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PROVIDING OPTIMUM LIGHTING AND REDUCING HEAT GAIN THROUGH INVESTIGATION OF DIFFERENT WAVELENGTH EFFECT OF COLORS IN TRANSPARENT FACADES: SMART WINDOW DESIGN TOOL

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BY

Bahar SULTAN QURRAIE

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IN
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The thesis study titled "PROVIDING OPTIMUM LIGHTING AND REDUCING HEAT GAIN THROUGH INVESTIGATION OF DIFFERENT WAVELENGHT EFFECT OF COLORS IN TRANSPARENT FACADES: SMART WINDOW DESIGN TOOL" is submitted by Bahar SULTAN QURRAIE in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Architecture Gazi University by the following committee.

Supervisor: Prof. Dr. Figen BEYHAN

Architecture Department, Gazi University

I certify that this thesis is a graduate thesis in terms of quality and content. ....

Chairman: Assoc. Prof. Dr. Arzuhan Burcu GÜLTEKİN

Department of Department of Real Estate Development, Ankara University

I certify that this thesis is a graduate thesis in terms of quality and content . ...

Member: Assoc. Prof. Dr. Semra ARSLAN SELÇUK

Architecture Department, Gazi University

I certify that this thesis is a graduate thesis in terms of quality and content. ....

Member: Assoc. Prof. Dr. İdil AYÇAM

Architecture Department, Gazi University

I certify that this thesis is a graduate thesis in terms of quality and content. ....

Member: Assoc. Prof. Dr. Filiz SÖNMEZ

Architecture Department, Erciyes University

I certify that this thesis is a graduate thesis in terms of quality and content. ....

Date: 07/02/2019

I certify that this thesis, accepted by the committee, meets the requirements for being a Doctor of Philosophy Thesis.

…………………….………

Prof. Dr. Sena YAŞYERLİ

Dean of Graduate School of Natural and Applied Sciences

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Bahar SULTAN QURRAIE
07/02/2019

ŞEFFAF CEPHELERDE RENKLERİN FARKLI DALGA BOYU ETKİLERİNİN İNCELENMESİ İLE OPTİMUM AYDINLATMA VE ISI KAZANÇLARININ AZALTILMASI: AKILLI PENCERE TASARIM ARACI

(Doktora Tezi)

Bahar SULTAN QURRAIE

GAZİ ÜNİVERSİTESİ

FEN BİLİMLERİ ENSTİTÜSÜ

Şubat 2019

ÖZET

Yapılaşma sektöründe hızla gelişen saydam cepheler özellikle aşırı ısı kazancına, parlamaya ve olumsuz radyasyon etkilerine neden olan istenmeyen güneş ışınlarının kontrolünde zayıf bir performansa sahiptir. Geleneksel mimari örnekler incelendiğinde, sıklıkla kullanılmış olan renkli camların, görsel konfor için ihtiyaç duyulan aydınlatma düzeyini sağlayabildiği ve istenmeyen güneş ışınlarına karşı bariyer oluşturduğu anlaşılmaktadır. Bu bağlamda "Doğal aydınlatmanın istenilen düzeyde sağlanması ve aşırı ısı kazançlarının önüne geçilmesi amacıyla geleneksel mimarinin cam yüzeylerinden gelen öğretiyle renkli polimerlerden yararlanmak mümkün mü?'' sorusuna cevap aramayı amaçlayan bu çalışmada; 500 yıldan fazla bir süredir binalarda kullanılan Orosi camlarından yola çıkılmış ve güneşe maruz kalan büyük cam yüzeylere sahip cephelerde kullanmak üzere, mekanın ihtiyacına göre değişik renklerin ışık geçişine, absorbe etme ve yansıtma özelliklerine bağlı olarak cam yüzeylerinin renkli camlarla tasarlanmasına imkan tanıyacak bir program geliştirilmiştir. Bölgesel iklim verilerine göre MATLAB yazılım dili kullanılarak yazılan program, büyük saydam cephe yüzeylerinin arkasında kalan mekanların görsel ve ısıl konfor koşullarını dikkate alarak farklı dalga boylarına sahip renklerin hangi yüzde ile saydam yüzeylerde yer alması gerektiğini ortaya koymakta ve tasarımcılara konfor koşularını sağlayarak farklı renk kombinasyonları ile cephe tasarlama olanağı sunmaktadır. Bu amaçla çalışma sürecinde incelenen Orosi camlarında en çok kullanılan üç ana ve üç ara renk belirlenmiş ve bu renklerin iki cam arasında hareketli jaluziler olarak kullanılması öngörülerek yazılan programın doğruluğu incelenmiştir. Renkli şeffaf polimerler olarak hazırlanan jaluzi prototiplerinin güneş ışığı karşısındaki performansını ortaya koyan veriler laboratuvar çalışmaları ile elde edilmiş ve yazılım içerisine yerleştirilmiştir. Yaz ve bahar dönemlerinde saydam yüzeyin yer aldığı zon da dikkate alınarak program çalıştırılmış, böylece saydam yüzeyin arkasında bulunan mekanın ihtiyaçları doğrultusunda hangi rengin hangi yüzde ile o pencerede bulunması gerektiği sonuçlarına ulaşılmıştır. Bulunan sonuçlara göre tasarlanan pencerelerin mekan konforu üzerindeki etkileri Grasshoper-Rhino yazlımı ile kontrol edilmiş ve yazılımın işlerliği ortaya konmuştur. Saydam cephelerin istenmeyen güneş ışınlarının kontrolü için performansının artırılması amacıyla renklerin özelliklerinden yararlanılabileceğini doğrulayan bu tez çalışmasının enerji verimliliğinin sağlanmasında tasarımcılar, mimarlar ve bundan sonraki akademik çalışmalar için öncü olabileceği düşünülmektedir.

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PROVIDING OPTIMUM LIGHTING AND REDUCING HEAT GAIN THROUGH INVESTIGATION OF DIFFERENT WAVELENGTH EFFECT OF COLORS IN TRANSPARENT FACADES: SMART WINDOW DESIGN TOOL

(Ph. D. Thesis)

Bahar SULTAN QURRAIE

GAZİ UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

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ABSTRACT

The amount of energy consumed to ensure that a large part of human life passes through comfort conditions in sustainable buildings corresponds to 40% of total energy consumption. In hot climates, which are dependent on foreign energy supply, the work carried out to reduce cooling loads within the scope of increasing energy efficiency in the buildings has an important share. It is also an important indicator of the quality of the space to avoid excessive heat gain, prevent glare and to avoid damage due to radiation effects, by controlling or removing undesirable sunlight from building facades in buildings or atrium structures with large glass surfaces. This study seeked to answer the following question: "Is it possible to make use of colored polymers through what have be learned from the glass surfaces of the traditional architecture in order to provide natural illumination at the desired level and to prevent excessive heat gains?" Based on Orosi glasses which were frequently used especially in mosques, mausoleums and madrasahs for more than 500 years, this study was developing a program that allows glass surfaces to be designed with colored glasses depending on the light transmission, absorption and reflection characteristics of different colors according to the needs of the space, for use on facades with large glass surfaces exposed to the sun. The colored transparent polymers along with old and new concept would be designed as window prototype according to every area, and the moving shading elements would be placed in window as blinds. Throughout this project, programs are written using the MATLAB software language according to the climate data of each field. After the data obtained via the laboratory studies of polymers has been placed in this software, the color and number of blinds and accordingly window prototypes would be clear. The window prototypes would be determined as two rows of blinds - as summer and winter type - according to the window and the zone where it is located and would be placed in double or triple glazed windows. To checkout SWDT, by drawing two samples in the program and obtaining the results of the window and the percentage of output colors, samples were simulated in Rhino with the aid of Grasshopper, and the outputs were compared with previous results. The simulation results of the designed window SWDT can be shifted to any type of window geometry with the definition of two season s' types. This method combining the past teaching with the contemporary technologies can also be a solution to reduce the consumed energy with the aim of increasing the quality of the space, and will bring different dimensions to the facade design for the architects.

Science Code	:	80114
Key Words	:	Colored Transparent Filters, SWDT, Window Systems, Energy Efficiency, Wavelength ranges, Lighting Transmittance, Irradiation
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LIST OF SYMBOLS AND ABBREVIATIONS

In this study symbols and abbreviations used is presented below with descriptions.

Symbols	**Explanation**
$\mathbf{A_s}$	The shading area of window glass
A	Glazing area
$\mathbf{C_0}$	The speeds of propagation for electromagnetic radiation in a vacuum
$\mathbf{F_1}$	Circumsolar anisotropy coefficient, function of sky condition
$\mathbf{F_2}$	Horizon/zenith anisotropy coefficient, function of sky condition
$\mathbf{F_w}$	The correction factor for glasses
$\mathbf{g_{\perp}}$	The solar energy transmission factor for the beam measured in laboratory conditions and perpendicular to the surface
I	The incident global solar radiation
$\mathbf{I_b}$	Direct beam radiation
$\mathbf{I_{dh}}$	Diffuse solar horizontal radiation
$\mathbf{I_r}$	Radiation reflected from the ground in front of the surface
IR	Infrared radiation
Is	Sky radiation
$\mathbf{I_t}$	The ground-reflected radiation received
UV	Ultraviolet Radiation
V	Frequency
VIS	Visible radiation
$\boldsymbol{\alpha}$	Elevation angle
$\boldsymbol{\beta}$	tilt of the surface from the horizontal
$\boldsymbol{\gamma}$	Surface azimuth of window plane
$\boldsymbol{\delta}$	Declination angle
$\mathbf{\Delta T_{GMT}}$	Difference of the local time (lt) from Greenwich mean time in hours
$\boldsymbol{\varepsilon}$	Tilt angle

Symbols	Explanation
λ	Wavelength
ρ	The ground reflectivity or albedo
τ_λ	Spectral transmission
φ	Azimuth angle
Φ	Local latitude
Φs, month	Monthly average solar gains

Abbreviations	Explanation
ASHRAE	The american society of heating refrigerating and air-conditioning engineering
CFD	Computational fluid dynamics
CTF	The colored transparent filters
DOE	Department of energy
EoT	Equation of time
GMT	Greenwich mean time
GSC	Geometrical shading coefficient
HRA	Hour angle
LAT	Local apparent time
LST	Local solar time
LSTM	Local standard time meridian
LT	Local time
SHGC	Solar heat gain coefficient
SWDT	Smart window suggestion tool
TST	True solar time

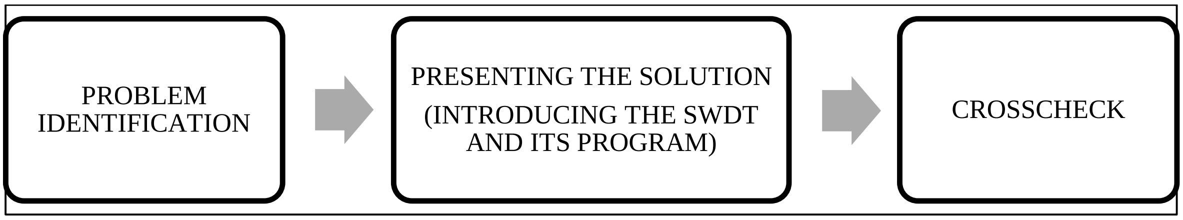
1. INTRODUCTION

Problem state / Definition of the problem

In today's advanced sustainable architecture occupancy, space and the elements that shade them have become very important. In innovative architecture, the choice of these elements has been in the direction of increasing energy gain. Glasses integrated with solar radiation are sometimes static and sometimes adapt to the circular movements of the sun, an energy source, and move in synchronism, which we consider to be a part of kinetic architecture. The materials selected as shading members are usually chosen from those that have opacity. However, semi-transparent materials also function as shading. It pushes back the heat that the sun's rays contain as energy, and provides light. To reach the thesis goal three parts submitted. As you see in Table 1.1 first of all the problem of research must be defined and after this part the solution must be presented. And at the end to peruse of solution’s action, the third part must be recognize to check out it.

In this thesis, being in harmony with nature is an extremely important goal. Glasses used with the latest technology can transfer energy, record and change characters. At this point the radiation hazard that arises when trying to make maximum use of the renewed energy source is ignored when considered the recovered energy. Due to many factors of today’s world, headaches and fatigue are seen in people who reside in large structures with prolonged atriums. The main reason for this is the combination of non-natural products, and the radiation generated by electric-magnetic fluxes. This study to reduce this radiation aims at the use of healthy and functional properties of stained glasses.

Table 1.1. The general scheme of study process diagram



Recommended window technology covers the following topics: machinery, electricity, electronics, mechatronics, computers, software and hardware. It is aimed to use transparent polymers absorbing waves emitted from sunlight – the energy source - as shading elements.

In the computer program, the system is defined and then placed in the window's place. Then the data obtained by measuring with the help of sensors will be transferred to the computer and if necessary the blinds will move. By this means, colored transparent polymers and mechanical movements will be an important step in kinetic architecture.

Purpose of the research

Obtaining undesirable sunlight in the summer months and ensuring sufficient natural lighting for indoor comfort conditions and developing a model for the purpose of minimizing the energy consumed for cooling by avoiding excessive heat gain are the basis of the project. The model to be created combines the color glass applications that were commonly used in the past with the present technology and predicts the use of color features. The color percentages calculated based on the zone, climate, position and the given window size data will – by the recognized method – be able to provide designers with an opportunity to create different compositions by providing indoor comfort conditions in the context of thermal and lighting without needing test potential on the facades nor another shading element.

Research question

Is it possible to providing optimum lighting and reduce heat gain using colors s in transparent facades?

To reach the answer of this head question, the answers of following questions should be extracted:

Can the windows shading system be designed by using colored transparent materials or not?

Are transparent polymers with colored nature useful for shading or not?

Can the window design system be designed due to window position and climate? So how will be the percent of the clothing of colors on glass surface?

How can be reachable to have optimum area percentage of colored transparent materials relative to glass area? How can be the percentages appropriate due to daylighting and solar radiation of hot seasons in different situations and climate positions?

Hypothesis of research

Colored transparent filters (CTFs) can be used as independent part of shades in shading systems. They can place in window shading system due to structure's climate and window's position and other parameters. The colors of CTFs can be defined due to maximum daylight transmittance and minimum solar radiation transfer in hot seasons of year.

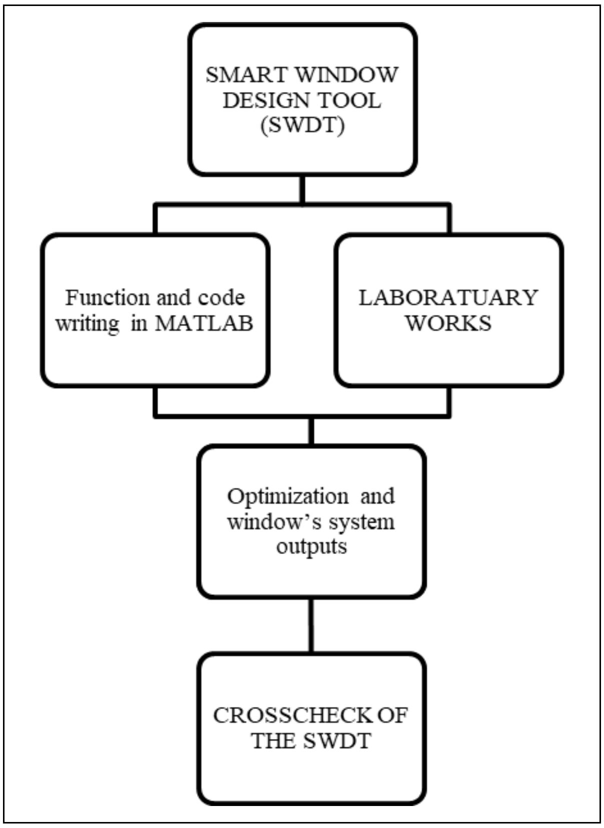
Importance of research

In the sustainable architecture, one of the first things that should draw attention is the harmonious relationship with nature. While such types of structures must be designed to enhance human and life quality, the danger of increased radiation due to increased rays of the sun is accelerating. We use colored glasses (based on historical architecture with stained glass facades) as a shade to avoid this.

Assumptions and premises

In this thesis, the data obtained by using the content analysis method and the experimental research method will be tested over and over in the laboratory and computer environment. So as can be seen in Table 1.2 to solve the indemnification problem of research smart window design tool (SWDT) was modeled in MATLAB.

Table 1.2. The process diagram of study

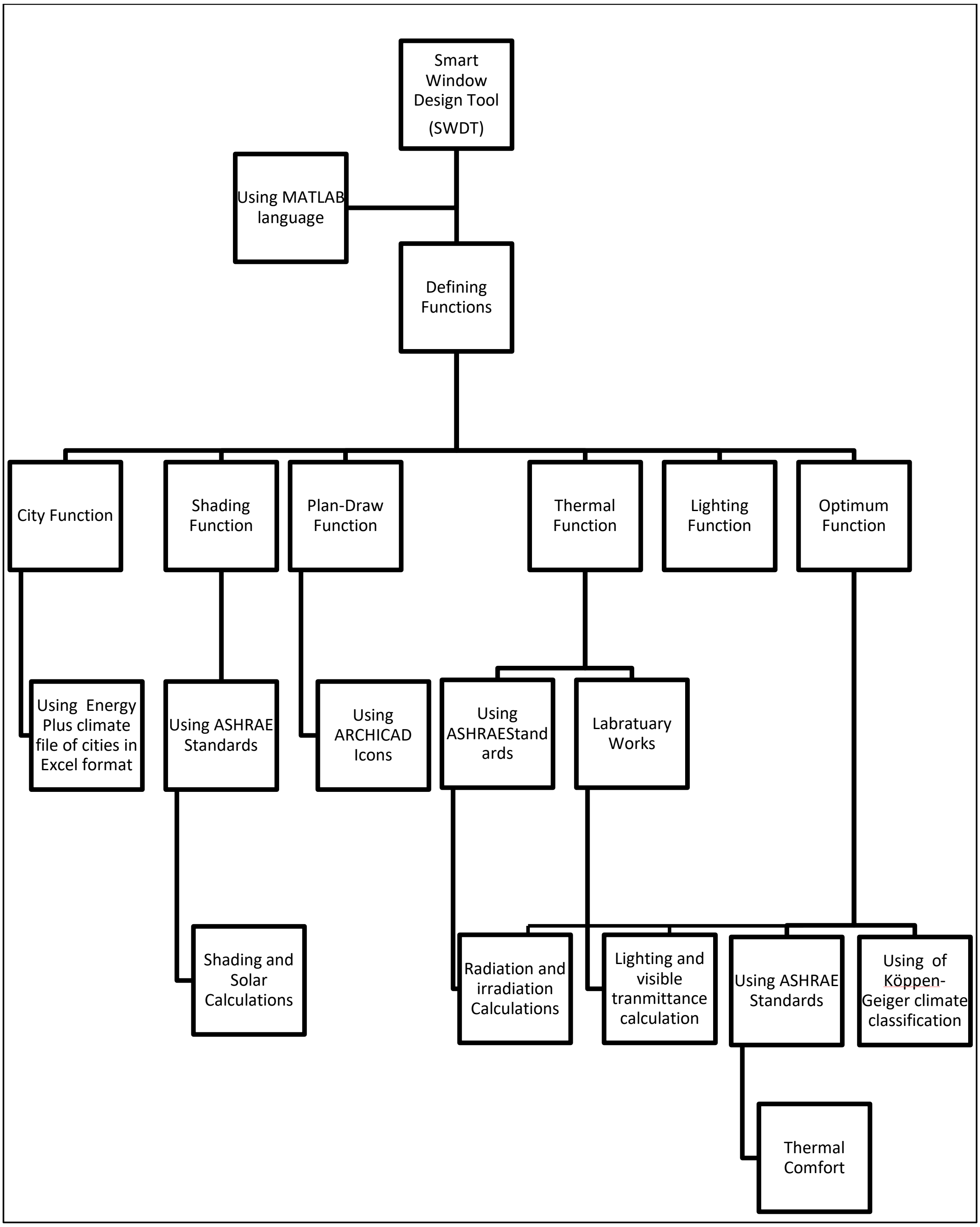


To coding the software tool in MATLAB some functions were defined due to ASHREA standards, previous softwares and laboratory results of CTFs spectra transmittance in different wavelengths. Providing the software tool will be end by optimizing and rendering the window's system outputs. At the end the tool must be check out. The crosscheck of the SWDT will be achieve by another software programs.

Creating the MATLAB software program

As indicated in the literature summary, a program is written with MATLAB software which is used for technical and scientific calculations including graphical data display and programming in different areas such as shading systems or finding heat gain coefficients, and aims at applying smart window usage to windows located in every direction of such a building. So the full scheme of SWDT coding process can be seen in Table 1.3 with all subcategories.

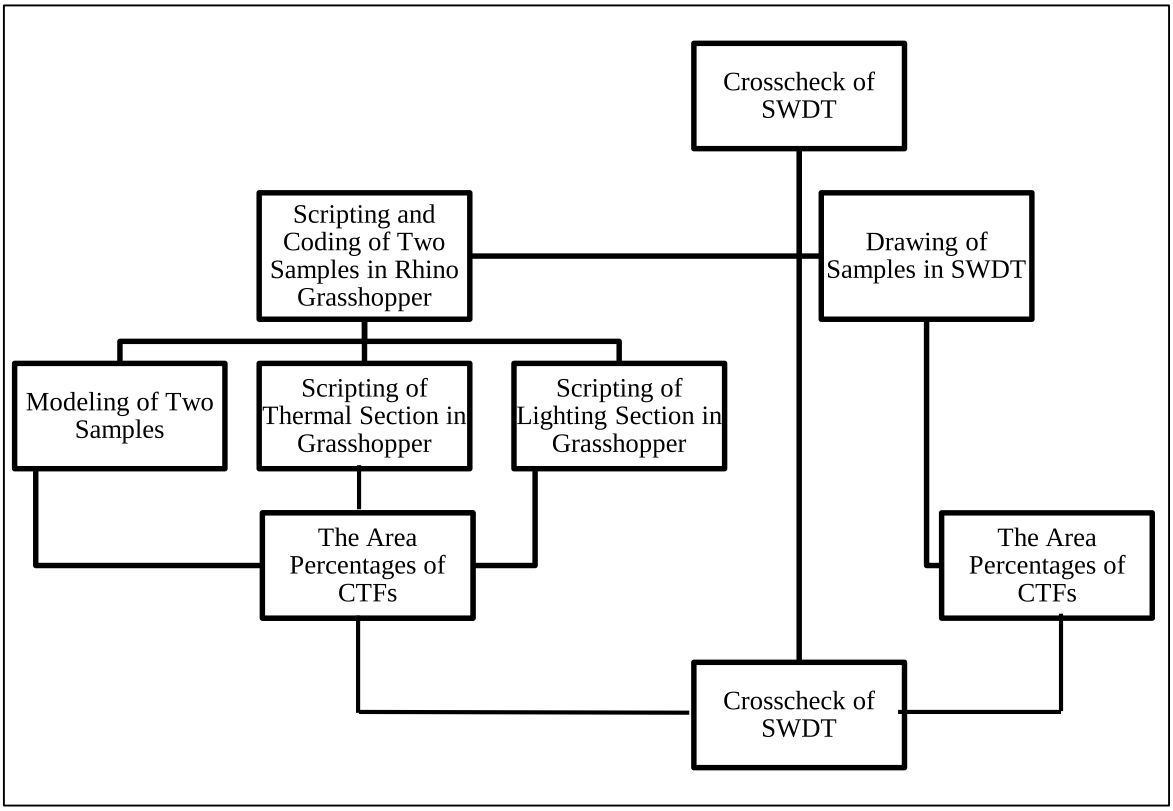
Table 1.3. SWDT coding process



Colored polymers pass through the experience in the laboratory experiment with the spectrophotometer and are classified according to their light transmittance in long areas. Then this classification is drawn graphically according to the energy of the sun's own wave length. According to these results, the monthly solar radiation gain obtained from the program and the illumination-wave length graph is obtained the ratio of the area of the polymer to the total area of the glass.

Later, to evaluate how the program works, by drawing samples in SWDT and obtaining the results of the window and the percentage of output colors, samples are simulated in Rhino with the aid of Grasshopper, and the outputs are compared with previous results. The simulation results of the designed window SWDT can be shifted to any type of window geometry with the definition of two season s' types. Table 1.4 contains the crosscheck Diagram of SWDT.

Table 1.4. Crosscheck diagram of SWDT



<u>Limitations</u>

The goal of laboratory studies are grouping of the polymers tested according to the obtained data and the table, writing in the program - according to the month and two types of results. It is very important to analyze the data correctly and to enter and conclude these analyzes correctly in software. The preparation and operation of test products is the most critical stage of the project. The sensitivity and success to be shown at this point is very important in order to put the project back on track and to test the experiment elements swiftly.

Definitions and terminologies used in the thesis

The colored transparent filters: The colored transparent filters (CTFs) examples of examined colors in the form of translucent polymer layers can be assembled in the form of shutters (vertical) in two rows of two-wall or three-wall windows.

Wavelength transition tests: The wave length through the polymers being tested

Blind: Curtains arranged in an order from selected polymers between the glasses of the proposed windows

Window prototypes: Classification of colored polymers according to summer and winter software program

Smart Window Design Tool (SWDT): Software program's execution using MATLAB program for the proposed windows. A new software is presented to provide the percentage of optimal colored areas used in the shading system of the shadow inside the window. In this programming language, climate and design factors of the window, the position of it and the zone that it is located on, were considered.

Two seasons of summer and autumn-spring: By default, it has been investigated in two seasonal groups. Because of the need for shadowing generally in the summer and partially in spring and autumn, depending on the location.

Smart Window Suggestion: CTFs in the form of translucent polymer layers can be assembled in the form of jalousie shutters (vertical blinds) inside double glazed windows or triple glazed windows.

Spectral Radiation Transmissions of Colored films: The integral of graph of Transmission spectra by CTF's color to wavelengths.

Procedure

In Chapter One, we have the summarization of the outcomes and findings of applied research work, discuss the tools, responsive feedback from the kinetic pattern, research limitation and potential area for further research. This chapter presents the background of the research motivation, which led to a general theoretical background and framework. This framework and background research includes the inspiration, aim, research question, methodology, and exegesis structure.

Chapter Two elucidated the related literature review on wavelengths and types of glasses and daylight and thermal heat transmission performance. The summaries of this review suggest stained glass that can adapt in today's window design as CTF to respond to the sun as heating and lighting source.

Chapter Three described a method by posing a tool of evaluation and calculation (SWDT) by MATLAB coding for the evaluation of CTFs' colors and their area percent. SWDT is presented to evaluate the performance of window in respond to the daylight and solar energy. This method is tested in window design with exploiting transparency and shading properties of stained glasses from chapter three and four with reflection of critical review in Chapter Two.

Chapter four presented an integration of five different tools, Rhino, Grasshopper, Energy-Plus, Radiant and Daysim used to explicate an algorithm that approved SWDT's validity. Firstly two different zones with different window parameters in Ankara was drawn in SWDT, secondary simulated schemes was developed by the test algorithm. To find the best percent and eliminating technical difficulties of manual simulations of 6 colors area percent of CTFs optimization of results occurred. The simulations proved the efficiency of the SWDT's results as CTF's percent in two different zone samples.

Chapter five addresses the research again in the research theme and purpose frameworks and includes the architectural and energy aspects discussed in the thesis.

Chapter Six presents the conclusion of the research and offers some suggestions and directions for future researches that could be investigated in the area of responsive kinetic facades.

2. LITERATURE REVIEW AND THEROTICAL FRAMEWORK

Considering the possibility of using transparent colored materials in the shadowing of windows to be a question, research and projects carried out in this field were first surveyed. In this regard, many types of glasses and the amount of energy passing through them at different wavelengths were investigated. On the other hand, the types of shadings used in the windows and the disadvantages and benefits of each were separately evaluated.

2.1. Transparent Materials and Transitive Wavelength

Transparent materials transmit the definite wavelengths of sunlight that some of them are in visible part. So to realize the effect of transmittance spectra due to wavelengths this section was studied.

2.1.1. Criteria of solar controlled transparent materials

It has the ability to transmit electromagnetic waves and provides access to the sun's rays, because the glass carries the name of a transparent material. Even the most opaque glasses do not pass most of the ultraviolet and infrared waves. The US Department of Energy (DOE) suggests that having spectrally selective capabilities of glasses causes a reduction in the solar load of the building (Alvarez et al., 2005). This organization as can be seen in Figure 2.1 proposes to the areas located in cold climates use of glasses whit visible and infrared ranges that maximally transmit radiation; while the proposal for areas in hot climates is to use glasses that provide maximum transmission of visible radiation.

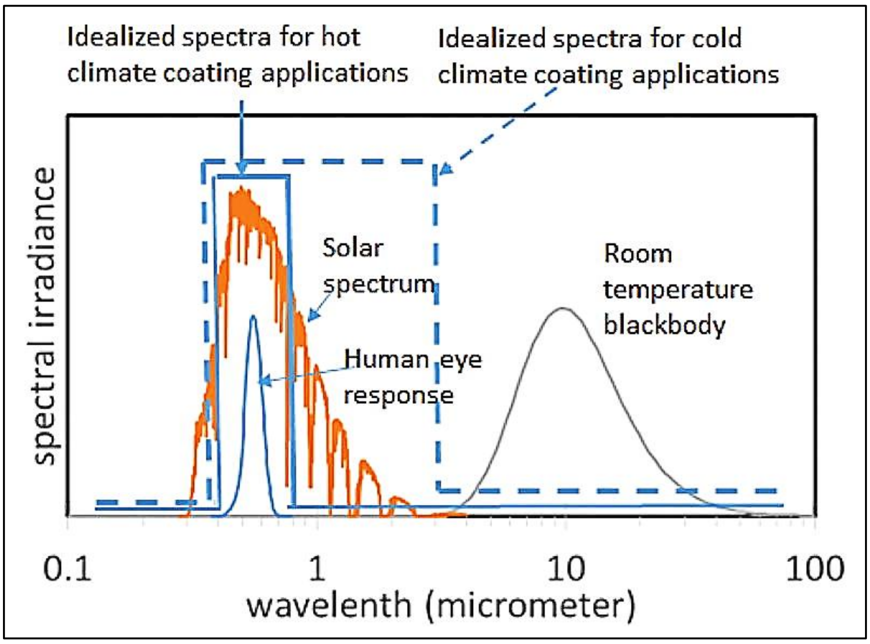


Figure 2.1. Transmission spectra by the US Department of Energy for hot and cold climates (Haghshenas and Ghiyabaklu, 2006)

For the reason shown in Figure 2.1 and Figure 2.2. that more than 46% of solar energy consists of waves in the visible spectrum, preventing a part of these spectra plays a major role in the heating of the building (Gies, Roy and Udelhofen, 2004). But the organization doesn’t envisage this role, perhaps because of the fear that the indoor will be dark.

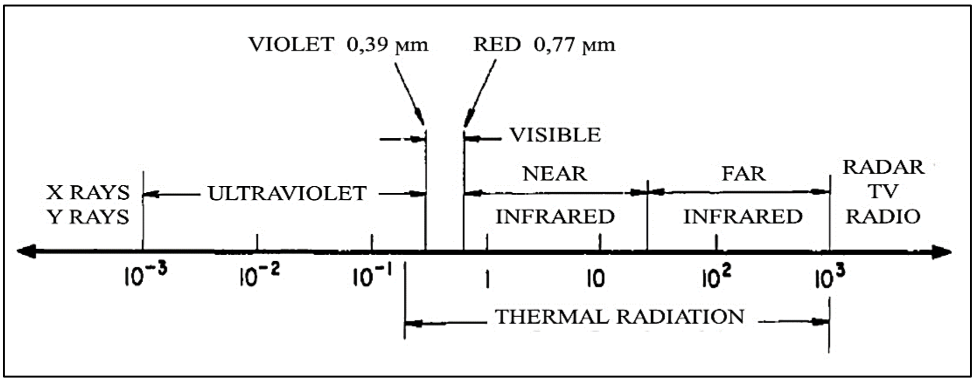


Figure 2.2. Thermal Radiation in spectrum of electromagnetic radiation (Muhammad Iqbal, 2012)

However, the brightness intensity of the sunlight is more than necessary in some countries, and all the spectrums entering the space cause some eye diseases in addition to the space heating and space heating.

2.1.2. Infrared zone control (Surface Coatings)

Glass can reflect, bend, transmit, and absorb light, all with great accuracy. The combinations of glass are managed to display various physical, chemical, and optical attributes that presents in table 2.1 (Morey, 1938).

Table 2.1. Common commercial glass types and their applications (Morey, 1938)

"Glass Type"	"Primary Component"	"Linear Thermal Expansion"	"Thermal Shock Resistance"	"Chemical Resistance"	"Applications
"Borosilicate"	SiO_2, B_2O_3	-30-60*10^{-7}/ºC	Average - High	High	"- Industrial equipment - Exterior lighting - Laboratory and kitchen glassware"
"Soda – Lime Silicate"	SiO_2, Na_2O, CaO	-80-100*10^{-7}/ºC	Low	Average	"- Food and beverage containers - Windows - Lamp envelopes"
"Phosphates"	P_2O_3	-90-110*10^{-7}/ºC	Low	"Low/ except high resistance to hydrofluoric acid"	

Architectural glass comes in three different strength categories (Vigener and Brown, 2009): "annealed glass, heat-strengthened glass and fully-tempered glass". Generally Annealed glass is the most useful glass in architectural buildings. Due to (Vigener and Brown, 2009): "It has good surface flatness because it is not heat-treated and therefore not subject to distortion typically produced during glass tempering". As (Morey, 1938) mentioned: "its properties fit ordinary temperatures represent the frozen-in equilibrium corresponding to some, usually unknown, higher temperature. Heat-strengthened and fully-tempered glass are heat-treated glass products", heated and smothered rapidly in such a way to compress the residual surface in the glass. Definitely the compression of the glass surface increases the resistance to the fracture of the heated glass. So due to (Hubert): "Because of the compression in the glass, heat strengthened glass is approximately twice as strong as annealed glass of the same thickness. Tempered glass is approximately 4 to 5 times as strong as annealed glass of the same thickness. Except for this increase in mechanical strength, all other properties of the glass remain unchanged including glass deflection".

It is float or plate glass that has been heated and rapidly cooled, increasing its inherent strength and ductility. Similar to heat-strengthened glass, the heat-treatment generally results in some distortion. If it breaks, fully-tempered glass breaks into many small fragments, which makes it suitable as safety glazing under certain conditions. It is used for windows that are exposed to high wind pressure or extreme heat or cold (Savić, Đurić-Mijović and Bogdanović, 2013). Properties of annealed and fully-tempered glass are comparatively provided in Table 2.2.

Table 2.2. Properties of glass (Savić et al., 2013)

	"Annealed glass"	"Tempered glass (fully tempered)"
"Strength"	59–150 N/mm2	7–28 N/mm2
"Young's modulus"	70 kN/mm2	70 kN/mm2
"Density"	2.4 kg/m3	2.4 kg/m3
"Thermal coefficient of expansion"	8.8*10−6 K−1	8.8*10−6 K−1
"Poisson's ratio"	0.22	0.22

Transmittance refers to the percentage of radiation that can pass through glazing. Transmittance can be defined for different types of light or energy, e.g., "visible light transmittance," "UV transmittance," or "total solar energy transmittance." (Mitchell, Kohler and Arasteh, 2006)

In terms of solar control, the properties of the glass vary depending on the value of radiation conductivity. The radiation conductivity value can be changed by applying the coating layers obtained from some precious metals and / or metal oxides onto the glass as can be seen in Figure 2.3. Such coatings directly affect the rate and intensity of the radiation conductivity (Sev, Gür and Özgen, 2004).

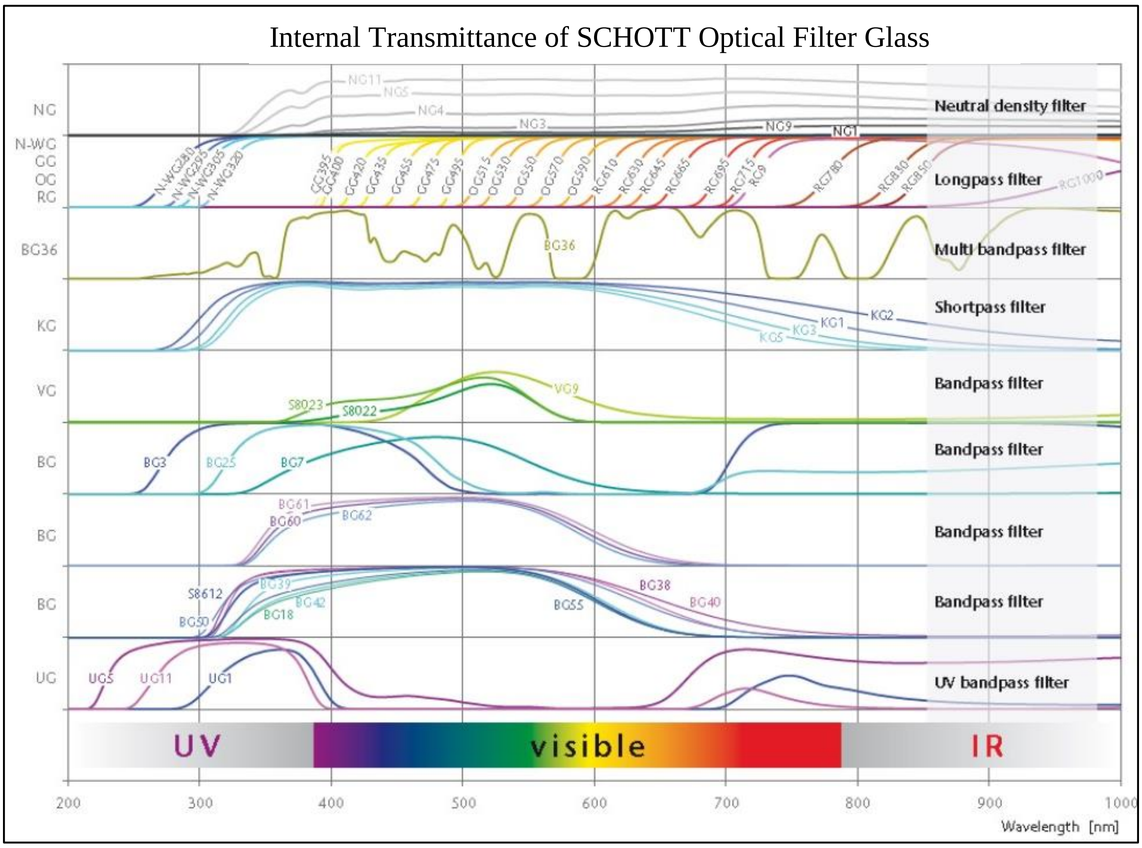


Figure 2.3. Transmission spectrums of filtered coated glasses (Schott, 2015)

In reflective and selective coatings, the main metals used for solar control layers made from reflective metal oxides are titanium, chromium, nickel and iron. These metals also have absorption properties (Karlsson, 2001).

Better thermal insulation is achieved by low emissivity low-E coatings. Low-E coatings can reduce the emission value of the glass surface from e ~ 0.87 to e ~ 0.04. Thus, infrared radiation can be reduced by up to 20% without lowering the light transmittance below 77%. In the market there are usually glasses with emission values between e 0.04 and 0.16 (Harvey, 2012). Glasses with these values are especially important for the production of heat-insulated glass units.

As can be seen in three different composition of single glazing given in table 5 by (Karlsson, 2001): “The first is just a clear float glass (named Float), the second a doped tin-oxide coating (SnO_2:F), normally produced directly on the glass production line by spray pyrolysis and the third is a thick silver coating (Ag^+), protected by two dielectric tin-oxide layers, which also anti-reflect the silver layer. Coatings of this latter type are normally produced by sputtering techniques. The tin-oxide coated glazing perform as a low-e glazing having a T_{sol} of about 67 % and a ε_{th} of about 15 %, and the thick silver as a solar control glazing having a T_{sol} of about 38 % and ε_{th} of about 8 %" as shown in table 2.3. In table 2.3; "ε_{th} – values are not calculated but estimated. Optical constants from Rubin26 (float), Roos27 (SnO2:F), Palik28 (Ag, Sio2)" (Karlsson, 2001).

