
15	47,9	14	51,4	31	77,3	76				
16	35	3	43,3	42	85,8	87				
17	24,2	7	35,9	52						
18	13,5	16	25,5	61						
19	2,21	25	5,83	70						

Istanbul region

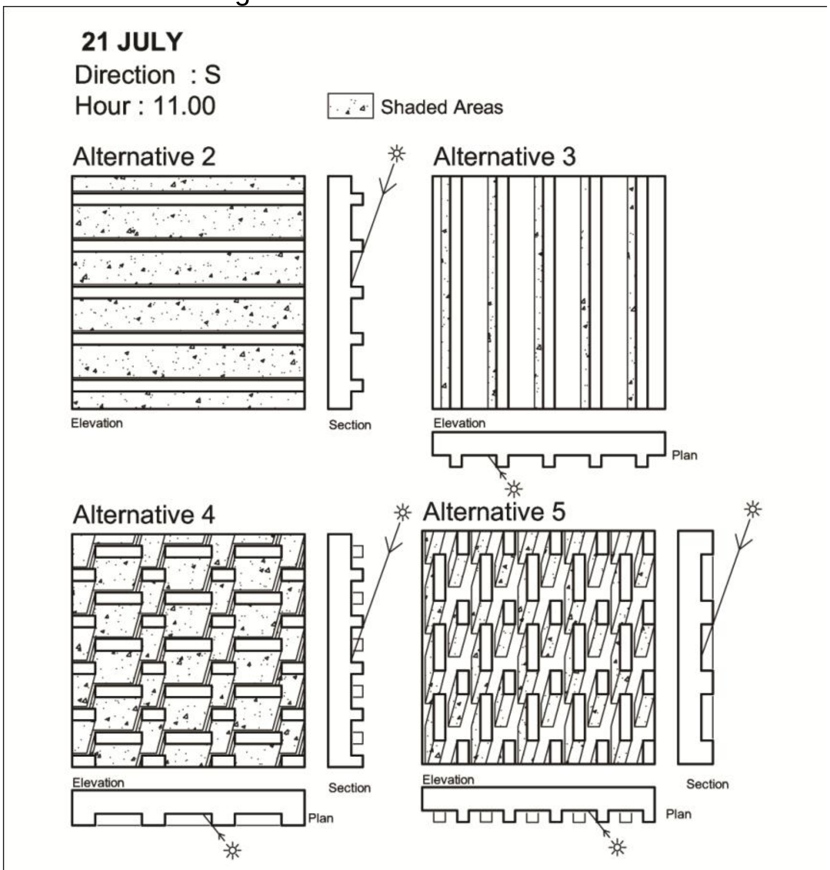

Figure 3. *Shaded and irradiated areas for 11 am on July 21st with orientation to the south*

- Calculation of sol-air temperatures affecting shaded and irradiated areas on the opaque component

In this study, sol-air temperatures are taken as outdoor design temperatures. The sol-air temperature is a theoretical external temperature that determines a temperature equal to the combined effect of solar radiation and outdoor temperature on any building component so that it is higher than the actual outdoor air temperature. The hourly values of sol-air temperatures for opaque components are calculated by means of the following formula (ASHRAE, 1993);

$$t_{eo} = t_d + \frac{I_T . a_o}{\alpha_d} \qquad [5]$$

t_d : Outdoor air temperature, ^oC

I_T : Intensity of total solar radiation on the opaque component surface, W/m^2

a_o : Absorbtivity of the opaque component surface

α_d : External surface heat transfer coefficient, $W/m^{2o}C$

The sol-air temperatures for the shaded and irradiated areas of the building façade can be calculated separately with respect to the intensity of the direct and diffuse solar radiation. The intensity of the overall intensity of solar radiation is equal to the sum of the intensities of direct and diffuse radiation. In case the component remains in the shade, the value for direct radiation is taken to be zero.

Daily values of sol-air temperatures (t_{eoo}) for opaque components are calculated by means of the following formula;

$$t_{eoo} = \left(\sum_{i=1}^{24} t_{eo}\right) / 24 \qquad [6]$$

Sol-air temperatures were used as the outdoor design temperatures.

