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Daylight and Energy Oriented Architecture Design Support Model

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ABSTRACT

Daylight and energy are a fundamental input for architectural design. It is vital to have a stock of knowledge that will enhance the bond between daylight and other physical environment data. This study aims to develop a new model of thinking that will bridge the gap between daylight, thermal comfort and energy data and the design process.

The proposed "Design Support Model" is an interactive one; with a primary focus on the uniqueness of each design, especially in terms of the designer inclination. The model first determines the designer's inclination in issues of physical environment, with the help of the Analytical Hierarchy Process (AHP). Control tables have been developed, for variables of function, climate zone, tendency and the designer inclination, in line with limit values prescribed by the literature and standards. After all physical environment issues are mapped out for each factor concerning the space at hand, the model provides the designer with solution alternatives for the defined problems. A weighted ranking of decisions is obtained, again using the AHP mathematical decision-making method, so that designers can evaluate the proposed solution alternatives and make their own mind for their own design.

Key words: Daylight; Thermal Comfort; Energy; Architectural Design Stage; (Analytic Hierarchy Process) (AHP); Design Support Model

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1. INTRODUCTION

Physical environment, climatic factors, and the daylight which is combination of these two, are providing important data for architectural design. Physical environment factors, which play an important role in design and affect the quality of life in the space, need to be given priority at the design stage; they can also be very difficult to manage. Utilizing the daylight design effectively, of course, is only possible through the use of all other physical environment values. In today's spaces, however, the daylight factors are often omitted during the design process. This results in a decrease in the overall quality of the space, holding back its potential for more productivity. The physical environment values are only considered when the time comes for development stage, and unfortunately, this quest is completed as soon as the basic requirements are met. The solution to the problem is to include the physical environment values at the early stages of the design process, leading the way to alternative solutions for architects.

Considering that the changeability of the design decreases as the design process proceeds, we can say that any decision for alteration brings more implications for costs and time, as we get closer to the final stage of the design process. This study claims that a methodology that includes daylight and all other physical environment values in the early stages of the design process, will increase the overall quality of the designed space, saving time and money for all parties involved.

An architectural project goes through certain stages from the point where the designer starts to think about the project, to the moment when the construction is finished. Although there are many different approaches to the design process, it is possible to talk about, broadly, three stages: concept, development and construction. Figure 1 illustrates flexibility for alterations and the cost of alterations throughout the design process. The physical environment values are usually evaluated at the development stage. However, if the daylight and other physical environment values were to be evaluated during the concept stage, projects would benefit from increased overall quality and productivity, including reduced costs and time saving. Not only does this approach improve quality, but it also helps the designer avoid many practical but challenging problems that could arise in the later stages of the project. The model proposed in this study makes use of contemporary computer technologies, which makes it all the more useful in terms of its compatibility with today's design techniques and its ability to generate faster results.

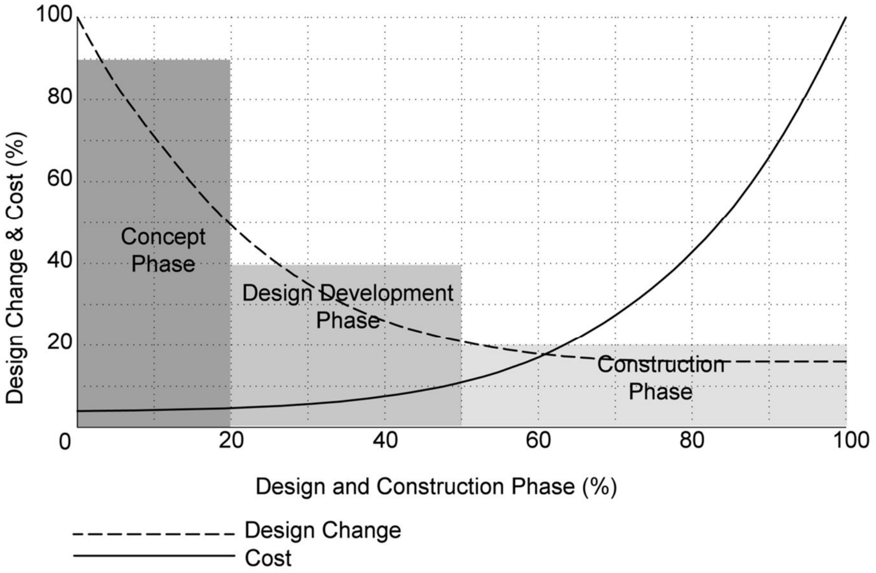


Figure 1. Flexibility for alterations and the cost of alterations throughout the design process [1].

The fact is, few architects are fully knowledgeable about daylight and other physical environment variables, and almost none have internalized the information in the literature, which is already limited. Thus, there is an obvious need for a support system that will aid and guide architects throughout the design process. This study proposes a new model that will support designers to make decisions, especially during the early design process, about daylight and other physical environment factors. The objective of this study is to develop a model that builds a relationship of daylight and other physical environment factors, with space and design.

2. LITERATURE REVIEW

Daylight has played an important role in shaping architectural design, from the early periods of architecture history. Daylight is a spatial design input that, when used productively, influences the quality of the space, giving people more comfort, and harmony with the natural environment. Therefore, architects put a lot of thought into this issue, even today.

In the past, before buildings were illuminated by electricity, the structure-daylight relation has been a critical one for architects. As artificial lighting started to be used widely, the issue of lighting started to be viewed by architects as artificially solvable. However, with the 1970s, came a new concern regarding scarcity of resources, which brought the daylight issue back to life. As a factor increasing spatial comfort and energy efficiency, daylight has started to become a separate field of study, attracting more and more scientific attention.

The benefits of daylight in architecture can be evaluated in two categories[2][3]:

Energy Saving and Reduction of the Heating Load: A significant proportion of total energy consumption of a building goes to lighting. Increasing the ratio of natural lighting directly decreases electricity consumption and all relevant energy costs [4][5].

Comfort, Productivity and Health: It is a proven fact that daylight increases personal performance, productivity and health. Experiments in school buildings yield better results in samples where the daylight factor is used effectively. In commercial spaces, daylight is known to increase sales. People are known to have better sleep patterns in those residences relatively more exposed to daylight. Research conducted in hospitals indicate the significance of daylight in the healing process of patients whose beds are placed near the window [6][7][8].

Medical science has defined inadequate daylight as a cause of headache, and overexposure to it as a cause of eye strain[9]. Appropriate use of the illumination factor is found to be a major determinant of one's visual performance, state of mind, preferences, satisfaction level and health. Correct use of illumination is found to be of supporting value for work performance, social relations and interpersonal communication [10][11]. Additional research regarding daylight, thermal performance and energy has verified the strong relation between daylight and other physical environment factors.

There are a limited number of methods available for the design process, specifically for the early stages, mostly because the data we have is very vague and uncertain. A very small proportion of the input we have is made up of definite decisions, and that makes it harder to choose between methods. The Analytic Hierarchy Process (AHP) is defined as the best one available among multiple criteria decision-making systems for resolving physical environment problems emerging at the design stage. In multiple criteria decision-making systems, the criteria are prioritized differently. In addition to the criterion value of alternatives, the ability of these values to meet the objectives must be measurable, as well. The Analytic Hierarchy Process, developed by T.L. Saaty, allows the decision maker(s) to recognize their own decision-making mechanisms, therefore helping them make decisions that are more appropriate for their own unique situation. Besides illustrating the interaction and the relative relation between decision elements, the AHP also allows for measuring the consistency of results or judgments. The AHP is a method that explains the way one perceives a complex problem and that provides an opportunity for them to resolve the problem in a systematic manner [12-15].