Table 2.3. Layer thickness and integrated parameters for float, SnO2 and Ag+ samples (Karlsson, 2001)

	"Float (4mm thick)"	SnO_2:F "Low-e"	Ag+ "Solar control"
"Coated layers"	-	SnO_2:F/SiO_2	SnO_2/Ag/ SnO_2
"Coating thickness"	-	300/100 nm	30/20/60 nm
T_{sol} (%)	82	67	38
R_{sol} (%)	7	9	51
T_{vis} (%)	89	90	59
ε_{th} (%)	84	≈15	≈8

The effect of cold mirror coatings is opposite to that of low-E coatings because they reflect visible light rays, allowing the passage of infrared rays. Such coatings are applied to the reflectors of dichroic lamps used in places such as the operating theater.

Ceramic-enamel coated glasses reflect about 25% of the sun's rays. It is generally accepted that almost no sunlight has passed from the surface of the coated surface (Harvey, 2012).

The angular selective coatings control the light and image transition according to the selected direction. A new development in this regard is the formation of a microscopic metallic lamellar structure directly on the glass surface by magnetic field release.

2.2. Smart Glasses

Glass systems providing dynamic control in high performance façade systems are generally described as "smart glasses". The term "smart" refers to the ability of glass systems to be controlled in response to changing environmental conditions. Smart glasses are generally glass which can change their optic properties from transparent to color depending on the temperature, light intensity or electrical field on them, and they are divided into two groups as passively and actively controlled glasses:

- Glasses with passive control: Photochromic and Thermochromic glasses
- Glasses with active control: Electrochromic glasses

2.2.1. Photochromic material

In photochromic glass, TiO2 and TiN coatings are used with different layering methods (Anonymous, 2014). These glasses are sensitive to daylight and their permeability varies according to the changes in daylight. Heat absorption rate increases when they change their permeability. On cold sunny days, they absorb the sun's heat and the room's source heat, and then radiate some heat again around it (Esmer, 2012). On hot sunny days, they do not reflect solar energy as much as reflective glass. They react automatically and do not allow independent control.

“Advantages: without energy consumption the color of glass can change according to sunlight. This is normally in form of a coating which can be added to the glass layer” (Pahlavan, 2011). Due to (Aguilar and San Román, 2014) Figure 2.4 shows: “the shifting of the hydrogen of 1,4-dihydroxy anthraquinonoid under the light stimulus, which leads to the color change of the material.”

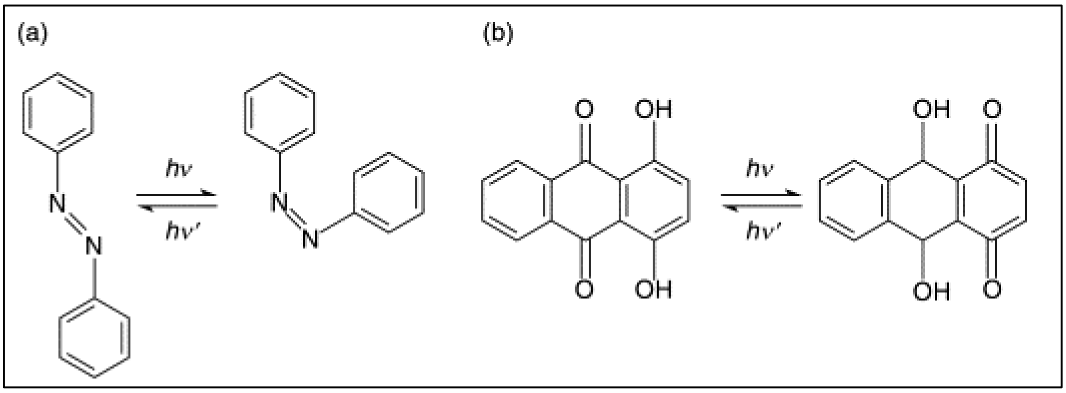


Figure 2.4. Different photo isomerization-based photochromisms: (a) photo isomerization of azobenzene and (b) tautomerization of 1,4-dihydroxy anthraquinonoid (Aguilar and San Román, 2014)

Disadvantages: The process of production and receiving to the coating is advanced so that involves a lot of money. These materials are responsive to heating that they cannot stable as building material for long time. Furthermore, they cannot be administrate by user (Ritter, 2007). Considering these disadvantages, usage of photochromic glasses as building material is not recommended.

2.2.2. Thermotropic - thermochromic material

Heat sensitive thermochromic glasses change color as the glass surface temperature reaches a certain level. Thermochromatic transparent materials are designed to prevent the passage of thermal energy (infrared heat). They change their optical properties in response to temperature changes (Esmer, 2012). These materials consist of liquid or jellied glass sandwiched between layers of glass. What is missing in these systems is the possibility of reducing visible light transmission and infiltrating the window unit of the liquid phase to affect its long-term stability (Anonymous, 2014). Figure 2.5 shows the color changing according to the thermochromic glass temperature.

Figure 2.5. Change according to thermochromic glass temperature (Anonymous, 2014)

Advantages: as shown in Figure 2.5 the thermochromic glass changes its opacity without energy usage.

Disadvantages: The thermochromic glass can restrict the outdoor vision and prevent to see outside.

2.2.3. Active smart glasses - electrochromic materials

The electrochromic glasses that provide active control can be controlled manually or automatically. With the help of a low electric current, the solar heat gain coefficients and the light transmittances of the glass can be changed linearly at certain intervals (Esmer, 2012). Figure 2.6 shows an operation principle of an electrochromic window: First glass or plastic layer conductive oxide, the electrochemical layer (for example tungsten oxide), Ion conductor (electrolyte) and its source. And the second conductive oxide layer, the second layer of glass or plastic is found.

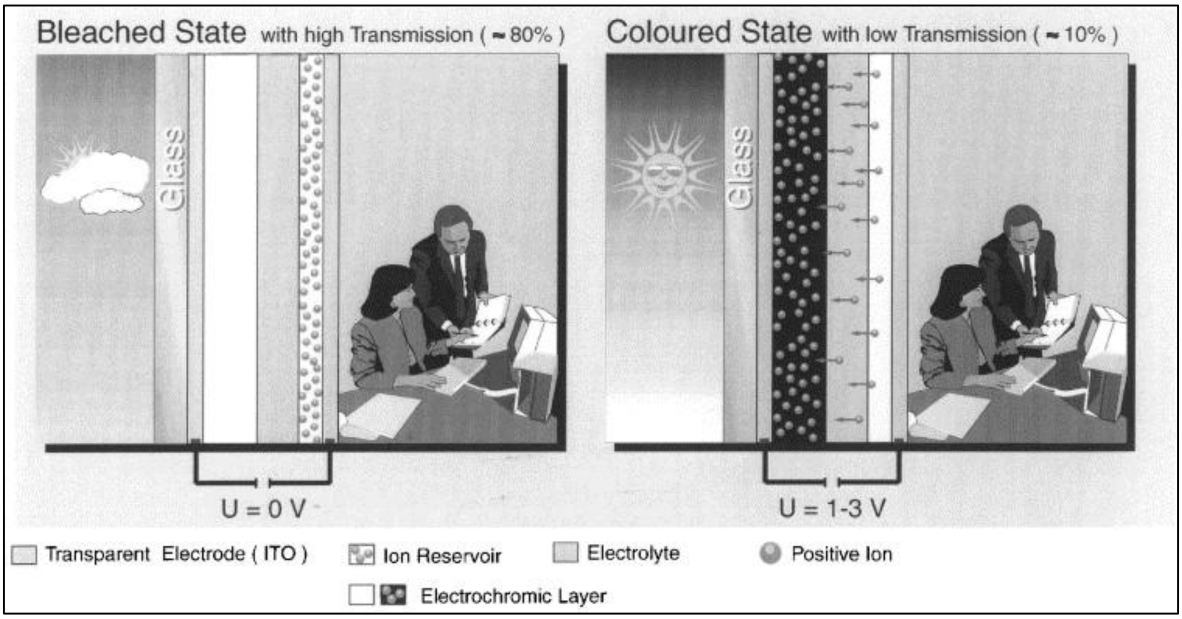


Figure 2.6. Operation principle of an electrochromic window (Ritter, 2007)

Electrochromic transparent materials change their optical properties when an electric current passes through the unit. A thin metallic film is placed on the glass in a process similar to the production of low-e glasses. The color of electrochromic glasses can be controllably changed (Anonymous, 2014). The performances of the electroactive windows are increased by the lighting systems that take advantage of daylight. At the same time, daily electrical energy consumption has been reported to be reduced by 6-24% compared to other conventional window systems of electroactive windows, and improvement in control of glare levels has also been reported (Tavil, 2004).

Each control strategy has different effects on the building's thermal behavior and comfort conditions. For example, photochromic glasses are not susceptible to solar heat gains, while being suitable for controlling the indoor daylight level. Thermochromic glasses respond to thermal effects but cannot effectively provide daylight permeability. Dynamically controllable electrochromic glasses have a higher potential in terms of user comfort and energy efficiency than other smart glass technologies, especially in high performance building applications. Interior views of supposed windows in a cloudy and a sunny day have been shown in Figure 2.7.

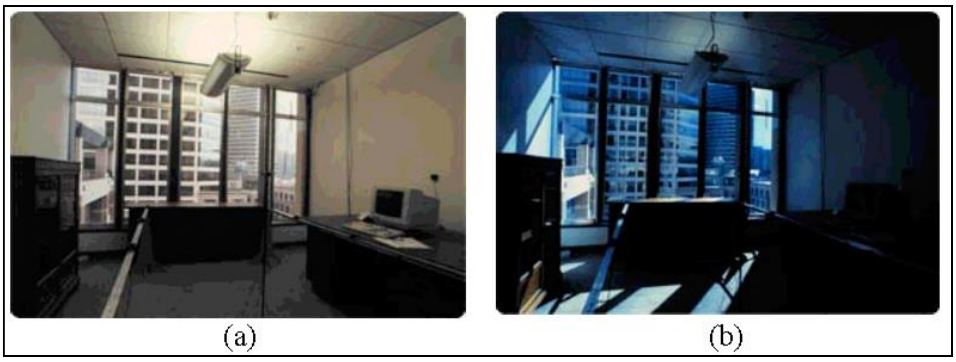


Figure 2.7. Interior views of windows. a: Clear (cloudy day) b: Colored (sunny day) (Tavil, 2004)

In electrochromic glass systems, a potential of 1 to 5 volts is applied to the tungsten oxide film layer, which is applied as a multilayer film layer of about 1 micron thickness, so that the glass surface can shift from transparent to colored, thus reducing the sunshine and solar heat gain from the glass surface (Esmer, 2012). The advantages and disadvantages of types of Electrochromic glass has been shown in table 2.4.

Table 2.4. Comparing types of active smart glass (Casini, 2014)

SPD – Suspended particle devices	Inorganic Electrochromic materials Glass	LC and PDLC - Privacy Glass
The glass switches from clear to dark mode in seconds	It takes from 10 to 20 minutes to the glass to switch from clear to dark mode	Glass turns from clear states to opaque state in milliseconds
It works as a simple laminated glass	Only works as IGU (insulated glass unit), which requires special frame and gas infiltration	It works as a simple laminated glass
Provides the user to accurately determine the amount of light, glare and radiation transferring by a window.	Glass cannot be adjusted to an intermediary amount of light	Only instant privacy function
Disadvantages; Complex installation, complex manufacturing, less safety because of electricity, with 60-110 voltage electricity power	Disadvantages: Change color gradually, high processing cost with battery electricity power	Disadvantages; Complex installation, complex manufacturing, less safety because of electricity, the entrance of light is the same visibility will change, with 60-110 voltage electricity power

2.3. Glass Types, Properties and Applications

Regardless of the production process, normal glass is synonymous with flat glass. As (Brinckerhoff and DNV) mentioned: "Float glass has a perfectly flat, brilliant surface, whereas sheet glass has slight distortions. Both are referred as normal (annealed) glass and can be processed to obtain many different varieties of glass for use in buildings". The properties are presented in Table 2.5.

Table 2.5. Properties and applications of normal (annealed) glass (Haldimann, Luible and Overend, 2008)

Types of Normal Glass	Glass Clear Glass	Glass Wired glass	Glass Stained glass	Glass Patterned, Figured or rolled glass	Glass Extra clear glass	Glass Ceramic printed glass
Properties	- High lighting transfer - Optical clarification - Can be developed to other types of glass	Having fire protection exclusivity.	Reducing energy transmissions	Interior usage like bathrooms	- High lighting transfer more than 92 percent	- Original display through the life of the glass - Shading abality
Density	"2.42 – 2.52 g/cm3"					
Tensile strength	"40 N/ sq. mm"					
Compressive strength	"1000 N/ sq. mm"					
Modulus of elasticity	"70 GPa"					
Coefficient of linear expansion	"9 x10 -6 m / mK"					

Table 2.5. (continues) Properties and applications of normal (annealed) glass (Haldimann, Luible and Overend, 2008)

Available thickness	"2 mm - 19 mm"					
Normally available sizes up to	"2440 mm x 3660 mm (Bigger sizes can also be made)"					
Color	Clear	wire mesh	Grey, Bronze, Green, Blue and Pink etc.	with Figures or patterns on one face	Clear	silk screen
U value	"5.7 W/sq m K for 12mm thick to 6.4 W/sq. m. K for 19mm thick"					
UV transmittance	"06% for gray 12 mm thick to 80% for clear 2 mm thick"					
Shading co-efficient	"0.5 for 12mm thick gray to 1.0 2mm thick clear"					
Visible light transmittance	"20% for gray 12 mm thick to 90% for 2 mm thick clear"					
Applications	Any transparent component of building	In fire protection	Any transparent component of building	Interior architecture	Jewelry and artificial materials	curtain walls, Bathroom Installation and other Any transparent component of building

- Laminated glass is constructed of several layers of glazing (normal or tempered glass) with several layers of a transparent/ pigmented polyesters (Polyvinyl Butyral [PVB]) putted into the glazed panes. Segments will stick to PVB and reduce the risk of injury if the glass is cracked (Bansal and Doremus, 2013).

- Tempered Glass is manufactured by rapidly cooling the annealed flat glass when it is heated near to its softening point (approximately 650ºC) to enforce “compressive stresses of 770 kg/m2 to 1462 kg/m2 on the surfaces and edge compression of the order of 680 kg/m2” (Gunasekaran, Emani and TP, 2010). “After tempering uniform compression is formed over the surface while tensile stress formed inside the glass plate. During the rapid cooling down process the exterior of the Tempered glass rapidly cooled and solidified yet the interior of the glass cooling procedure rather slower” (Hubert, 2015). By becoming smaller of interior it turns out the compressive stress over the formed to the interior, thereby enhanced the toughness and its refractory stability of the glass.

“The flexural rigidity of the tempered glass and its resistance to shock are three to five times higher than ordinary glass in the same thicknesses. Under the load of bending force the upper surface endures the compressive stress while its lower surface endures the tensile stress. So the ordinary glass will be broken whereas the tempered glass will not break under the same load” (Lawn and Marshall, 1977).

- The reflective glass exposes like a mirror with presentation of the outdoor under most daytime conditions. “Thin infrared reflective films” include a metal layer. A metallic coating applied to one side of glazing have high reflectance with low emissivity in the infrared range (Mohelnikova, 2009). Figure 22.8 shows spectral reflectance of metallic films by Mohelnikova.

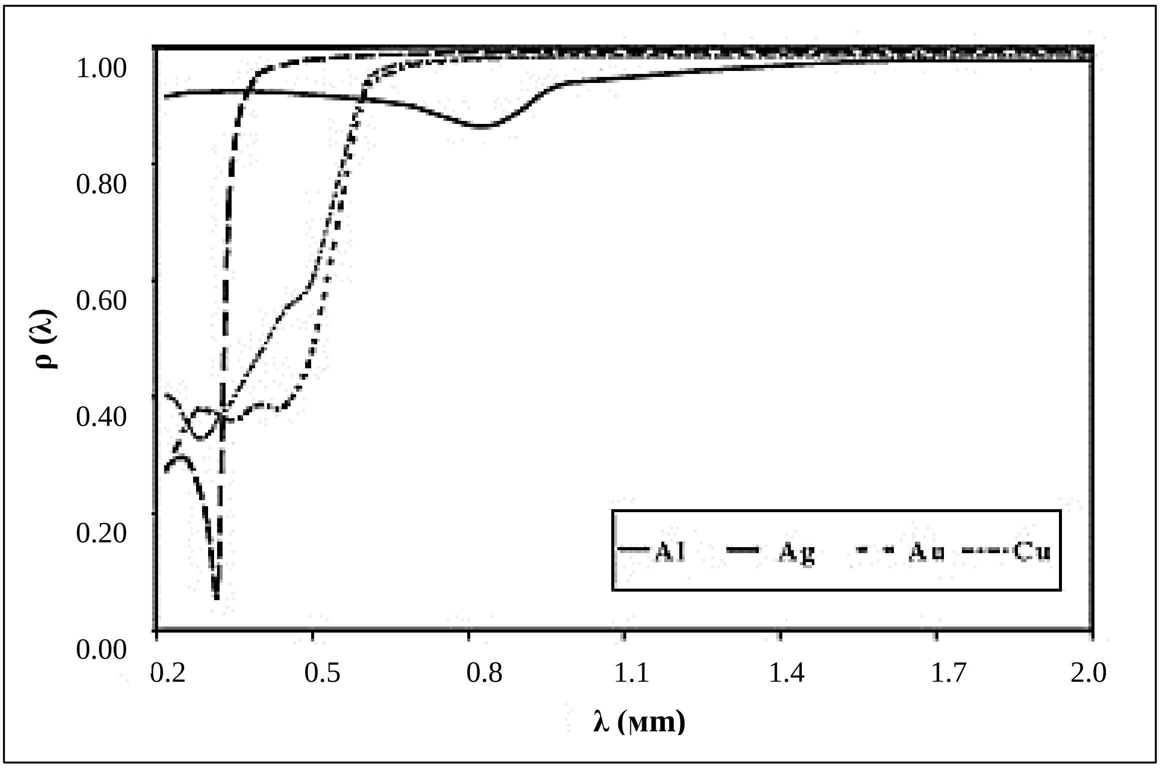


Figure 2.8. Spectral reflectance of thin metal films of aluminum (Al), silver (Ag), Gold (Au) and Copper (Cu) (Mohelnikova, 2009)

Therefore the reflected glass is colored due to the coating of metal oxides on the glass. The coating can be exerted to clear or tinted glass. They reduce solar gain and the air conditioning load and permit optimum light transmission (Gunasekaran et al., 2010).

- The insulating glass typically involves multiple glazing panes sealed in the edge of glass area. The panes are kept each other structurally along their settings by various sorts of edge seal systems (Van Den Bergh, Hart, Jelle and Gustavsen, 2013). The damp of space between panes is adjusted by desiccants punted in the leaky spacer that may be aluminum, composite plastics etc. The space between panes be stacked with dry air or other gases such as Argon, Krypton for better thermal efficiency or hydrogen fluoro-oxide for better acoustic efficiency (Gunasekaran et al., 2010).

Table 2.6 shows the properties and applications of glass types.

Table 2.6. Properties and applications of glass types (Haldimann et al., 2008; Gunasekaran et al., 2010)

<table>
<tr><th>Types of Glass</th><th>Laminated Glass</th><th>Tempered or Tempered Glass</th><th>Reflective Glass</th><th>Insulating Glass</th></tr>
<tr><td>Density</td><td>2.42 – 2.52 g/cm3</td><td>2.42 – 2.52 g/cm3</td><td>2.4 – 2.5 g/cm3</td><td rowspan="5">-Heat transmission reduction
- Cooling load decreasing
- Noise pollution reduction
- energy savings</td></tr>
<tr><td>Tensile strength</td><td>32 N/sq. m</td><td>120 to 200 N/sq. mm</td><td rowspan="4">- Gracing exterior design
- energy savings by reduction of solar heat gain
- Improves occupants comfort as interior temperature variations are less and easier to control.
- Modifying lighting transmittance and reflectance.
- Decreasing the air conditioning load of the buildings</td></tr>
<tr><td>Compressive strength</td><td>1000 N /mm2</td><td>1000 N /sq. mm</td></tr>
<tr><td>Modulus of elasticity</td><td>70 GPa</td><td>70 GPa</td></tr>
<tr><td>Coefficient of linear expansion</td><td>“9 x 10–6 m / mK”</td><td>“9 x 10–6 m / mK”</td></tr>
<tr><td>Available thickness</td><td>“4.38 mm – 20.76 mm
(other thickness can also be made to order)”</td><td>“3 mm - 19 mm”</td><td>“3 mm - 12 mm”</td><td>Custom made</td></tr>
<tr><td>Normally available sizes up to</td><td>“2000 x 3210 mm (Bigger sizes can also be made)”</td><td>“2440 mm x 3660mm(Bigger sizes can also be made)”</td><td>“2250 x3210 mm (Bigger size can also be made)”</td><td>Custom made</td></tr>
<tr><td>U value</td><td>“2.84 W/sq. m. K for 3 mm thick clear to 5.96 W/sq. m. K for 6 mm
thick clear”</td><td>“5.7 W/sq. m. K for 12 mm thick clear to 6.4 W/sq. m. K for 2 mm
thick clear”</td><td>“5.1 to 5.7 W/sq. m.K for 6mm thick”</td><td>0.64 W/sq. m. K for 6mm thick
[6mm air space] to 0.56W/sq.m.K
for 6mm thick [12.9mm air space]</td></tr>
<tr><td>UV transmittance</td><td>“30% for bronze 6 mm thick to 80% for 6 mm thick clear”</td><td>“06% for 12 mm thick gray to 80% for 2 mm thick clear”</td><td>-</td><td>-</td></tr>
</table>

Shading co-efficient	"0.5% for 6 mm thick gray to 0.9% for 6mm thick clear"	"0.5% for 6 mm thick gray to 0.9% 6mm thick clear"	"0.25 - 0.552 for 6mm thick"	"0.52 for 6 mm thick gray to 0.95 for 6 mm thick clear monolithic"

Table 2.6. (continues) Properties and applications of glass types (Haldimann et al., 2008) (Gunasekaran et al., 2010)

Visible light transmittance	"25% for 6mm thick bronze to 90% for 6mm thick clear"	"20% for 6mm thick bronze to 90%6mm thick clear"	"5 – 40% for 6 mm thick"	"37% for 6mm thick gray to 87% for 6mm thick clear monolithic"
Application s	Exterior and interior transparent surfaces	Exterior and interior transparent surfaces	- Solar control usages - Building facades	- Building facades

2.4. Stained Glass Windows

Due to (Savić et al., 2013) stained glass contains; "minerals that color the glass uniformly through its thickness and promote absorption of visible light and infrared radiation".

"The Medieval period in Europe lasted from approx. 500 A.D.-1450 A.D. This was when knights and noblemen ruled towns, castles and countryside. Churches played a big role in daily life as Christianity spread organized religion through Europe" (Zenner, 2008).

As (Morey, 1938) said : "The first record of stained glass using referred to Adalberon, Bishop of Rheims, when rebuilding the cathedral in 969-988 A.D.".

Color in stained glass is in conjunction with psychology and emotions. The spiritual impression of everyone is being revealed by crossing the threshold of historical place filled by color lighting. Inspissated reds and majestic yellows are colors that were commonly putted into stained glass because of the sensations they pointed. (Zenner, 2008).

So since the Middle Ages, colloidal gold and silver have been comprehensively applied in stained glass. Transition through a colloidal silver concludes yellow light and transition through colloidal gold concludes amethyst red. The great colored lighting from the stained glass of the Sainte Chappelle in Paris is considered to be majorly due to the Nano-plasmonic resonances (Stockman, 2011).

The glass produced from natural materials (e.g. sand, limestone, plant ashes) so the color changing appeared by adding the heavy metals. “In the Middle Ages, stained glass was made by melting a mixture of washed siliceous sand and a flux. The flux used was either mineral (“natron”) or plant-based (beech or fern-ash). The staining was attained during the fusion process by the addition of variable amounts of different metal oxides (Co, Mn, Cu, Fe etc.)” (Sterpenich and Libourel, 2001).

The enriching colors by plasmonic metal particles are promptly outward to the eyes in view of the fact that the light absorbs and diffuse at optical frequencies. The most ancient model of that is “CE Lycurgus cup from the British museum, whose glass looks green in reflected light but ruby red in transmitted light. The colors are complementary, evidence that there is little optical loss inside the glass. Investigation has shown that the dichroic glass contains nanocrystals of a gold-silver alloy at a fraction of less than 1%” (Stockman, 2011).

2.4.1. Orosi glasses

Traditional building technologies have taught us a lot about how to design. Orosi glasses are one of these technologies. Orosi first began to be used in the Safavid era. For years, it has protected Iran from burning, hard and violent sunlight. This architectural element has kept its importance for years. It has been understood that Orosi lenses play an important role as severe solar rays damage Iranian woven fabrics which are very valuable and easily deformable. The Orosi glasses, which were actively used until the end of the Qajar period in 1930, were left to the widespread glass as modern architectural practices began. As can be seen in Figure 2.10 Nasirolmolk mosque is one of the examples of this period. In recent times, these glasses have come back to life in a building built in Tehran, in 2015 by Keivani office (Figure 2.9).

Figure 2.9. Seven story building, view from colored glass (Anonymous, 2016)

In order to prove this, researches on Orosi glasses, laboratory measurements and working methods have been carried out. Evaluations were made on Orosi with colored glass combinations under certain light (Tahbaz, Djalilian, Mousavi and Kazemzade, 2015).

Figure 2.10. Nasirolmolk mosque, 1873 Qajar period

In sustainable architecture, solar rays are supported for solar energy sources and the most appropriate choices are made for efficiency. For recyclable materials, studies have been carried out to reduce sunlight. At this point, contradiction (duality) has been created in sustainable architecture.

Colored glasses are aesthetically, climatically, traditionally and symbolically used, and integrated with daylight. It is a technique used to reduce sunlight in Iranian traditional architecture. Through years of use, it has been able to control the solar energy in depth and is preferred over the different types of structures found in the extreme hot climates of Iran. Types of colored glasses and materials used in their structure defined in Table 2.7 by (Hami, 2000).

Table 2.7. Types of colored glasses and materials used in their structure (Hami, 2000)

Colored Glass Types				
Glass color	Blue	yellow	Green	Red
material	cobalt	Sulfur	worm	copper

Figure 2.11. Chinese knotting in Orosi windows (Sarbangoli and Pourlamar, 2014)

Especially in the year when the sky is cloudless and clear, it has been determined to be over sunny for 280 days. Solar-based heating ranges from 4000-7000 MJ per square meter (Khorasanizadeh, Mohammadi and Aghaei, 2014). This seems to be a potential danger to us.

Orosi are used in wooden cages in pure four colors of blue, green, yellow and red, and they are mounted together in natural ways without using metal as can be seen in Figure 2.11. According to their color, they showed variability in reducing the damage rates. At the same time, Orosi glasses attract attention with their beauty and they are popular by the users by affecting the human soul.

2.4.2. Experimental investigations on Orosi glasses

The preferred absorber spectrum in the range of visible wavelength causes the formation of color in the glass. The effects of the glasses - reducing the energy input - is proved that visible transmission and radiant energy range are calculated in these various glasses only in the visible region of the light. The amount of radiant energy transmission has been investigated in these glasses to show the apparent radiant spectrum, the amount of light, and the ability to block the entry of energy after comparison with the amounts in normal glasses (based on whether the sensitivity of the human eye is the same for different visible wavelengths). The aim of this research is to open another window from the path of Iranian historical architecture. In addition, the concept of reducing brightness intensity and optimal utilization of sunlight using colored glass are used in climatic conditions with high cold loads. The researches on Orosi glasses at 2006 and 2015 show the green, blue, red and yellow glasses, the light visibility and the amount of light passing through long wavelengths are investigated. Accordingly, the results on the spectrophotometer are as follows:

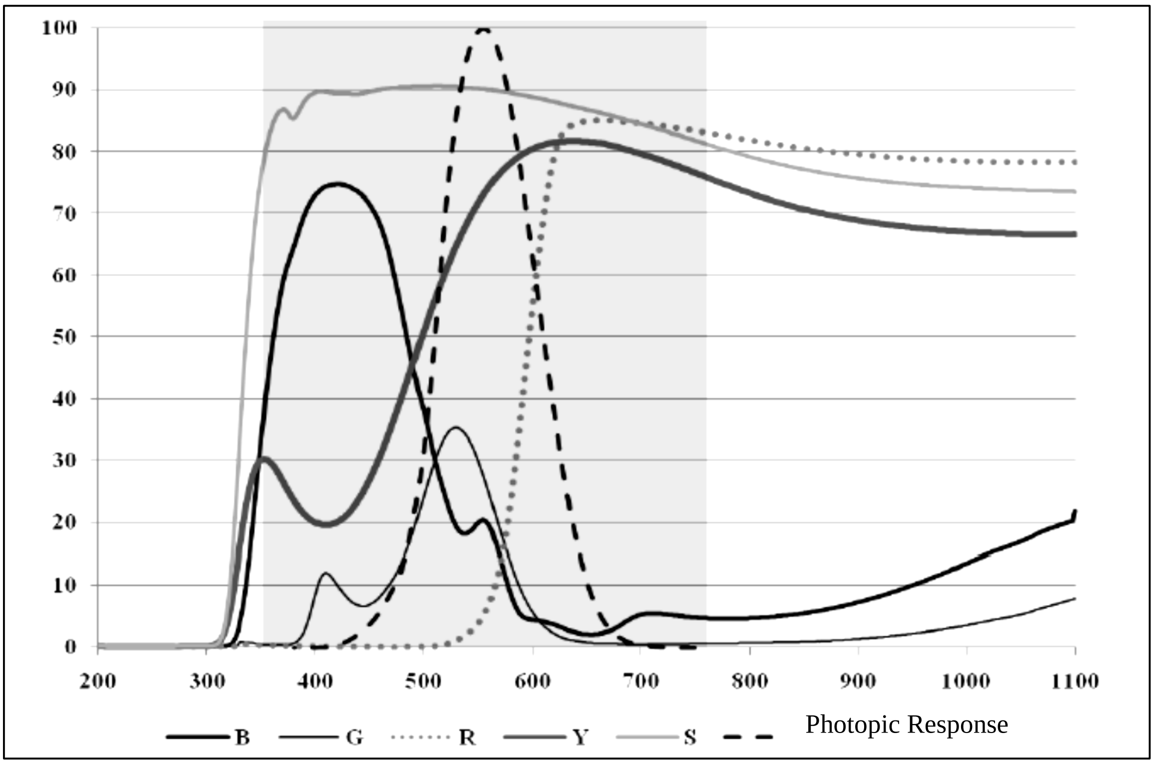


Figure 2.12. Test results of the transmission spectra were obtained from the colored glass (Haghshenas, Bemanian and Ghiabaklou, 2015)

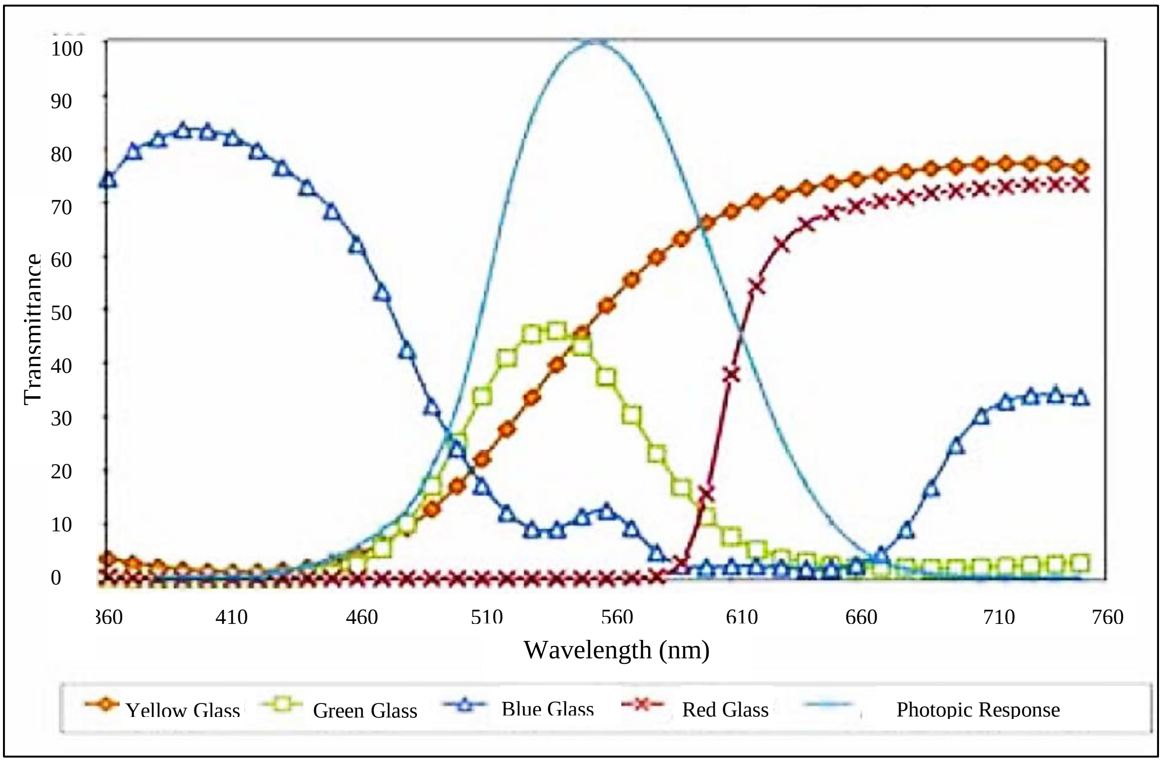


Figure 2.13. Test results of transmission spectra ranged from colored glass samples to wavelengths between 460-750 nm (Haghshenas and Ghiyabaklu, 2006)

According to the results of the research by (Haghshenas et al., 2015), as shown in Figure 2.12 and Figure 2.13, the transmission specimen does not match the human susceptibility curve in glass specimens. Blue and Red glasses are the colors with the highest human susceptibility. But yellow glasses provide the most light; they pass the yellow-orange spectrum and the maximum spectrum is between 62-75 nm which does not include the visual sensitivity of people. The highest transmission spectrum for green glasses is also suitable for people's visual senses and is considered as the most suitable color according to the optimum glass light transmission (Haghshenas and Ghiyabaklu, 2006).

In the reviews carried out by (Haghshenas and Ghiyabaklu, 2006) and (Gorji and Monfared, 2017), in order to obtain the spectral transmission of sunlight as well as the percentage of radiant energy passing through in the visible area of each Orosi, the area of each of the colored glasses used in them has been determined. To achieve this goal, using the AutoCAD software, all Orosies have been computerized simulations. The AutoCAD simulations of Orosi windows by (Haghshenas and Ghiyabaklu, 2006) and (Gorji and Monfared, 2017) have been shown in Figure 2.14 and Figure 2.15.

Figure 2.14. The AutoCAD simulation of Orosi window of Dolatabad garden in Yazd (hot climate) (Haghshenas and Ghiyabaklu, 2006)

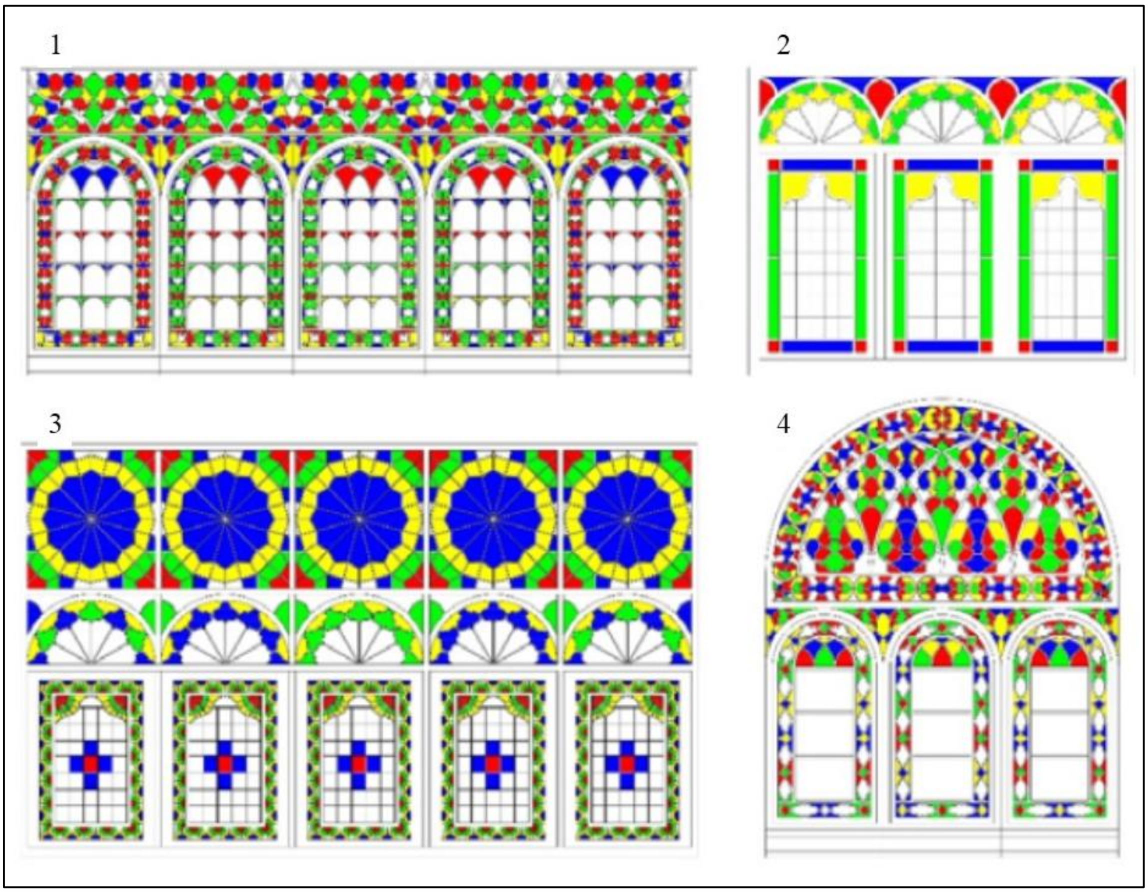
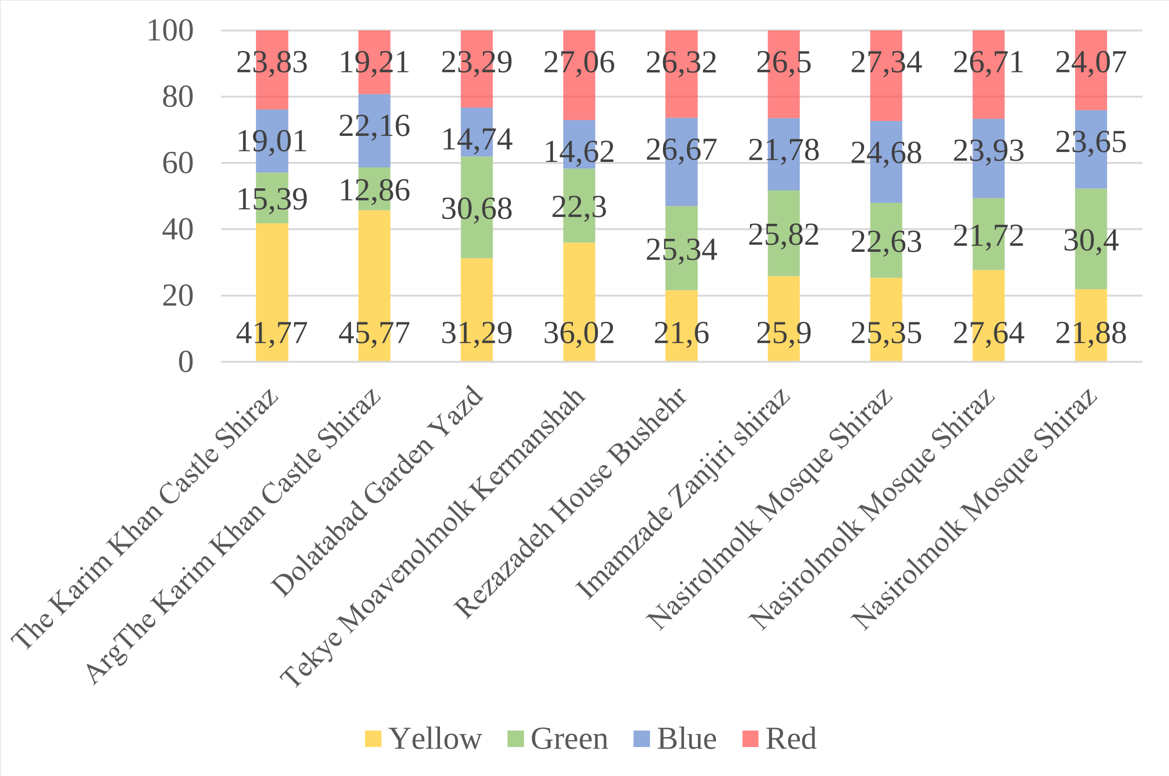


Figure 2.15. The AutoCAD simulation of Orosi windows of Qazvin houses (cold climate); (1) Mohasses house, (2) Shahidi house, (3) Mohasses house, (4) Shahidi house (Gorji and Monfared, 2017)

In the study of different Orosi samples, it was found that in all of them, colored and simple glasses were used together. Color glasses include blue, red, green and yellow. The amount of color glass used was different, but the remarkable thing is that in 91% of them, the area of the glass was colorless and simple more than 50% in cold climates' samples (Gorji and Monfared, 2017) and 100% colorful in samples of hot climates (Haghshenas and Ghiyabaklu, 2006). In an experiment that was carried out to determine the light transmittance at various wavelengths of colored and simple glasses belonging Qazvin houses, the percentage of light passing through simple glasses and yellow glasses was far more than the blue, red and green samples (Gorji and Monfared, 2017). Therefore, considering the high percentage of use of colorless and yellow glasses and high light transmission in them, it was determined that one of the factors influencing the selection of colored glasses in Iranian architecture was attention to climate. Because in the cold cities of Iran there was a greater need for sunlight to provide comfort to the inhabitants than the central and desert cities of

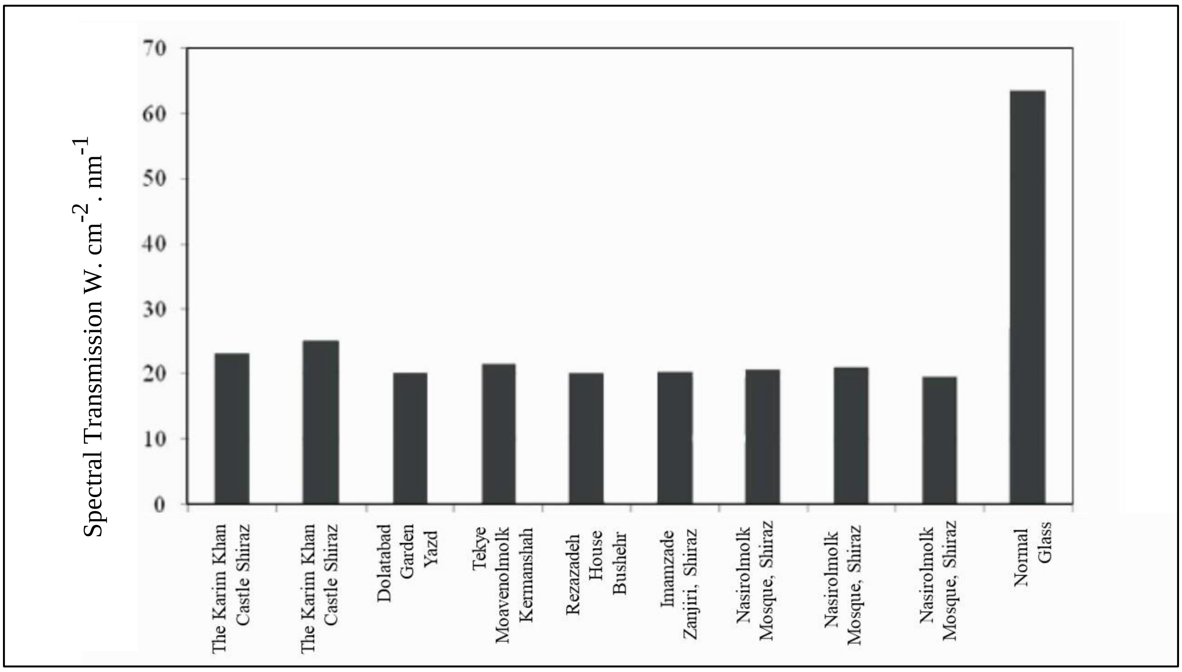
Yazd and Kashan. The area Percentage of colored glass used in the studied Orosies by (Haghshenas and Ghiyabaklu, 2006) in hot climate samples has shown in Table 2.8.