- *Determination of the cooling period*

The cooling period in the context of this study was taken from previous scientific studies which had established this period for various climatic regions of Turkey on the basis of regional meteorological and consumer data (Akşit, 2002), (Koenigserger, Ingersoll, Mayhew, Szokolay,1973). Sol-air temperatures were used as external design temperatures for the determination of the cooling period. Since sol-air temperatures change with the orientation of buildings the cooling period changes accordingly.

Figure 4 shows cooling periods related to different orientations for the region of Istanbul.

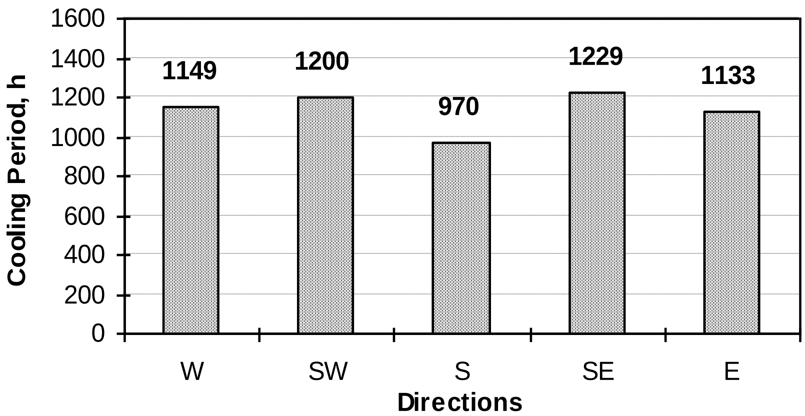

Figure 4. *Cooling period related to different orientations for the region of Istanbul*

- Calculation of heat gain per unit area of texture of the opaque component alternatives during the cooling period

Istanbul region for which the calculation was carried out is located in a temperate-humid climatic zone. Since the daily external air temperature change in this climatic zone is not as extensive as in the hot zone, the heat gain calculation in this study was carried out for a steady state.

The heat gain passed through the opaque façade component can be calculated with the formula below:

$$Q = U_o \,.\, (t_{eo} - t_i) \qquad [7]$$

Q : Amount of daily average heat gain per hour and unit area of the opaque component, W/m^2
U_o : Overall heat transfer coefficient of opaque façade component, $W/m^{2o}C$
t_{eo} : Sol-air temperature of the opaque component, ^oC
t_i : Indoor air temperature, ^oC

When the shaded and irradiated areas are taken into consideration, heat gain related to various factor values of the overall heat transfer coefficient established at various recesses and projections can be calculated with the formula below:

$$Q=\frac{[(U_1.A_{1s}.(t_{eos}-t_i))+(U_1.A_{1i}.(t_{eoi}-t_i))+(U_2.A_{2s}.(t_{eos}-t_i))+(U_2.A_{2i}.(t_{eoi}-t_i))]}{A_{1s} + A_{1i} + A_{2s} + A_{2i}} \qquad [8]$$

U_1 : Overall heat transfer coefficient of the projections of the opaque component, $W/m^{2o}C$
U_2 : Overall heat transfer coefficient of the recesses of the opaque component, $W/m^{2o}C$
A_{1s} : Shaded area on the projections of the opaque component, m^2
A_{1I} : Irradiated area on the projections of the opaque component, m^2
A_{2s} : Shaded area on the recesses of the opaque component, m^2
A_{2I} : Irradiated area on the recesses of the opaque component, m^2
t_{eos} : Sol-air temperature affecting the shaded façade areas, ^oC
t_{eoi} : Sol-air temperature affecting the irradiated façade areas, ^oC,

Heat gains during the cooling period per unit area of the texture of the opaque component are calculated by multiplying the values of daily average heat gains per hour and unit area with the number of hours of cooling period, thereby taking the orientation into account.

Figure 5 gives the variation of the daily average hourly heat gains per unit area of the alternatives for the design day (21 July) with due consideration of the orientation.

4. Comparison of the heat gains calculated according to façade texture alternatives and orientations for the cooling period

The main criterion which is used for the comparison is given below:
'The texture of the opaque component that provides minimum heat gain during the cooling period is qualified as the most appropriate one'.