3. A SUPPORT MODEL FOR DAYLIGHT AND PHYSICAL ENVIRONMENT DESIGN

During the design process, architects do not always make decisions on a rational or analytical basis; they may also make arbitrary decisions, simply based on instincts. However, decisions about technical issues and physical environment mostly revolve around analytical grounds. At this point, the designer's knowledge and experience play an important role in defining current problems.

This model developed to increase the effectiveness of daylight and other physical environment values in space design, focuses on the daylight. The scope of the proposed "Design Support Model" includes the factors of thermal performance and energy efficiency in relation to the daylight issue.

3.1. The Structure and Method of the Model

The model gets involved in the design process, in order to support the designer in physical environment issues during the early stages. The results provided by the model are, then, evaluated by the designer.

The model, as can be seen in the flowchart presented, is built upon five hierarchical steps:

- Data Collection
- Analysis
- Defining Problems and Limitations
- Recommendation of Alternative Solutions
- Decision-making (choosing among alternatives)

The scheme in Figure 2 illustrates how the model works.

a) Step 1: Data Collection

At the "data collection step" all of the model's inputs are organized. The designer makes many decisions throughout the design process. All of these decisions – in addition to all the information regarding the current situation of the design – provide the basis for the inputs of the model. The design inputs of the model are categorized into two groups. The first category covers the constants, those inputs that are assumed to be unchanging, either during the design process or during the flow of the model. The second category consists of design variables, the values of which the designer may change at various points along the design process. These inputs may be grouped under the following categories:

- Constant Values: Input that does not change at any point during the design process
    - Constants that are independent from the designer
    - Constants that are purposefully kept unchanged by the designer
- Variables: Input that can change or can be manipulated during the design process

Some features regarding the space are not constant throughout the design process. These features constitute the "Variable Model-Design Inputs". In fact, when the model recommends solutions for physical environment problems, the recommended alternatives are decisions based on the variable inputs, rather than the constants.

b) Step 2: Analysis;

At this step, the physical environment factors are classified into three modules: daylight efficiency, thermal efficiency and comfort, and energy efficiency. Each module consists of various factors, which are analyzed to come up with useful data. The modules used in this proposed model are specific to the scope of the study. The model can be developed further, by adding or modifying modules. The modules examined in this study, as default, are listed below with their sub-factors.

- Daylight Efficiency Module
    - Daylight Illuminance
    - Daylight Illumination Efficiency
    - Daylight Autonomy Factor
    - Daylight Regularity Factor
    - Daylight Glare Index
- Thermal Efficiency and Thermal Comfort Module
    - Opaque Surface Thermal Protection Factor
    - Transparent Surface Thermal Protection Factor
    - Solar Radiation Factor
    - Thermal Decrement Factor
    - Time Lag Factor
    - Thermal Comfort Factor
    - Thermal Regularity Factor
- Energy Efficiency Module
    - Heating Energy
    - Cooling Energy
    - Lighting Energy

Today, the analysis results can easily be obtained by using new generation design programs integrated with BIM (Building Information Modeling) processes. The model first checks if there is a three-dimensional architectural model available; this is crucial for the model in generating results. If there is no three-dimensional model, then, the model suggests making one. Then, the spaces of the design are evaluated to determine which of them are going to be chosen as the basis for analysis. At this point, the criteria for evaluation are how critical a space is to the design, and how much importance it plays in shaping the design.

After the three-dimensional model of the design is brought into the correct format for physical environment analyses, the results for each factor are recorded in the "Analysis Result Recording Data Pool". The designer may access the results, using their preferred analysis program. Table 1 shows daylight analysis stage.

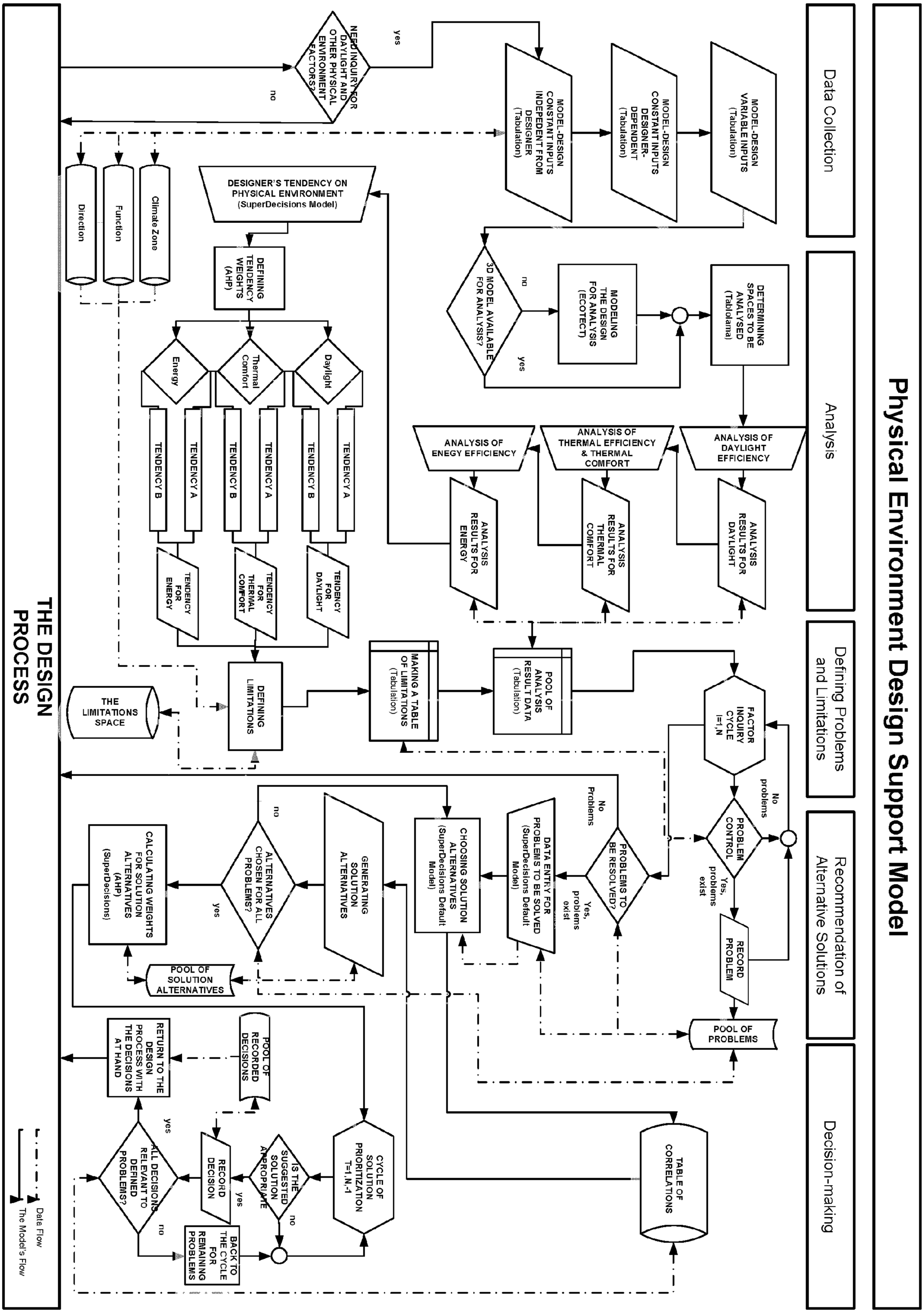


Figure 2. Flowchart for The Daylight and Physical Environment Design Support Model.