Table 2.8. The area Percentage of colored glass used in the studied Orosies of hot climate samples (Haghshenas and Ghiyabaklu, 2006)



The approximate percentage of transmitted energy from 12 samples analyzed by (Gorji and Monfared, 2017) and 9 samples by (Haghshenas and Ghiyabaklu, 2006) is between 19% and 72%. This means that in these buildings, about 28 to 81 percent of the solar radiation in the visible area does not directly enter the interior space. This helps to reduce the rise of the unfavorable temperature, especially in hot seasons, which requires a cooling load. Comparison of the energy transmission of Orosi samples in hot climate through radiation at the visible wavelength determined by (Haghshenas and Ghiyabaklu, 2006) in Table 2.9.

Table 2.9. Comparison of the energy transmission through radiation at the visible wavelength by Orosi samples in hot climate (Haghshenas and Ghiyabaklu, 2006)



By comparing the percentage of energy absorbed and reflected by Orosi glasses in the visible region relative to the total amount of solar radiation energy, in the studied samples, it was found that this value is between 12 and 24%. The average in all Orosies was about 17.8%. This figure indicates that the glass used in the Orosi can only reduce the amount of radiation entailed by the absorption and reflection in the visible wavelengths of the sun. In the case of light variations in Orosi samples according to wave length; yellow and blue colored glasses have a 1% glass usage difference on large and small scales and still the transmission spectra seems to be same.

The data obtained from the research by (Gorji and Monfared, 2017) shows that in 91% of the studied Orosies, more than 50% of light at 555 nm wavelength, which is the most sensitive to the human eye, passes through Orosi glasses. The remarkable point is that in half of the total Orosi, this amount is more than 60%. Transmission spectrum of Orosi compared with the spectrum of three bronze, colorless and blue glasses that were made according to the preferential spectrum, it turns out that the light transmission at 555 nm wavelength in these glasses is less than 60%; In this way, it can be concluded that in general, the studied Orosies are more suitable for the human eye in terms of light transmission than the three glasses. According to (Haghshenas and Ghiyabaklu, 2006) and (Gorji and Monfared, 2017);

“the percentage of energy passing through the visible area in each of Orosies, shows that about 28% to 81% of the solar radiation energy in the visible area does not pass through the Orosies and does not directly enter the interior spaces”. Therefore, considering that about 46.41% of the total solar radiation energy is in the visible range, the percentage of energy absorbed and reflected by Orosi glasses will be significant. Due to the relatively cold climate, which in winter there is a high need for internal space heating, this amount Lack of passage of radiation energy is acceptable value.

According to the above mentioned, it can be concluded that in traditional architecture, the use of Orosi with the proper and efficient use of colored glasses in accordance with climatic requirements is one of the suitable ways to control the light and energy entering the interior spaces.

So Due to what has been achieved by the previous researches, passing from traditional to modern and postmodern architectures, how to challenge colors in different climates to reduce the amount of solar radiation while providing the amount of Lighting comfort was studied, which is paid in detail in chapter three.

2.5. Shutters Shading Systems

As Schittich and others: “The building skin is the primary subsystem through which prevailing external condition can be influenced and regulated to meet the comfort requirements of the user inside the building” (Schittich, Lang and Krppner, 2006). So one of the most import components is window system with or without sun-shading device. As Kuhn and others: “Shading systems have to provide thermal and visual comfort both reliably and economically. At the same time, they should prevent unwanted solar gains in summer and permit high solar gains in winter” (Kuhn, Bühler and Platzer, 2001). It is so important that shading conditions in summer are more notable than solar approach in winter.

2.5.1. External system

External devices are more efficient in decreasing heat gains compared to interior shading systems, because they block most of the heating of solar radiation before it attains the indoor environment.

Hien and Istiadji in their “Effects of external shading devices on daylighting and natural ventilation” named research investigated daylighting and ventilation of external shading systems via Lightscape and Phoenics CFD simulations:

“The shading device with shading coefficient of 0.55 can admit daylight with illuminance exceeding the recommended level and vertical shading devices are not effective in enhancing daylighting and natural ventilation.”(Hien and Istiadji, 2003).

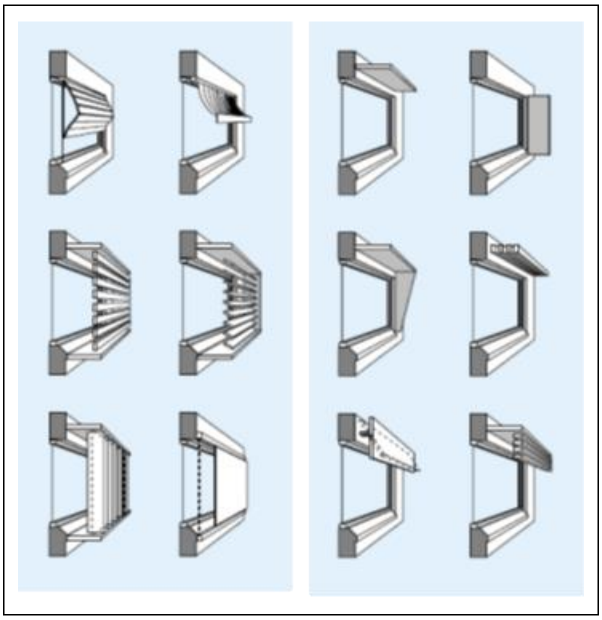


Figure 2.16. External shading device types (Stack, Goulding and Lewis, 2000)

As can be seen in Figure 2.16, external shading is usually constructed in horizontal projections, vertical louvers or permanent shutters. Due to shutter systems, moveable external shading can be adapted to climate, and can be wholly automated (Stack et al., 2000).

“Effective external shading blocks all or most direct sunlight, although it admits indirect light from the sky. It typically reduces solar heat input by 80% to 90%” (Wulfinghoff, 1999). So these shading devices will have very effective role in reducing building energy load.

External devices can be designed in fixed or Retractable and adjustable systems and include:

- Horizontal projections
- Vertical fins
- Diagonal fins

- Egg–crate
- Roof overhangs
- Window reveals

As Freewan in his thermal performance analyses of external shading devices: “Diagonal fins perform better compared to vertical fins, and slightly better than egg crate in reducing air temperature” (Freewan, 2014).

2.5.2. Internal devices

Internal shading classified into roller, venetian blinds or curtains forms and are usually adjustable or retractable, therefore it can provide night-time block out (Stack et al., 2000). Internal shading devices as shown in Figure 2.17 scatter “the heat to the air gap between the shading device and the glazing” (Datta, 2001) so external devices are more efficient than internal ones.

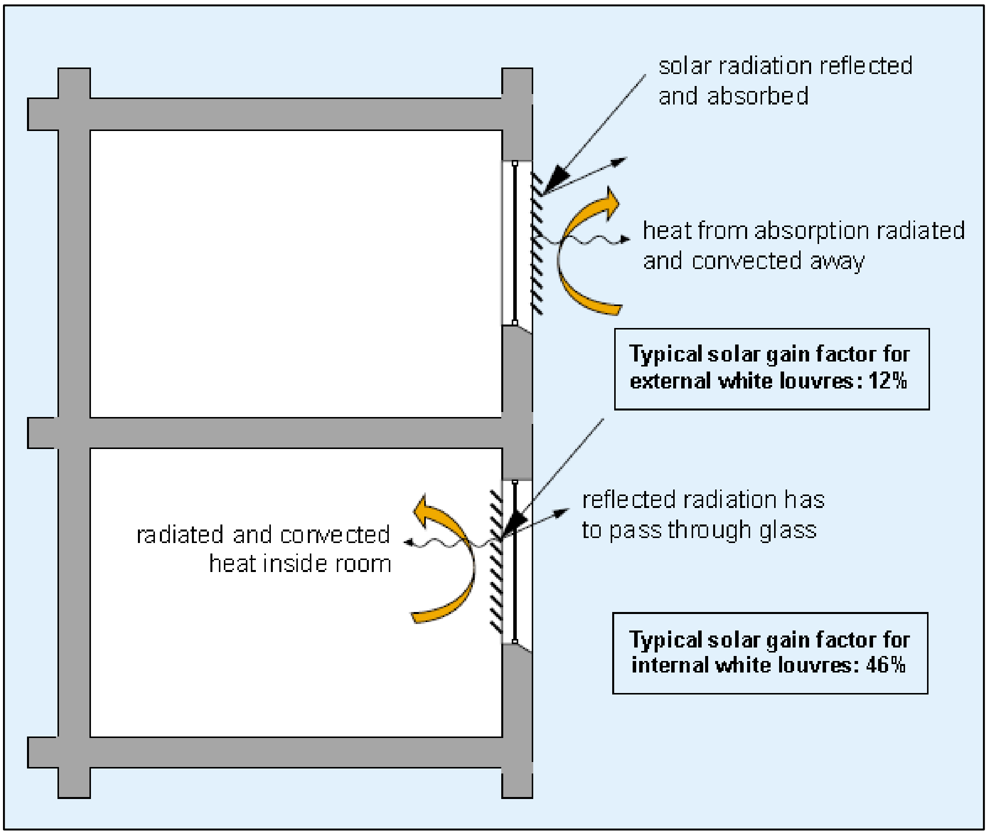


Figure 2.17. External versus internal devices (Stack et al., 2000)

2.5.3. Mid-Pane devices

Mid-pane shading devices are sometimes settled between the panes of a double glazed and triple-glazed unit. In some commercial and official constructions the devices are manufactured within a curtain wall. Generally, horizontal glossy louvres or venetian blinds are used in this kind of shading. Both of them adjust stare but glossy louvres are more capable to arrest solar heat gain (Stack et al., 2000). Figure 2.18 shows an operation of mid-pane device against solar radiation.

Due to Lomanowski and Wright: “Mid-pane devices when accompanied by effective ventilation to the outside combine the advantages of external and internal shades. Heat gains are dissipated to the outside, but the shades are protected from the severity of the outdoor climate. Mid-pane devices are particularly effective in controlling glare” (Lomanowski and Wright, 2009).

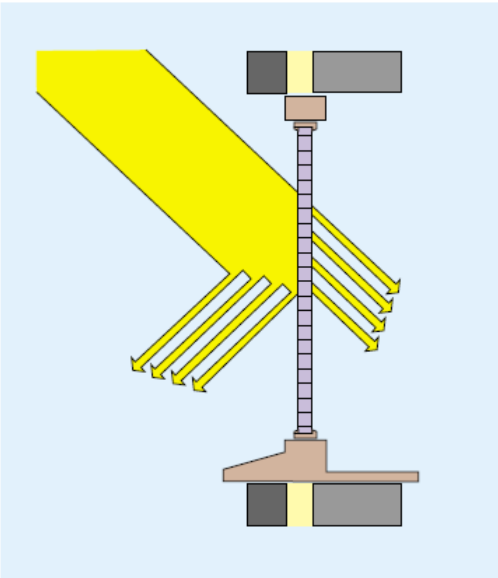


Figure 2.18. Mid-pane device (Stack et al., 2000)

3. MATERIAL AND METHOD

However, it is seen in the literature section that how to provide sufficient lighting to prevent heat gain in indoors and to provide visual comfort. These features are based on researches on Orosi glasses in the literature section. In the researches carried out on Orosi glasses, while the historical process of Colored glasses is defined according to the definition, usage and benefits, it is determined that sufficient visual comfort can be achieved within the space. However, it is shown that the heat gain is not reduced and thus the cooling load is not needed. These two properties are proved by the percentage of the spectrum passing through the colored glasses (different wavelengths).

According to the researches, radiation does not consist of just the percentage of transition in the long wavelength section. For this purpose, the use of CTFs on the facades in which today's architecture, especially on large transparent glass surfaces, based on colored glasses, was thought to provide these benefits. In this sense, the 4 primary colors were used in Orosi glasses. Two colors were added to these four primary colors at the time of the thesis and the percentage of transition of the 6 primary colors to the spectrum at different wavelengths was excluded. And by connecting these results, it was investigated whether there could be a design method in which heat gain could be prevented and lighting comfort could be provided. A program was developed for this.

In this part of the thesis, a method for answering the thesis questions is presented. As can be seen in the literature preview of the previous chapter, the positive effect of the colored glasses on the lack of passing the solar heating energy was revealed. In this chapter, taking this issue into account, a strategy to use this feature is to be considered for shadowing in windows. Due to the difference in the value of the radiant energy passing through the colors and the intensity of the light transmission, the percentage of proper area for each color relative to the total area of the window for shading should be determined.

A minimum usage of five percent from each checked color is considered by default. Examples of tested colors include polymer filters (CTFs) in three main colors and three sub-colors. CTFs in the form of translucent polymer layers can be assembled in the form of jalousie shutters (vertical blinds) inside double glazed windows or triple glazed windows. Detecting the percentage of area for each color in the entire glass is done according to the climatic characteristics of the design, orientation, window dimension, and other influential features in window shading. On the other hand, the measurement of the amount of radiation energy and the brightness of each color was carried out in the laboratory by two types of spectrophotometer in three infrared, visible and ultraviolet regions.

In order to answer the questions in the project, with using the programming language, a new software is presented to provide the percentage of optimal colored areas used in the shading system of the shadow inside the window. In this programming language, climate and design factors of the window, the position of it and the zone that it is located on, were considered. This information is transmitted by the user with drawing and importing data to the software. Climatic factors were obtained using ASHRAE standard, and formulas, geometry of shading design and radiant level of the window surface by using the previous activities performed in this field and related software.

Then, by entering the amount of radiation energy and light, passing through the transparent polymer color layers obtained from the laboratory and optimizing it, the area of each color in the two seasons of summer and autumn-spring is obtained from the total glass surface of the window. The optimization was carried out according to user design conditions and the ideal temperature inside the summer and autumn-spring. The colored polymers in the two roller rails were considered as a drop-in-color system, one of which was for summer and one for fall-spring in the window. In the case of close proximity, the percentage of area in the two roller rails are considered according to the studied climate in the single-regression system.

At the end, to check out program's validity crosscheck action was introduced. Two office zones selected in Ankara was drawn in SWDT and other software environment. Rhino-grasshopper was chosen to test the samples and extract CTFs' area percent. The area percent of CTFs deduced from rhino-grasshopper compared with SWDT's results.

3.1. Smart Window Design Tool (SWDT)

One of the most fundamental problems of today's architecture is preventing of excessive heat gain caused by large glass facades facing the sun and reducing the cooling loads inside. One of the methods that can be used to prevent this problem is colored glasses usage. The use of colors can be performed as a method, depending on the characteristics of the colors that have different transmission percent of spectra in different wavelengths.

It was necessary to see the wavelength properties of colors first of all while developing this program. To this respect the study was carried out with different requests.
The MATAB software program is a comprehensive calculation program and therefore is used as a basis. There were basic formulas and standards to be used in the program. And they were entered with two-dimensional modeling codes. Since SWDT is in the form of two-dimensional drawing, it is aimed that the window, wall and zone information will be entered more easily by the user. While writing the program, it is aimed to solve the two basic problems. The first goal is to avoid losing visual comfort that is allowing more light to pass through. And the second is to obtain less heat gain. To achieve these, ASHRAE standards, which are a worldwide standard, have been used.

As mentioned in introduction, the answer to the thesis problem is provided by the new software program. The programming of this software is provided in the MATLAB language, each of which is coded in two phases. The first phase, based on performance, which was codified in three separate functions compared to the performance, and the second phase, which the results obtained in the laboratory in terms of the amount of energy and light passing through the transparent polymeric samples (colored transparent filters (CTFs)were imported into the software. Then the optimization coding of each color for each month was written according to the ASHRAE standard and the months of summer and autumn-spring could be extracted from the geographic region. At the end of the day, the percentage of the area for each transparent polymer was more than the total area of the glass (if the shutters were taken vertically) for summer or autumn-spring.

“MATLAB®” is a high-performance software written primarily for scientific and technical computations involving numerical calculation, graphical data display and programming. Typical uses of “MATLAB” program are summarized as: Mathematics and computation / Algorithm development / Modeling, simulation and pre-processing / Data analysis and visual effects supported visualization / Scientific and engineering graphics / Application development (Kattan and Books, 2011).

The name "MATLAB" achieves from "MATrix LABoratory". MATLAB was initially created by Fortran Linpack and Eispack projects and was written in the late 1970s to supply easier access to these programs. At first, that was assisting scholars to answer questions using matrix-based material. "Today, with its built-in library and its programming features, it has found a widespread use as a highly efficient research, development and analysis tool in the university environment (especially in all branches of science such as mathematics and engineering) and in the industrial environment as well" (Kattan and Books, 2011).

By using the MATLAB software program, it is aimed to apply smart windows to windows located in every direction of the building.

3.1.1. City function

First of all climate is being identified and many cities of the world are already included. If the user does not found the desired city, the excel climate data needs to be added to energy plus site (https://energyplus.net/weather). The user transfers the program climate conditions by selecting the city. The screenshot of XLS climate file belonging to Tabriz city can be seen in Figure 3.1. The large scale of this figure with more details comes in Appendix part.

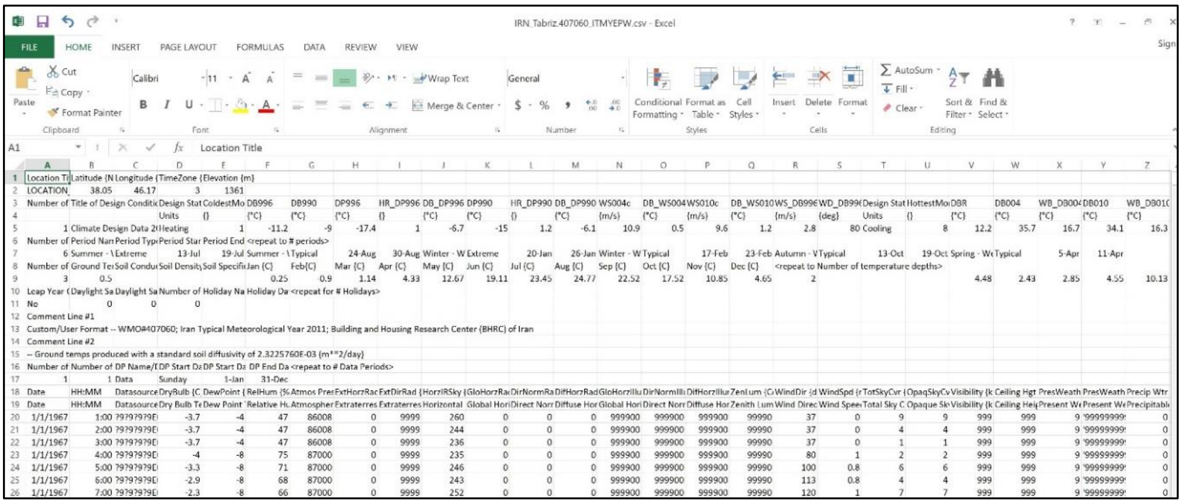


Figure 3.1. The screenshot of XLS climate file belonging to Tabriz city

3.1.2. Shading function

Shading mode is a principal part in increasing energy efficiency. The shading function was written to achieve more accurate color percentages in two season formats (summer and spring-fall), based on the shadows in front of the window in the building. It should not be overlooked that the effect of existing shadows is effective in radiation and light transition.

Due to (Niewienda and Heidt, 1996): “Shaded areas on the radiation collecting solar aperture, however, may be useful or detrimental for the system, depending on its type and objective. The knowledge of light and shadow finds very important applications within solar architecture and urban planning”. Normal action is controlling theoretical analyses of solar heat gain coefficient (SHGC) or energy saving simulation of structures during specified time for Shading behavior test (Ye, Xu, Sha, Yue and Zhang, 2016). As (Pongpattana and Rakkwamsuk, 2006) states; “In order to evaluate the performance of a shading device, the ability to compute the amount of shaded and unshaded area due to the shadow cast on a window by the sunray is required”.

To calculate the shading on a window plane, Jones rendered the shaded area by defining vanguard edge components of the bump and the bottom of the window. This system was also applied for content calculation of solar radiation on a vertical plate (Yanda and Jones, 1983). Trigonometric method is the other one which has been perused with considering the existence of awnings, parapets and over- hangs. Their geometries are characterized by rectangular shapes are conformed the geometry of shading on the parallel plane of the window and concurrent to its vertical axis (Bekooy, 1983).

The other method is SOMBRERO, due to (Niewienda and Heidt, 1996) is “a PC-program written in Turbo-Pascal, calculates the GSC (geometrical shading coefficient), the proportion of shaded area of an arbitrarily oriented surface surrounded by shading elements as a function of time end location”. And as (Hiller, Beckman and Mitchell, 2000) introduces; TRNSHD which is another PC-program “was developed for building simulations with TRNSYS, it is a stand-alone tool that is not restricted to either buildings or TRNSYS and thus can be used to solve other shading problems”.

Another software tool was performed by (Pongpattana and Rakkwamsuk, 2006) which uses Auto-CAD for graphically designing the geometry of shading system and MATLAB to prepare the algorithmic simulations. And the other program written in MATLAB developed by (Keller and Costa, 2011) which calculates the solar radiation and shadows on a rectangle surface. Due to (Melo, Almeida, Zilles and Grimoni, 2013); “Quaschning and Hanitsch

(1995) and Cascone et al. (2011) had presented methodologies to calculate the direct shading factor through the polygon projection method and the diffuse shading factor through the radiance integration along the sky dome surfaces seen through a PV surface point". The system developed by Cascone et al. (Cascone, Corrado and Serra, 2011) is more complicated than Quaschning and Hanitsch's one (Quaschning and Hanitsch, 1995). It was created by "MATLAB software tool" which insert the exterior environment information from DXF files.

Shading-Plus is the other one to calculate solar heat gain coefficient (SHGC) is developed based on Energy-Plus (the computer simulation system) and uses as its core simulation engine (Ye et al., 2016).

All of these researches and simulation machines have details and advantages to reach the opinion, but all do not encompass all the field to draw a suitable window system and shading form according to the plan and other criteria such as environmental elements. To achieve this issue and solving the problem of research in shading with colored transparent filters (CTFs), the graphical program has been written in MATLAB program language. So user must insert location, time and other data with drawing the plan of the project. As mentioned earlier, CTFs are placed vertically in double glazed windows in the form of vertical blinds. It is recommended to open and close the blinds according to the user's request or sensors. Since normal shadings in buildings are above, it is assumed that there will not be much difference in color locations. However there may be differences in color locations on the lateral shadings, which is not included in this study. In later projects, the effect of shadings in the building can be explored in place of vertical or horizontal CTFs.

<u>Solar position</u>

"The solar position in relation to a point on the Earth's surface can be determined by the solar azimuth angle φ and by the solar elevation angle $\propto$. There are various methods to calculate the value of these parameters with geo-location data, date and time" (Blanco-Muriel, Alarcón-Padilla, López-Moratalla and Lara-Coira, 2001; Melo et al., 2013; Michalsky, 1988; Reda and Andreas, 2004).

All the developed algorithms and following equations have been used in this section from Declination angle to Azimuth angle advanced by (ASHRAE, 2009) so all the definitions of equations come into quotation marks because of directed citation of equations. Even although the hour angle is supposed positive if counterclockwise.

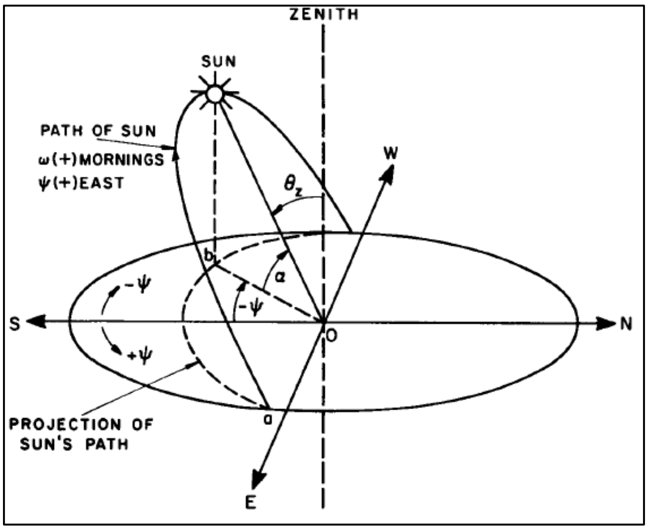


Figure 3.2 Sun's zenith, altitude, and azimuth angles (M Iqbal, 2012)

Declination angle

“The declination angle, the angle between the earth's equatorial plane and the ecliptic plane”, denoted by δ. “If the Earth were not tilted on its axis of rotation, the declination would always be 0°. However, the Earth is tilted by 23.45° and the declination angle varies plus or minus this amount. Only at the spring and fall equinoxes is the declination angle equal to 0°”.

$$\delta=23.45^{o} \sin [360/365(d-81)] \tag{3.1}$$

Where d is the day of the year with Jan 1 as d = 1.

Local standard time meridian (LSTM)

“The Local Standard Time Meridian (LSTM) is a reference meridian used for a particular time zone and is similar to the Prime Meridian, which is used for Greenwich Mean Time”. The (LSTM) is calculated due to the Equation3.2:

$$LSTM=15^{o}.\Delta T_{GMT} \tag{3.2}$$

Where ΔT_{GMT} is the difference of the Local Time (LT) from Greenwich Mean Time (GMT) in hours.

Equation of Time (EoT)

“The equation of time (EoT) (in minutes) is an empirical equation that corrects for the eccentricity of the Earth's orbit and the Earth's axial tilt”.

$$EoT = 9.87 \sin(2B) - 7.53 \cos(B) - 1.5 \sin(B) \quad (3.3)$$

Where B=3603/65(d−81) in degrees and d is the number of days since the start of the year.

Time correction factor (TC)

“The net Time Correction Factor (in minutes) accounts for the variation of the Local Solar Time (LST) within a given time zone due to the longitude variations within the time zone” and also incorporates the EoT (as can be seen above in Equation 3.3).

$$TC = 4\,(Longitude - LSTM) + EoT \quad (3.4)$$

The factor of 4 minutes comes from the fact that the Earth rotates 1° every 4 minutes.

Local solar time (LST)

“The Local Solar Time (LST) can be found by using the previous two corrections to adjust the local time (LT)”.

$$LST=LT+TC60 \quad (3.5)$$

Hour angle (h)

“The Hour Angle converts the local solar time (LST) into the number of degrees which the sun moves across the sky. By definition, the Hour Angle is 0° at solar noon. Since the Earth rotates 15° per hour, each hour away from solar noon corresponds to an angular motion of the sun in the sky of 15°. In the morning the hour angle is negative, in the afternoon the hour angle is positive".

$$h = 15^{o} (LST - 12) \tag{3.6}$$

Elevation angle (α)

"The elevation angle is the angular height of the sun in the sky measured from the horizontal".

$$\alpha = \sin^{-1} [\sin \delta \sin \phi + \cos \delta \cos \phi \cos h] \tag{3.7}$$

Where δ is the declination angle, ϕ is the local latitude and *h* is the Hour angle.

Azimuth angle (φ)

"The azimuth angle is the compass direction from which the sunlight is coming. At solar noon, the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere".

$$\varphi = \cos^{-1} [\sin \delta \cos \phi - \cos \delta \cos \phi \cos h \cos\alpha] \tag{3.8}$$

"Where δ is the declination angle, ϕ is the local latitude and HRA is the Hour angle Solar radiation data are often recorded in terms of local apparent time (LAT) , also called true solar time (TST)" (Wilson, 1980).

Shadow computation

Whenever the direct radiation does not impact a surface certainly there would be shadows. To compute the shadow of slabs or walls on the window the thesis benefits from previous works (Cascone et al., 2011; Hiller, 1996; Keller and Costa, 2011; Melo et al., 2013; Niewienda and Heidt, 1996; Pongpattana and Rakkwamsuk, 2006; Ye et al., 2016) which calculated the geometry of shadow on "Global Coordinate System xyz" (the x-axis along the south direction, the y-axis along the east direction and the z-axis along the zenith direction);

The equation (Equation 3.9) of a tilt plane through the origin is "ax + by + cz = 0", where the tilt plane will be our case study window surface as can be seen in Figure 3.3 .

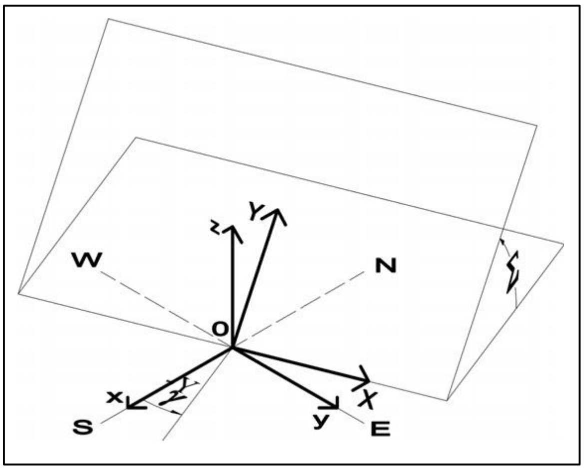


Figure 3.3. Window surface "Coordinate Systems" (Cascone et al., 2011)

$$e = \begin{cases} a = \cos\gamma \sin\varepsilon \\ b = \sin\gamma \cos\varepsilon \\ c = \cos\varepsilon \end{cases} \tag{3.9}$$

Where XY is window surface coordinate system and γ is the surface azimuth of window plane (angle between south and -Y) and ε is the window surface (wall) tilt angle (normally 90º).

To set the solar vector due to zone and time s will be reached;

$$S = \begin{cases} l = \cos\varphi \cos\propto \\ m = \sin A \cos\propto \\ n = \sin\propto \end{cases} \tag{3.10}$$

Where φ is solar azimuth angle and ∝ is solar elevation angle.

So when e.s will be negative the sun is in the back of window surface so we will have full shadow, and when it will be positive we will have the shadow of obstacles.

To determine the shadow of obstacles, the corner points with $P_0(x_0, y_0, z_0)$ will be considered and to find P' (the shadow of P on window surface) we have these equation;

$$t = -\frac{ax_0+by_0+cz_0}{al+bm+cn} \tag{3.11}$$

$$P'\left(x'_0,\ y'_0,\ z'_0\right) = \begin{cases} x' = x_0 + l.t \\ y' = y_0 + m.t \\ z' = z_0 + n.t \end{cases} \tag{3.12}$$

We need to turn it to the x y plane because it is difficult to organize it in three dimensions. According to this, two matrixes are defined;

$$R_z(\frac{\pi}{2}+\gamma) = \begin{bmatrix} \sin\gamma & \cos\gamma & 0 \\ \cos\gamma & \sin\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3.13}$$

$$R_x(\varepsilon) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin\varepsilon & -\sin\varepsilon \\ 0 & \sin\varepsilon & 1 \end{bmatrix} \tag{3.14}$$

The first matrix (R_z) is the true mode of Equation 3.15. by (Cascone et al., 2011). So the matrix of Equation 3.13 has been utilized in Shading Function.

$$R_z(\frac{\pi}{2}+\gamma) = \begin{bmatrix} -\sin\gamma & -\cos\gamma & 0 \\ \cos\gamma & -\sin\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3.15}$$

To find P' in new xy coordinate system;

$$P'\left(X_0, Y_0\right) = \left(R_z . R_x\right) . P'\left(x'_0,\ y'_0, z'_0\right) \tag{3.16}$$

So the shadow of the corner points of obstacles will be reached. With connecting them we have the geometry of shadow on the window surface.

The calculation of tree shadows and environment items is performed according to the Vegetation model of (Cascone et al., 2011). A screenshot from coding of "Shading" function written in MATLAB program can be seen in figure 3.4. The source codes of all functions comes in Appendix part.

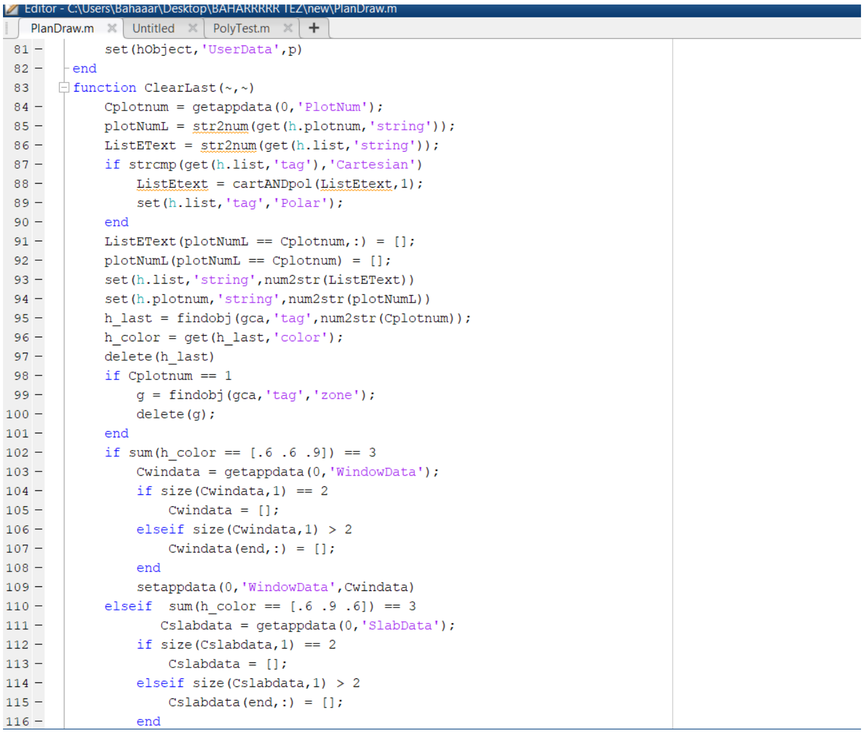
```
HiR = SkyEmi * Sigma .* TempDry .^ 4;
LSTM = 15 * TimeZone;
B = 360 / 365 * (d - 81);
EoT = 9.87 * sind(2 * B) - 7.53 * cosd(B) - 1.5 * sind(B);
TC = 4 * (Lon - LSTM) + EoT;
LST = HourM + TC / 60;
HRA = 15 * (LST - 12);
DeclinationAng = 23.45 * sind(B);
SunR = 12 - acosd(-tand(Lat) .* tand(DeclinationAng)) / 15;
SunS = 12 + acosd(-tand(Lat) .* tand(DeclinationAng)) / 15;
RandS = (HourM > SunR) .* (HourM < SunS);
ElevationAng = asind(sind(DeclinationAng) .* sind(Lat) + ...
    cosd(DeclinationAng) .* cosd(Lat) .* cosd(HRA)).* RandS;
RandS(RandS == 0) = NaN;
AzimuthAng = acosd((sind(DeclinationAng) .* cosd(Lat) - ...
    cosd(DeclinationAng) .* sind(Lat) .* cosd(HRA)) ./ ...
    cosd(ElevationAng)).* RandS;
% ----------------------------------------------------------
load('TestData');
% --------- l,m,n ------------------------------
s.l = cosd(AzimuthAng) .* cosd(ElevationAng);
s.m = sind(AzimuthAng) .* cosd(ElevationAng);
s.n = sind(ElevationAng);
% --------- P calculation -----------------------
% P = cell([2 * U.SlabNum + length(U.OutsideWall) 2]);
% for j = 1 : 2 : 2 * U.SlabNum
%     P{j,1} = cat(1, U.AwningSlab{j}, repmat(U.SlabGH(j),1,...
%         size(U.AwningSlab{j},2)));
%     P{j + 1,1} = cat(1, U.AwningSlab{j}, repmat(U.SlabGH(j) + U.SlabH(j),1,...
%         size(U.AwningSlab{j},2)));
% end
j = -1;
for i = 1 : length(U.OutsideWall)
    P{i + j + 1,1} = cat(1, U.OutsideWall{i}, repmat(U.ZoneGH + ...
```

Figure 3.4. A screenshot from “Shading” function, MATLAB program

3.1.3. Plan-Draw function

The "Plan-Draw" function is defined to find the position of the window relative to the building and the environment of the building. The Plan-Draw function is intended to allow the user to easily enter window, zone, wall and shading in two dimensions. In order for the user to enter the building data here, this function is described in the MATLAB program and then its codes are entered. Then, two dimensional drawings and position data are combined in three dimensional matrices. The icons used here and the selection of the required data are taken from ARCHICAD program.