$a_o = 0.40$

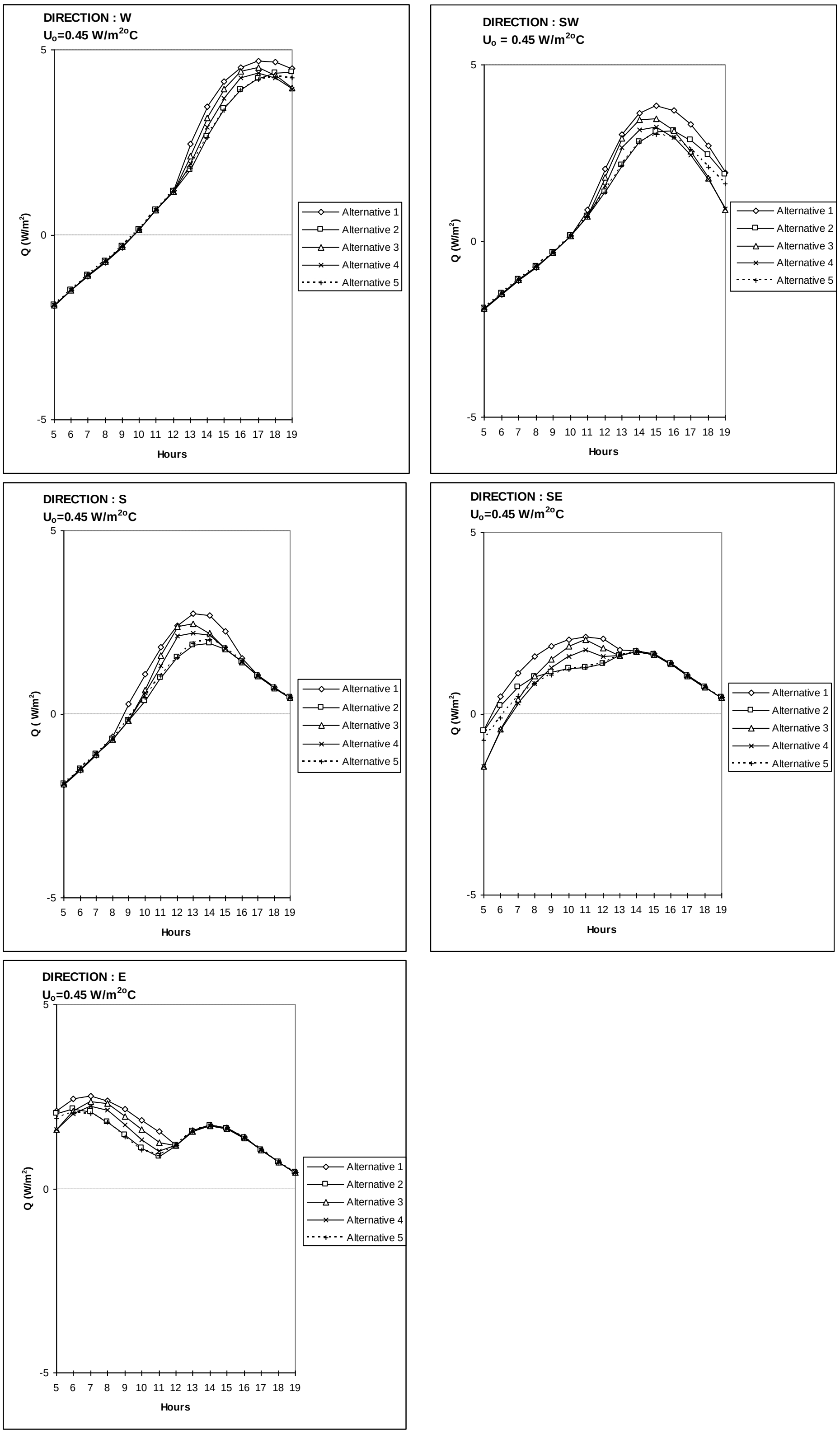

Figure 5. *Variation of the daily average hourly heat gains per unit area of the different alternatives.*

Comparison of the heat gains calculated and the selection of the appropriate alternative for the texture of the opaque component can be realized by means of graphics. Hourly heat gains of the texture of the opaque component alternative with respect to orientation can be plotted on the same graphic. This display allows comparison of different alternatives for each hour of the day. Since the alternative with minimum heat gain requires minimal mechanical cooling energy consumption, it is the most appropriate alternative from the cooling energy conservation point of view.