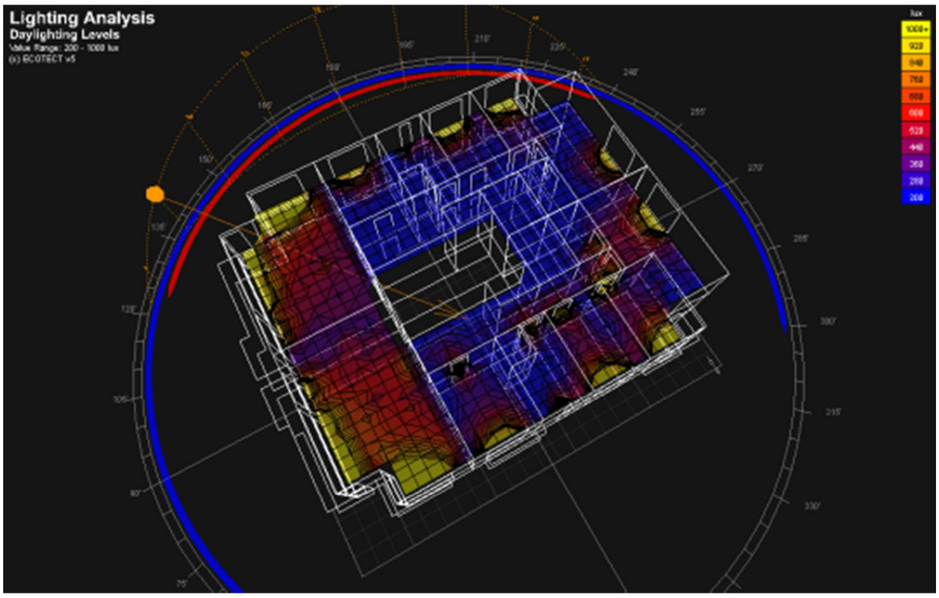
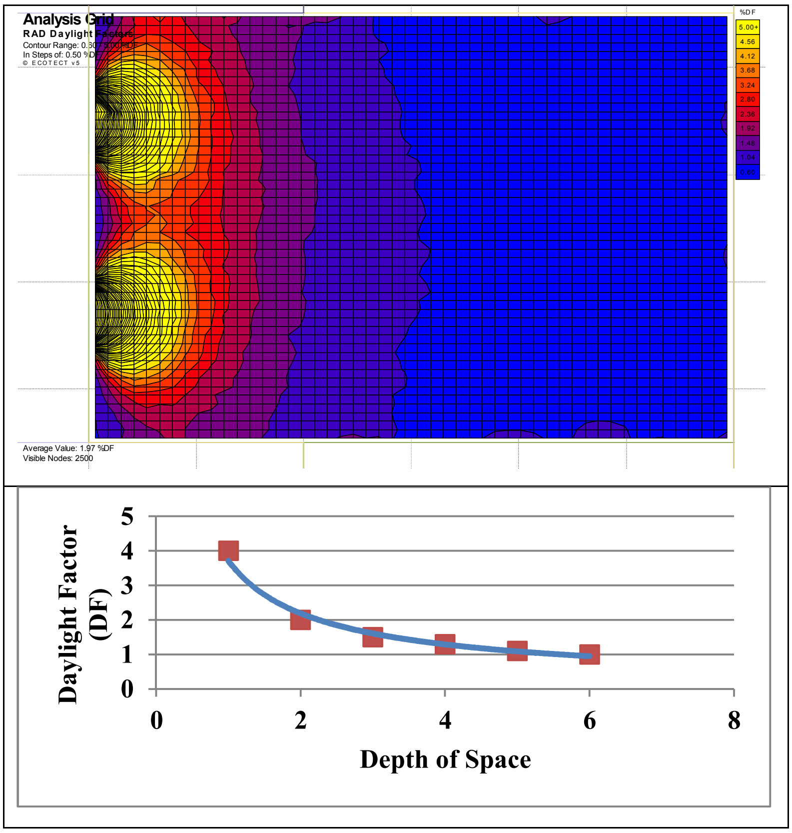


Figure 3. Daylight Analysis.

The factors in the Daylight Efficiency Module allow for a wide range of daylight analyses. Apart from the basic necessity for illumination, this module checks the parameters of visual comfort by evaluating factors, such as glaring and yearly changes in daylight. Thus, an extensive analysis of daylight becomes possible with the model.

Table 1. Analysis of The Daylight Regularity Factor.



The Thermal Efficiency and Thermal Comfort Module not only evaluates the impact of material on thermal protection, but also conducts the analyses necessary for thermal comfort, setting a spatial standard on this issue. The module puts forth the varying factors for varying climate conditions of Turkey, in a simple and comprehensible manner for the designers. These factors, once understood, are more easily evaluated and included in the design process. Using the ISO 7730 Standard [16] and other relevant standards of comfort, the model controls the quality of the space to a great extent.

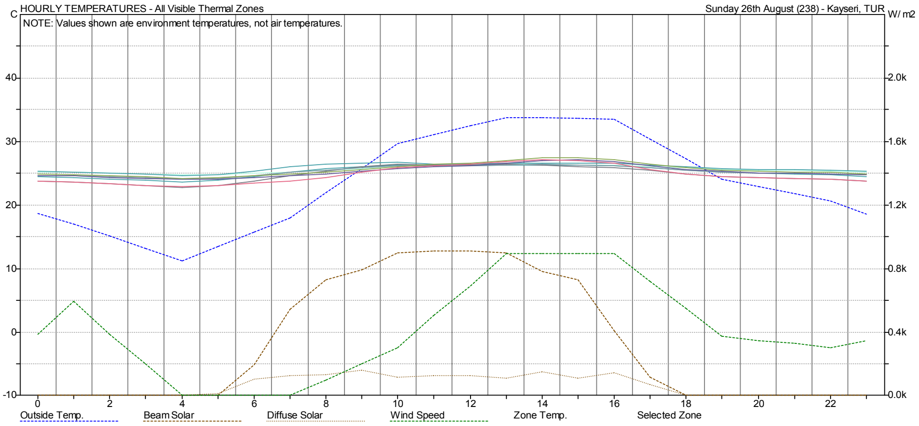


Figure 4. Analysis of Spatial Comfort for the Hottest Day of the Year.

The Energy Efficiency Module provides a system of checks and balances based on energy, no matter what alteration is made throughout the design process. This system is extremely crucial for the sustainability of the design. An approach that presents energy, both in total and in its sub-factors allows the designer to view their own idea in terms of energy distribution.

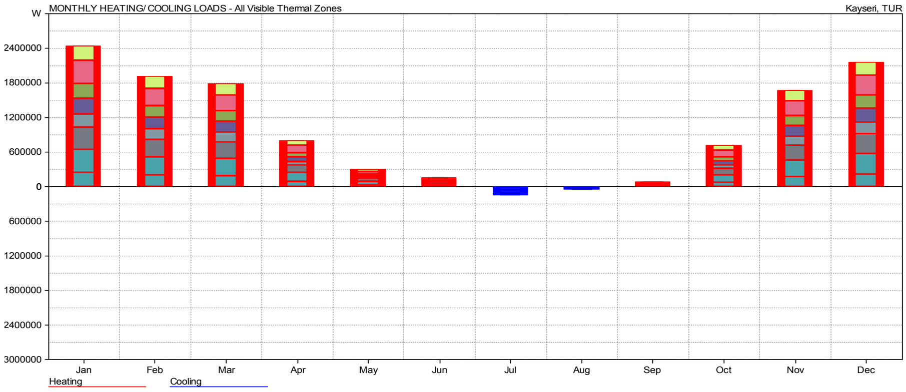


Figure 5. Heating-cooling Analysis for One Year.