According to this function user must draw the zone plans one by one and ensure that the necessary data are entered. A screenshot from coding of "Plan-Draw" function written in MATLAB program can be seen in Figure 3.5.



```
        set(hObject,'UserData',p)
    end
function ClearLast(~,~)
    Cplotnum = getappdata(0,'PlotNum');
    plotNumL = str2num(get(h.plotnum,'string'));
    ListEText = str2num(get(h.list,'string'));
    if strcmp(get(h.list,'tag'),'Cartesian')
        ListEtext = cartANDpol(ListEtext,1);
        set(h.list,'tag','Polar');
    end
    ListEText(plotNumL == Cplotnum,:) = [];
    plotNumL(plotNumL == Cplotnum) = [];
    set(h.list,'string',num2str(ListEText))
    set(h.plotnum,'string',num2str(plotNumL))
    h_last = findobj(gca,'tag',num2str(Cplotnum));
    h_color = get(h_last,'color');
    delete(h_last)
    if Cplotnum == 1
        g = findobj(gca,'tag','zone');
        delete(g);
    end
    if sum(h_color == [.6 .6 .9]) == 3
        Cwindata = getappdata(0,'WindowData');
        if size(Cwindata,1) == 2
            Cwindata = [];
        elseif size(Cwindata,1) > 2
            Cwindata(end,:) = [];
        end
        setappdata(0,'WindowData',Cwindata)
    elseif  sum(h_color == [.6 .9 .6]) == 3
          Cslabdata = getappdata(0,'SlabData');
        if size(Cslabdata,1) == 2
            Cslabdata = [];
        elseif size(Cslabdata,1) > 2
            Cslabdata(end,:) = [];
        end
```

Figure 3.5. A screenshot from "Plan-Draw" function

According to this function, after drawing the zone by user; the exterior walls, shading, and windows must be drawn to determine the criteria. The schemes of drawing part of the software tool have been shown in Figure 3.6 and 3.7.

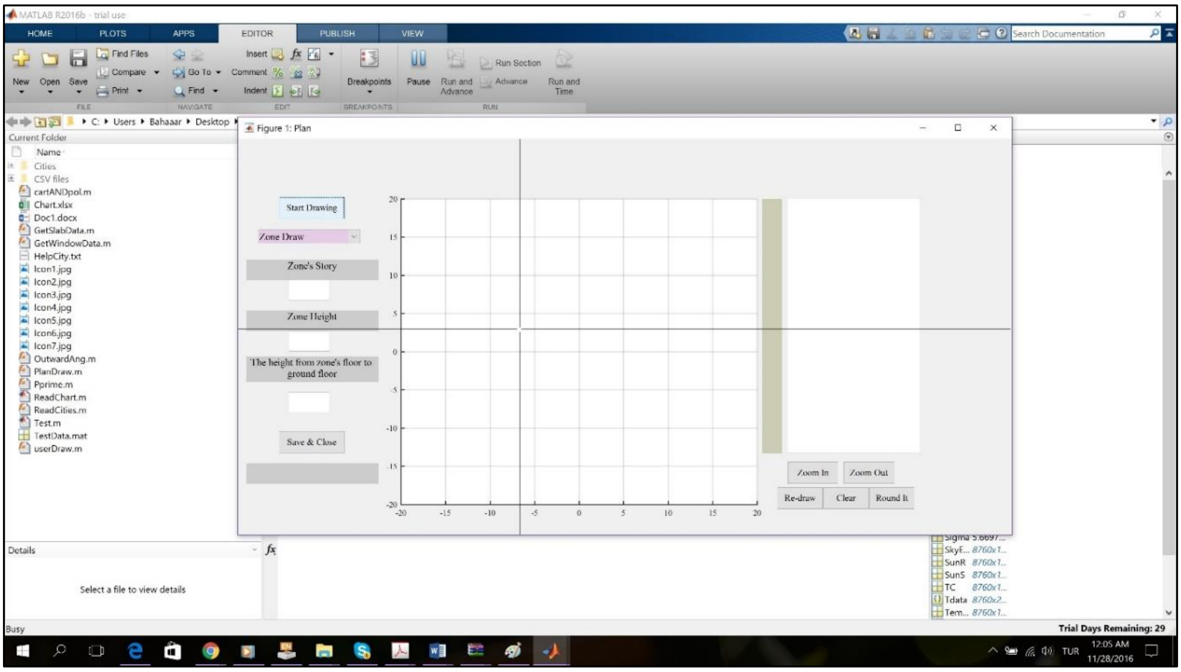


Figure 3.6. Ready to draw (Zone draw); Plan-Draw function of software tool written in MATLAB program

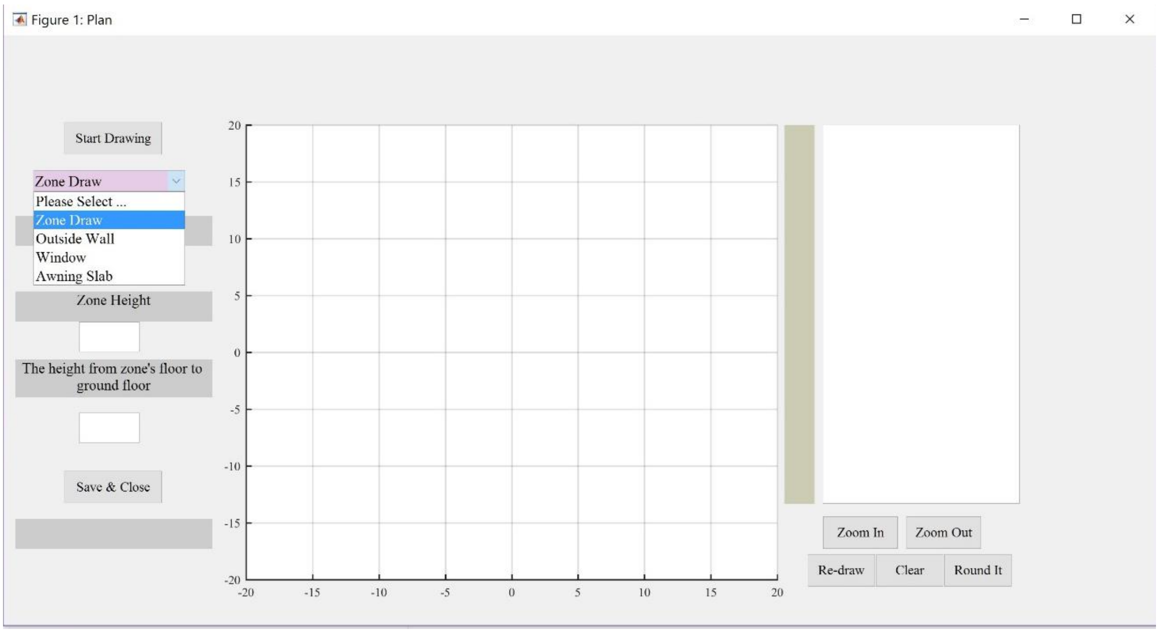


Figure 3.7. Ready to draw; Plan-Draw function of software tool written in MATLAB program

The window position (x, y, z) will be defined after entering height of the window and height from the floor. Shadowing on windows is explained as time and geometry according to sun azimuth and sun height angle. After this step, the shadowing will be simulated on daily basis according to the user's plan.

3.2. Laboratory Works 1: Radiation Transmission

This part seeks to obtain the amount of energy and light passing through the color samples to enter these data into the designed software. In this regard, specimens in the laboratory were tested by two types of spectrophotometer devices. The BECKMEN DU 530 spectrophotometer was used to measure the transmission of light through the visible and infrared wavelengths and the FT-IR spectrophotometer in ultraviolet wavelengths for each of the six colors of transparent polymer specimens. In each of the transparent colored samples (CTFs), the percentage of passing light in comparison to the wavelength and the required calculations of the amount of energy and brightness passing through each of the translucent polymers (CTFs) are gained by obtaining a graph.

3.2.1. Spectral dependence of transmittance

Due to Iqbal: "Thermal radiation, emitted by the agitation associated with the temperature of matter, is commonly called heat and light" (Muhammad Iqbal, 2012). As we know, most of the solar radiation reaching the surface of the earth is in the thermal radiation range.

When solar radiation comes into the atmosphere, a section of the "Incident Energy" is emitted by dispersion and a section by absorption. "Both influence the extraterrestrial spectrum by considerably modifying the spectral energy passing through the atmosphere" (M Iqbal, 2012). Figure 3.8 shows the value for direct normal spectral irradiance (the radiation arriving on the ground directly in line from the solar disk) under varying values of α. (Where; w is Thickness of perceptible water (cm), α is Wavelength exponent in Angstrom's turbidity formula (dimensionless) and β is Angstrom's turbidity parameter (dimensionless))

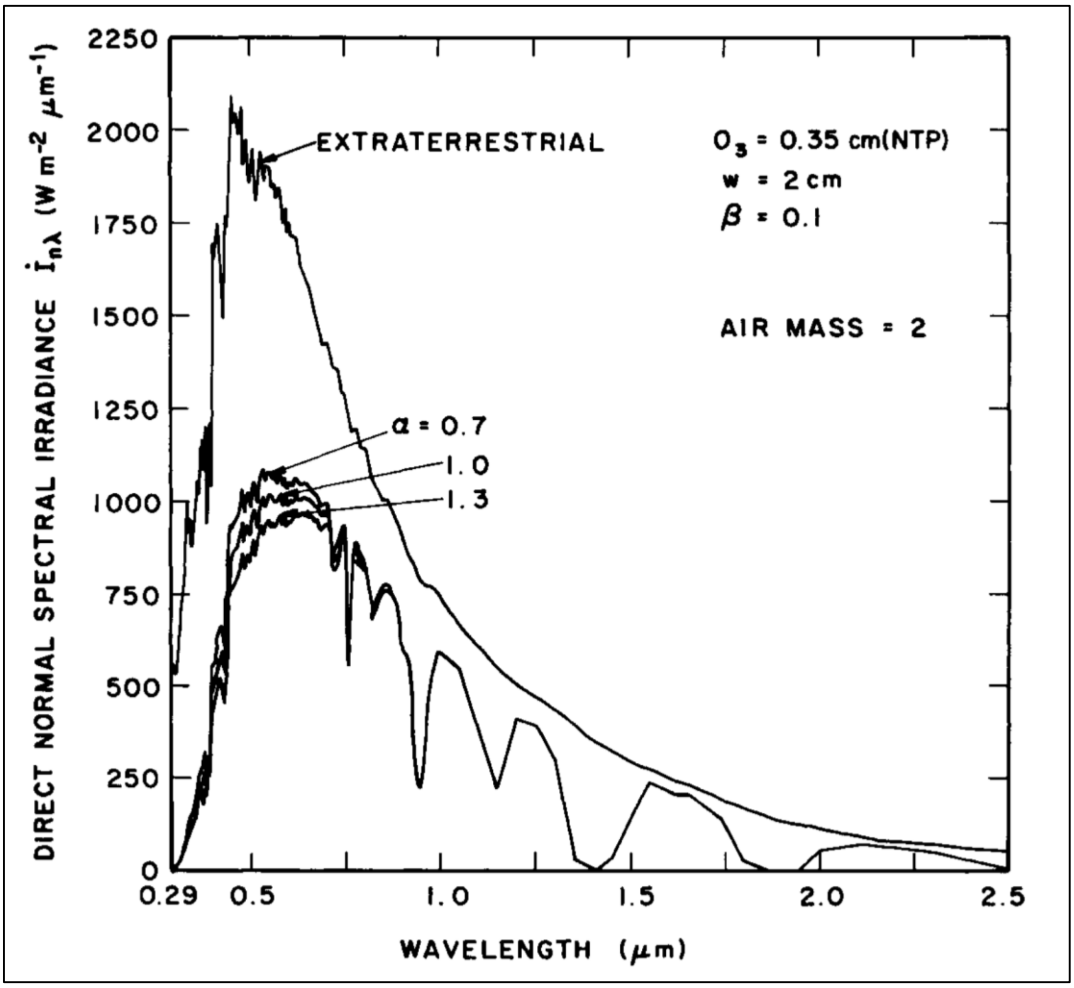


Figure 3.8. Direct normal spectral irradiance under varying values of α

3.2.2. Thermal radiation

The spectrum of electromagnetic radiation encompasses y rays, x rays, ultraviolet radiation, light, heat, radio waves, and radar waves. Electromagnetic radiation is generally classified by wavelength, though frequency and wave number are also used. Frequency (v) as shown in Equation 3.17 has the advantage over wavelength of not changing when radiation passes from one medium to another (Günther et al., 2011):

$$\text{Frequency (V)} = C_0 / \lambda_{vac} \tag{3.17}$$

Where C_0 is the speeds of propagation for electromagnetic radiation in a vacuum ($C_0 = 2.998 * 10^8$ m/sec) and λ is wavelength.

As Iqbal expresses: “Thermal radiation encompasses the wavelength range 0.2-1000 μιη. The visible spectrum may be considered within 0.39-0.77 μιη as table 3.1. The ultraviolet (UV) spectrum may be divided into three bands as table 3.2 and the infrared (IR) portion of thermal radiation is generally divided into two parts as table 3.3”(Muhammad Iqbal, 2012):

Table 3.1. The wavelengths of visible spectrum

Colors	Wavelengths of visible spectrum
“Violet”	0.390-0.455 μηι
“Blue”	0.455-0.492 μιη
“Green”	0.492-0.577 μηι
“Yellow”	0.577-0.597 μιη
“Orange”	0.597-0.622 μιη
“Red”	0.622-0.770 μιη

Table 3.2. The wavelengths of ultraviolet (uv) spectrum

Colors	Wavelengths of visible spectrum
“Near UV”	0.3-0.4 μιη
“Far UV”	0.2-0.3 μιη
“Maximum UV”	0.001 -0.2 μιη

Table 3.3. The wavelengths of infrared (ir) spectrum

Colors	Wavelengths of visible spectrum
"Near IR"	0.77-25 μηι
"Far IR"	25-1000 μιη

So the spectrally integrated direct irradiance on a surface normal to the sun's rays (also called direct normal radiation) and at mean sun-earth distance is given thus (Wald, 2018):

$$I_n = \sum_{\lambda=0}^{\infty} I_{0n\lambda}\ \tau_\lambda\ \Delta\lambda \qquad (3.18)$$

Direct normal irradiance within various bands by Iqbal have been shown in Table 3.4. Whereas can be seen in Figure 3.8: $\mathrm{w} = 2\ \mathrm{cm}, \mathrm{O_3} = 0.35\ \mathrm{cm}\ (\mathrm{NTP}), \alpha = 1.3, \mathrm{I_{sc}} = 1367.$

Table 3.4. Direct normal irradiance within various bands (Muhammad Iqbal, 2012)

			Fraction of direct energy in different colors, λ (μm)							
θ_z (degrees)	β	I_n (W m^{-2})	uv <0.39	Violet 0.39–0.455	Blue 0.455–0.492	Green 0.492–0.577	Yellow 0.577–0.597	Orange 0.597–0.622	Red 0.622–0.77	ir >0.77
0.0	0.0	1053.30	0.04	0.08	0.06	0.13	0.03	0.04	0.18	0.45
60.0	0.0	934.01	0.02	0.06	0.06	0.13	0.03	0.04	0.19	0.47
70.0	0.0	853.01	0.01	0.05	0.05	0.13	0.03	0.04	0.19	0.49
80.0	0.0	689.18	0.00	0.03	0.04	0.11	0.03	0.04	0.20	0.55
85.0	0.0	525.18	0.00	0.01	0.02	0.07	0.02	0.03	0.20	0.64
0.0	0.1	895.12	0.03	0.07	0.06	0.12	0.03	0.04	0.18	0.48
60.0	0.1	688.19	0.01	0.05	0.05	0.11	0.03	0.04	0.18	0.53
70.0	0.1	558.62	0.01	0.03	0.04	0.10	0.03	0.04	0.18	0.58
80.0	0.1	334.38	0.00	0.01	0.02	0.06	0.02	0.03	0.17	0.69
85.0	0.1	166.73	0.00	0.00	0.00	0.02	0.01	0.01	0.12	0.83
0.0	0.2	766.07	0.02	0.06	0.05	0.12	0.03	0.04	0.17	0.51
60.0	0.2	518.89	0.01	0.03	0.04	0.10	0.02	0.03	0.17	0.59
70.0	0.2	381.62	0.00	0.02	0.03	0.08	0.02	0.03	0.17	0.66
80.0	0.2	181.35	0.00	0.00	0.01	0.03	0.01	0.02	0.13	0.80
85.0	0.2	67.60	0.00	0.00	0.00	0.01	0.00	0.00	0.06	0.93
0.0	0.3	659.98	0.02	0.05	0.04	0.11	0.03	0.04	0.17	0.55
60.0	0.3	399.40	0.01	0.02	0.03	0.08	0.02	0.03	0.16	0.65
70.0	0.3	270.33	0.00	0.01	0.02	0.06	0.02	0.02	0.15	0.72
80.0	0.3	107.15	0.00	0.00	0.00	0.02	0.01	0.01	0.09	0.88
85.0	0.3	32.36	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.97

3.2.3. Spectral radiation transmissions of colored films

As mentioned before, in this section the amount of energy passing through the transparent colored specimens (CTFs) is examined. To do this, and to harmonize the laboratory environment with real windows, color filters were placed between the two ordinary glasses and the third glass with spacing inside. The graph of the spectra transmitted percentage from both devices is put together and completed for each sample. Then, according to the corresponding formulas, the amount of energy passing through each sample color can be calculated.

In laboratory tests as can be seen in Figure 3.9:

- The type of glasses is “Soda-lime Optical Glass” with 2 mm thickness.

- The colored transparent filters (CTFs)are in 6 color of “green, yellow, blue, red, orange and purple” and the pieces are in type of “Fomito Flash Speedlight Color Gel Kit Filter 30HP W/gel band and Reflector for Canon, Nikon, Olympus, Pentax, Yongnuo, Neewer and Godox”.

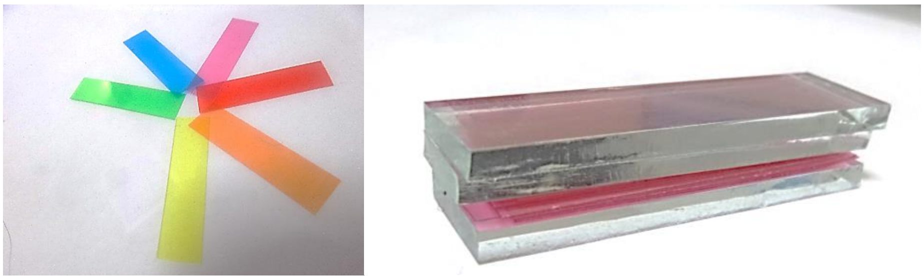


Figure 3.9. Colored transparent filters (CTFs) as test samples and Tested Sample with colored filter

In order to be closer to the actual conditions in the lab work, colored filters were placed in the bathtub with glass. And thus, the sample was prevented from moving in the bathtub and the spectrum was obtained in a vertical manner. Normally, certain conditions occur due to the fact that liquid is put into the bathtub; but since the samples are solid, it was very important to pay attention to how they are placed, keep them clean and suitable for the full bathtub size.

UV-VIS wavelengths transmittance as shown in Figure 3.10 calculated by BECKMEN DU 530 Spectrophotometer in 190-1100 nm wavelengths.

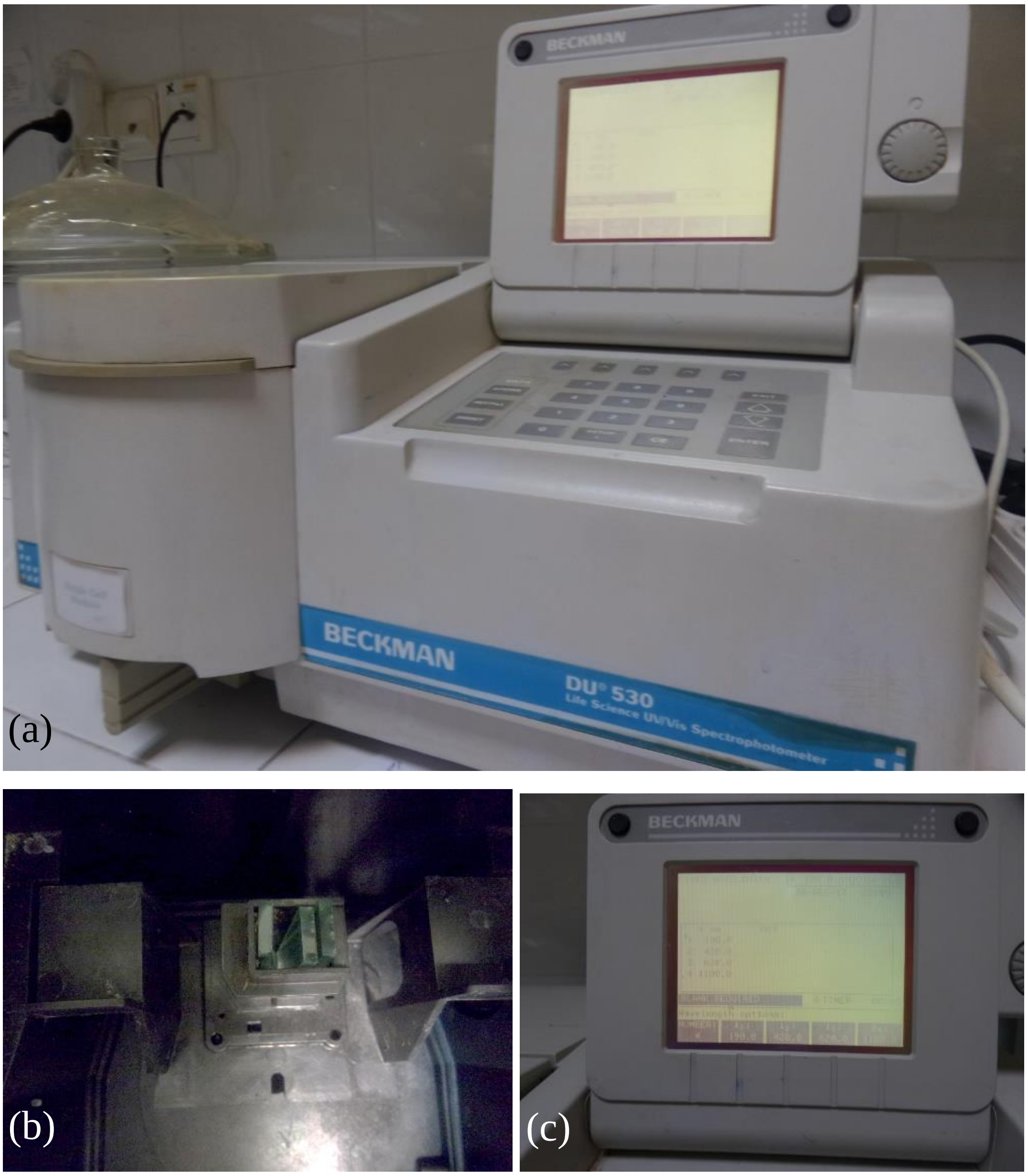


Figure 3.10. (a) and (c) BECKMEN DU 530 Spectrophotometer and (b) the sample located in[1]

In the devices, the percentage of transition of the spectrum according to different wavelength is shown and the graph is drawn in each wavelength region. Of course, the closer the wavelengths are, the closer the graphics are to be correct.

After selecting the wavelength range, light source and transmission part of the spectrophotometer, the reading values can be recorded and the transmission curve can be drawn.

[1] Hacettepe University, Environmental Engineering Laboratory

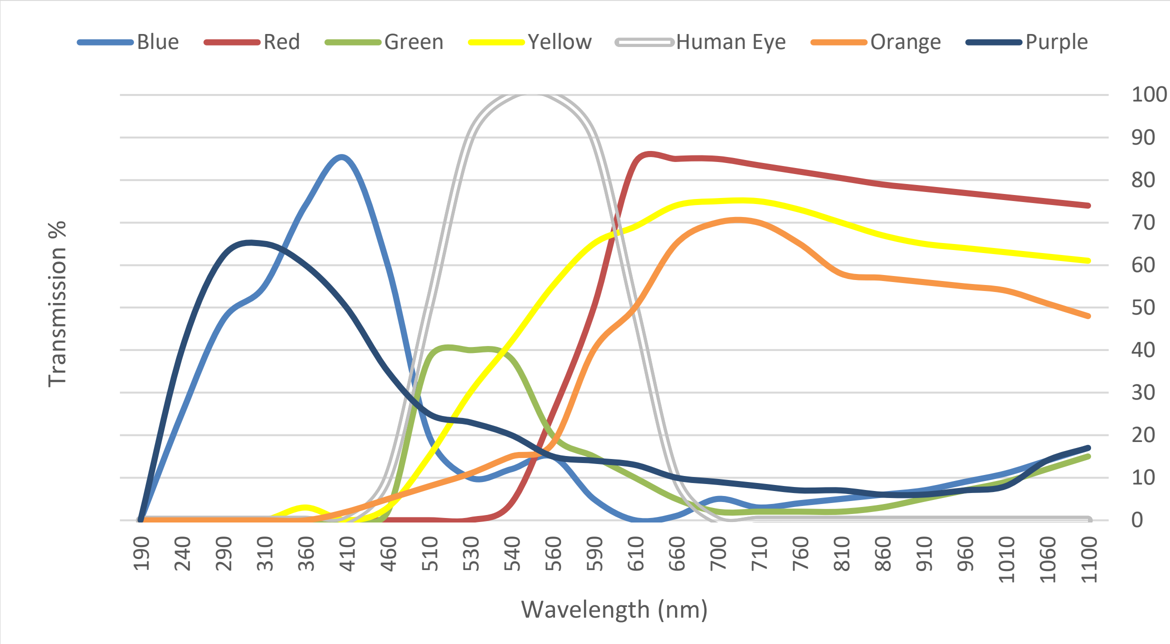


Figure 3.11. Transmission spectra by CTF's color in the wavelength range of 190-1100 nm

As can be seen in Figure 3.11 transmission percent of spectrum through the samples between 190-1100 nm had been achieved by BECKMEN DU 530 Spectrophotometer. As determined by colors in the figure each color has different amount of transmission at different UV-VIS wavelengths. Human eye sensitivity curve has been specified in the figure. As literature preview the average normal sighted human eye is most sensitive at a wavelength of 555 nm. The highest percentage of transmittance spectrum occurred in 610nm by passing through red sample.

Near Infrared wavelengths transmittance as shown in Figure 3.12 calculated by GL-6021 Galaxy Series FT-IR Spectrometer, with Infrared MIO465-0053-03 in 1100-3000 nm wavelengths.

Figure 3.12. GL-6021 Galaxy Series FT-IR Spectrometer [2]

Thus the transition percentage from the two devices was combined in the range of UV-VIS-IR wavelengths and the calculations were made via MATLAB. These two devices cover wavelengths of 190-3000nm. For longer ultraviolet wavelengths, different spectrophotometers should be used, which is not necessary with the reduction of solar energy.

[2] Hacettepe University, Chemistry Engineering Laboratory

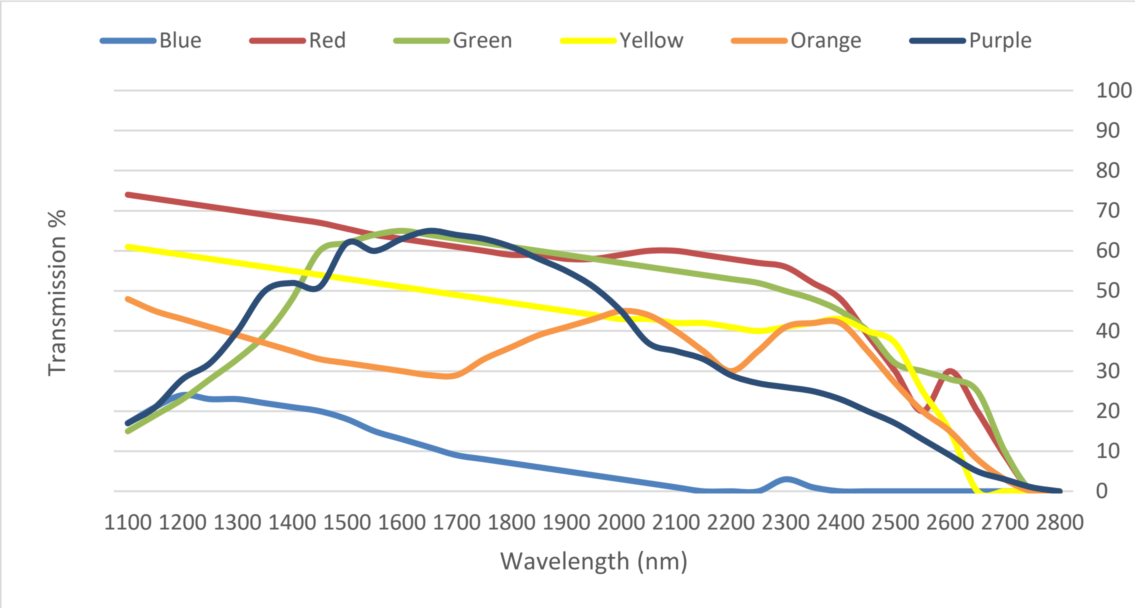


Figure 3.13. Transmission spectra by CTF's color in the wavelength range 1100-3000 nm

As is clear in Figure 3.13 transmission percent of spectrum through the samples between 1100-3000 nm had been achieved by GL-6021 FT-IR Spectrometer. All colors have different transmittance amount at different infrared wavelengths.

Then, the obtained graphs of Transmission spectra by CTF's color are plotted along the wavelengths surveyed in the two devices (Figure 3-14).

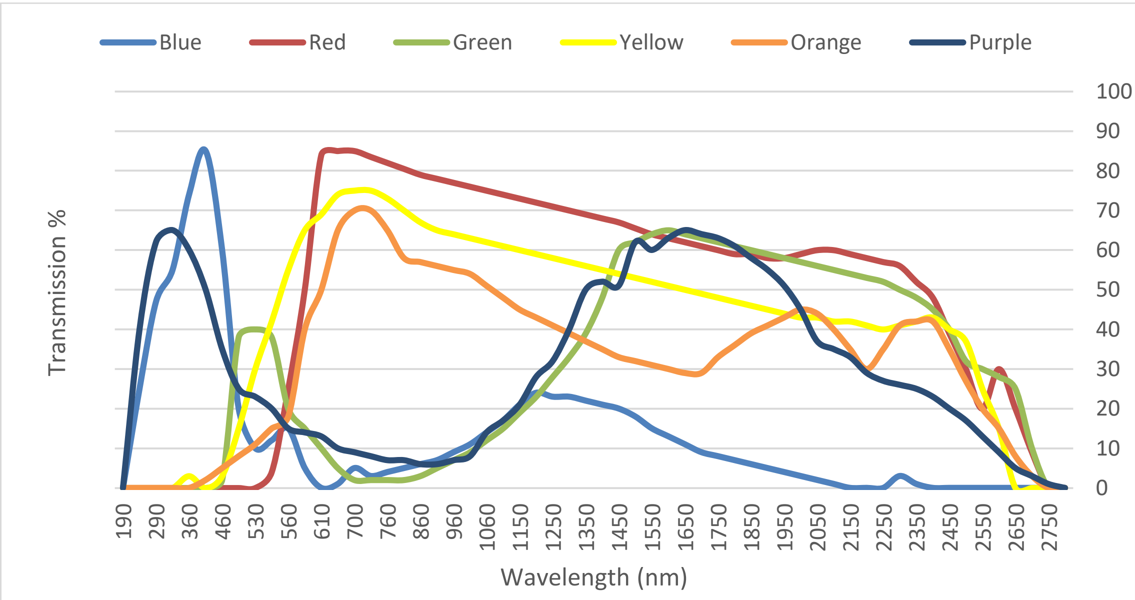


Figure 3.14. Transmission spectra by CTF's color in the wavelength range between 190nm and 3000 nm

After achieving the transmission spectra of each color of CTFs the thermal and lighting transmittance of CTF will be defined. So for thermal transmission we have these integral formulates:

If there is an angular dependence of τ_λ, the total transmittance at angle θ can be written as shown in Equation 3.18 (Duffie and Beckman, 2013):

$$\tau\ (\theta) = \frac{\int_0^\infty \tau_\lambda\ (\theta)\ I_{\lambda i}\ (\theta) d\lambda}{\int_0^\infty I_{\lambda i}\ (\theta) d\lambda} \tag{3.19}$$

Due to (Duffie and Beckman, 2013)" In a multi-cover "system in which the covers have significant wavelength-dependent properties, the spectral distribution of the solar radiation changes as it passes through each cover".

And according to this point, as shown in equation 3.19 by (Duffie and Beckman, 2013): "at any wavelength λ, the transmittance is the product of the monochromatic transmittances of the individual covers". Therefor for N covers (N is 3 or 4 covers in this research):

$$\tau\ \alpha\ (\theta) = \frac{\int_0^\infty \tau_{\lambda,1}(\theta)\ \tau_{\lambda,2}(\theta)\ \ldots \tau_{\lambda,N}(\theta)\ \alpha_\lambda(\theta)\ I_{\lambda i}(\theta) d\lambda}{\int_0^\infty I_{\lambda i}\ (\theta) d\lambda} \tag{3.20}$$

After completing zone and other parameters' drawing, program can simulate incident direct and diffuse beam radiation.

"The incident global solar radiation (I) received by a surface, such as a window, is a combination of direct beam radiation (Ib), sky radiation (Is), and radiation reflected from the ground in front of the surface (Ir)" (Perez, Ineichen, Seals, Michalsky and Stewart, 1990):

$$I\ =\ I_b\ cos(\theta)\ +\ I_s\ + I_t \tag{3.21}$$

θ is the incident angle of the sun's rays to the surface.

$$I_s\ =\ I_{dh}\ [0.5\ (1 -\ F_1)(1\ +\ cos\beta) +\ F_1\ a/b\ +\ F_2 sin\ \beta]$$

Where

“I_{dh} = diffuse solar horizontal radiation

F_1= circumsolar anisotropy coefficient, function of sky condition

F_2= horizon/zenith anisotropy coefficient, function of sky condition

β = tilt of the surface from the horizontal

a = 0 or the cosine of the incident angle, whichever is greater

b = 0.087 or the cosine of the solar zenith angle, whichever is greater”.

“The ground-reflected radiation (I_t) received by a surface is assumed isotropic and is a function of the global horizontal radiation (I_b), the tilt of the surface from the horizontal (β), and the ground reflectivity or albedo (ρ)” (Perez et al., 1990):

$$I_t = 0.5\rho I_b \,(1 - cos\,(\beta)) \tag{3.22}$$

If we ignore the shadow of sky radiation and reflected radiation from ground, we can reach to the following equation (Equation 3.22) for the energy received by the window glass;

$$I_w = (A - A_s)\, I_b \, cos(\theta) + \; A\, I_s \; + A\, I_t$$

Where A is glazing area and A_s is the shading area of window glass.

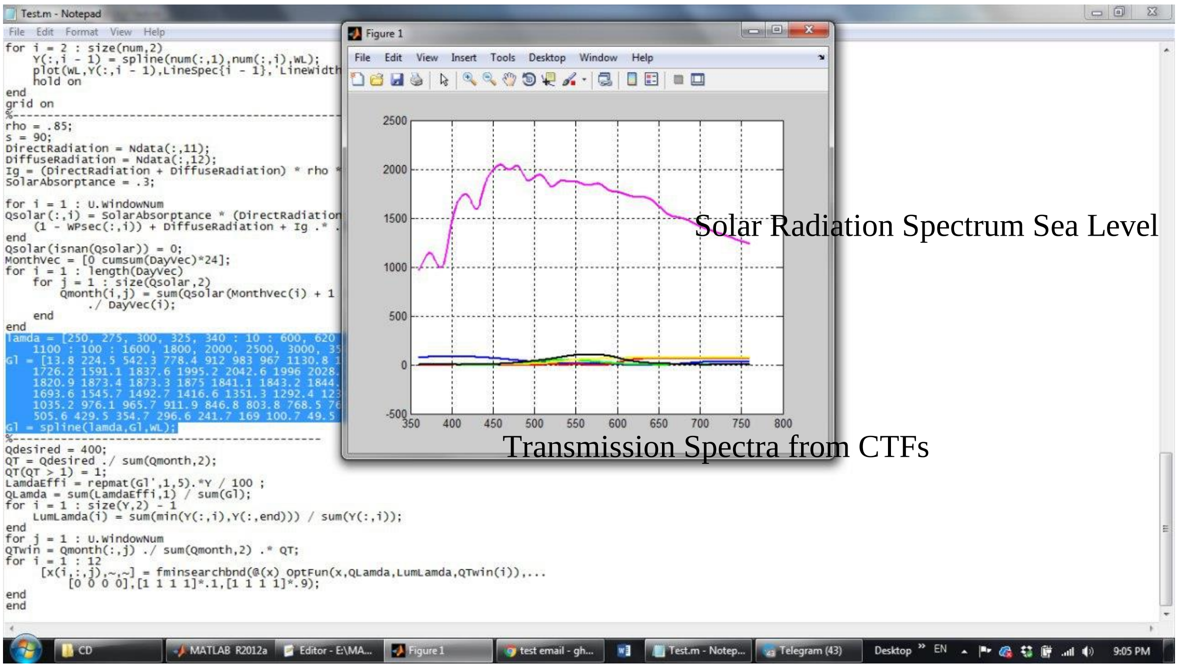


Figure 3.15. Solar radiation spectrum energy versus transmission spectra from CTFs in the wavelength range 360 to 760 nm

After coding all the necessary equations in MATLAB Table 3.5 can be exported and two diagrams of "Solar Radiation Spectrum Sea Level" and "Transmission Spectra from CTFs" can be multiplied to each other. Figure 3.15 shows solar energy and transmission spectra in one chart in MATLAB program during the coding process. Figure 3.16 shows the multiplied diagram of transmission and radiation in the wavelength range 190 to 3000 nm.

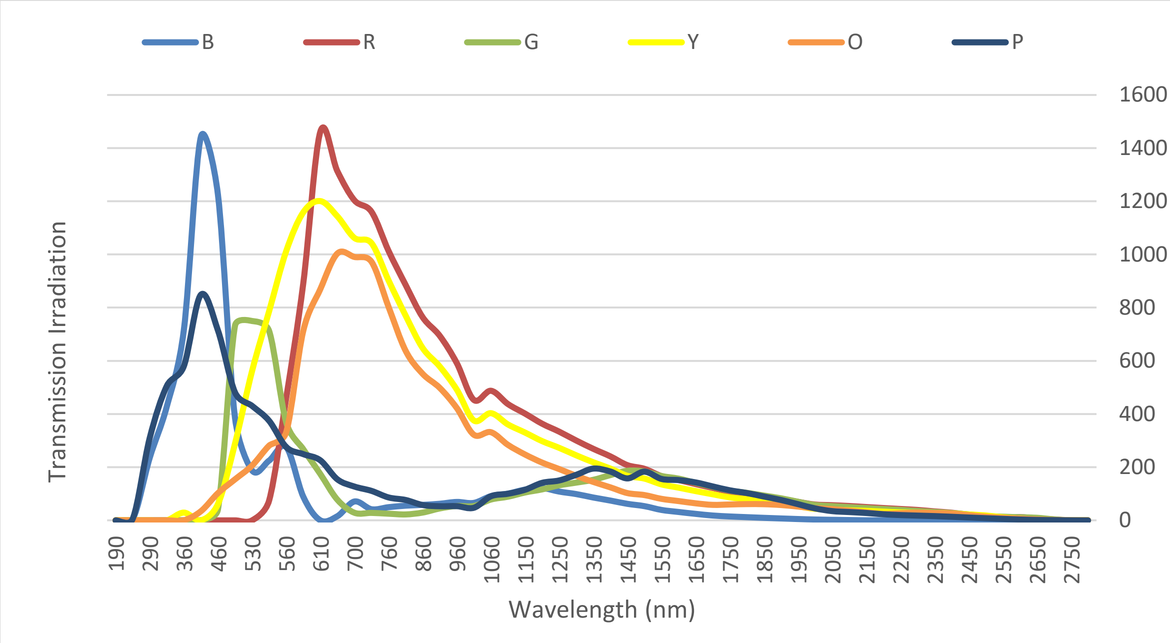


Figure 3.16. Transmittance irradiation by CTFs in the wavelength range of 190- 3000 nm

Transmittance irradiation by colors can be seen in Figure 3.16 which is the multiplication of each color's transmittance to solar radiation in the wavelength range of 190- 3000 nm.
So due to equations, the transmittance irradiation of CTFs at right angle 90º has been calculated as Table 3.5.

Table 3.5. Transmittance irradiation of CTFs and Transmittance Irradiation of CTFs per Solar Irradiance

	Blue	Red	Green	Yellow	Orange	Purple
Transmittance Irradiation	296042.6	662585.8	296847.7	616126.4	474173.4	356262.5
Transmittance Irradiation/Solar Irradiance	0.221444	0.495623	0.222046	0.460871	0.354688	0.266489

So compared to other colors, red and yellow samples transmitted the highest amount of solar irradiation and blue, purple and green ones have the lowest amount of irradiation transmittance.