Figure 6 shows the different heat gains per unit area of the opaque façade alternatives with respect to their orientation. Alternative 2 which is oriented south ensures the lowest heat gain.

$a_o = 0.40$

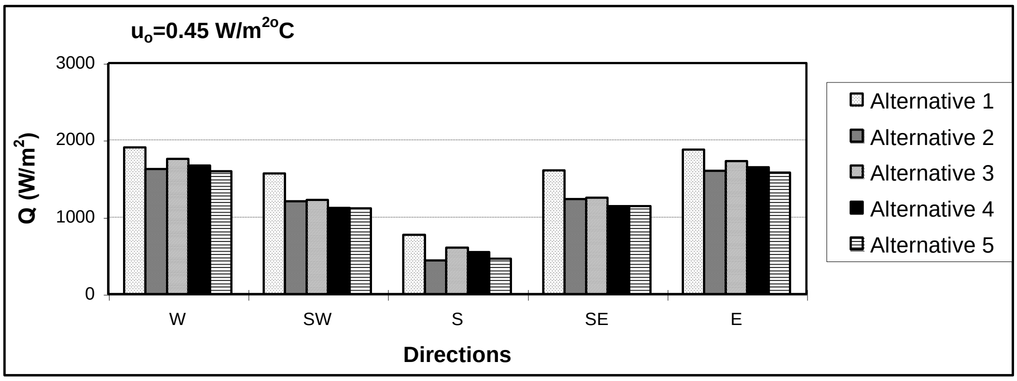

Figure 6. *Heat gains per unit area of the different alternatives during the cooling period*

Conclusion

In this study different opaque façade alternatives have been compared with respect to their heat gain. In Figure 7 the reduction in heat gain of the different alternatives during the cooling period has been given as percentage of the flat façade alternative without recesses and projections (alternative 1). For the south-oriented alternative 2 for example, this reduction reaches a value of 43.45%. In other words, the cooling load of alternative 2 is 43,45% less than for the flat façade of alternative 1.

Detailed comparision of the different opaque façade alternatives yields the following results:

- Orientation of the façade to the south results in a reduction of the cooling load of 43.45% for alternative 2, 21.54% for alternative 3, 40.30% for alternative 4 and 29.22% for alternative 5 as compared to alternative 1.
- Orientation of the façade to the southwest and southeast results in a reduction of the cooling load of 23.05% for alternative 2, 21.98% for alternative 3, 28.87% for alternative 4 and 28.71% for alternative 5 as compared to alternative 1.
- Orientation of the façade to the west or east results in a reduction of the cooling load of 14.67% for alternative 2, 7.85% for alternative 3, 16.06% for alternative 4 and 12.38% for alternative 5 as compared to alternative 1.