Every design and designer approach physical environment values differently. The designer, based on their approach, priorities and preferences, can build a hierarchy of the three modules – daylight, thermal efficiency and energy. Thus, the model requires a definition of the designer's approach towards physical environment issues. In this way, the designer is able to access solution alternatives that are more applicable to their unique situation. "Hierarchical Weight Ratios" are used for this purpose. The hierarchical structure of the physical environment variables, in other words, the "Physical Environment Tendency" is determined for each design, by the designer, using the AHP (Analytic Hierarchy Process).

At this point, the designer, as the AHP suggests, fills in the two-way comparison matrices for main themes (modules) in order to transfer to the system their own tendencies. The SuperDecisions software is used for the AHP method. It presents the priority of each module according to the Project, therefore helping the designer prioritize between options, and make decisions. The designer is accepted to have Level A (High) inclination if their tendency weight is over 0.5 for any subject; Level B (Standard) if it is under 0.5. Level B represents the standards imposed by legal provision, whereas Level A represents not only the quality standards recommended by the relevant literature, but also the possible Standard level of future designs.

c) Step 3: Defining Problems and Limitations

This is the stage where the data gathered during the analysis stage are evaluated, and the design problems are defined. A "Table of Limitations" is needed, in order for the analysis data to be evaluated. The Table of Limitations is the table that defines the limit value necessary for the data that has been generated. The necessary limit values defined for each factor will change according to these levels. Limit values for all factors covered by this study have been derived from the available literature, and a Table of Limitations, including Level A and Level B values, has been constructed. As a result of the inquiry, those factors that do not meet the defined limit values are recorded as "Problems Requiring Resolution". The proposed model is designed not for calculating solution alternatives for each problem, but specifically for generating the best set of solutions for the whole set of problems defined.

The Table of Limitations consists of various limitations regarding the designer's physical environment tendency, climate region, function and direction. This highly variable and extensive table makes it much easier for the designer to make evaluations. The model generates different data for different levels of tendency; presuming the unique character of each design and determining the physical environment tendency, in interaction with the designer. For climate regions, the model refers to the currently applied legal standards. Therefore, four different tables of limitations have been constructed in accordance with the four climate regions defined by TS825 [17] "Code of Thermal Insulation in Buildings" in Turkey. This feature of the model differs across countries or climate regions. Table 2 shows 1.Climate Region of Turkey limit values according to climate region, function and the designer's inclination.

Table 2 A. Table of Limitations, prepared for the 1.Climate Region of Turkey, presenting the designer's limit values according to climate region, function and the designer's inclination.

Table of Limitations **Turkey – Climate Region 1**		**A Design tendency Level**				**B Design Tendency Level**			
		Residence	**Office**	**School**	**Hospital**	**Residence**	**Office**	**School**	**Hospital**
Daylight	Daylight Illuminance (min Lx)	200	500	400	400	100	300	200	250
	Daylight Illumination Ratio (min %)	-	80	70	70	-	70	60	60
	Daylight Autonomy Factor	To be assessed by the designer.							
	Regularity Factor (max)	-	0,2	0,2	0,3	-	0,3	0,3	0,5
	Daylight Glare Index (max)	-	22	22	20	-	22	22	20
Thermal Comfort and Efficiency	Thermal Protection - Opaque Surface (max U)	0,65				0,7			
	Thermal Protection - Trasparent Surface (max U)	2,6				2,8			
	Solar Radiation Factor (max %)	3%				3%			
	Thermal Decrement Factor(min %)	West, Southwest >25%, South, Southeast >15%, East, North, Northeast, Northwest > 10%							
	Time Lag (min hours)	West, Southwest > 12 hours, South, Southeast >10 hours, East, North, Northeast, Northwest >8 hours							
	Thermal Comfort Factor (max PPD)	-	10%	10%	10%	-	20%	20%	20%
	Thermal Regularity Factor (max)	3C^0							
Energy	Total Energy (EP) (kWh/m^2-years)	EP < 0,4*RG				0,4*RG ≤ EP <0,8*RG			
	Heating Energy (max) (kWh/m^2,years)	44,1 x A/V + 10,4							
	Assessment of Cooling Energy	-	+	+	+	-	+	+	+
	Assessment of Lighting Energy	-	+	+	+	-	+	+	+

(EP) = Total Yearly Energy calculated for the space
(RG)= Total Energy Limit Value imposed by the Turkish Code of Energy Performance in Buildings [17].
(A/V) = Area/ Volume

d) Step 4: Generating Solution Alternatives

The model hereby developed, seeks to find integrated solutions to design problems. This is a feature that meets one of the very basic needs of designers, who struggles to find the most logical and practical solution for all of the problems they have defined.

The solutions proposed for the defined problems by the model are comprised of "Model-Design Variable Inputs". These inputs cover all possible quantitative variables regarding daylight and other physical environment issues. The "Table of Correlations" shows the relation between physical environment factors and "Model-Design Variable Inputs". Therefore, the model first uses "Table of Correlations" to come up with possible solution alternatives among all model-design variables.

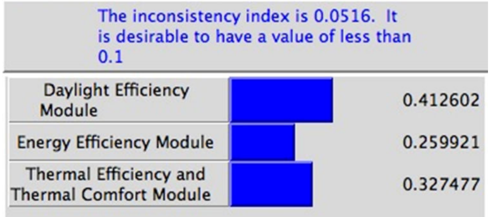
The model makes use of the AHP method, first to calculate the weight of each physical environment factor, then to prioritize them in terms of their effect on the design. This allows to give prior attention to those factors that are the most critical to the design.

The designer's decision for or against a solution is determined by the hierarchical structure of a multiplicity of criteria regarding the design problems. The same applies to physical environment issues. The model assumes that the hierarchical structure of physical environment factors varies for each unique project and/or designer, but it also accepts that a standard evaluation is possible, based on generalizations and logical prioritization of factors. The hierarchical structure, which allows the designer to calculate the weight of solutions, is of a flexible quality. However, a general hierarchy is built, mainly because the purpose of the model is to aid the designer in dealing with physical environment issues.

Another reason for making generalizations about the hierarchical structure is that some physical environment factors are constant, in terms of their importance, regardless of their relevance to other factors. To illustrate, if the illumination level of the space is already insufficient, then the problem of daylight glare loses its importance, at least for the time being. Therefore, it is important that the effect and the priority of factors on the design must be considered in the decision-making process.

There is a mathematical correlation, as well as a logical one, between the defined problems and all design variables that the architect can generate. An experienced architect uses this logical correlation, especially for physical environment issues, to formulate solutions or to make alterations in the design. The model, by using the AHP method for calculating possible solutions, simulates this exact behavior of the architect. It makes correlations between the physical environment problems and all decisions that may become solutions; generates different priority values for each solution alternative; taking into assessment the design case and the designer's inclination. The designer, then, evaluates the outputs to make his or her final decision.