3.2.4. Light transmission

In this section, according to the diagram of light passing percentage through the devices, with considering the corresponding equation, the light transmission level of each color becomes accessible to each other.

Due to the obtained graphs of transmission spectra of CTFs, the percentage of light passing through two devices for each of the colors has been investigated.

“The light transmittance of the composite was measured at a wavelength from 200 to 1100 nm using a transmission optical spectrometer” (Sato, Iba, Naganuma and Kagawa, 2002).

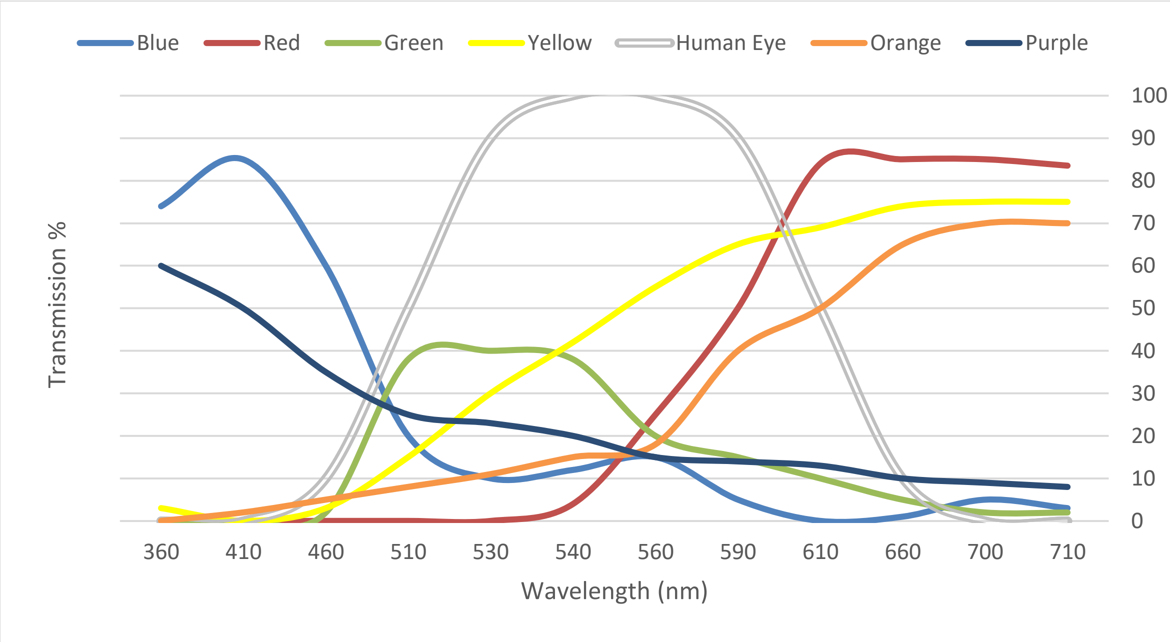


Figure 3.17. Transmission Irradiation Ranged from CTFs based on whether the sensitivity of the human eye is the same for different visible wavelengths

Transmission spectra by CTF’s to wavelengths drawn by MATLAB between 360-710 nm can be seen in Figure 3.17, where the black graph is the sensitivity of the human eye. So to calculate the ratio of light transmission of CTFs to each other Equation 3.22 can be used:

$$\text{Lum Lamda(i)} = \frac{\int_{\min \lambda i, \lambda p}^{max\, \lambda i, \lambda p} \tau_{\lambda}}{\int \tau_{\lambda p}} \qquad (3.23)$$

Table 3.6. Light transmission of CTFs

	Blue	Red	Green	Yellow	Orange	Purple
$\int_{400}^{700} \tau_\lambda$	4055	3300	3775	5320	3170	4950
Lum Lamda (400-700)	0.347323	0.282655	0.32334	0.455675	0.27152	0.423983

Luminance transmittance of CTFs can be seen in second row of Table 3.6 as a proportion ratio to the sensitivity of human eye. Yellow and purple have the most lighting transmittance in comparison with other colors.

3.3. Optimization and Window's System Outputs

In order to describe the Smart Window Designed Tool (SWDT), computer programs are written according to climate and sunlight considering the position of the windows and their surroundings. The program is resistant to Two season types (spring-autumn and summer) and presents the areas and numbers of the panes according to the transmission wavelengths of the panes. It then allows each window to move with the sensors according to the daily sun position and severity.

World map of the "Köppen- Geiger climate classification" updated (as supplemental material on the internet at "http://koeppen-geiger.vu-wien.ac.at/") have been used to determine the two suggestion seasons of summer and spring-autumn in program.

As shown in Figure 3.18, climatic parameters relevant for the determination of the climate class are the mean temperature of the warmest month (T_{max}), the mean temperature of the coolest month (T_{min}), the total annual precipitation (P_{ann}), the annual mean temperature (Tann) and a dryness index (P_{dry}). P_{dry} is $2 \cdot T_{ann}$ if rain occurs primary in winter, $2 \cdot (T_{ann} + 28)$ if rain occurs primary in summer or $2 \cdot (T_{ann} + 14)$ otherwise. The following Figure illustrates which criterions are used for the determination of the main climate classes.

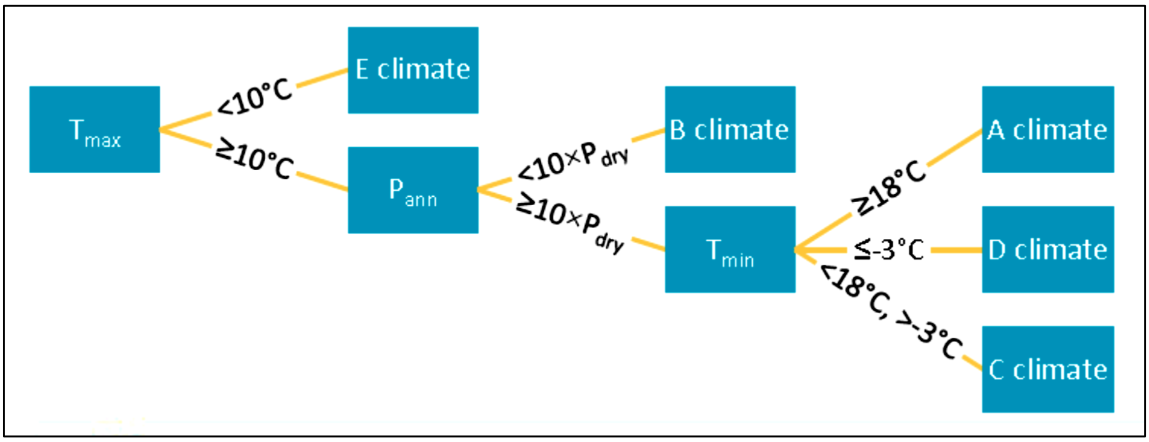


Figure 3.18. Climate formula in “Köppen- Geiger” climate classification

“Key to calculate the third letter temperature classification (h) and (k) for the arid climates (B) and (a) to (d) for the warm temperate and snow climates (C) and (D). Note that for type (b), warm summer, a threshold temperature value of +10 ◦C has to occur for at least four months. The criteria are explained in the text” (Kottek, Grieser, Beck, Rudolf and Rubel, 2006). The “Updated World Map of the Köppen- Geiger climate classification” has been shown in Figure 3.19.

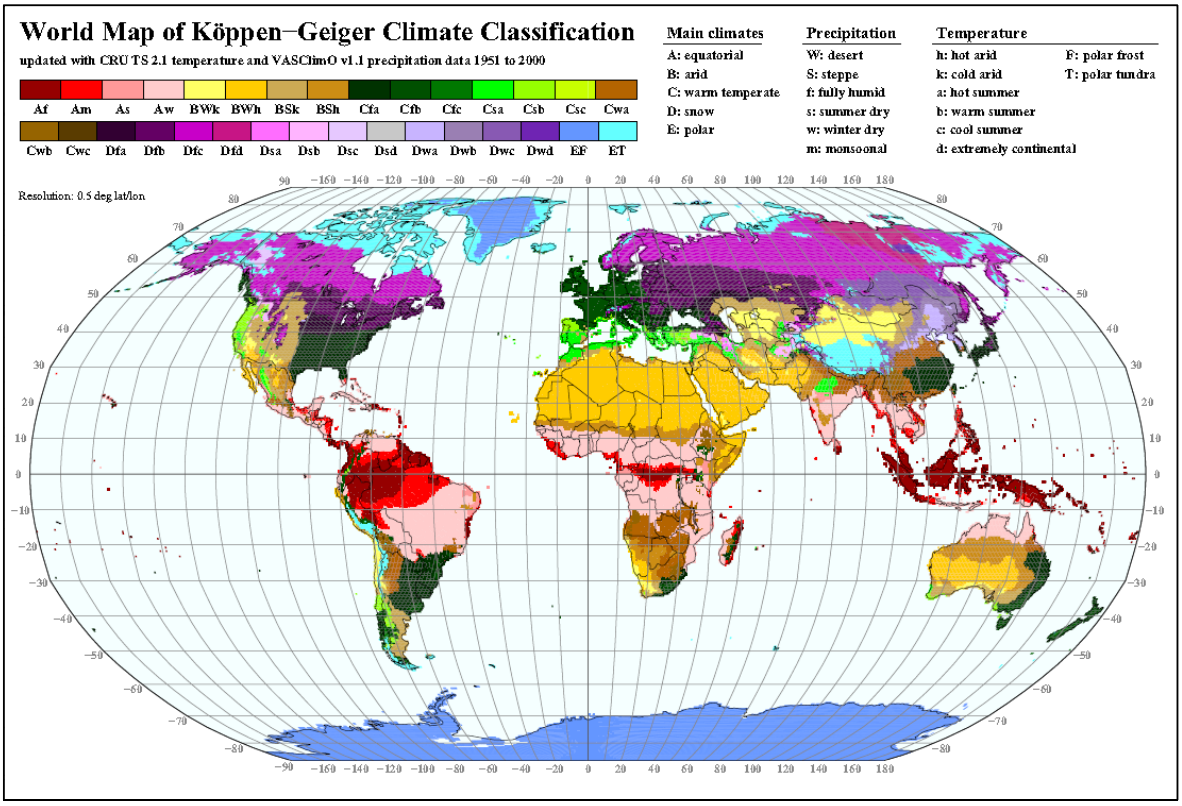


Figure 3.19. World Map of the “Köppen- Geiger” climate classification updated

Climate and their season classification placed in northern and southern hemisphere have been shown in table 3.7. Samples in rainy climates can be eliminated of test.

Table 3.7. A and B Climate classifications and seasons

Climates	Summer	Spring/Automn
A (Northern)	May, June, July, August	December, January
A (Southern)	November, December January, February	June, July
B (Northern)	May, June, July	August, September October, March, April
B (Southern)	November, December January, February	March, April, September October
C (Northern)	June, July, August	September, October November, March April, May
C (Southern)	December, January February	March, April, May, September, October November
D	June, July , August	September, October April, May

Due to (ASHRAE, 1981);

“In the summer, the coordinates are: T_o = 22.6-26.0°C at 16.7°C T_{dp} and T_o= 23.3-27.2°C at 1 .7°C. T_{dp}.”

The sloped sides are defined, by (ASHRAE, 2017);

“ET = 22.8°C and 26.1°C. The Maximum limit for mean air velocity in the winter is 0.15 m/s. In the summer the limit is nominally 0.25 m/s, increasing an additional 0.275 m/s for each °C above 26°C dry-bulb temperature, up to a maximum of 0.8 m/s for temperatures above 28°C.”

Due to (ASHRAE, 1981);

"In the winter, operative temperature and humidity limits are defined by a comfort zone on the psychrometric chart having the following coordinates: T_o = 19.5-23.0°C at 16.7°C T_{dp} and T_o = 20.2-24.6 C at 1.7°C T_{dp}."

The sloped sides are defined by (ASHRAE, 2017);

"The new effective temperature, ET. The winter limits are ET= 20.0 C and 23.6°C."

As (ASHRAE, 1981); "No uniformity limits are defined by the following conditions: the vertical air temperature difference between the 0.1 and 1.7 m heights shall not exceed 3°C; radiant temperature asymmetry in the vertical direction shall be less than 5°C and in the horizontal direction less than 10°C; and the floor surface temperature shall be between 18°C and 29°C".

Different glass types have different properties for the amount of solar radiation reflected, transmitted, absorbed, and re-radiated (Mitchell et al., 2006).

What happens in this part is the evaluation, calculation and finding the optimum of two charts in terms of solar radiant and lighting according to season in the zone. So the multi-objective optimization function have been written in MATLAB (as can be seen in Figure 3.20) to find the case of colors and their area percent. The last function has been introduced due to and lighting transmittance of CTFs in their case study where the irradiation transmission must be minimum and the lighting transmittance must be in its maximum level.

est.m × OptFun.m × +

```
function Obj = OptFun(guess,QLamda,LumLamda,QT)
a = guess(1);
b = guess(2);
c = guess(3);
d = guess(4);
obj1 = sum([a b c d] .* LumLamda) -.6;
obj2 = sum([a b c d] .* QLamda(1:4))-QT;
obj3 = sum([a b c d]) - 1;
Obj = obj1 ^ 2 + obj2 ^ 2 + obj3 ^ 2;
end
```

Figure 3.20. A screenshot from "Optimization" function

3.4. Program Analysis and Smart Window Suggestion

The model to be created combines the stained glass applications that were commonly used in the past with the present technology and predicts the use of color features. Due to many factors of today's world, some fatigue are seen in people who reside in large structures with prolonged atriums. The main reason for this is the combination of non-natural products, and the radiation generated by electric-magnetic fluxes. This study to reduce this radiation aims at the use of healthy and functional properties of Orosi glasses.

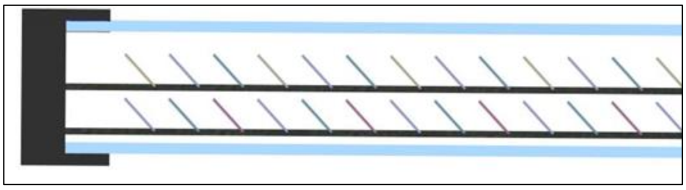


Figure 3.21. The plan view of suggested window

The system is composed of mid-pane shading device between the panes of a double glazing with external vent on top. The colored transparent filters (CTFs) between these two glasses will be placed vertically in two rows of jalousies as vertical blinds as shown in Figures 3.21 and 3.22.

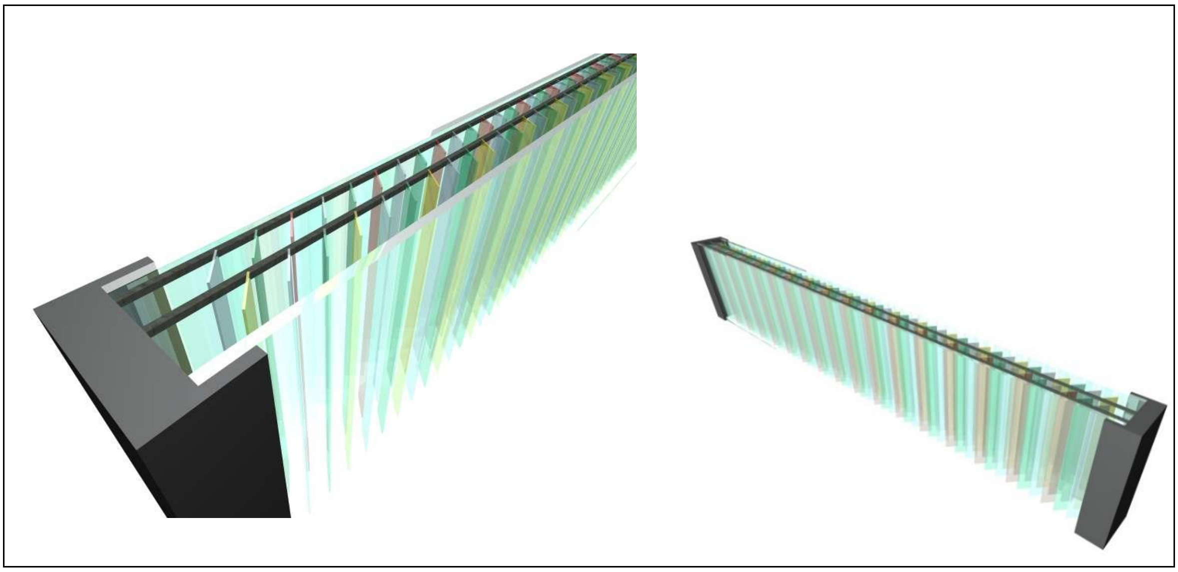


Figure 3.22. The defined smart window system

The system considered as double glazed with ventilation to the outside due to Figure 3-19, however it is expected that mid-pane shading device in triple glazed one with top vent to the outdoor will be more responsive. Evacuating heated air via external vent located at the top can be seen in the section view of suggested window in Figure 3.23.

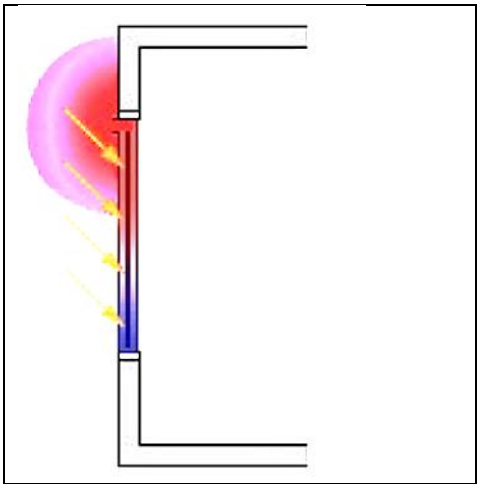


Figure 3.23. The position of CTFs' shading device in section view with the vent located at the top

3.5. Crosscheck of the SWDT

To evaluate how the program works, by drawing samples in the program and obtaining the results of the window and the percentage of output colors, samples are simulated in Rhino with the aid of Grasshopper, and the outputs are compared with previous results. The simulation results of the designed window SWDT can be shifted to any type of window geometry with the definition of two season s' types. So to pursue the action of program, crosscheck part recognized to check it out. To develop this part energy and lighting simulation programs used to code and script in rhino-grasshopper was defined:

3.5.1. Energy simulators, inputs and outputs

The required data for simulations and outputs are varied in different software, but their inputs and outputs of these software can be as follows (AB, 2013). It should be noted that the methods of information display and receiving are varied in different software. The input data of simulator software are as follows:

- Climate Data: climate data is the basis of all heating simulations. This data are inputted to the software for a given period or completely a year period.
- Building Geometry : form and size and kind of surrounding of thermal zones , openings , shelters , position of building against sun and other related information for building

volume are all specified by defining the building geometry for the software. In some cases, the initial geometry of environment may be drawn in other software such as CAD and then input to the simulator.

- Construction Type: including the type of structure, materials and other specifications of building geometry.
- Type/ Amount of air conditioners equipment usage: inputting this data is one of the most difficult steps of working with simulators by architects. Considering the direct effects of air conditioners on heating issues and energy consumption rate in buildings, this is necessary in some simulators to define the specifications of these equipment, while in other ones there are default values.
- Occupancy and residents information: the rate of internal loads is specified with an hour-hour schedule. The type of coverage and individuals activities in these periods is also needed by the software for simulations.
- Kind and rate of other equipment (like lighting) usages
- Other information : this information may be varied for different cases , for example the close/open status of openings

After simulating, simulator software may have different outputs as follows:

- Rate of humidity and temperature of each thermal zone
- Temperature of different surfaces in thermal zones
- Variables for air conditioners equipment
- Rate of energy consumption of all components or whole building
- Rate and kind of thermal behavior between neighbor thermal zones
- Rate of receiving solar energy

3.5.2. Energy-plus software

Energy-Plus is one of the most important simulation and Energy Analysis Software for buildings. This software can calculate cooling and heating loads using basic data such as physical structure, residents, mechanical and electrical systems as well as annual climate data. It also can calculate the temperature of air or all spaces of a building based on its specifications, mechanical systems and topography in any time intervals.

The software has not any Graphical User Interface and its inputs and outputs are textual. In the main page of this program, one window is specified for rows list in which different data for describing all building's elements are classified and listed. Users have to define and insert required data fields in order to make possible for the software to simulate the heating performance of the building and produce related outputs for the user (Zhang, 2009).

Although the lack of Graphical User Interface makes its usage difficult to some extent , but the software can be used along with many GUI programs as a powerful simulator motor. In other words, users can use other GUI Software to provide text inputs for Energy Plus and facilitate their required results (Kim, Jeong, Clayton, Haberl and Yan, 2015). This software is considered as one of the most popular ones in building energy simulation having different options for simulating inactive and renewable systems such as photovoltaic panels (Bazjanac, Maile, O'Donnell, Rose and Mrazovic, 2011).

The Energy-Plus Software is a combination of two valid older software namely DOE-2 and Blast. Normally, this software simulates buildings hourly conditions. Considering different air conditioners and other existing buildings' equipment, the software presents the accurate needed energy content of buildings. The output of Blast software can be used to calculate the building biological cycle cost (Crawley, Lawrie, Pedersen and Winkelmann, 2000). However, the Energy-Plus Software has some limitations for the number of heating zones and simulation area which should be known before starting simulation process.

3.5.3. Other applications of energy simulator

Some of energy simulator software specially designed for architecture development, can also simulate renewable energies effectiveness rate and inactive systems. These software programs are especially useful for initial designs and applying scales.

In other words, the software can use energy simulations as input data to analyze new outputs, for example cost and bills. Life cycle cost, etc.

However, there are some specialized software programs for this purpose. BEES (Singh, Berghorn, Joshi and Syal, 2010), Athena (Ravel and Newville, 2005) are two most common software which can calculate cost and bills and life cycle cost from construction to destruction. However, it should be noted that the input data of these software programs are based on regional information. Verifying building life cycle cost will suggest the building aspects such as economical resistance and environmental issues in their life cycle.

3.5.4. Lighting simulation

Lighting Simulation is one of the most common ones in architecture design. The results of Reinhart Curves suggested the highly usage of lighting simulator software for initial design. Considering the image nature of these simulations, so they have more usages compared with energy and thermal software. The chart of different methods and usage rate of lighting simulation softwares for predicting lighting design results by architects, engineers and researchers developed by Reinhart and Fitz can be seen in Figure 3.24.

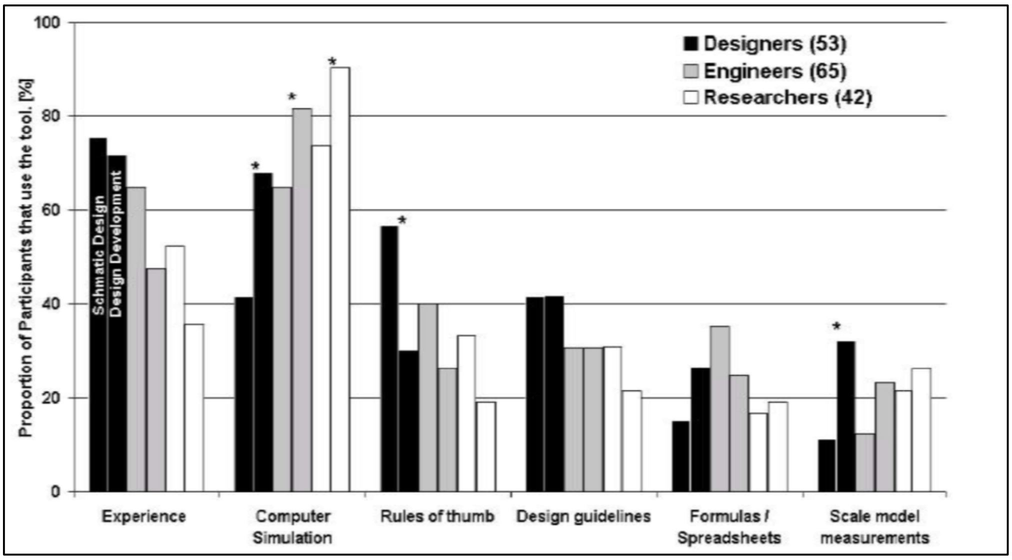


Figure 3.24. Different methods and usage rate of lighting simulation software for predicting lighting design results by architects, engineers and researchers (Reinhart and Fitz, 2006)

Lighting simulation is very important in initial steps of design. In his Curve, Reinhart (Reinhart and Fitz, 2006) has presented different changes after good lighting design for buildings as shown in Figure 3.25. And these changes include many design elements.

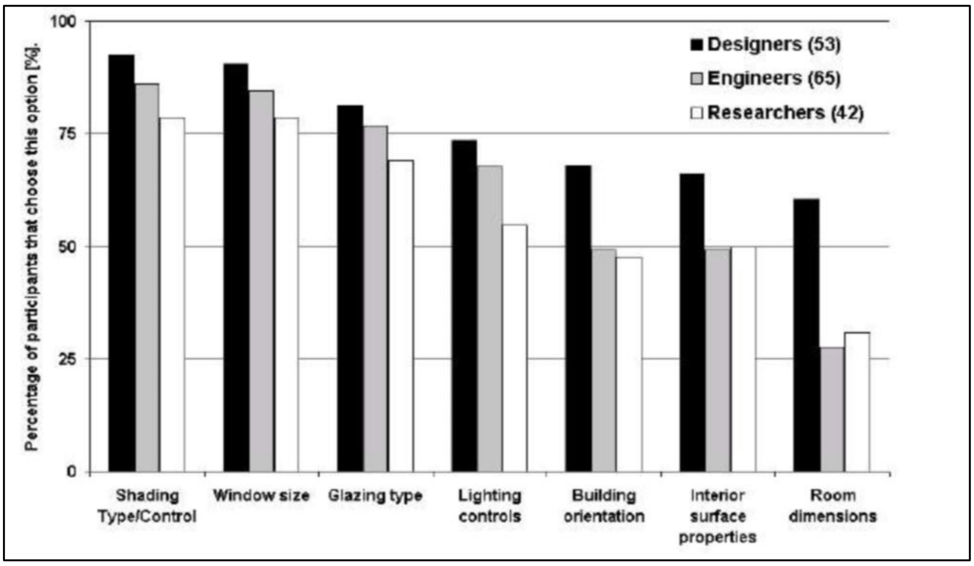


Figure 3.25. Type and rate of changes applied for achieving suitable lighting level in architecture (Reinhart and Fitz, 2006)

In lighting simulation, the electrical lighting and natural received light should be considered simultaneously. Items such as natural lighting received from outside of building (direct, scattered and reflecting), space geometry, space coverage material, form, location and surface of openings, shelter type and material , and other lighting equipment, have all direct effects on internal space lighting quality (Figure 3.26).

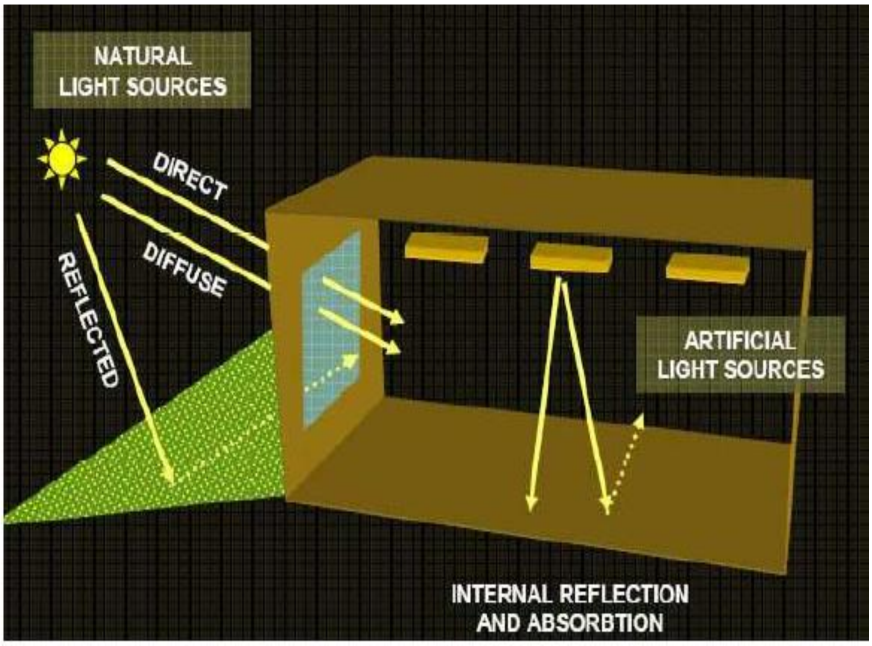


Figure 3.26. Affecting factors and lighting simulation mechanisms (Baker and Steemers, 2003)

Two common methods for lighting simulations are: Ray Tracing and Radiosity (Wallace, Cohen and Greenberg, 1987).

In ray tracing method, as can be seen in Figure 3.27, the software emits some rays from observer point and then images their reflection after reaching different subjects in a room on an imaginary plane(Cohen and Wallace, 2012). This process will be repeated until all subjects in the room will be imagined.

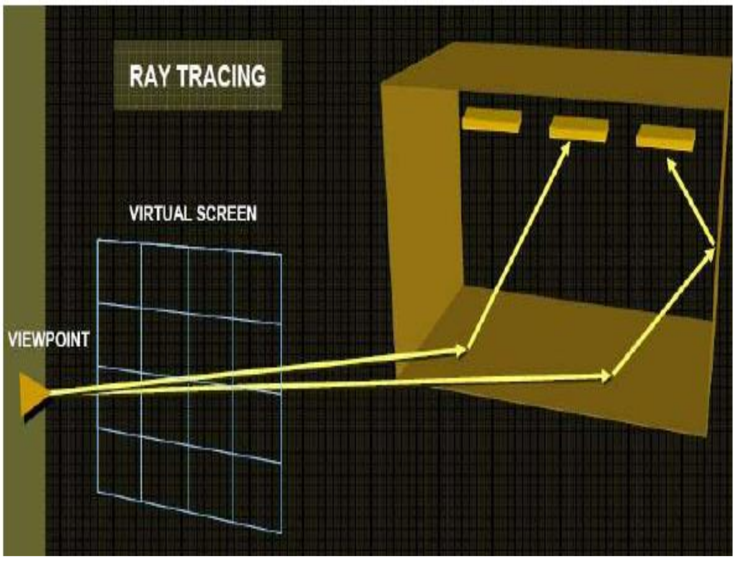


Figure 3.27. Schematic curve of Ray Tracing method (Hill and Kelley, 2001)

In Radiosity method, the software converts all planes into smaller ones and then calculate the lighting rate transferred between them(Cohen and Wallace, 2012). In this method, lighting is started from light resources and its reflection paths will be followed in internal space (Figure 3.28).

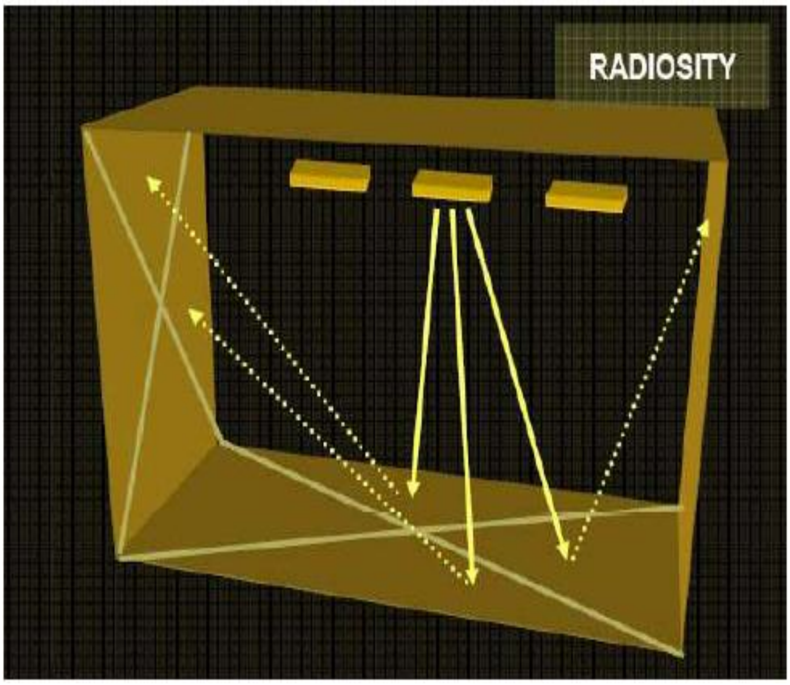


Figure 3.28. Schematic curve of Radiosity method (Chan and Tzempelikos, 2012)

Simulation software can use either one or both of these methods. There are different outputs for these software programs. These outputs can be as numerical, imaginary, color images and/or a combination of imagine output and its imaged information on it (Chan and Tzempelikos, 2012).

The lighting simulation software are most commonly used in two fields: design for day light and design for artificial lightings. Generally, in initial architectural design, architects do not consider artificial lighting, while providing natural lighting is so critical. Day lighting analyzer helps architects for this purpose. In many software programs, lighting simulation has the same quality as photographs. Additionally, these images can be analyzed.

Figure 3.29 presents a sample of day light simulation (Ochoa, Aries and Hensen). In the right side image, the illuminance level was imaged on a 3D Space. The drawn lines suggest the margin of regions with the same illuminance level. These two images together enable the designer to percept the lighting quality and quantity simultaneously.

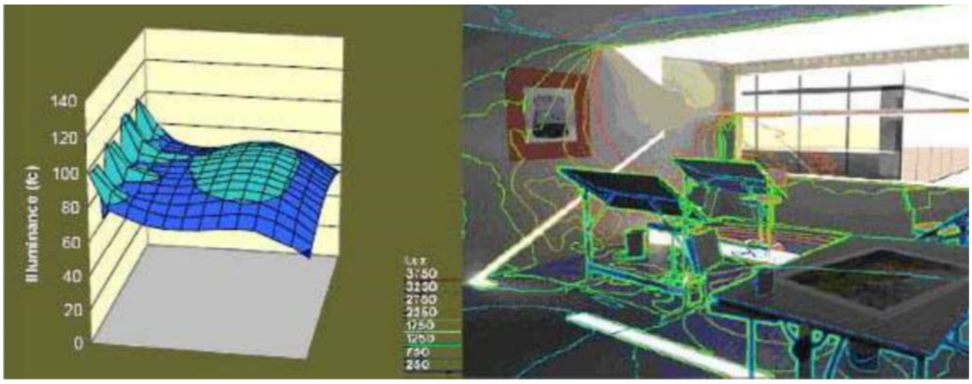


Figure 3.29. A sample of lighting stimulator software outputs, illuminance level in room space (left side) and room lighting simulation (right side) (Ochoa et al.)

There are several software available for lighting simulation. One of them is AG132. The software can input DWG and DXF files to render and analyze artificial and natural lighting. Lighting conditions can be measured for a given time and interval using AG132 (Figure 3.30) (Shikder, 2009). One of the other advantages of this software is its discounts for academic students and masters.

Figure 3.30. Sample of AG132 outputs (Shikder, 2009)

Radiance is one of the other common and highly applicable lighting simulation motors .This simulator motor which works under Windows and Linux is free and can be used for lighting simulation in different spaces and materials. Different software such as IES Radiance, Daysim, Rayfront, Echotect etc… use Radiance for lighting simulation. Form Z RadioZity (Kralikova and Kevicka, 2012) and Lumen Micro (Ubbelohde and Humann, 1998) are another available lighting simulator Software.

Radiance is one of the most applicable lighting simulation software in which simulation is done using radiance tracking and its free version is available for non-commercial applications. At first, this software was established by USA Energy Ministry and Switzerland Federal Government. Now, its copy right is for California university (Compagnon, 1997).

Figure 3.31. Sample of radiance software outputs (Ward, 1994)

Radiance is a set of analysis and lighting design display software. Space geometry, material, reflector surfaces, time, date, and sky status are the inputs of this software for lighting simulation. Using calculated values, the software results can be presented as 3D color images, numerical values, and displaying information on images. A sample of radiance software outputs have been shown in Figure 3.31. (Ward, 1994).

One of the most important aspects of this software is the non-limitation of space geometry and diverse materials id simple lighting simulation. Radiance can be used either for simulating lighting quality and rate or testing innovative design methods in research centers. This software presents different methods for problem solving which can be used for time saving and performing accurate simulations.

3.5.5. Coding in Rhino Grasshopper

Geometry is one of the most basic architectural infrastructures by which the relationships between forms, currents and spaces, and their size and proportion, the composition of components, and the relationships between whole of them and their components are examined. Due to the fact that it is presented in computer space, geometry has the ability to communicate with the programming language within 3D software modeling. Establishing the relationship between programmer bases and geometry in 3D software has led to the use of algorithmic processes in the design of shapes and volumes.

Algorithmic architecture attempts to determine the parameters affecting the physical behavior of the building in the process of continuous analysis, to effect architecture at the right time and correct the design in feedback loops. Insistence of a designer on the advancement of a formic-special idea and then the coercion of the engineering team to build that design is not the best way of architecture anymore. Algorithmic design-analysis cycles investigate and produce the options, and after completing various analyzes on the design, they resolve deficiencies and problems of it. Design provides guidance in a repeatable cycle of influencing and weighing parameters and generating options before analyzing and receiving feedback, and re-applying them to design parameters to produce revised options, and then repeats itself to eventually achieve desirable result, which, responded to the best possible wishes as the final output. The softwares used in this essay is defined in three broad areas, which together perform a process of optimization in order to reduce energy consumption. Generator algorithm section. Heat section and lighting section.

To investigate all possible scenarios and create sample spaces, it is first needed to define the algorithm of producing the geometry of the model as a parameter that we call it the generating algorithm. Generator algorithms are in the architecture of algorithms that can produce all design scenarios. These algorithms cover special issues of space design and architecture in CAD software in combination with its features and commands. This algorithm performs a change in percentage of colored glasses by selecting several input items and controlling them. And by changing its parameters, all permutations produced by the combination of different percentages of colored glasses can be made. In order to define the generator algorithm and geometry in 3D space, the Rhino software and the Grasshopper plugin were used. With the help of this plugin, a parametric model can be produced and changed the specification of the model by modifying its constituent parameters. To determine the thermal effects, the Energy Plus software engine and to determine the lighting effects of the computing engine, the Radians and Daysim software were used. To transfer information between the generated geometry in the Grasshopper header and the computational engine, the Honeybee add-on, which is the graphical interface of the computing engines, was selected. In optimization section Galapagos solution plugin was utilized. Figure 3.32 shows the work flow diagram of simulations of samples in software environment.

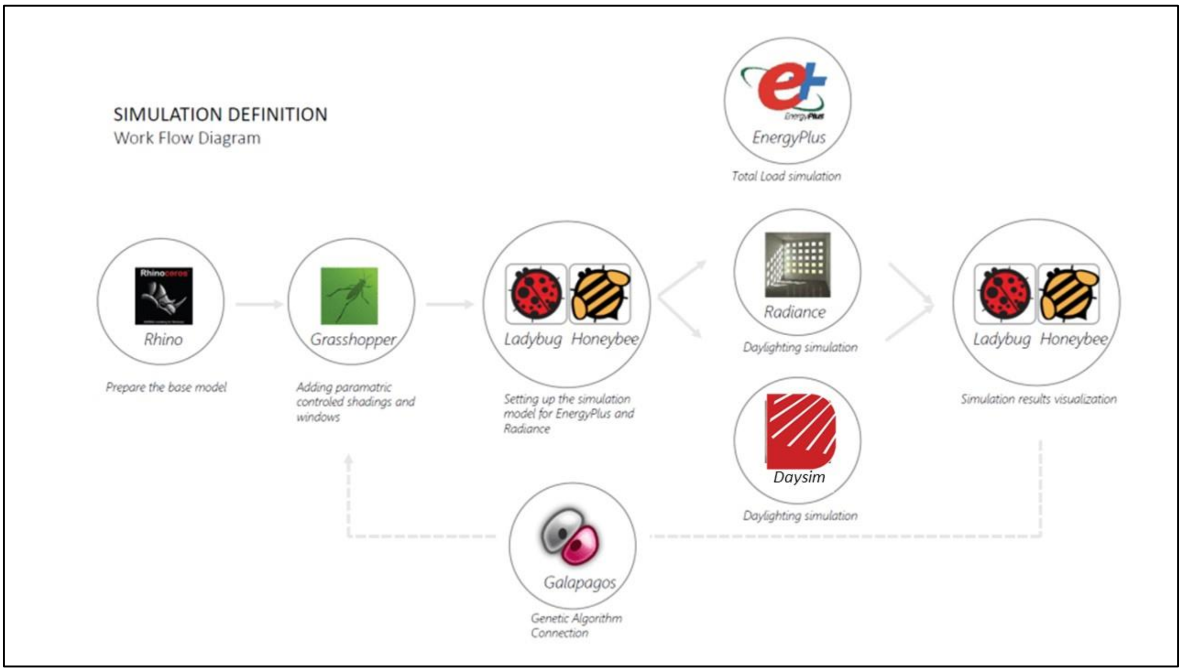


Figure 3.32. Samples simulation diagram in Rhino- Grasshopper

4. CASE STUDY

In the process of urban development, the western axis of Ankara had a linear development over time by means of construction. In addition to the situation of public and private institutions, there is also an urban formation. There have been developments in different periods of time and this process is still going on. It is aimed to create a regional center in TEPE PRİME project which is built on this axis surrounded by fences and shaped with different properties.