a_o = 0.40

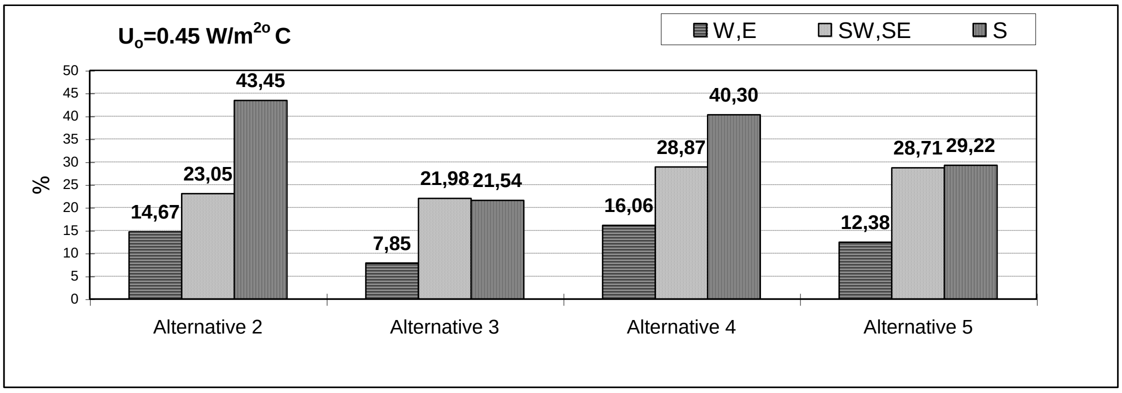

Figure 7. *Reduction in heat gain as percentage for different alternatives during the cooling period compared to Alternative 1*

As can be seen from the results of the comparison, with changes in the opaque façade at the architectural design stage it is possible to reduce heat gain and with it cooling energy expenses.

This study is of particular interest for developing countries such as Turkey where expenses for cooling energy constitute an important part of the total energy expenses. As a result of this study, it should be stressed that the contribution of the appropriate architectural design to the reduction of energy consumption in the operation of the finished buildings can be considerable.

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Soğutma enerjisi korunumu açısından opak cephe elemanı tasarımı

Bu makalede, soğutma enerjisi korunumu açısından opak cephenin tasarımına yönelik bir çalışmanın sunulması hedeflenmektedir. Çalışmada ele alınan yaklaşım, tasarım aşamasında geliştirilmiş olan farklı opak cephe alternatiflerinin, yönlendiriliş durumuna bağlı olarak soğutmanın istendiği dönemde ısı kazançlarının karşılaştırılması ve farklı alternatifler arasından en az ısı kazancını sağlayan alternatifin seçilmesini kapsamaktadır. Uygulama çalışması, özellikle soğutma enerjisi harcamalarının fazla olduğu bölgelerde, mimarın tasarım aşamasında geliştireceği farklı opak cephe alternatifleri ile ısı kazançlarının azaltılabileceğinin ortaya konulması amacıyla gerçekleştirilmiştir.

Binalarda kullanılan cephe dokularının, günün her saatinde cephe yüzeyinde oluşturduğu gölgeli ve güneşli alanların değişimiyle, ısı kazancı miktarlarının değişiminde önemli rol oynayacağı açıktır. Soğutmanın istendiği dönem için ısı kazancı miktarı hesaplarında, her doku ve her saatteki gölgeli ve güneşli alanlar farklı olacağından her doku için ısı kazançları farklı olacaktır. Soğutmanın istendiği dönemde, binalarda yapma soğutma sistemlerinin minimum düzeyde çalışmasını sağlayan dolayısıyla soğutma enerjisi tasarrufu sağlayan cephe dokuları tercih edilmelidir. Diğer bir deyişle, en az ısı kazancını sağlayan cephe dokusu alternatifinin seçilmesi gerekmektedir.

Cepheler aracılığı ile ısı kazançlarının azaltılması, özellikle soğutma enerjisi maliyetlerinin yüksek olduğu ve soğutmaya ihtiyaç duyulan dönemin uzun olduğu bölgelerde önem kazanmaktadır. Türkiye'de, ılımlı ve sıcak iklim bölgelerinde soğutma enerjisi maliyetleri, ısıtma enerjisi maliyetlerinin 4-5 kat üzerinde olmaktadır. Bu nedenle özellikle ılımlı ve sıcak iklim bölgelerinde soğutma enerjisi maliyetlerinin düşürülmesi gerekli olmaktadır. Soğutma enerjisi maliyetlerinin minimize edilmesi, soğutmaya ihtiyaç duyulan dönem süresince cepheler aracılığı ile ısı kazançlarının azaltılması ile olanaklı olabilmektedir. Bu çalışmada soğutma dönemi iklimsel konfor koşullarının gerçekleştirilebilmesi için mekanik soğutma sistemlerine ihtiyaç duyulan dönem olarak tanımlanmaktadır. Bilindiği gibi mekanik soğutma sistemlerinin görev payı minimize edilirse, soğutma enerjisi giderleri de azaltılabilecektir.