The model is set up as such: the hierarchical structure is first formed amongst the physical environment issues (modules). Because the model is based on daylight, the hierarchical weight is given to the Daylight Efficiency Module. The energy module is given relatively less weight, simply because a design that is fully satisfied in terms of daylight and thermal efficiency is assumed to be energy efficient at a satisfactory level. Figure 6 illustrates the hierarchical relation between modules.

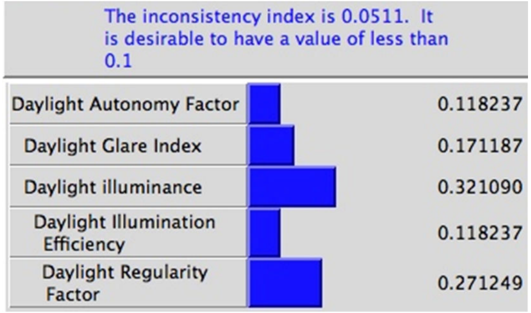


The inconsistency index is 0.0516. It is desirable to have a value of less than 0.1

Daylight Efficiency Module	0.412602
Energy Efficiency Module	0.259921
Thermal Efficiency and Thermal Comfort Module	0.327477

Figure 6. Comparison of hierarchical priority between the modules.

The Daylight Efficiency Module is composed of six factors. A sub-hierarchy is also constructed among these factors. Figure 7 shows the hierarchical structure of factors comprising the Daylight Efficiency Module.



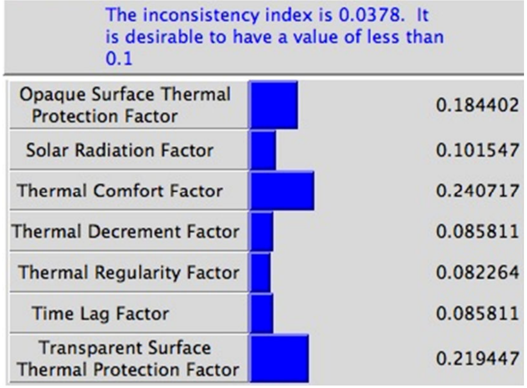
The inconsistency index is 0.0511. It is desirable to have a value of less than 0.1

Daylight Autonomy Factor	0.118237
Daylight Glare Index	0.171187
Daylight illuminance	0.321090
Daylight Illumination Efficiency	0.118237
Daylight Regularity Factor	0.271249

Figure 7. The hierarchical priority of factors comprising the Daylight Efficiency Module.

The hierarchy of sub-factors has been constructed, again, considering variables that render others null in certain conditions. For example, in terms of the quality of a space, the first important issue that comes to mind is the daylight illuminance. In a space that is not well-lit, so to say, issues regarding daylight regularity or glare become secondary concerns.

The Thermal Efficiency and Thermal Comfort Module is made up of seven factors. The sub-hierarchy constructed for these factors is shown in Figure 8.



The inconsistency index is 0.0378. It is desirable to have a value of less than 0.1

Opaque Surface Thermal Protection Factor	0.184402
Solar Radiation Factor	0.101547
Thermal Comfort Factor	0.240717
Thermal Decrement Factor	0.085811
Thermal Regularity Factor	0.082264
Time Lag Factor	0.085811
Transparent Surface Thermal Protection Factor	0.219447

Figure 8. The hierarchical priority of factors comprising the Thermal Efficiency and Thermal Comfort Module.

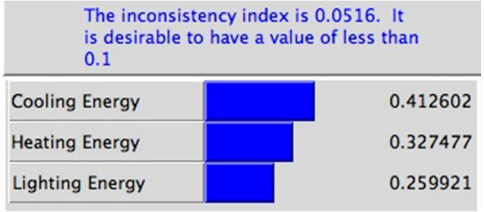
The distribution of weights indicates that the Thermal Comfort Factor is assigned more weight, compared to other factors in the same module. This fact is congruent with the aim of the model, that is, to reflect the total spatial quality on the design by increasing comfort in living.

The Transparent Surface Thermal Protection Factor is evaluated as the design variable that has the highest correlation to daylight, but also as the one that the designer can alter without having to drop their overall decision.

The Time Lag Factor and the Thermal Decrement Factor come to play, only in hot climate regions. Thus, they have been given less weight in comparison to those factors that influence design in all climates.

Figure 9 shows the weight distribution amongst the Energy Efficiency Module, which is made up of three basic factors. Cooling energy is given more weight within the Energy Efficiency Module, because Daylight Efficiency and Thermal Efficiency modules already control the lighting energy and the heating energy.

The AHP method is used to define the correlation among Model-Design Variables and the effect of these variables on the factors, in order to be able to determine the most suitable solutions to problems arising in a design.



The inconsistency index is 0.0516. It is desirable to have a value of less than 0.1

Cooling Energy	0.412602
Heating Energy	0.327477
Lighting Energy	0.259921

Figure 9. The hierarchical priority of factors comprising the Energy Efficiency Module.

A network of relations is constructed using the AHP method; the solution priority of each variable is calculated by entering correlation data for mathematical binary matrices. Figure 10 shows AHP network of relations and Table 3 shows the physical environment factors and design variables (Solution Alternatives) used in the model