Figure 4.1. A view of Tepe Prime (A, B, C Blocks)

The design has been developed on a fiction based on the idea of agora from the ancient to the contemporary city. With the idea of a living public space with its outdoor spaces, different functions exist. Although it is a place to live with the users of the buildings, a "regional center" at the scale of its own with activity areas open to all citizens was targeted. Tepe Prime has a collection of offices, studio apartments and shops. When designing office buildings and studio apartments together, it is thought to live with spaces reflecting the texture, dynamism and activity diversity of the city.

The building ID is as bellow:

Design Team	Ali Osman Öztürk
Assistant Architect	Eser Çengel
	Nurten Asil
	Filiz Önder
	Süreyya Atalay
	Canan Karakaya
	Mehmet Güner
Mechanical Project	GMD Engineering
Electric project	Akay Engineering
Static Project	High Project Construction limited company
Landscape Project	Dalokay Archiecture

Architecture Office (s)	A Design, Architectural Application, Consulting Construction industry and trade limited company
Employer	Tepe Construction Industry Inc.
Project Date	2007 - 2008
Production Date	2008 – 2010
Land Owner	Cement Manufacturers Association of Turkey
Land area	28.227 m^2
Closed area	92.750 m^2
Project Type	Business Center - Office
Type of Construction	Mixed
Contractor	Tepe Construction Inc.

As it is known, Tepe Prime project consists of curtain walling systems, glass panel covering elements. On the glass curtain walls of the Tepe prime buildings, the opened casements were constructed as vent Orosi-concealed casements. The glass type used in the facade is colored reflective coated glass.

The building automation system works on a server computer that enables the management and operation of the facility by combining other mechanical systems besides HVAC automation. The whole system, including the computers used and the building automation software, was chosen to operate continuously for 365 days and 24 hours. TAC VISTA Building Automation software that combines all systems in the facility is with unlimited point capacity. In this way, the system has both unlimited modular and software expansion capabilities. The HVAC automation system constitutes most of the building automation system. A total of 2000 points are monitored and controlled in the HVAC automation system. The main equipment monitored and controlled via the system are as follows: Mixed air and fresh air conditioning plants, Chiller, Dry Coolers, Boilers, Pumps with equal ageing and frequency invertor heating-cooling system, Exhaust fans, Drainage and sewage pumps. The situation plan of Tepe Prime can be seen in figure 4.2.

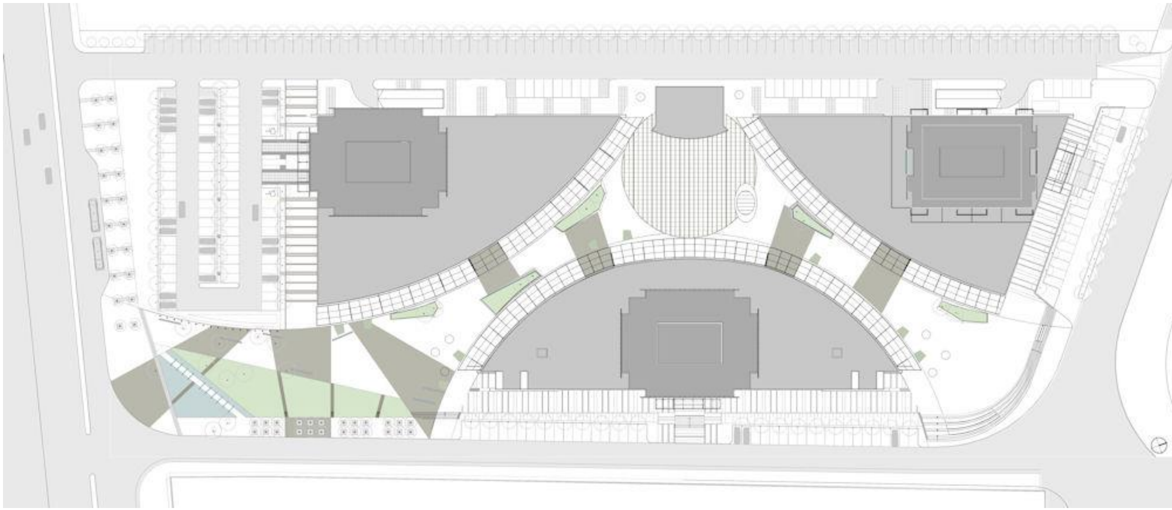


Figure 4.2. Tepe Prime- situation plan

The data of A block is given below.

Floor area:……………………. …… …………………....………….…….……930 m2

Ceiling Area without Owning Slab:………………… ……….………………….930 m2

Ceiling Area with Owning Slab: …………………………………………...…….2050 m2

Owning Slab Area: ………………………………………………..…..………….1120 m2

Volume of building: ……...………………………………………..…………….91200 m3

Eastern facade window area: ……………………………………………………..1985 m2

Western facade window area: ………………………………………….……………1980 m2

Northern facade window area: ………………………………………..…………..1915 m2

Southern facade window area: ……………….……………………..…………….1910 m2

Total façade area (AT): …………………………...……………………………...7790 m2

Total window area (AW): …………………………………………………..……9980 m2

AW / AT:…………………………………… ……………………………………... 78%

Within the scope of the project, a total of 250 lighting points can be monitored and controlled via the building automation system. Common areas, facade, environment and road lighting can be controlled both manually and via automatica time programs, while the lighting points can be monitored via graphic animation SCADA screens. Lighting automation modules are directly connected to the system via LON communication.

As is known, the high ratio of glass on the external facade causes undesired heat gains in summer and increases cooling energy consumption especially in buildings with cooling system.

In the Prime Block A, firstly heat gains were calculated and the monthly average solar energy of the building was determined. Monthly average solar gains (Φs, month) are calculated in accordance with TS 825 for the Tepe prime south front.

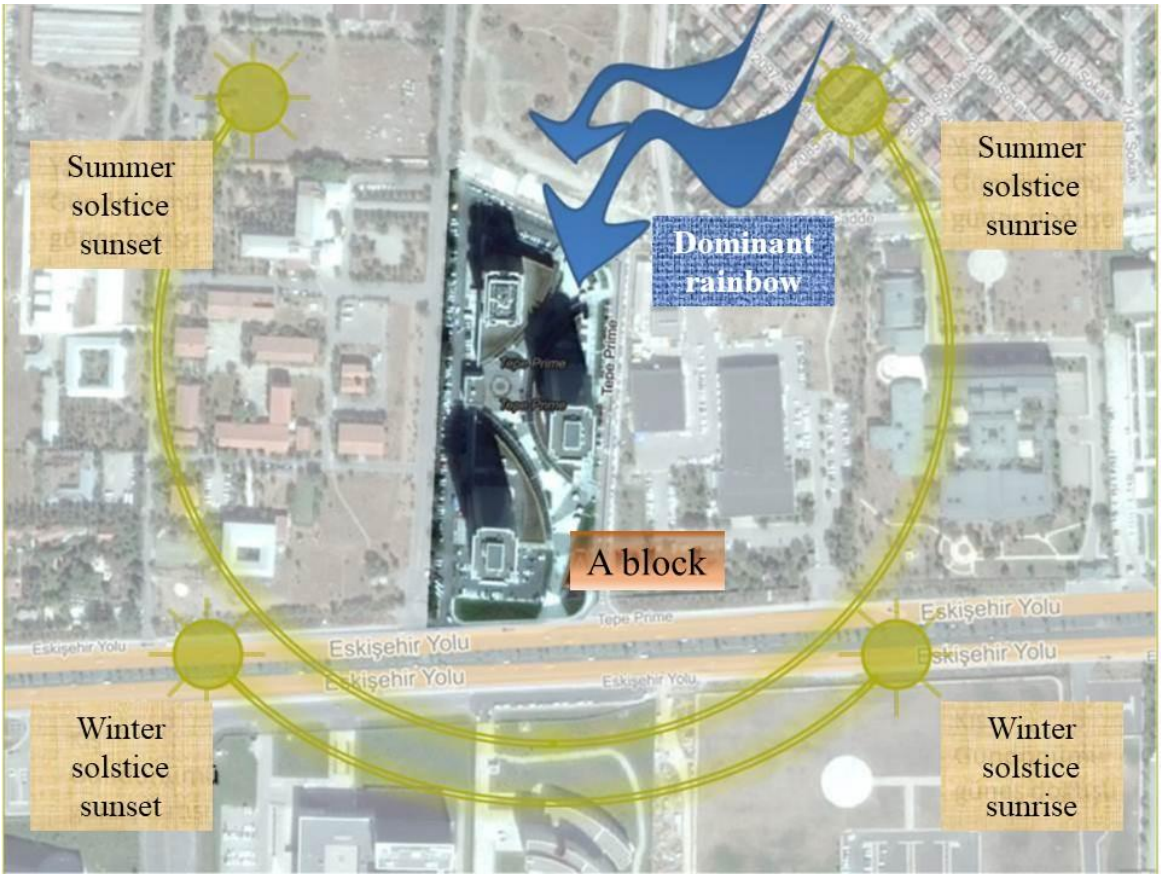


Figure 4.3. Tepe Prime (A Block) Analysis

In the Prime Block A, firstly heat gains were calculated and the monthly average solar energy of the building was determined. Monthly average solar gains (Φs, month) are calculated in accordance with TS 825 for the Tepe prime south front.Monthly average solar gains (Φs,manth):

In this part, the calculations are calculated according to TS 825; (TS825, 2013)

$$\Phi s, \text{month} = \Sigma\, ri, \text{month}.\ gi, \text{month}.\ li, \text{month}.\ Ai \quad (4.1)$$

For the shading factor to be used during the calculation of solar energy gains, ri, month = 0.8 is selected as the building is considered to be Discrete.

Solar energy transmission factor:

$$gi, \text{month} = \text{Fw.g}_{\perp} \quad (4.2)$$

Here;

Fw : It is the correction factor for glasses.

$g_{\perp}$: It is the solar energy transmission factor for the beam measured in laboratory conditions and perpendicular to the surface. In the absence of measurement values for “$g_{\perp}$”, photochromic glass which has been used in Tepe Prime, 0.50 is valued. So:

0,80 * 0,50 = 0,40

“Ai”: Total window areas for each direction

“Ii,month”: for each month is taken from the table below.

Isouth, August = 93 W/m2

Iwest,August = 106 W/m2

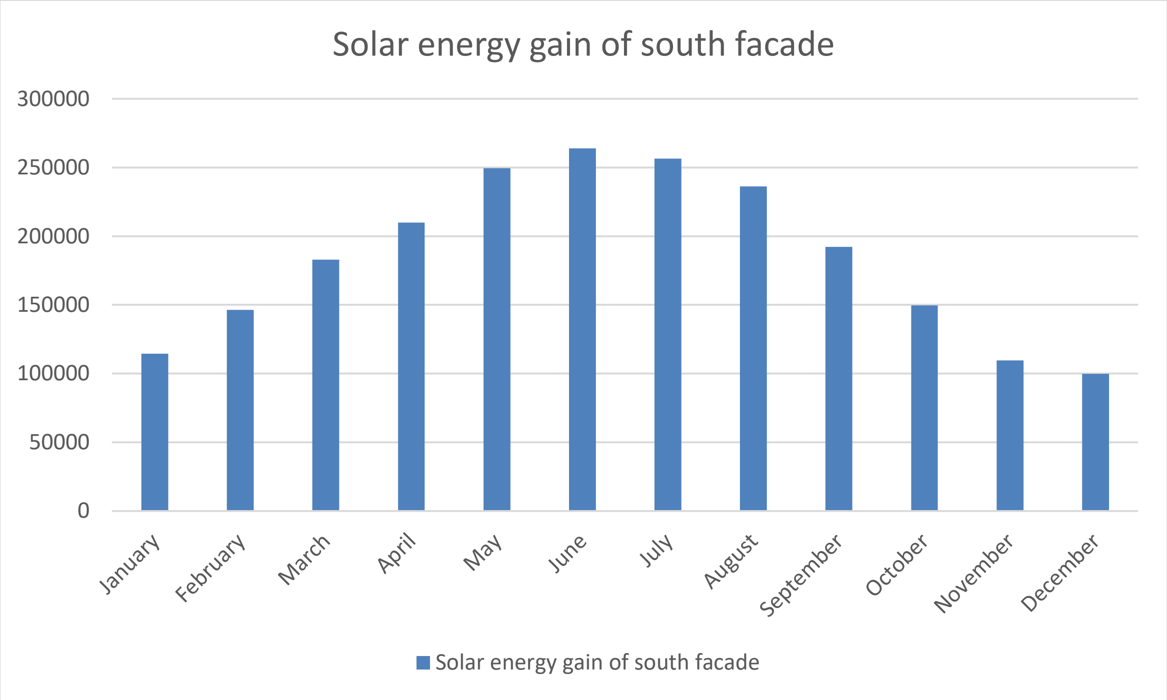
Table 4.1. Average monthly solar radiation intensity to be used in calculations for all degree day zones in W/m2 (TS825, 2013)

	January	February	March	April	May	June	July	August	September	October	November	December
I_{south}	72	84	87	90	92	95	93	93	89	82	67	64
I_{north}	26	37	52	66	79	83	81	73	57	40	27	22
$I_{east/west}$	43	57	77	90	114	122	118	106	81	59	41	37

According to Table 4.1, the samples were selected from the south and west-east fronts because the monthly solar radiation intensity was high on these sides.

The most important problem that may arise from the use of glass curtain wall is the overheating of the building in summer and the emergence of greenhouse effect in the interior. Due to the high heat gain in the summer months, the samples were selected from the western and southern facades. The high heat gain from the A block south facade is determined in Table 4.2 by month:

Table 4.2. Solar energy gain of south façade W/m2



In houses, schools and normal buildings φi, month must be:

$$\varphi i, \text{month} \leq 5 \times An \quad (4.3)$$

So it should be less than 145920 W / m2. It is not as can be seen in the table 4.2.

As discussed in the literature review section, different glass types or double-skin facade design and different shading systems are used to prevent heat gain. They also reduce the visual comfort of the indoors.

Two estimated samples are in Ankara, located in the northern hemisphere the sun follows an arc rising in the east and setting in the west. According to Table 4.1, the samples were selected from the south and west-east fronts because the monthly solar radiation intensity was high on these sides. So the essential facades for solar heat gain are south and west.

1^{st} sample is the zone from south façade and the 2^{nd} one is from west (Figure 4.4).

Although the Tepe Prime complex received the EID (Energy Identification Document), there is still no note available. In the block A, which is a 19-storey office building, while the entire building is covered with glass material, aluminum cladding panels are used to create a visual effect on the corner projections. This building constructed with structural silicone system closing via lattice beam carrier system and used for building facades gives an impression of an uninterrupted flat glass facade via 6-12-6 mm blue photochromic glass with U value of 2.74 W / m2K in transparent parts, 6 mm blue colored single glass in opaque parts and steel profiles. Table 4.2 calculation of heat gain was made through these glasses.

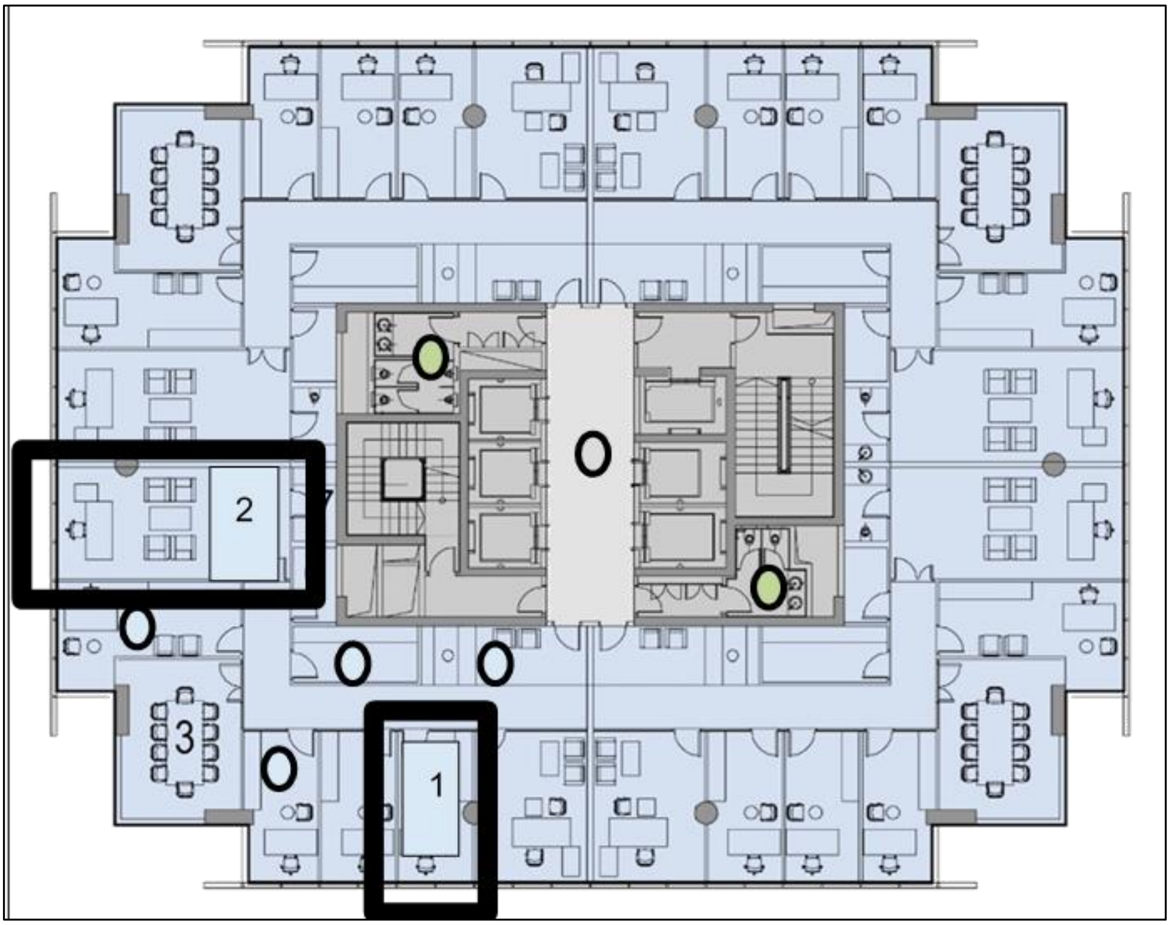


Figure 4.4. The 18th floor's plan of A block (official building) of TEPE PRIME and the location of 1st and 2nd samples

To obtain the CTF's outputs, two sample are considered by drawing in SWDT. Afterwards to examine the correctness of the functions and SWDT software, the results will be compared with analyzing program.

4.1. Simulation in SWDT

To check out program's validity crosscheck action was introduced. Two office zones selected in Ankara was drawn in SWDT and other software environment. Rhino-grasshopper was chosen to test the samples and extract CTFs' area percent. The area percent of CTFs deduced from rhino-grasshopper compared with SWDT's results.

First of all, the plans of samples must be drawn in SWDT and all the required parameters enters into the software. Therefore the CTFs' area percent results due to months and seasons will be obtained. First sample drawing in SWDT presented in Figure 4.5 and second sample in Figure 4.6.

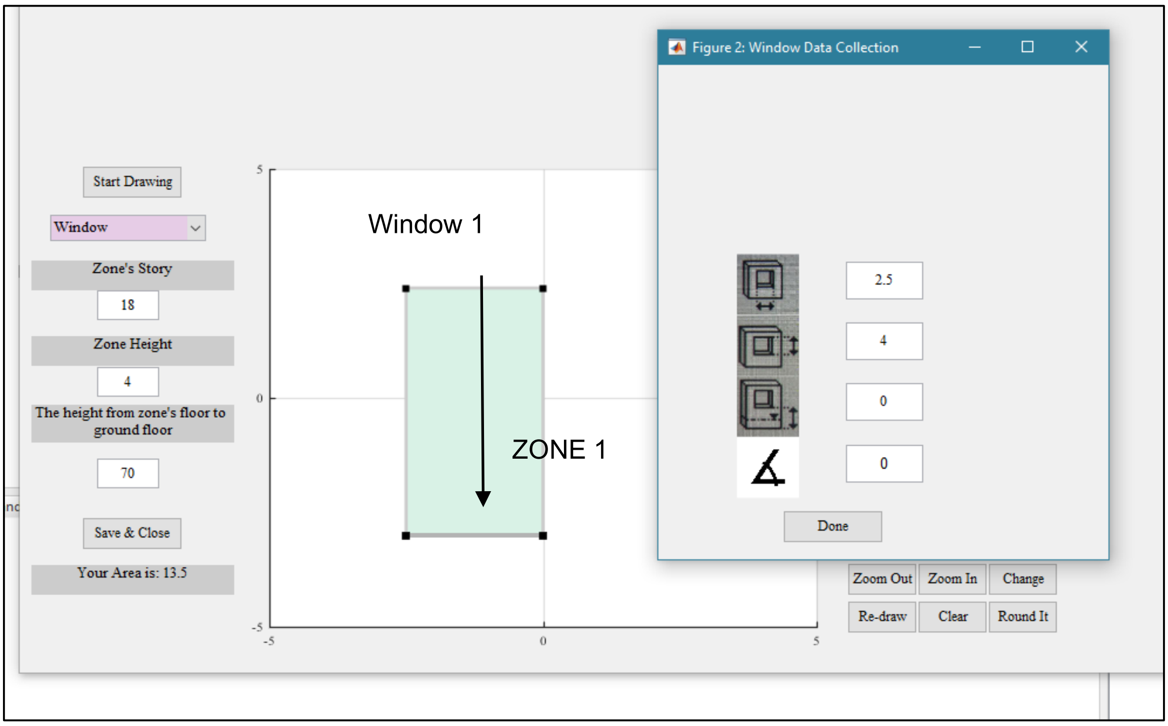


Figure 4.5. First sample drawing in smart window design tool

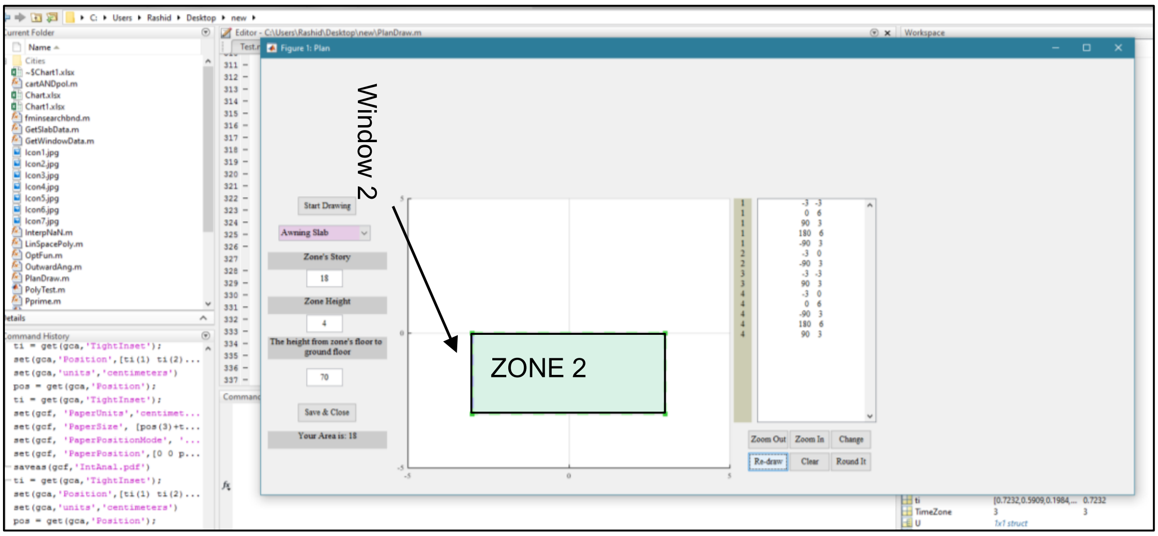


Figure 4.6. Second sample drawing in smart window design tool

The monthly of average direct and diffuse beam radiation incident on the window 1 and 2 can be seen in Figure 4.7. The solar heat gain graph in the figure below obtained by SWDT program.

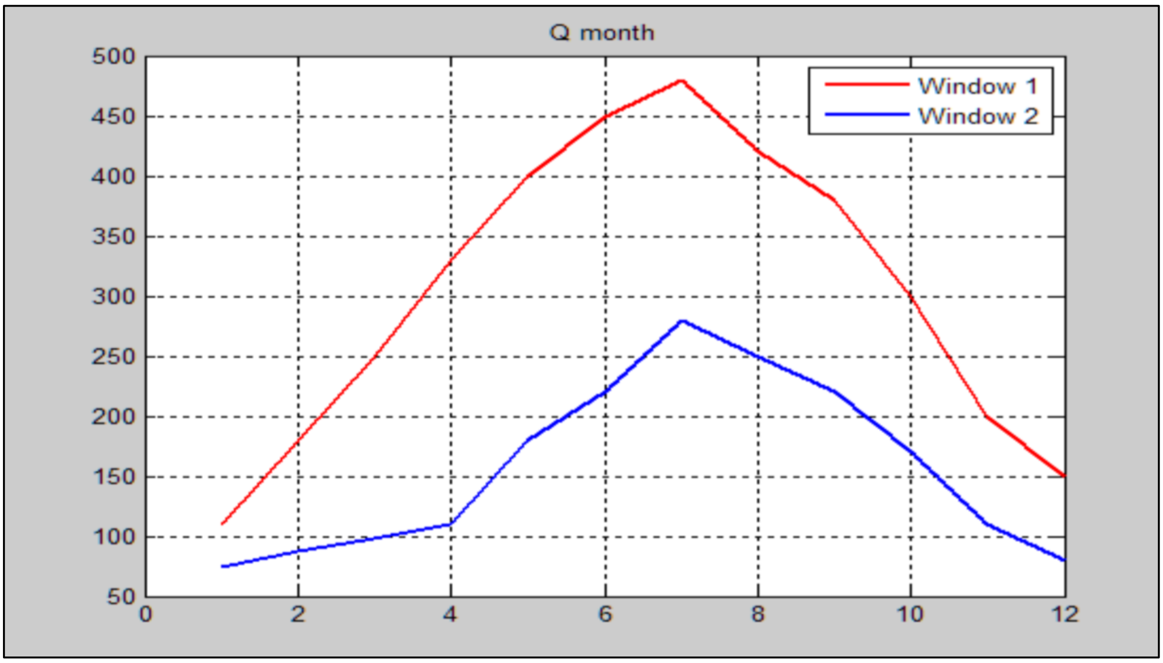


Figure 4.7. The monthly of average direct and diffuse beam radiation incident on the window 1 and 2

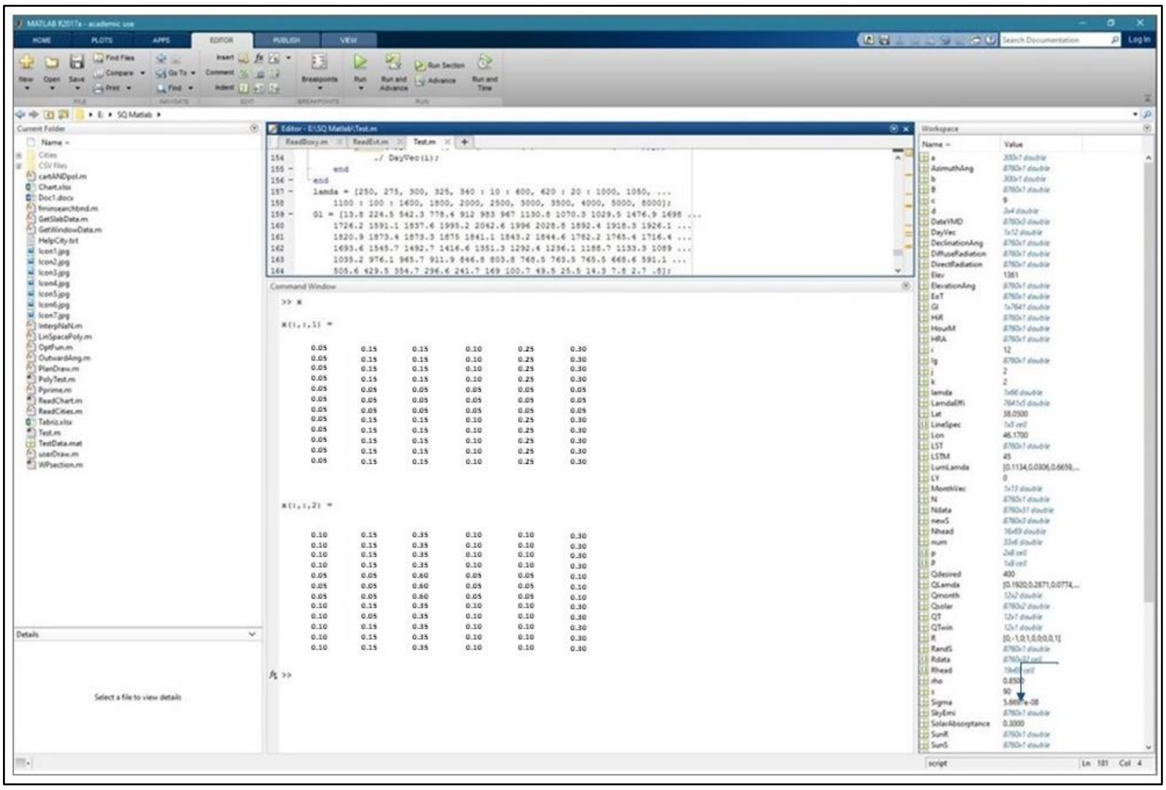


Figure 4.8. CTFs' color area percent

Therefore, the result of CTFs' area percent achieved as can be seen in Figure 4.8 and Figure 4.9. Blue area is the largest one at both of samples in summer.

The result is as below (Figure 4.9):

1st sample color area:

In summer: Yellow5%, Red5%, Blue75%, Green5%, Orange5%, Purple5%.

In Autumn-Spring: Yellow5%, Red15%, Blue15%, Green10%, Orange25%, Purple30%.

2nd sample color area:

In summer: Yellow5%, Red15%, Blue60%, Green5%, Orange5%, Purple10%.

In Autumn-Spring: Yellow10%, Red5%, Blue35%, Green10%, Orange10%, Purple30%.

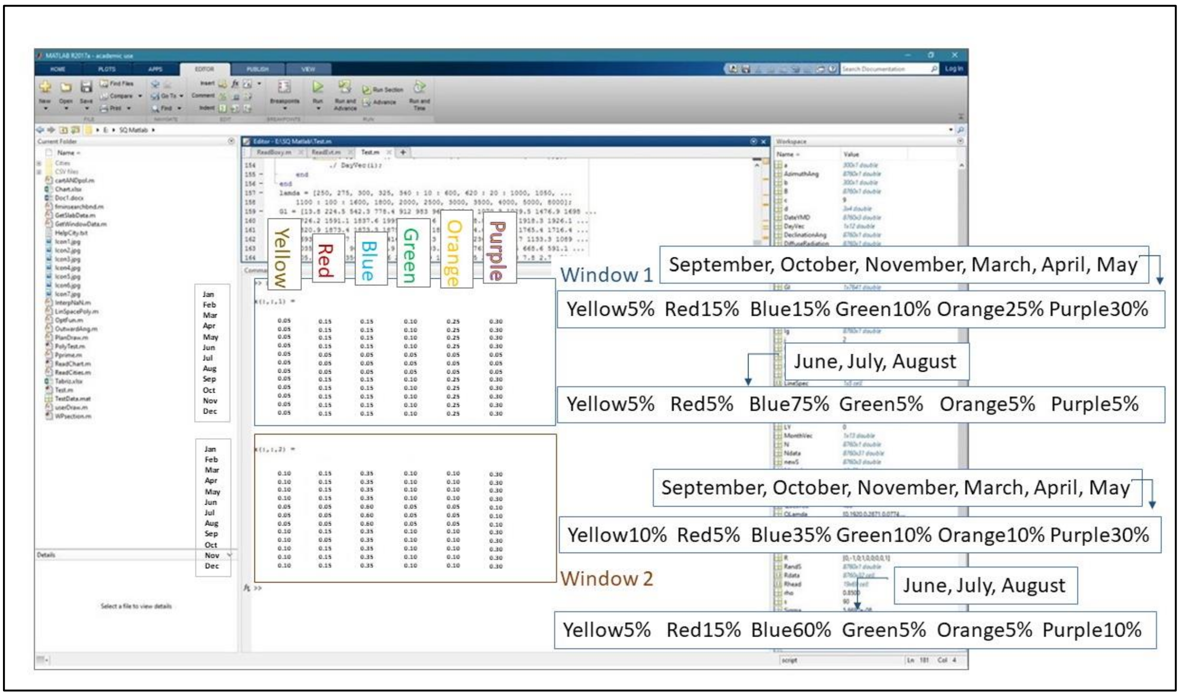


Figure 4.9. Percent determination in result output of SWDT

4.2. Simulation in Rhino- Grasshopper

To test the program, the results (CTFs' area percentages) obtained after drawing the two samples selected in the 18th floor in Tepe Prime block A in both SWDT and grasshopper-Rhino are compared.

Colored glasses have different thermal and lighting properties, and the effect that the color of glass has on energy consumption is the result of thermal effects and brightness. The scripting of start parameters (user defined parametric inputs) were listed in Figure 4.10.

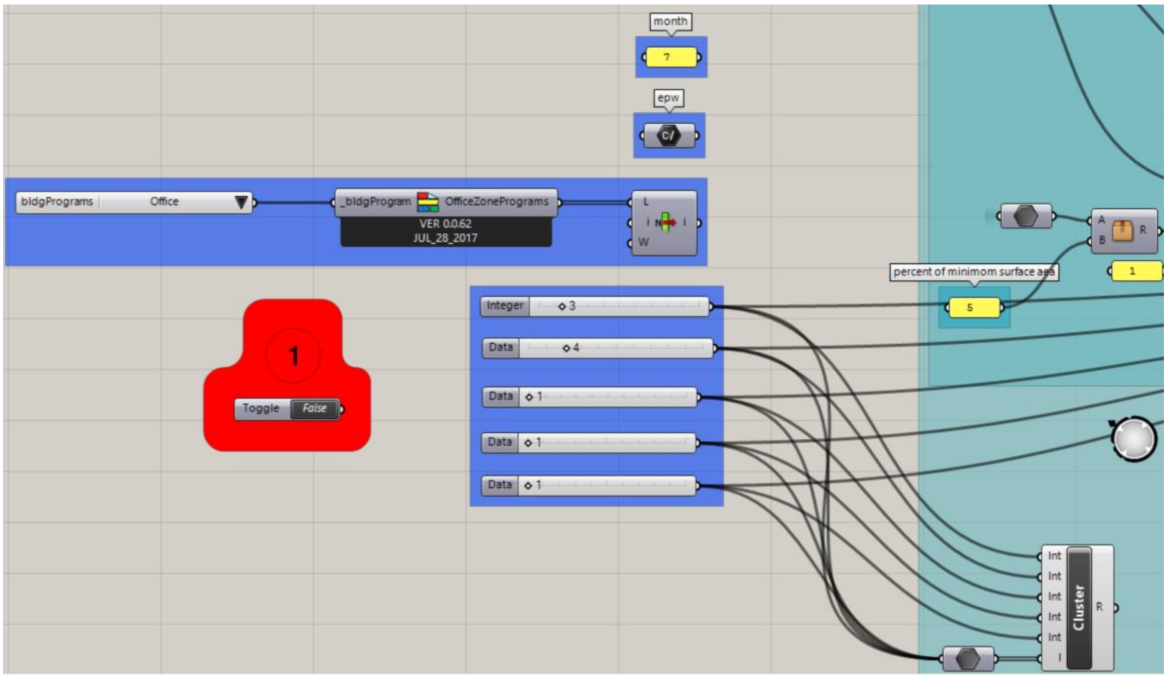


Figure 4.10. Start parameters: user defined parametric inputs

So, in the next step, with the aid of thermal simulators and lighting, the effect of change in the percentage of colored glasses on energy consumption was calculated and the results were analyzed. To determine the thermal effects, the Energy Plus software engine and to determine the lighting effects of the computing engine, the Radians and Daysim software were used. To transfer information between the generated geometry in the Grasshopper header and the computational engine, the Honeybee add-on, which is the graphical interface of the computing engines, was selected.

Thermal analysis uses thermal properties of materials. These specifications in colored glass include thickness, thermal conductivity and transmittance rates of radiation at various frequencies. The thickness of the glass was 2 mm and the conductivity coefficient was 0.9 w/mk. The transmission rate of the received radiation also varies according to the glass color (Figure 4.11).

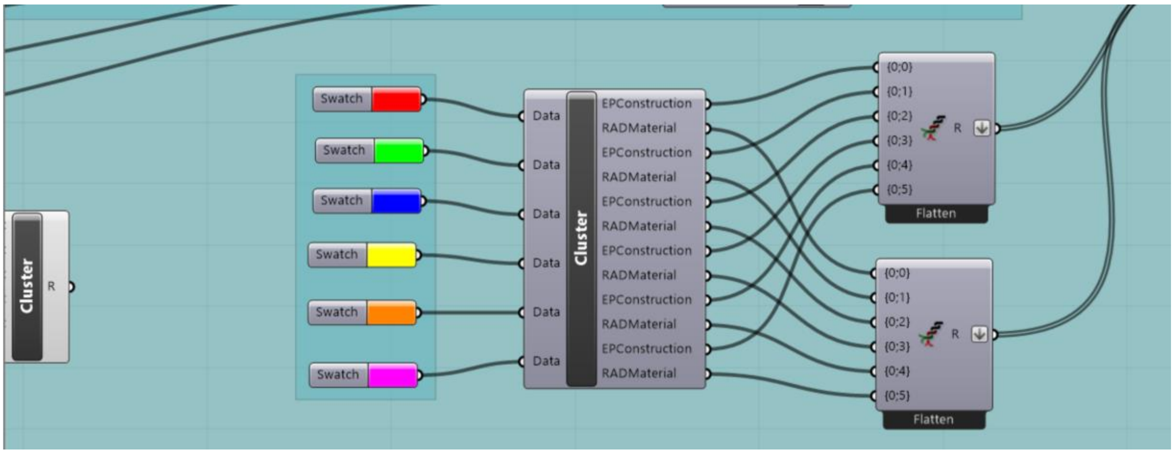


Figure 4.11. Colors and glasses properties algorithm

The middle part in Figure 4.11 is a cluster that contains the material properties as glass thickness, solar and visible transmittance for each color as shown in Figure 4.12:

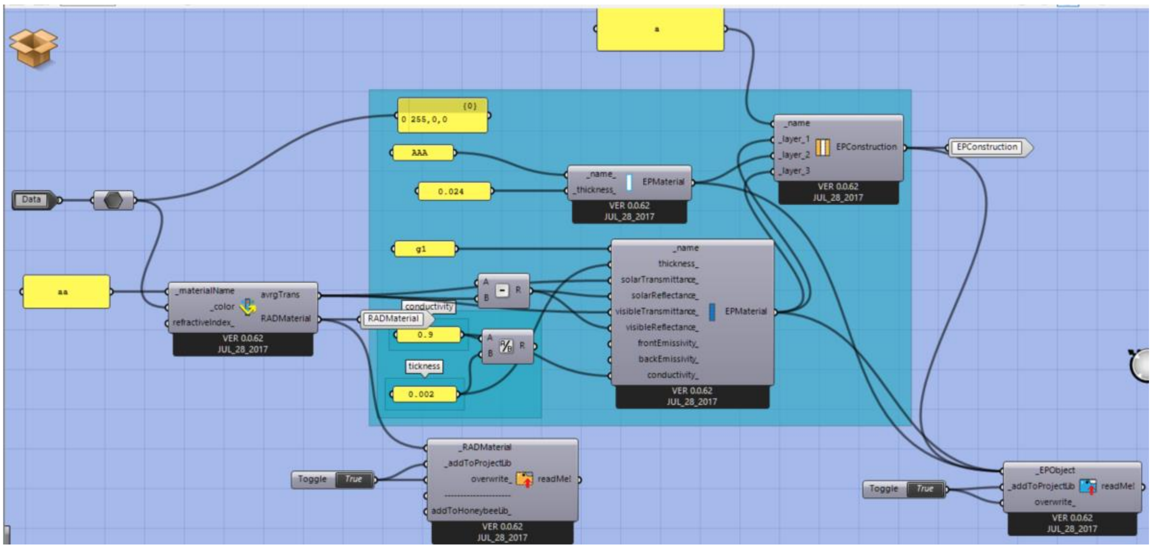


Figure 4.12. The inside parameters of material cluster

Since our goal is to estimate the influence of the percentage of colored glasses in energy consumption, the other thermal zone levels are defined as adiabatic to exclude their heat transfer in the calculations. Estimation of energy consumption depends on the amount of operation and the hours of mechanical facilities being on. Therefore, the cooling set point and heating set point were defined respectively as the thermal zone for switching on and off mechanical installations at 25 and 20 degrees Celsius. The number of users in the thermal zone is 2 person who each need 15 cfm of fresh air through ventilation. The thermal analysis was carried out for a warm month of year from 8 to 18 and also the cold load factor was calculated as well. Eventually, the amount of energy consumed by the illumination unit will be accumulated during the same period as is obtained by analyzing the radians and the Daysim. The algorithm of thermal analysis in Grasshopper can be seen in Figure 4.13.