Soğutma enerjisi maliyetini dolayısıyla bina cephesinden ısı kazançlarını azaltmak için;

- Cephe opak ve saydam bileşenine ait toplam ısı geçirme katsayısı için uygun değerlerin belirlenmesi,
- Isı kazancının yüksek olduğu opak veya saydam yüzey alanlarını azaltmak ve
- Cephede gölgeli alanlar yaratarak güneş ışınımının ısıtıcı etkisini azaltıcı önlemler almak

gerekmektedir.

Bu çalışmada; soğutma enerjisi korunumunu hedefleyen cephe dokusunun belirlenmesi hedeflenmektedir. Çalışmanın adımları ise aşağıdaki gibidir:

1. Cephe Dokusu ve Cephe Dokusunu Oluşturan Opak Bileşene Ait Alternatiflerin Belirlenmesi

Cephe dokusunu oluşturan cephe opak bileşenine ait alternatiflerin toplam ısı geçirme katsayılarının ve optik özelliklerinin belirlenmesi ve bu değerlere bağlı olarak opak bileşenlere ait katmanlaşma detayları için yapım sektöründe kullanılabilecek çeşitli alternatifler geliştirilmesi yolu ile en uygun cephe opak bileşeni ve katmanlaşma detayı alternatiflerinin belirlenmesi gereklidir. Cephe opak bileşeninin bazı bölümlerinde, dokudan dolayı farklı kalınlıklar mevcuttur. Bu nedenle, farklı kalınlıklardaki kesitlerin toplam ısı geçirme katsayıları da birbirinden farklı olacaktır

Soğutma enerjisi korunumu sürecinde etkili olan cepheye ilişkin diğer değişkenlerin seçilmesi için, cephenin baktırılabileceği yönler ve cephe dokusuna ait cephe opak bileşenlerinin optik özellikleri belirlenmelidir.

2. Cephe Dokusu Alternatifleri İçin Birim Alandan Kazanılan Isı Miktarlarının Hesaplanması

Cephe dokusu alternatifleri için farklı katmanlaşma detaylarına bağlı olarak birim alandan kazanılan ısı miktarlarını hesaplamak için izlenen yol aşağıda açıklanmıştır.

- Hesaplamaların Yapılacağı Tasarımın Dayandırıldığı Günün Belirlenmesi
- Tasarımın Dayandırıldığı Dış Koşullarının Belirlenmesi

Tasarımın dayandırıldığı gün için; güneş ışınımı, dış hava sıcaklığı gibi iklim elemanlarına ait değerler gerçek atmosfer koşullarına göre belirlenmelidir.

- Tasarımın Dayandırıldığı İç Koşullarının Belirlenmesi

Tasarımın dayandırıldığı iç koşullar, iklimsel konfor açısından cephe opak bileşenine ait termofiziksel özelliklerin belirlenmesinde uygulanan tasarım değişkenleridir. İklimsel konfor açısından bir hacimdeki iç yüzey sıcaklıklarının, iç hava sıcaklığı kadar önemli olduğu bilinmektedir.

- Ele Alınan Cephe Dokusu Alternatiflerine Göre Tasarımın Dayandırıldığı Gündeki Tüm Saatler İçin Cephede Oluşan Gölgeli ve Güneşli Yüzeylerin Belirlenmesi ve Alanlarının Hesaplanması

Cephede oluşan gölgeli alanları hesaplayabilmek için, profil açıları ve genişlik açıları kullanılır. Genişlik açıları, cepheye dik konumlandırılmış düşey elemanların duvara paralel kenarlarının gözleme noktası ile oluşturdukları düzlemlerin duvar düzlemi ile yaptıkları açılardır. Profil açıları ise, güneşin yükseliş açısı ve cephe-güneş azimut açılarına bağlı olarak hesaplanabilmektedir.

- Tüm Saatlere Göre Cephede Oluşan Gölgeli ve Güneşli Yüzeyler İçin Sol-Air Sıcaklıkların Hesaplanması

Sol-air sıcaklık, dış hava sıcaklığı ve güneş ışınımının birleşik etkisini ifade eden teorik bir sıcaklıktır ve dış hava sıcaklığından daha yüksektir.