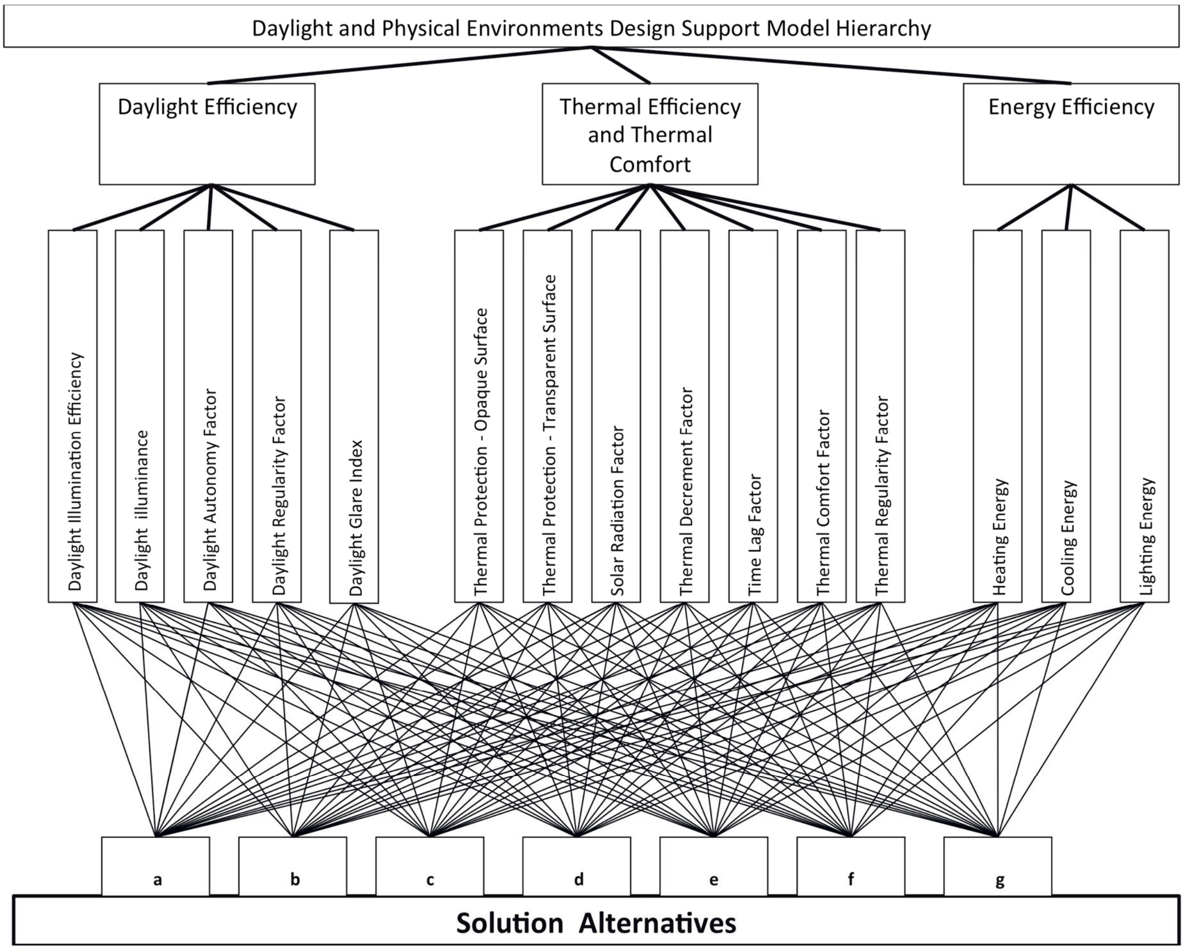


Figure 10. The AHP Scheme the model provides.

The AHP method can be used dynamically, in contrary to its presented default form. The designer is enabled to manually exclude factors from the AHP. In this way, the AHP can calculate the priorities of only those alternatives that are correlated to the factors listed in the "Pool of Problems".

Table 3. The "Table of Correlations" showing the physical environment factors and design variables

(Solution Alternatives) used in the model.

TABLE OF CORRELATIONS		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
Daylight	Daylight Illuminance	🟥	🟥	🟥		🟥	🟥	🟥			🟥							🟥			
	Daylight Illumination Efficiency							🟥											🟥		
	Daylight Autonomy Factor		🟥				🟥	🟥			🟥							🟥			
	Daylight Regularity Factor	🟥				🟥		🟥			🟥							🟥			
	Daylight Glare Index	🟥				🟥	🟥	🟥										🟥			
Heat	Thermal Protection (Opaque)											🟩				🟩					
	Thermal Protection (Transp.)				🟩				🟩	🟩			🟩								
	Thermal Comfort	🟩			🟩				🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩
	Thermal Regularity	🟩			🟩				🟩			🟩		🟩	🟩					🟩	
	Thermal Decrement	🟩			🟩		🟩		🟩	🟩		🟩		🟩	🟩	🟩				🟩	🟩
	Time Lag	🟩										🟩		🟩		🟩	🟩			🟩	🟩

	Solar Radiation	🟩					🟩	🟩	🟩	🟩	🟩										
Energy	Heating Energy	🟦	🟦		🟦		🟦		🟦	🟦		🟦		🟦	🟦	🟦				🟦	🟦
	Cooling Energy	🟦	🟦		🟦		🟦		🟦	🟦		🟦		🟦	🟦	🟦				🟦	🟦
	Lighting Energy	🟦	🟦	🟦		🟦	🟦	🟦			🟦							🟦	🟦		

Solution Alternatives

a) Fullness/Emptiness Ratios of the Facade
b) Geometry of Space
c) Indoor Materials Reflectance Coefficient
d) Conduction Through Facade Transparent Surface Thermal Transmittance
e) Light Permeability of Transparent Surface in Facade
f) Direct Daylight Blocking Ratio of Facade
g) Form of Shading Devices
h) IR transmittance (Permeability) Value of Transparent Surface
i) IR (Infrared) Retention Value of Transparent Surface in Space
j) Geometry of Transparent Surface
k) Heat Transfer Coefficient of Opaque Component of the Envelope (U-value)
l) Emptiness and Transparent Surface Area Ratio
m) Opaque Surface IR Reflection and Absorption Ratio
n) Opaque Surface Direct Radiation Ratio (Opaque Surface Shading Rate)
o) Opaque Building Envelope Form (Surface Area Change)
p) Thermal Capacity of Building Elements
q) Effectiveness of Daylight Directing Technology
r) Lighting Control
s) Indoor Natural Ventilation Condition
t) External Air Convection Ratio

e) Step 5: Decision-Making for Solutions

The "Definition of Solution Weights" operation simulates the behavior of an architect, who is experienced in physical environment issues. Therefore, it can generate various results, according to the variety and composition of problems. After calculating the solution weights of "Model-Design Variables", the proposed model carries out an interactive operation with the designer, in order to produce the most suitable set of solution alternatives. The purpose of this interactivity is to allow the designer the freedom to assess and choose between solution decisions. Furthermore, the solutions recommended by the model are just "features". For example, if the model suggests "A Change in the Value of Thermal Permeability of Transparent Façade", the architect may obtain this result by changing the characteristics of the glass that is used, or they may prefer to use layered glass material instead. The designer is, thus, allowed to make their own decisions and to choose how they will implement this decision.

Sometimes, among the alternatives proposed by the model, even the one with the highest priority may not solve all problems. The designer chooses this alternative, based on an understanding that it can only solve those problems that are related to it. For those problems left unsolved, another high priority alternative that is suitable for the case must be chosen. The designer may continue to choose solutions, until there are no problems left to attend. The model is a "Design Support System". The designer is the one who considers its suggestions. The designer can work the model again at any stage of the design process.

The SuperDecisions software is used for executing the AHP method. The generalized hierarchical relation between modules is entered into the system. This hierarchical structure, including all factors and solution alternatives, has been constructed as a result of a comprehensive research, conducted within the scope of this study. With reference to values derived from the relevant literature, binary matrix methods have been used to classify data. A designer interface is built upon these correlative logical data, to obtain a practical use for the model. This way, the designer is able to obtain unique results, just by selecting the problems on the interface. The user interface is shown in Figure 8.

The interface shows a list of the three modules and their sub-factors, the user marks the problems that describe the situation at hand. The software makes the mathematical correlation between these problems and the solution alternatives, and then it calculates the weights of these solutions. In this process, the AHP method, as a matter of fact, is used in a different manner than the usual. A new AHP hierarchy is generated for every composition of problems; the priority of an alternative changes as a consequence of changing problems. In this respect, the model can be said to have a more dynamic, more flexible way of using the AHP method.

To test the credibility of the model, three sample designs (A, B, and C) with distinct problems regarding physical environment have been used. Table 4 contains a list of physical environment problems that may arise after the analysis stage of design.

Table 4. Design problems defined as a result of the analysis of three different designs.

Parameters of Daylight and Physical Evironment		**Design A**	**Design B**	**Design C**
Daylight	Daylight Illuminance	Problem detected	-	-
	Daylight Illumination Ratio	–	-	-
	Annual Daylight Effectiveness	-	Problem detected	-
	Regularity Factor	-	Problem detected	-
	Daylight Glare	-	-	Problem detected
Heat	Thermal Protection (Opaque)	-	-	Problem detected
	Thermal Protection (Transp.)	-	-	-
	Thermal Comfort	Problem detected	-	Problem detected
	Thermal Regularity	-	-	-
	Thermal Decrement	-	-	-
	Time Lag	-	Problem detected	-
	Solar Radiation	-	-	-
Energy	Heating Energy	-	-	Problem detected
	Cooling Energy	Problem detected	-	-
	Lighting Energy	-	-	-

The solution weights can be obtained by simply marking the current problems of the design on the interface, as shown in Figure 11. Table 5 demonstrates solution weights calculated for the problems of Design A, B and C. The results differ vastly between the three sample designs. It can be seen that the model suggests different sets of solutions for different sets of problems.