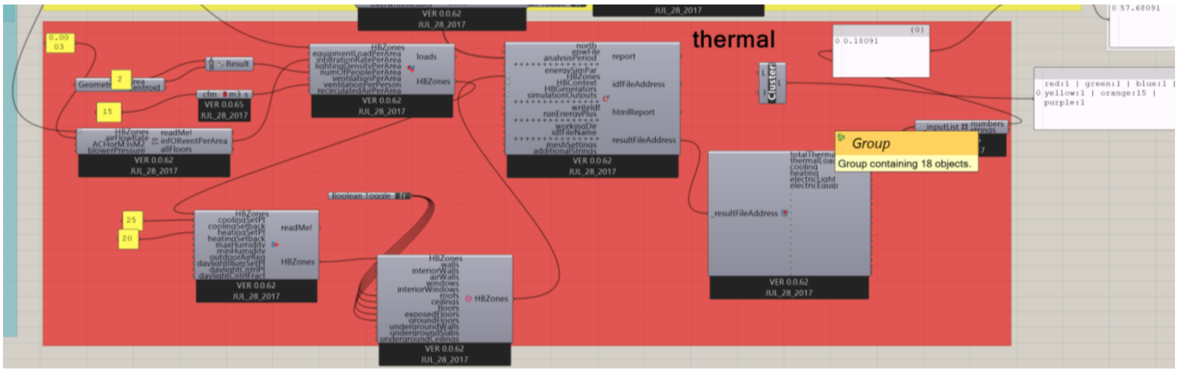


Figure 4.13. The algorithm of thermal analysis in Grasshopper

In analyzes of lighting optical properties of surfaces are used exposed to light. These specifications in colored glasses include refractive index, reflection and passing visible light rays, that is variable due to the color of the glass. The Radians software calculates the brightness of the light according to the optical properties of the surfaces for a given moment and it can't cover a period. Since the thermal energy analysis is done for a monthly period, light analyzes should be made for a monthly interval. This work was done by the software Daysim. The Daysim is used for lighting analyzes from the Radians computing engine, for a specified range. The algorithm of lighting analysis in Grasshopper can be seen in Figure 4.14.

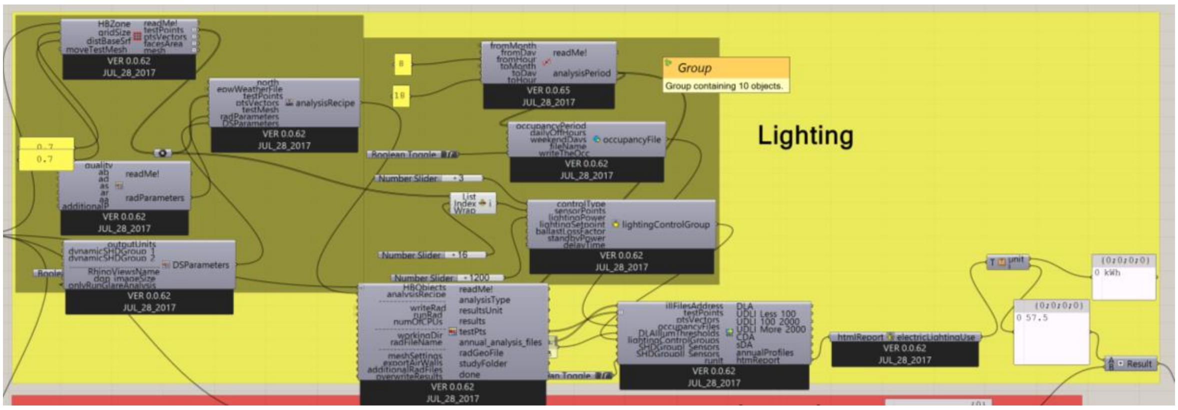


Figure 4.14. The algorithm of lighting analysis in Grasshopper

The way of working in estimating the amount of energy used in the lighting unit is to turn the on and off process of artificial light into a natural light. And to say that when the natural light level of the room is less than optimal, artificial lighting turns on and compensates the lack of brightness. In this way, the number of hours that lamps are on is determined, and by determining the power consumption of the lamps, the amount of light can be consumed. The desired brightness value (set point) is considered 300 lux and power consumption is 1200 watts. After calculating the energy consumption of the lighting sector, this number was combined with the thermal energy consumption and their totality was the measure of the optimal layout of colored glasses.

As previously mentioned, to analyze the software facility we must have a software space as real test. So for our samples the algorithms was been written to define parametric objects in “Grasshopper” with “Ladybug” and “Honeybee” connection plugins. To calculate and analyze the solar irradiance “Energy-Plus” have been added and to test daylighting “Radiance” and “Daysim” have been used. And all these plugins can be reached by Rhino graphic program to see our changes.

The geometry modeling of samples in grasshopper started as can be seen in Figures 4.15 and 4.16 with start parameters:

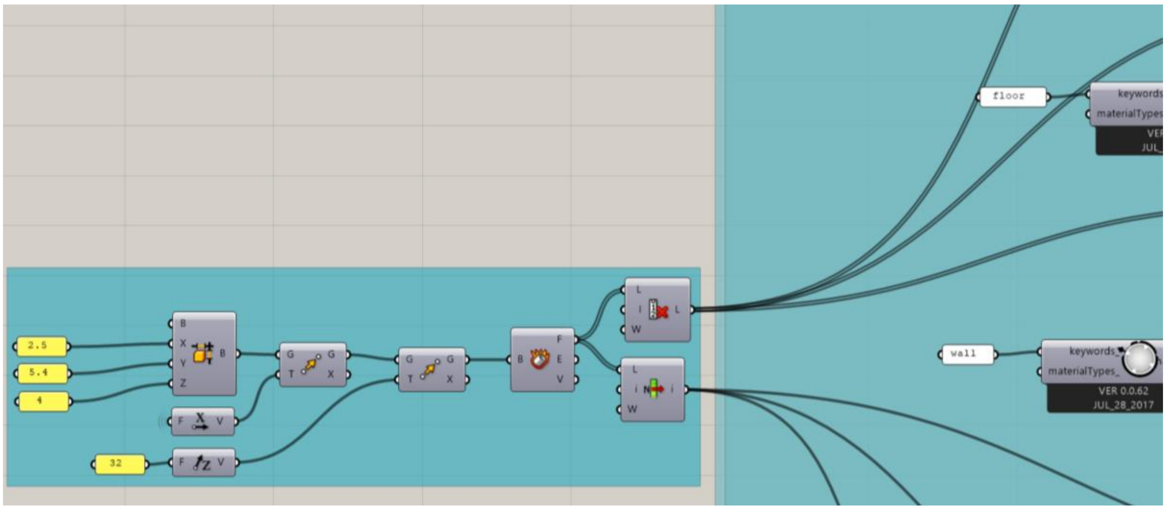


Figure 4.15. Start parameters in modeling first sample

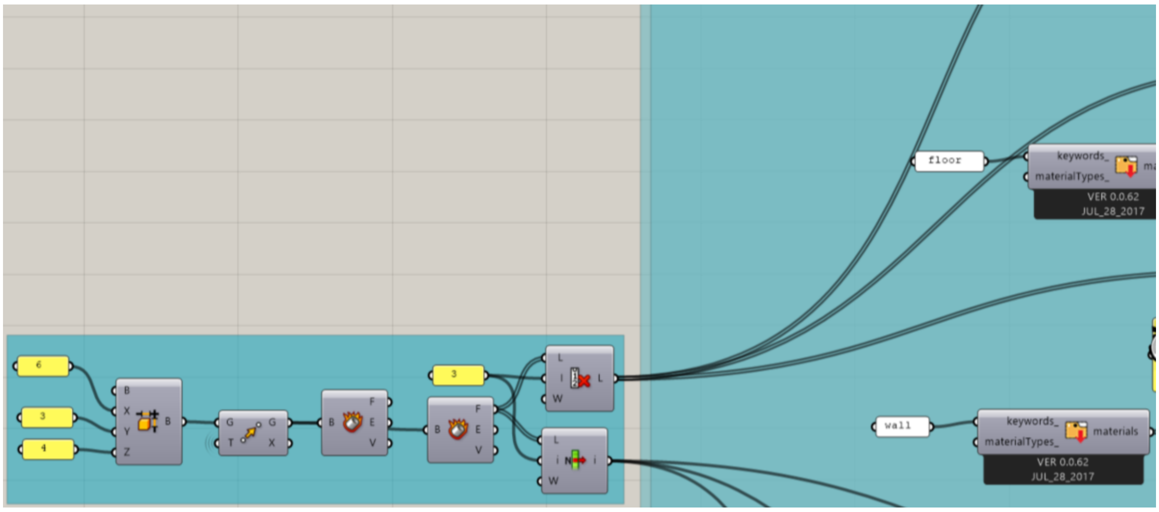


Figure 4.16. Start parameters in modeling second sample

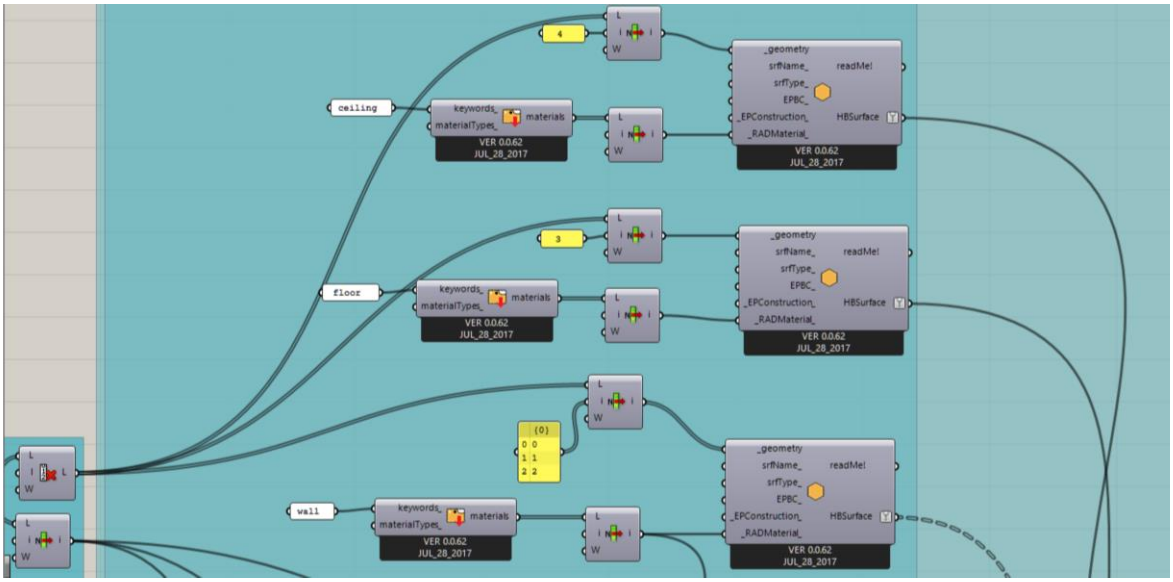


Figure 4.17. Middle section of code in modeling part

To analyze the results samples are modeled in Rhino-Grasshopper as can be seen in a screenshot of modeling in Figure 4.18. Thermal and lighting algorithms have been added as shown. So the results of simulation of electricity consumption and final optimization will be reached.

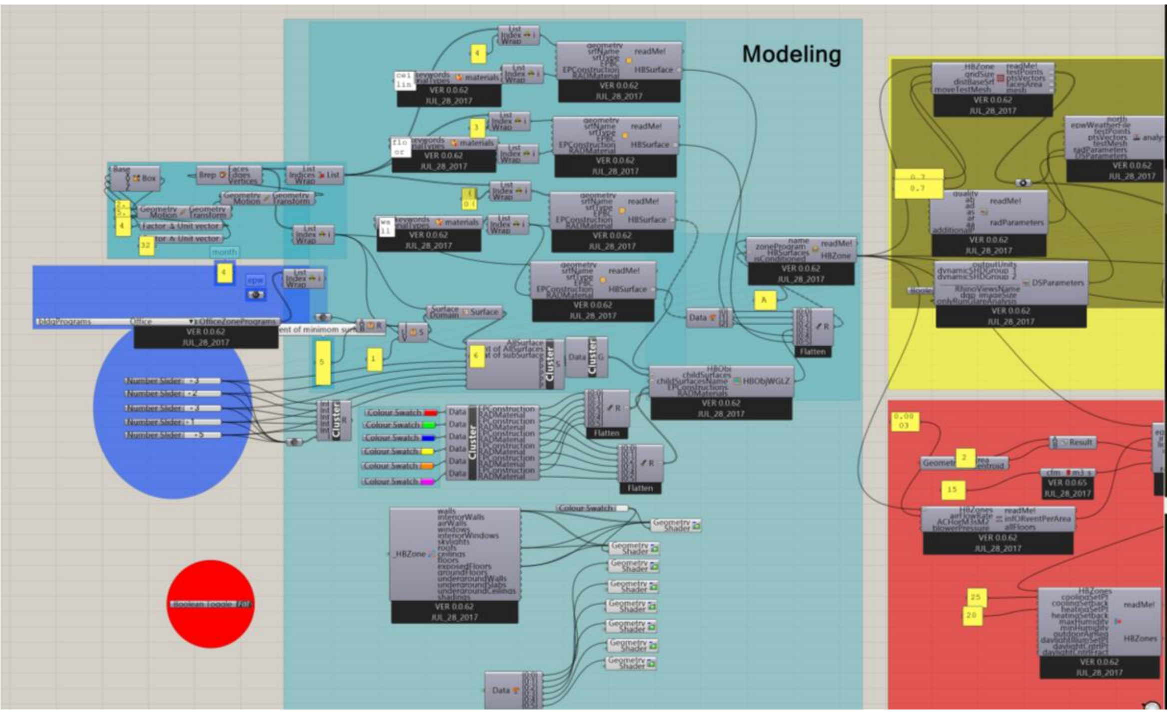


Figure 4.18. The algorithm of modeling of 1st sample in Grasshopper

So monthly cooling load of zones will be cached and due to day lighting and cooling energy, required electricity energy in “kwh” will be achieved. GALAPAGOS (Genetic Algorithm and Presentation-Assisted Graphic Object layout System) (Schumacher, 2014) solution plugin are used to optimize countless responds of inquiry. Max stagnant and Population are selected as 20 and 10 with choosing Initial boost on 2 in Evolutionary solver part of GALAPAGOS. So the results of seasons achieved as can be seen in Figure 4.19.

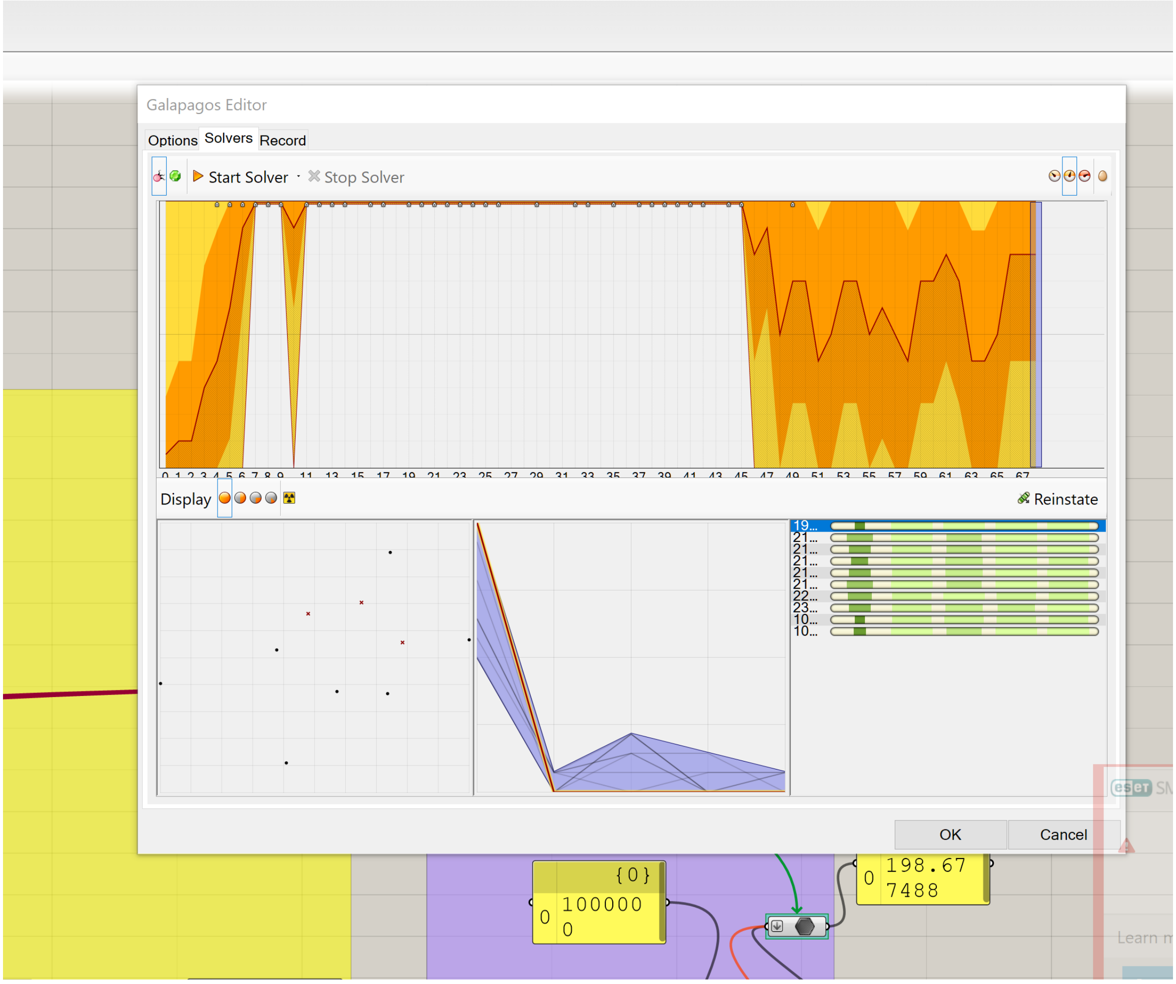


Figure 4.19. First sample optimization result in summer and total energy consumption with Galapagos

The optimization result with best reply to minimum thermal transmission and maximum daylighting transfer due to Galapagos optimization machine for 1st sample has been shown in Figure 4.20 and 4.21. And the optimization conclusions for 2nd sample can be seen in Figure 4.22 and 4.23.

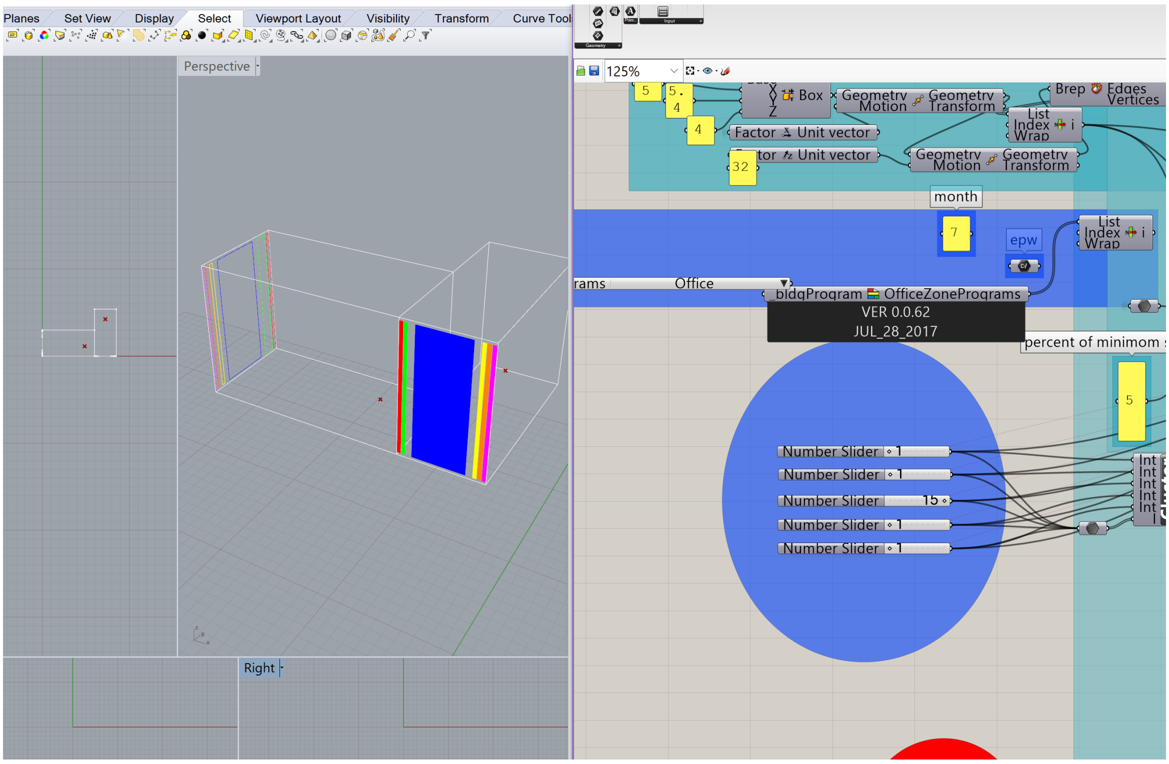


Figure 4.20. First sample optimization result in summer and CTFs optimal scheme with Galapagos

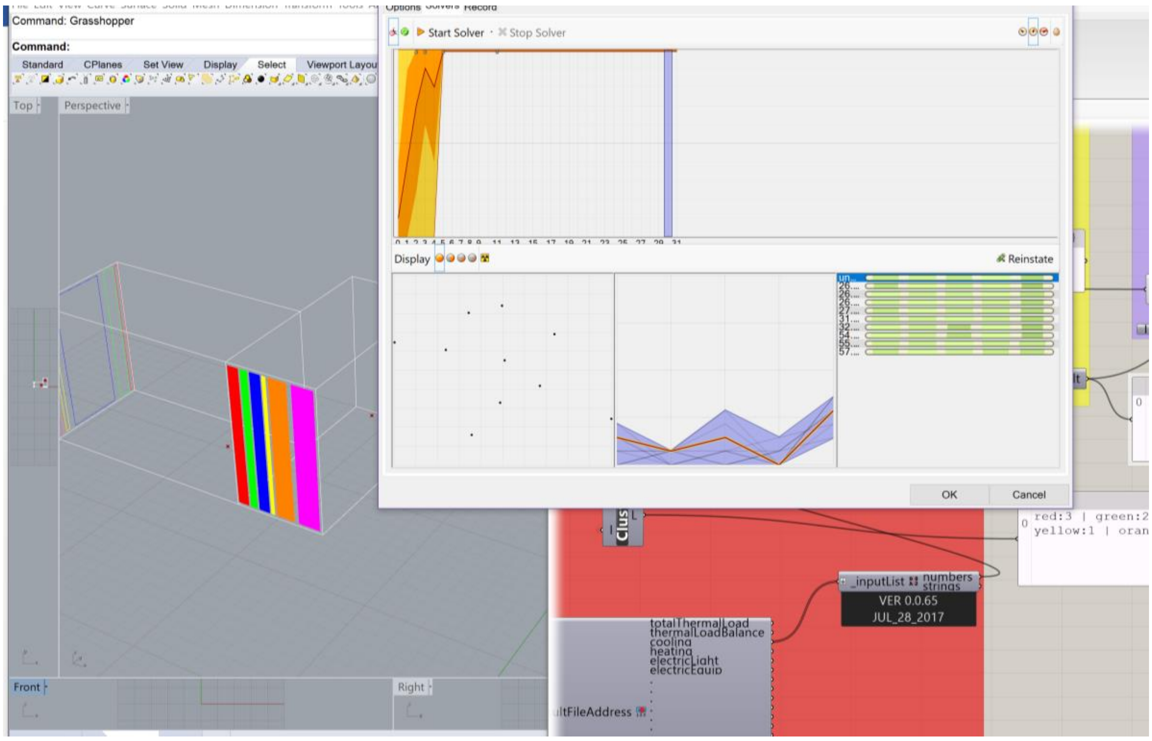


Figure 4.21. First sample optimization result in autumn-spring with Galapagos

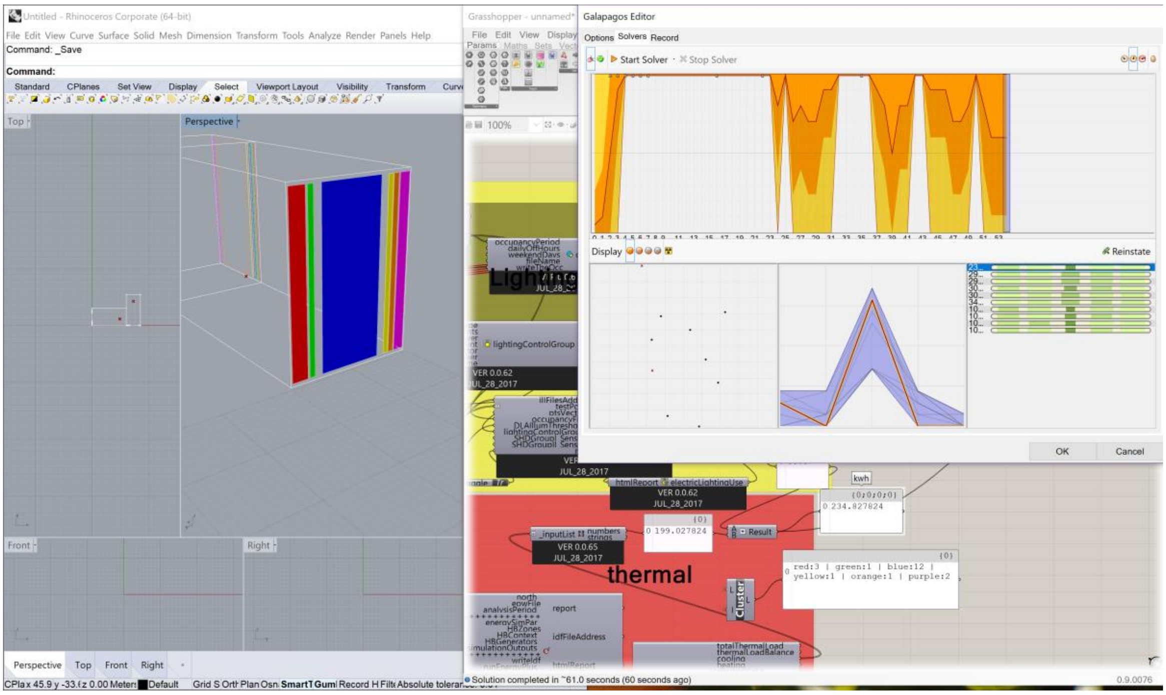


Figure 4.22. Second sample optimization result in summer and total energy consumption with Galapagos

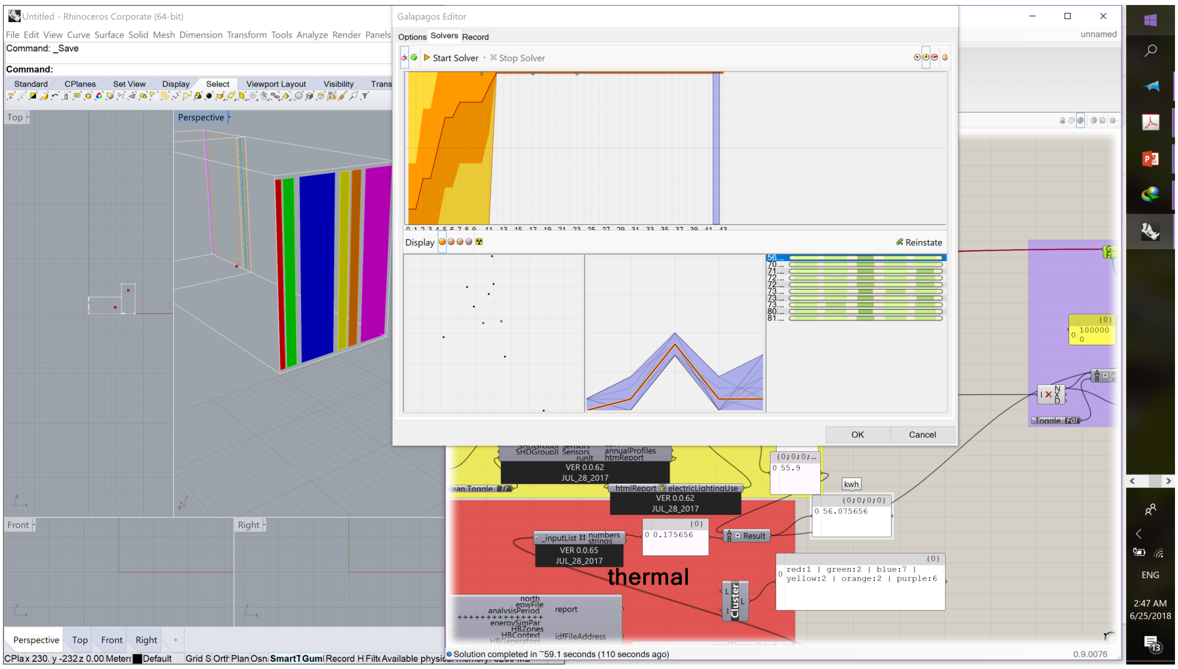


Figure 4.23. Second sample optimization result in autumn-spring and total energy consumption with Galapagos

Due to optimization results which achieved by Galapagos optimization machine to estimate the minimum thermal transmission and maximum daylighting transfer for 1st and 2nd sample have been shown in below:

1st sample color area:

In summer: Yellow5%, Red5%, Blue75%, Green5%, Orange5%, Purple5%.

In Autumn-Spring: Yellow5%, Red15%, Blue15%, Green10%, Orange25%, Purple30%.

2nd sample color area:

In summer: Yellow5%, Red15%, Blue60%, Green5%, Orange5%, Purple10%.

In Autumn-Spring: Yellow10%, Red5%, Blue35%, Green10%, Orange10%, Purple30%.

Accordingly, the results of analyzing program and optimization system is as same as the SWDT's results. The simulation results of two software environment discusses in discussion part in chapter 5.

5. DISCUSSION

According to the researches, radiation does not consist of just the percentage of transition in the long wavelength section. For this purpose, the use of CTFs on the facades in which today's architecture, especially on large transparent glass surfaces, based on colored glasses, was thought to provide these benefits. In this sense, the 4 primary colors were used in Orosi glasses. Two colors were added to these four primary colors at the time of the thesis and the percentage of transition of the 6 primary colors to the spectrum at different wavelengths was excluded. And by connecting these results, it was investigated whether there could be a design method in which heat gain could be prevented and lighting comfort could be provided. SWDT program was developed to reach these two aıms.

To code the desired tool (SWDT); all the required climatic and geometric characteristics effective parameters in window design were considered. Archicad software is selected as a parametric template in 2D space with 3D parameters input. It was considered parametric inputs to draw the desired plan and fill the window, wall and floor parameters blanks. The output part of SWDT is the number groups of CTFs' percent.

In material and method after drawing the zone plans and importing all parametric and climate data of two samples we faced another architectural design issue in proof test of SWDT. In order to define the generator algorithm and the output of geometry in 3D space, the Rhino software and Grasshopper plugin were used. It was observed the result of simulations or color changes of CTFs in Rhino software as 3D form.

Energy-plus software is selected as an energy design guide in Chapter Three to design the SWDT. The climate data of cities added to energy plus site (https://energyplus.net/weather). All the calculations and computational simulations were exported directly or indirectly from relevant sources.

As Winkelmann states: "The solar radiation transmitted by a system of glass layers and the solar radiation absorbed in each layer depend on the solar transmittance, reflectance and absorptance properties of the individual layers". (Winkelmann, 2001) So transmittance wavelengths of CTFs calculated by two type of spectrophotometer in UV, Visible and

Infrared wavelength range. The transmittance charts and the calculation of results showed lighting and solar energy percent to importing to SWDT.

To test the program, the results (CTFs' area percentages) obtained after drawing the two samples selected in the 18th floor in Tepe Prime block A in both SWDT and grasshopper-Rhino are compared. The presented algorithm in crosscheck part was utilized of Energy-Plus, Radiant and Daysim tools in lighting and thermal analysis of CTFs.

First sample's summer simulation results in Rhino- grasshopper Due to Galapagos optimization plugin is as shown in figure 5.1. So lighting energy consumption is 42.8 kWh and cooling energy consumption is 155.87 kWh. And according to the simulation it was the lowest amount of all random simulated phases by Galapagos algorithm.

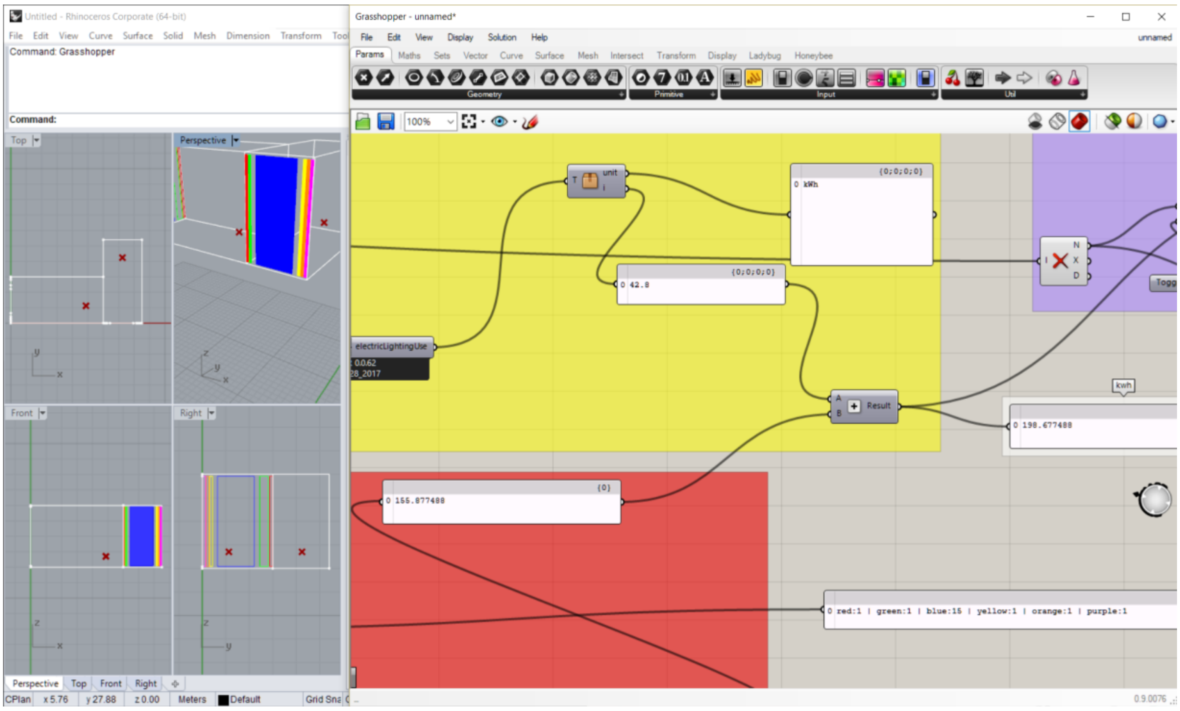


Figure 5.1. The first sample's simulation results with Rhino- grasshopper in summer

And as shown on Figure 5.2 the summer and spring-autumn phases of CTFs' area percentages of first sample calculated by SWDT:

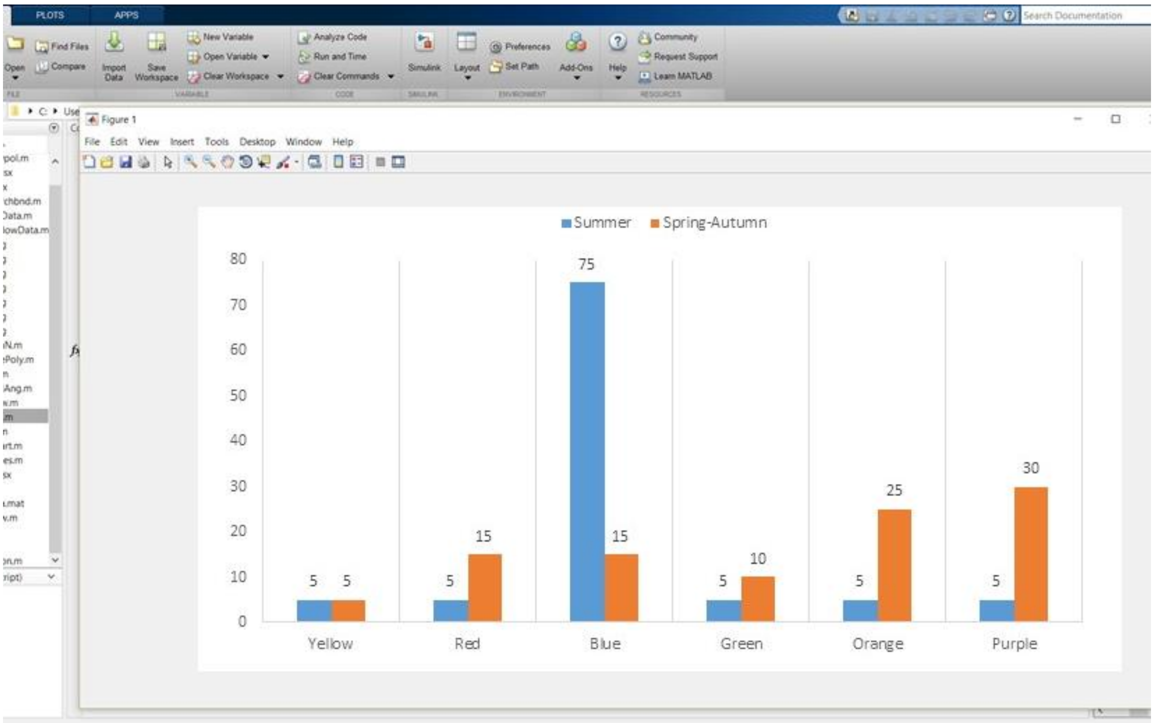


Figure 5.2. The first sample’s percentages of CTFs

First sample’s simulation spring-autumn results in Rhino- grasshopper Due to Galapagos optimization plugin is as shown in Figure 5.3. So lighting energy consumption is 0 kWh and cooling energy consumption is 0.18 kWh. And according to the simulation it was the lowest amount of all random simulated phases by Galapagos algorithm.