- Soğutmanın İstendiği Dönemin Belirlenmesi

Bu çalışmada soğutmanın istendiği dönem süresi İklimsel Konfor Grafiği aracılığı ile belirlenmektedir. İklimsel Konfor Grafiği'nde görülen 'Durgun Hava Koşulları İçin Konfor Bölgesi'nin üst sınırını belirleyen 0.25 m/sn hava hareketi hızı eğrisi ve iç çevrede izin verilebilen maksimum hava hareketi hızını belirleyen 0.8 m/sn iç hava hareketi hızı eğrisi arasında kalan dönem, doğal vantilasyonla konforun ihtiyaçlar açısından sağlanabileceği dönemdir.

0.80 m/sn'nin üzerinde iç hava hareketi ihtiyacı istenen dönem ise doğal vantilasyonun yetersiz kaldığı ve istenen iç iklimsel koşulların sağlanabilmesi için soğutma enerjisine ihtiyaç duyulan dönemdir.

Her ayın 21. günlerine ait 10 yıllık saatlik ortalama dış hava sıcaklığına bağlı olarak hesaplanan sol-air sıcaklıklar ve bağıl nemlilik değerleri İklimsel Konfor Grafiğine işlenerek hacim içersinde istenen hava hareketi hızları (V_{ist}) belirlenebilmektedir.

- Soğutmanın İstendiği Dönem İçin Cephe Dokusu Alternatiflerinin Birim Alanlarından Kazanılan Isı Miktarlarının Hesaplanması

Cephe dokusunun birim alanından kazanılan dönemlik ısı miktarları, yönlere göre birim alandan kazanılan günlük ortalama saatlik ısı miktarlarının soğutmanın istendiği dönemin saat sayısı ile çarpılması sonucunda bulunmaktadır.

3. Soğutmanın İstendiği Dönem İçin Yönlere ve Cephe Dokusu Alternatiflerine Bağlı Olarak Hesaplanan Isı Kazancı Miktarlarının Karşılaştırılması

'Soğutmanın istendiği dönemde minimum ısı enerjisi kazancını sağlayan alternatif en uygun alternatiftir' kriteri uyarınca karşılaştırma yapılmaktadır. Bu kriter uyarınca soğutmanın istendiği dönem süresinde en düşük ısı enerjisi kazancını sağlayan alternatif belirlenebilmektedir.

Hesaplanan ısı kazancı miktarlarının karşılaştırılması ve uygun katmanlaşma detayı ve cephe dokusu alternatifinin seçilmesi grafikler yardımıyla yapılabilir. Yönlere göre her bir katmanlaşma detayı ve cephe dokusu alternatifinin saatlik ısı kazancı miktarları aynı grafiğe işlenerek gün saatlerinde her saat için farklı alternatiflerin karşılaştırılması mümkün olabilir. Bu grafikler yardımı ile ele alınan farklı doku alternatiflerinde minimum ısı kazancını sağlayan alternatif, yapma soğutma enerjisi harcamalarının minimize edilmesini sağlayacağından soğutma enerjisi tasarrufu açısından en uygun alternatif olarak seçilebilmektedir.

Bu çalışmada farklı opak cephe alternatifleri, ısı kazaçları açısından birbirleri ile karşılaştırılmıştır. Karşılaştırma sonuçlarından görüldüğü gibi, mimarın tasarım aşamasında opak cephelerde yapacağı düzenlemelerle, ısı kazançlarını ve dolayısıyla soğutma giderlerini azaltması mümkün olabilmektedir.

Bu çalışmalar, özellikle Türkiye gibi soğutma enerjisi harcamalarının toplam enerji harcamaları içersinde önemli bir yeri olan gelişmekte olan ülkeler için önem taşımaktadır. Sonuç olarak, tasarım aşamasında enerji ekonomisi açısından mimar tarafından alınacak doğru kararların binanın işletmesi aşamasında enerji giderlerinin azaltılmasına önemli katkılar sağlayacağı gözardı edilmemelidir.