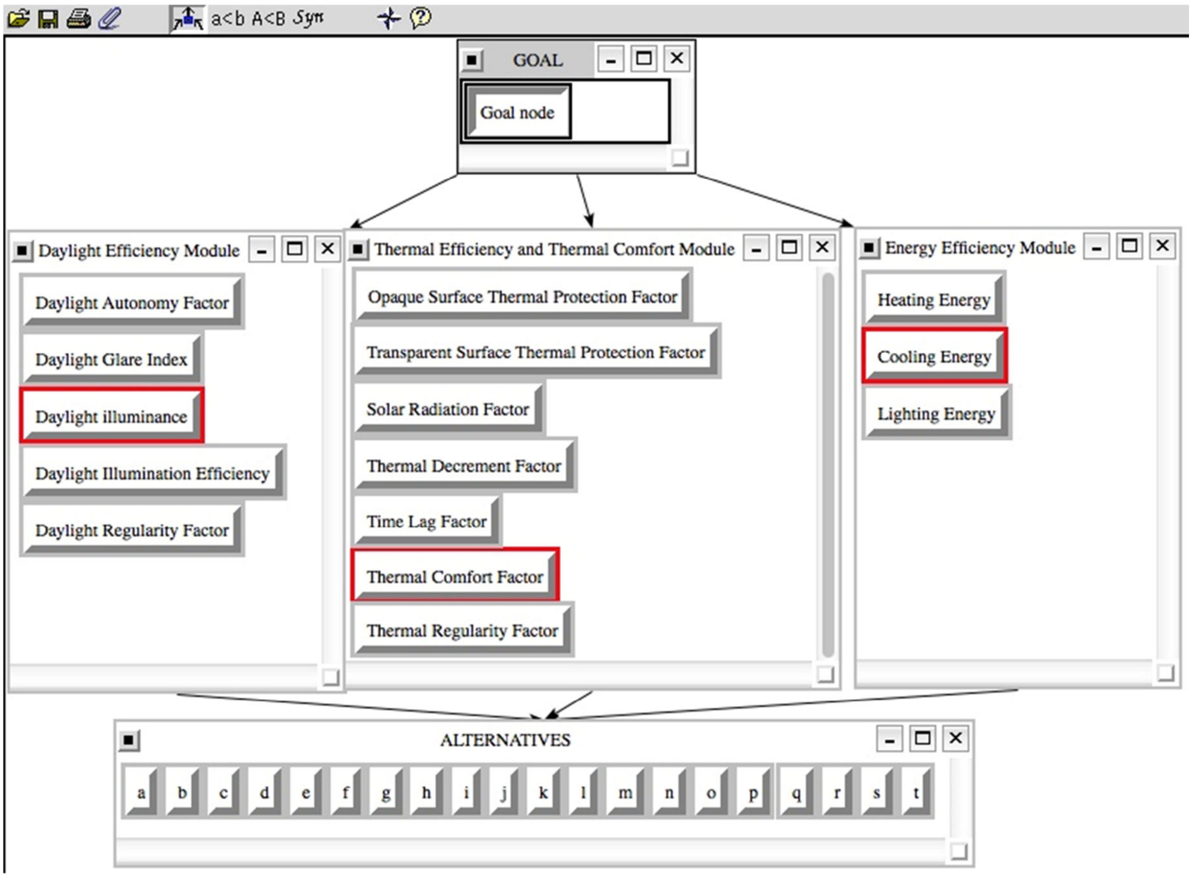


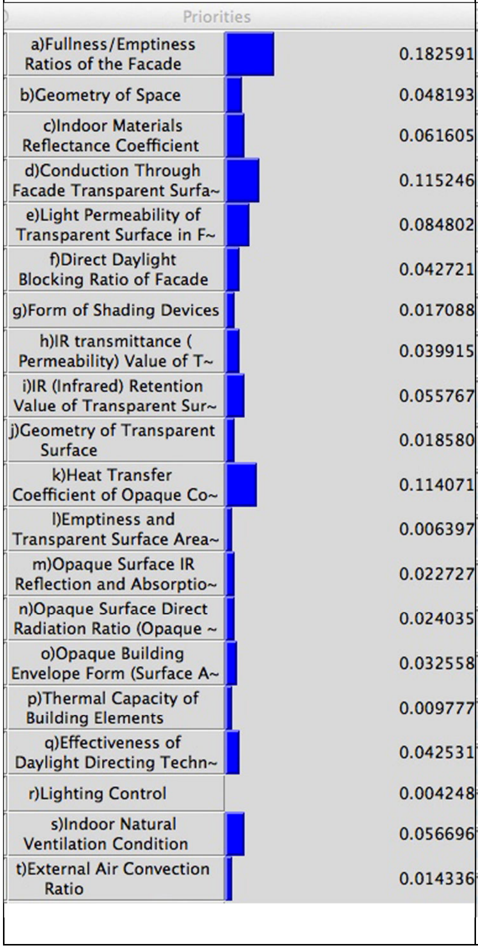
Figure 11. Marking existing problems on the interface, built into SuperDecisions.

Solution alternatives can be listed according to their relation-solution priority. However, this prioritization is not an absolute imposition on the designer. The designer evaluates this input, which is presented mathematically, to come up with a solution decision. The solution that has top priority mathematically, is the one that is recommended by the model. Where this solution does not suit the designer's needs, the model then recommends the next best alternative on the list. At this point, the solution alternative picked by the designer is expected to resolve those problems shown to be associated with it, on the Table of Correlations. The designer keeps making solution decisions, that is, choosing alternatives from the list, until there are no problems left to resolve.

This stage takes place in the model's flowchart, as a "**designer-active**" process for the purpose of allowing designers the freedom to make the decision that is most appropriate for them. The solution decisions defined by the model are only "suggested", and should always be evaluated by the designer. Thus, the model becomes a structure that supports the designer and allows guidance, while letting them make the final decision for their own design.

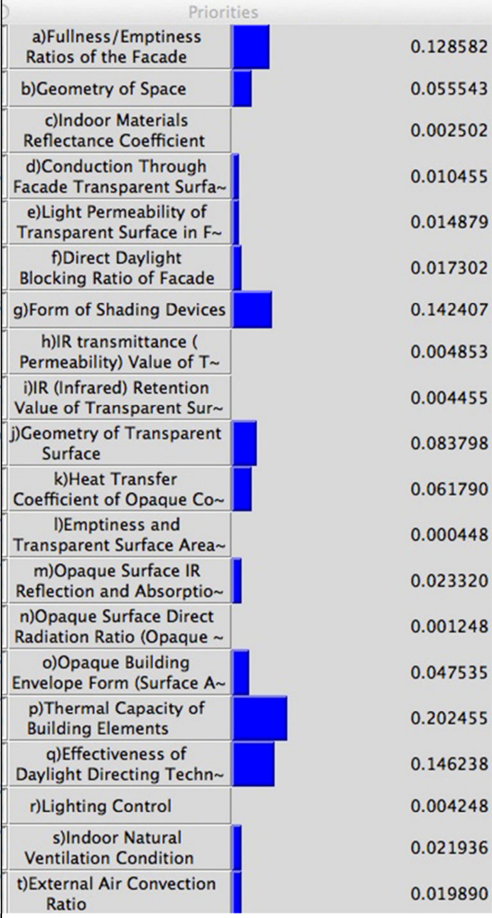
Table 5. The AHP Solution Priorities for Design A,B and C.

Design A



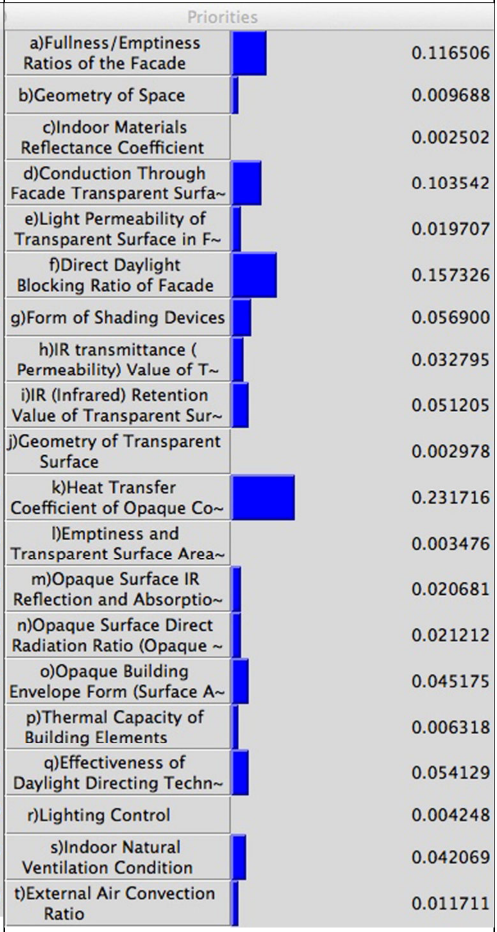
	Priorities
a)Fullness/Emptiness Ratios of the Facade	0.182591
b)Geometry of Space	0.048193
c)Indoor Materials Reflectance Coefficient	0.061605
d)Conduction Through Facade Transparent Surfa~	0.115246
e)Light Permeability of Transparent Surface in F~	0.084802
f)Direct Daylight Blocking Ratio of Facade	0.042721
g)Form of Shading Devices	0.017088
h)IR transmittance (Permeability) Value of T~	0.039915
i)IR (Infrared) Retention Value of Transparent Sur~	0.055767
j)Geometry of Transparent Surface	0.018580
k)Heat Transfer Coefficient of Opaque Co~	0.114071
l)Emptiness and Transparent Surface Area~	0.006397
m)Opaque Surface IR Reflection and Absorptio~	0.022727
n)Opaque Surface Direct Radiation Ratio (Opaque ~	0.024035
o)Opaque Building Envelope Form (Surface A~	0.032558
p)Thermal Capacity of Building Elements	0.009777
q)Effectiveness of Daylight Directing Techn~	0.042531
r)Lighting Control	0.004248
s)Indoor Natural Ventilation Condition	0.056696
t)External Air Convection Ratio	0.014336

Design B



	Priorities
a)Fullness/Emptiness Ratios of the Facade	0.128582
b)Geometry of Space	0.055543
c)Indoor Materials Reflectance Coefficient	0.002502
d)Conduction Through Facade Transparent Surfa~	0.010455
e)Light Permeability of Transparent Surface in F~	0.014879
f)Direct Daylight Blocking Ratio of Facade	0.017302
g)Form of Shading Devices	0.142407
h)IR transmittance (Permeability) Value of T~	0.004853
i)IR (Infrared) Retention Value of Transparent Sur~	0.004455
j)Geometry of Transparent Surface	0.083798
k)Heat Transfer Coefficient of Opaque Co~	0.061790
l)Emptiness and Transparent Surface Area~	0.000448
m)Opaque Surface IR Reflection and Absorptio~	0.023320
n)Opaque Surface Direct Radiation Ratio (Opaque ~	0.001248
o)Opaque Building Envelope Form (Surface A~	0.047535
p)Thermal Capacity of Building Elements	0.202455
q)Effectiveness of Daylight Directing Techn~	0.146238
r)Lighting Control	0.004248
s)Indoor Natural Ventilation Condition	0.021936
t)External Air Convection Ratio	0.019890

Design C



	Priorities
a)Fullness/Emptiness Ratios of the Facade	0.116506
b)Geometry of Space	0.009688
c)Indoor Materials Reflectance Coefficient	0.002502
d)Conduction Through Facade Transparent Surfa~	0.103542
e)Light Permeability of Transparent Surface in F~	0.019707
f)Direct Daylight Blocking Ratio of Facade	0.157326
g)Form of Shading Devices	0.056900
h)IR transmittance (Permeability) Value of T~	0.032795
i)IR (Infrared) Retention Value of Transparent Sur~	0.051205
j)Geometry of Transparent Surface	0.002978
k)Heat Transfer Coefficient of Opaque Co~	0.231716
l)Emptiness and Transparent Surface Area~	0.003476
m)Opaque Surface IR Reflection and Absorptio~	0.020681
n)Opaque Surface Direct Radiation Ratio (Opaque ~	0.021212
o)Opaque Building Envelope Form (Surface A~	0.045175
p)Thermal Capacity of Building Elements	0.006318
q)Effectiveness of Daylight Directing Techn~	0.054129
r)Lighting Control	0.004248
s)Indoor Natural Ventilation Condition	0.042069
t)External Air Convection Ratio	0.011711

4. DISCUSSION AND CONCLUSION

The purpose of the Holistic Daylight and Physical Environment Design Support Model is to provide support for the designer, earlier in the design process, therefore, to improve the quality of the design. The model proposes an interactive system, on which the designer can project their unique approach and actively make decisions. Through the use of the model, many physical environment factors – which are usually missed out due to the designer's inability to internalize the subject – are included in the design process. It helps the design to be more harmonious with the physical environment, to have high spatial comfort and to be sustainable.

Furthermore, the analysis stage, which forms the basis of the model, not only serves as a guide for the designer, but also is a reference for physical environment problems. During analysis, the designer may use any software that will provide them with the source data they need. The model has a structure that is compatible with the BIM (Building Information Modelling) process. With software supported by BIM, data generation in the analysis stage becomes easier and faster. The model also defines physical environment goals for Turkish Climate Regions, integrating these goals with the design process.

The physical environment values that have an influence on the design, at early stages are definitely correlated with each other. Viewing physical environment problems as an integrated whole, instead of trying to solve them one by one, brings about some sort of design optimization.

Although the proposed model aims for total quality by drawing attention to physical environment problems at early stages of design; it can also be used to solve daylight and physical environment problems at any stage, including post-construction. In short, the proposed model can be applied to any situation where the designer aims to increase spatial quality.

The model also presumes that an experienced designer would simultaneously go through the process of defining problems and decision making, which are influenced most by their expectations. Therefore, certain alterations in the logical weights of factors are expected.

The proposed model suggests solutions or interventions for defined problems, with an integrated approach similar to that of an experienced designer. It has been tested for its decision-making behaviour, and found to show the same dynamic characteristics portrayed by a real-life designer, who, of course, falls within the scope of this study.

The model has been found to be compatible with the design process, entering the process by the designer's will, and at the point where the designer feels like they need it. It generates information, and leaves to the designer how that information will be evaluated. This feature of the model facilitates the designer's journey to their desired result, rendering the model itself a designer-active and flexible structure. In terms of leaving the final say to the designer, the model can be viewed as a sustainable one, considering the fact that the design process has a highly complex structure, involving an almost infinite number of probabilities, as each designer is a unique individual.

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