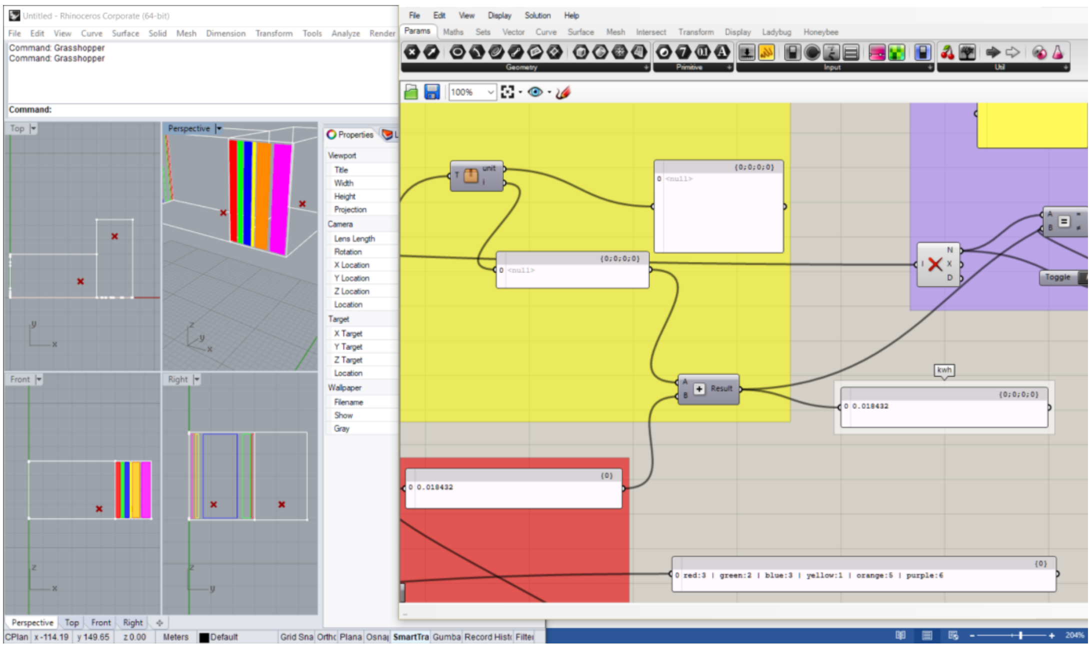


Figure 5.3. The first sample’s simulation results with Rhino- grasshopper in spring-autumn

So the crosscheck of first sample simulations in two software environment is as shown in Figure 5.4.

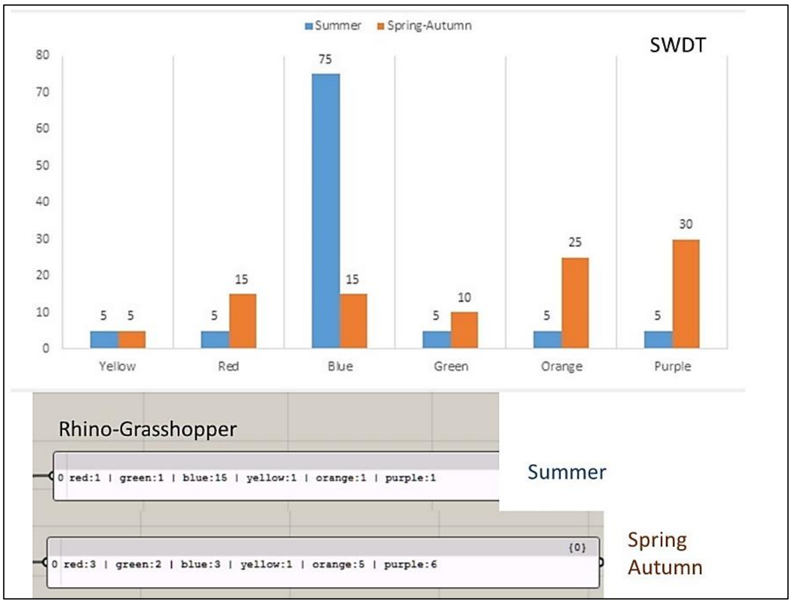


Figure 5.4. The crosscheck of first sample simulations in two software environment

Second sample's summer simulation results with Rhino- grasshopper Due to Galapagos optimization plugin is as can be seen in Figure 5.5. So lighting energy consumption is 35 kWh and cooling energy consumption is 199 kWh. And according to the simulation it was the lowest amount of all random simulated phases by Galapagos algorithm.

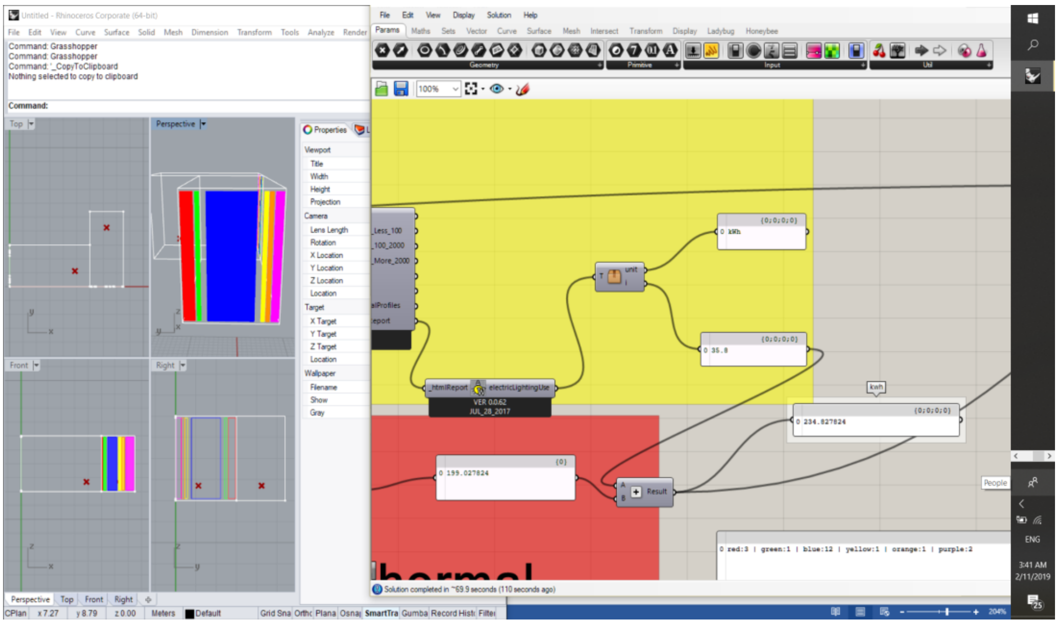


Figure 5.5. The second sample's simulation results with Rhino- grasshopper in summer

And as shown on Figure 5.6 the summer and spring-autumn phases of CTFs' area percentages of second sample calculated by SWDT:

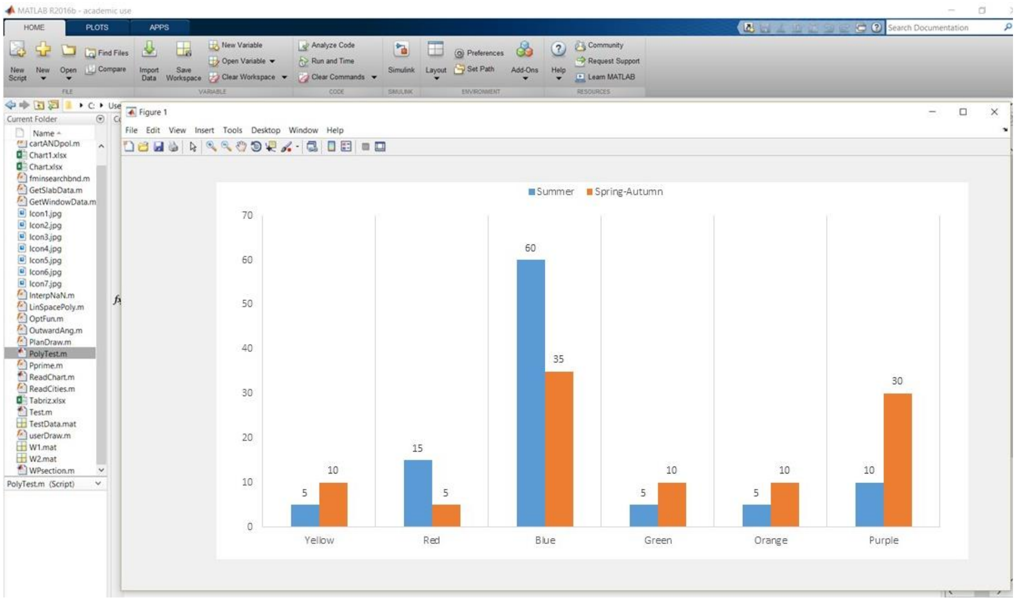


Figure 5.6. The second sample's percentages of CTFs

Second sample's spring-autumn simulation results with Rhino- grasshopper Due to Galapagos optimization plugin is as shown in figure 5.7. So lighting energy consumption is 55.9 kWh and cooling energy consumption is 0.175 kWh. And according to the simulation it was the lowest amount of all random simulated phases by Galapagos algorithm.

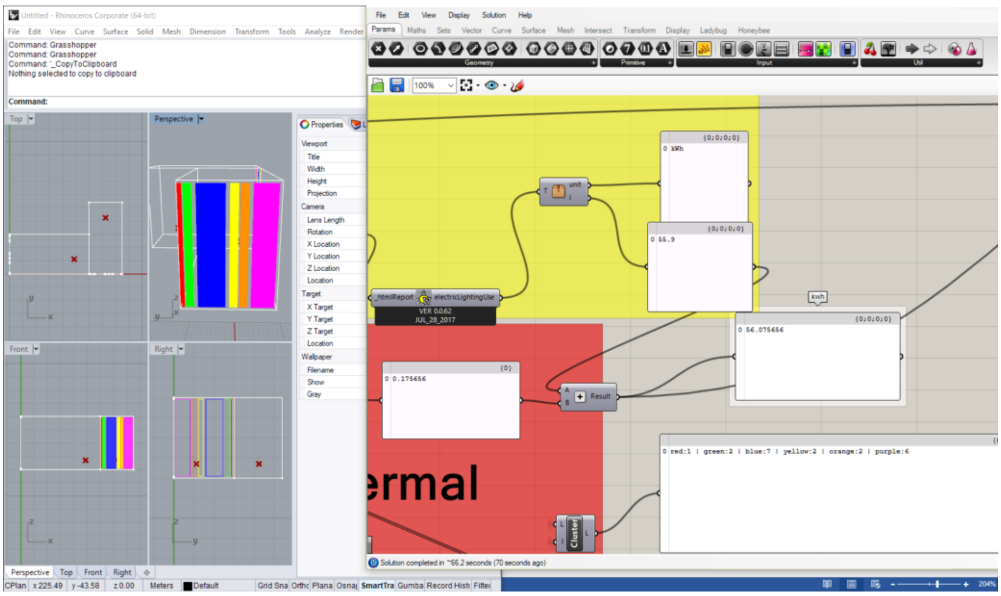


Figure 5.7. The second sample's simulation results with Rhino- grasshopper in spring-autumn

So the crosscheck of second sample simulations in two software environment is as shown in Figure 5.8.

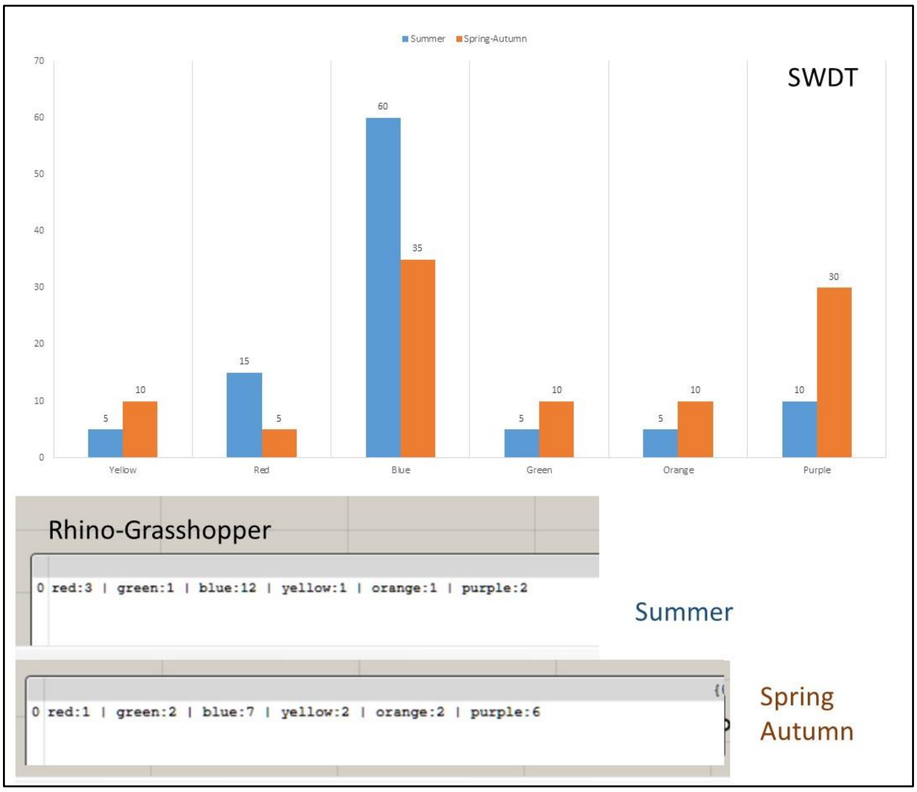


Figure 5.8. The crosscheck of second sample simulations in two software environment

According to the Crosscheck, the area percentages of CTFs have been proven to be exactly the same. The Galapagos optimum responses were the same as the results from the SWDT. However, every window may have more than one answer in the said season. In this test, an answer was obtained for each zone and each season format. The crosscheck table of two samples has shown in Table 5.1.

Table 5.1. The crosscheck table of two samples

Softwares	Seasons	Yellow	Red	Blue	Green	Orange	Purple
SWDT	Summer	5%	5%	75%	5%	5%	5%
	Spring/Autumn	5%	15%	15%	10%	25%	30%
Rhino-Grosshoper	Summer	5%	15%	60%	5%	5%	10%
	Spring/Autumn	10%	5%	35%	10%	10%	30%

As it was investigated in chapter two shading element can be transparent like stained glasses. To reach the healthier and more harmonious relevance with the environment, the colored property of stained glass was selected. Stained glasses because of their volume and weight could not be used in the desired window system. But they can be considered in another shading system like glasses made of Nano-Materials. So the colored transparent filters (CTFs) with 300 micron thickness was selected as shutters stayed on double or triple glazed window. The jalousie system of shutters were in two rows for two types of seasons in every climate.

Among the tools available to individuals and experts involved with the design process of architects and engineers, their most efficient energy evaluation software are energy simulation software. By creating the virtual environment of the building, these softwares provide the possibility to predict the performance of the building as close to reality as possible, and the designer will introduce new savings technologies by optimizing and improving his design (Hensen, 2002).

Over the past 50 years, more than 100 simulation programs related to the issue of energy in the building have been implemented and used by various organizations involved in this area. The most important of these applications are those that completely simulate the building, and specify such things like consumption in different periods, energy costs, temperature and humidity calculations, which are the results of the main indicators of energy performance in the building, in the form of different Outputs. There are several softwares that can receive physical information of a building and their output is the internal temperature or the amount of energy savings or how the heat flux is distributed, that are the results of Participation of component parts in the heat exchange. One of the most prominent software available is Energy Plus, with its first release was in 1998.

The most important question about the use of energy simulation software in the building may come to mind, is the reliability and accuracy of these software applications in energy consumption calculations in comparison with its actual amount. Researches carried out in this area indicate that these softwares calculate the energy consumption of the building with acceptable accuracy (Yu, Yang and Tian, 2008).

Several studies have been carried out in this field till now, including two studies in 2007 and 2008. In the first research, carried out by Skin and Turkman in relation to the comparison of the amount of thermal and cooling loads by Energy-Pus software and its actual amount in a 24-hour period, it shows that this difference is very small and, respectively, it is for thermal loads of 3 % and 5% of cooling loads (Eskin and Türkmen, 2008).

In a subsequent study by Neto and Fiorley in Brazil in 2008, it shows that Energy Plus software with an accurate about 13% simulates the energy consumption of the building, which is an acceptable value (Neto and Fiorelli, 2008).

6. CONCLUSION AND FUTURE REMARKS

Stained glasses have different thermal and lighting properties the effect of glass on energy consumption is a result of thermal and brightness effects. These features are based on researches on Orosi glasses in the literature section. It was shown that the heat gain is not reduced and visual comfort can be achieved indoor. These two properties are proved by the percentage of the spectrum passing through the colored glasses (different wavelengths). According to the researches, radiation does not consist of just the percentage of transition in the long wavelength section. For this purpose, the use of CTFs on the facades in which today's architecture, especially on large transparent glass surfaces, based on colored glasses, was thought to provide these benefits. And by connecting these challenges, it was investigated whether there could be a design method in which heat gain could be prevented and lighting comfort could be provided. The aim of this thesis was to develop a new tool available and new window product to architects for use in their design by daylight and radiant energy performance analyses of buildings. The proposed window model for designers are double or triple glazing windows with drip-CTFs in the middle of them. All the CTFs are only colored polymers without other perfections to have a non-harmful effect.

First of all, for this goal a program was needed to utilize the climate data of zone and some other data and calculations. The MATAB software program is a comprehensive calculation program and therefore is used as a basis. There were basic formulas and standards to be used in the program. And they were entered with two-dimensional modeling codes. Since SWDT is in the form of two-dimensional drawing, it is aimed that the window, wall and zone information will be entered more easily by the user.

While writing the program, it was aimed to solve the two basic problems. The first goal was to avoid losing visual comfort allowing more light to pass through. And the second was to obtain less heat gain. The SWDT software presented some steps to the architect in drawing zone plan to reach the fitters' colors of window and the percent of them. Climate data was entered as excel file according to the cities. According to this, the user's own city was also intended to be entered into the program in excel format. The shading function was written to achieve more accurate color percentages in two season formats (summer and spring-fall), based on the shadows in front of the window in the building. It should not be overlooked that the effect of existing shadows is effective in radiation and light transmittance.

In SWDT coding process, the Plan-Draw function was intended to allow the user to easily enter window, zone, wall and shading in two dimensions. In order for the user to enter the building data here, the function was described in the MATLAB program and then its codes were entered. Then, two dimensional drawings and position data are combined in three dimensional matrices. The icons used here and the selection of the required data were taken from ARCHICAD program.

SWDT coding was continued by thermal and lighting functions obtained from laboratory works on CTFs and their thermal and visible transmittance calculations. The transmission percentage from the two spectrophotometers was combined in the range of UV-VIS-IR wavelengths and lighting and thermal transmittance calculations of each CTF were made via MATLAB. Optimization function was coded at the end. The function was introduced due to irradiation and lighting transmittance of CTFs in their case study where the irradiation transition must be minimum and the lighting transmittance must be in its maximum level.

Secondly the proposed SWDT was tested and the results was assessed. The crosscheck of SWDT was performed to evaluate how the program works, by drawing samples in SWDT and obtaining the results of the window and the percentage of output colors, samples were simulated in Rhino with the aid of Grasshopper, and the outputs were compared with previous results. The simulation results of the designed window SWDT can be shifted to any type of window. This assessment was performed by definition of two zone samples and analyzing the results of SWDT by other Auxiliary software. The Rhino software and Grasshopper plugin were used in order to define the generator algorithm and the production of geometry in 3D space. Energy-Plus computing Engine was used to determine thermal effects and Radians and Daysim computing engines were used to determine the lighting effects.

To answer the main research question: “Is it possible to providing optimum lighting and reduce heat gain using colors s in transparent facades?” subsidiary questions have been mentioned:

“Can the windows shading system be designed by using colored transparent materials or not?

Are transparent polymers with colored nature useful for shading or not?

Can the window design system be designed due to window position and climate? So how will be the percent of the clothing of colors on glass surface?

How can be reachable to have optimum area percentage of colored transparent materials relative to glass area? How can be the percentages appropriate due to daylighting and solar radiation of hot seasons in different situations and climate positions?”

The suggested smart window with the shading included CTFs can be performed virtually and its software tool confirmed by energy simulation tests.

Due to Laboratory results CTFs can be used in shading systems as the research endeavored to utilize from them with extracting the optimum and appropriate percent of the clothing of colors on glass surface by SWDT written in MATLAB.

SWDT is presented to provide the percentage of optimal colored areas used in the shading system of the shadow inside the window. In this programming language, climate and design factors of the window, the position of it and the zone that it is located on, were considered. This information is transmitted by the user with drawing and importing data to the software.

So with answering the subsidiary questions, the answer of main question can be derived:

“To reach the maximum daylighting how can transparent materials be used for shading?”

CTFs in the form of translucent polymer layers can be assembled in the form of jalousie shutters (vertical blinds) inside double glazed windows or triple glazed windows.

And by answering the head question of research the hypothesis of research can be verified:

“Colored transparent filters (CTFs) can be used as independent part of shades in shading systems. They can place in window shading system due to structure’s climate and window’s position and other parameters. The colors of CTFs can be defined due to maximum daylight transmittance and minimum solar radiation transfer in hot seasons of year”.

The smart window considered as mid-pane shading with horizontal shutters and the SWDT developed to respond to its system. So if the direction of shutters changes to horizontally or other patterns, the effect of color compositions should need to be taken into account.

The smart window considered as mid-pane shading with horizontal shutters and the SWDT developed to respond to its system. So if the direction of shutters changes to horizontally or other patterns, the effect of color compositions should need to be taken into account. As can be seen in the diagrams and charts of simulations and comparison of them the SWDT was verified. However the spaces percent of colors are determined with drawing zone plan by user in the program due to all data climate and incident solar radiation and daylighting. The SWDT designed to use by architects can also be an energy sustainability tool for ease of design by considering the brightness and optimal heating of sun radiant energy. Forasmuch as the materials used and the shutter system applied in the proposed window seems to be economical considering the color of the CTF in the case of major production. It can be considered as a good alternative to current type of windows due to reduce of cooling load and lighting. And in the following, the results shows that the percent of blue area is the maximum in summer to reduce cooling load of zone.

For future works the material properties can be examined and Nano-materials can be tested literally for this issue. The pattern of colors can be analyzed and the collection of them for better respond of energy efficiency may be tested. The pattern, direction and geometry composition of used colors can be analyzed due to the window position, shading elements and the other considered properties. And the effect of this alteration on lighting and energy consumption can be calculated. Or the effect of the closed jalousies (vertical blinds) in winter and cold nights can be calculated to find out its positive or negative impact on reducing the heating load. Or the designed mid-pane window system can be triple glazed with ventilation between shading system and outside expected better performance than double glazed one. And finally the psychology aspects of effects of these windows using on users in different spaces with different land uses can be analyzed.

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APPENDICES

Appendix-1. Source codes of software

```
function [cityCell, cityStr] = ReadCities ()
f = dir(fullfile('F:', 'MATLAB','SQ','Cities', '*.xlsx'));
cityCell = {f.name}(Hubert)';
cityStr = [];
for i = 1 : size(cityCell,1)
    cityCell{i} = cityCell{i}(1 : end - 5);
    cityStr = strcat(cityStr , '|' ,cityCell{i});
end
cityStr = cityStr(2 : end);
end
```

```
% clc; clear all;
[num,~,~] = xlsread('Chart1.xlsx');
WL = num(1,1) : 1 : num(end,1);
LineSpec = {'b','r','g','y','k','m','k'};
for i = 2 : size(num,2)
    Y(:,i - 1) = spline(num(:,1),num(:,i),WL);
    plot(WL,Y(:,i - 1),LineSpec{i - 1},'LineWidth',2);
    hold on
end
grid on
```

```
function userDraw(handles)
%F=Figure;
%setptr(F,'eraser'); %a custom cursor just for fun

A=handles.axesUserDraw; % axesUserDraw is tag of my axes
set(A,'buttondownfcn',@start_pencil)
```

Appendix-1. (continues) Source codes of software

```
function start_pencil(src,eventdata)
coords=get(src,'currentpoint'); %since this is the axes callback, src=gca
x=coords(1,1,1);
y=coords(1,2,1);

r=line(x, y, 'color', [0 .5 1], 'LineWidth', 2, 'hittest', 'off'); %turning    hittset off allows you
to draw new lines that start on top of an existing line.
set(gcf,'windowbuttonmotionfcn',{@continue_pencil,r})
set(gcf,'windowbuttonupfcn',@done_pencil)

function continue_pencil(src,eventdata,r)
%Note: src is now the Figure handle, not the axes, so we need to use gca.
coords=get(gca,'currentpoint'); %this updates every time i move the mouse
x=coords(1,1,1);
y=coords(1,2,1);
%get the line's existing coordinates and append the new ones.
lastx=get(r,'xdata');
lasty=get(r,'ydata');
newx=[lastx x];
newy=[lasty y];
set(r,'xdata',newx,'ydata',newy);

function done_pencil(src,evendata)
%all this funciton does is turn the motion function off
set(gcf,'windowbuttonmotionfcn','')
set(gcf,'windowbuttonupfcn','')

function Ang = OutwardAng(W,Z)
if Z(:,1) ~= Z(:,end)
   Z(:,end + 1) = Z(:,1);
end
ep = 1e-2;
```

Appendix-1. (continues) Source codes of software

```
meanW = mean(W,2);
pslope = - (W(1,2) - W(1,1)) / (W(2,2) - W(2,1));
pline = @(x) pslope * (x - meanW(1)) + meanW(2);
if pslope == inf || pslope == -inf
    xy = [meanW(1)  meanW(2) + ep];
elseif pslope == 0
    xy = [meanW(1) + ep  meanW(2)];
else
    xy = [meanW(1) + ep pline(meanW(1) + ep)];
end
in = inpolygon(xy(1),xy(2),Z(1,:),Z(2,:));
if in
    A = cartANDpol([xy ; meanW'],1);
else
    A = cartANDpol([meanW' ; xy],1);
end
Ang = A(2,1);
end
function [p,w,d] = Pprime(U,c,Sigma,s,P)

Gamma = OutwardAng(U.Window{c},U.Zone);
n.a = cosd(Gamma) .* sind(Sigma);
n.b = sind(Gamma) .* sind(Sigma);
n.c = cosd(Sigma);
Shadow = n.a * s.l + n.b * s.m + n.c * s.n;
Shadow(Shadow < 0) = NaN;
Shadow(~isnan(Shadow)) = 1;
RzGamma = [ cosd(90 + Gamma) sind(90 + Gamma) 0 ;
           -sind(90 + Gamma) cosd(90 + Gamma) 0 ;
                  0                0        1 ];
% RxSigma = [ 1          0             0 ;
%             0   cosd(90 - Sigma) -sind(90 - Sigma);
```

Appendix-1. (continues) Source codes of software

```
%            0   sind(90 - Sigma)  cosd(90 - Sigma)];
% Rot = cat(3,RzGamma,RxSigma);
Rot = RzGamma;
% ---------- Window Rotation ---------------------
w = U.Window{c};
[aw,bw] = LineEq(w);
% ---------- Window Wall Match -------------------

for j = 1 : length(U.OutsideWall)
   for i = 1 : size(U.OutsideWall{j},2) - 1
      wallp =  U.OutsideWall{j}(:,i : i + 1);
      [ap,bp] = LineEq (wallp);
      if aw == ap andand bw == bp
         wallp = wallp';
         d = round(cat(2,wallp([1 1 2 2],:),U.ZoneGH(j) + ...
            [0 U.ZoneH(j) U.ZoneH(j) 0]')');
      end
   end
end
w = w(:,[1 1 2 2]);
w = cat(1,w,U.WindowGH(c) + [0 U.WindowH(c) U.WindowH(c) 0]);

if isequal(d',round(P))
   p = 0;
   return
end
mP = mean(d(1:2,2:3),2);
P(:,1) = P(:,1) - mP(1);
P(:,2) = P(:,2) - mP(2);
d(1,:) = d(1,:) - mP(1);
d(2,:) = d(2,:) - mP(2);
w(1,:) = w(1,:) - mP(1);
```

Appendix-1. (continues) Source codes of software

```
w(2,:) = w(2,:) - mP(2);
w = Rot * w;
d = Rot * d;
%-------------------------------------------------



% -----------------------------------------------
for i = 1 : size(P,1)
   t = -(n.a * P(i,1) + n.b * P(i,2) + n.c * P(i,3)) ./ ...
       (n.a * s.l  + n.b * s.m  + n.c * s.n);
   p(:,:,i) = cat(2,P(i,1) + s.l .* t, P(i,2) + s.m .* t,...
      P(i,3) + s.n .* t) .* repmat(Shadow,[1 3]);
   p(:,:,i) = permute(Rot * p(:,:,i)',[2 1]);
end
end
function [a,b] = LineEq (p)
a = (p(2,2) - p(2,1)) ./ (p(1,2) - p(1,1));
if a <  1e-5 andand a > -1e-5
   a = 0;
elseif  a >  1e5 || a < -1e5
   a =  inf;
end
if ~isinf(a)
   b = p(2,1) - a * p(1,1);
else
   b = p(1,1);
end
end

function Obj = OptFun(guess,QLamda,LumLamda,QT)
a = guess(1);
b = guess(2);
```

Appendix-1. (continues) Source codes of software

```
c = guess(3);
d = guess(4);
obj1 = sum([a b c d] .* LumLamda) -.6;
obj2 = sum([a b c d] .* QLamda(1:4))-QT;
obj3 = sum([a b c d]) - 1;
Obj = obj1 ^ 2 + obj2 ^ 2 + obj3 ^ 2;
end
```

Appendix-2. Graphics

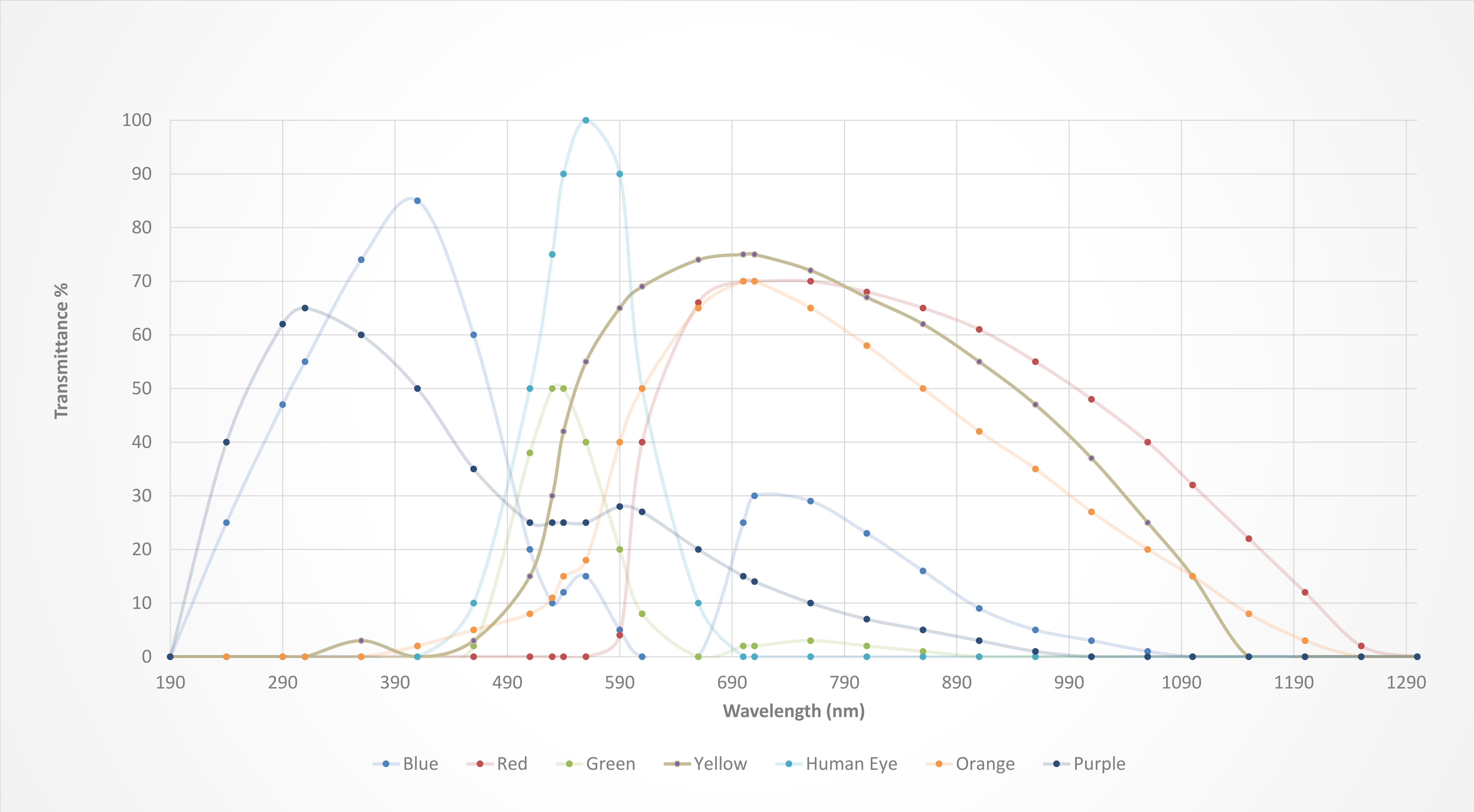

Figure 02.1. Transmission spectra by CTF's color to wavelengths between 190-1290 nm

Appendix-2. (continues) Graphics

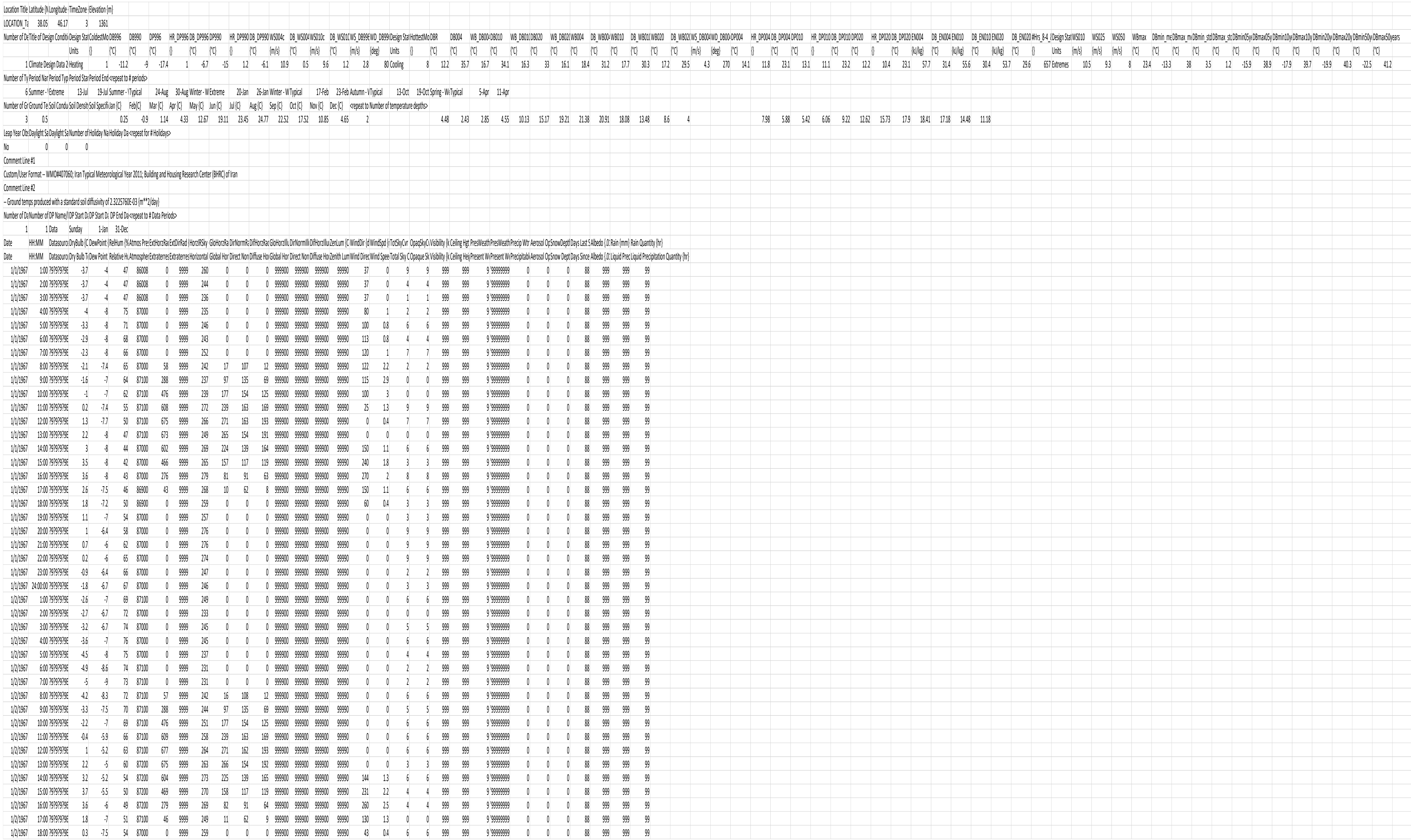

Figure 02.2. The screenshot of XLS climate file belonging to Tabriz city

Appendix-2. (continues) Graphics

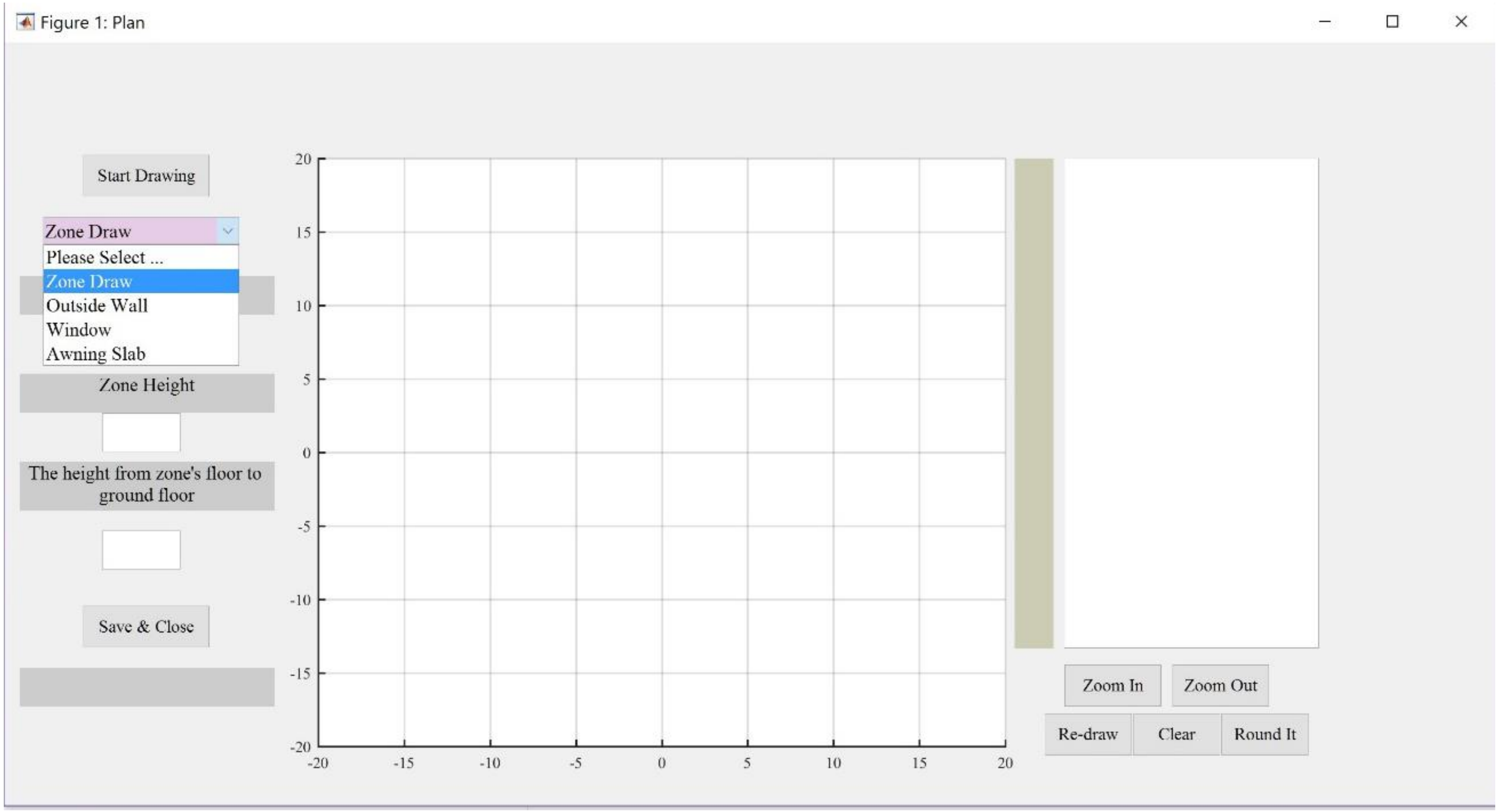

Figure 02.3. Ready to draw (Zone draw); Plan-Draw function MATLAB software program

Appendix-2. (continues) Graphics

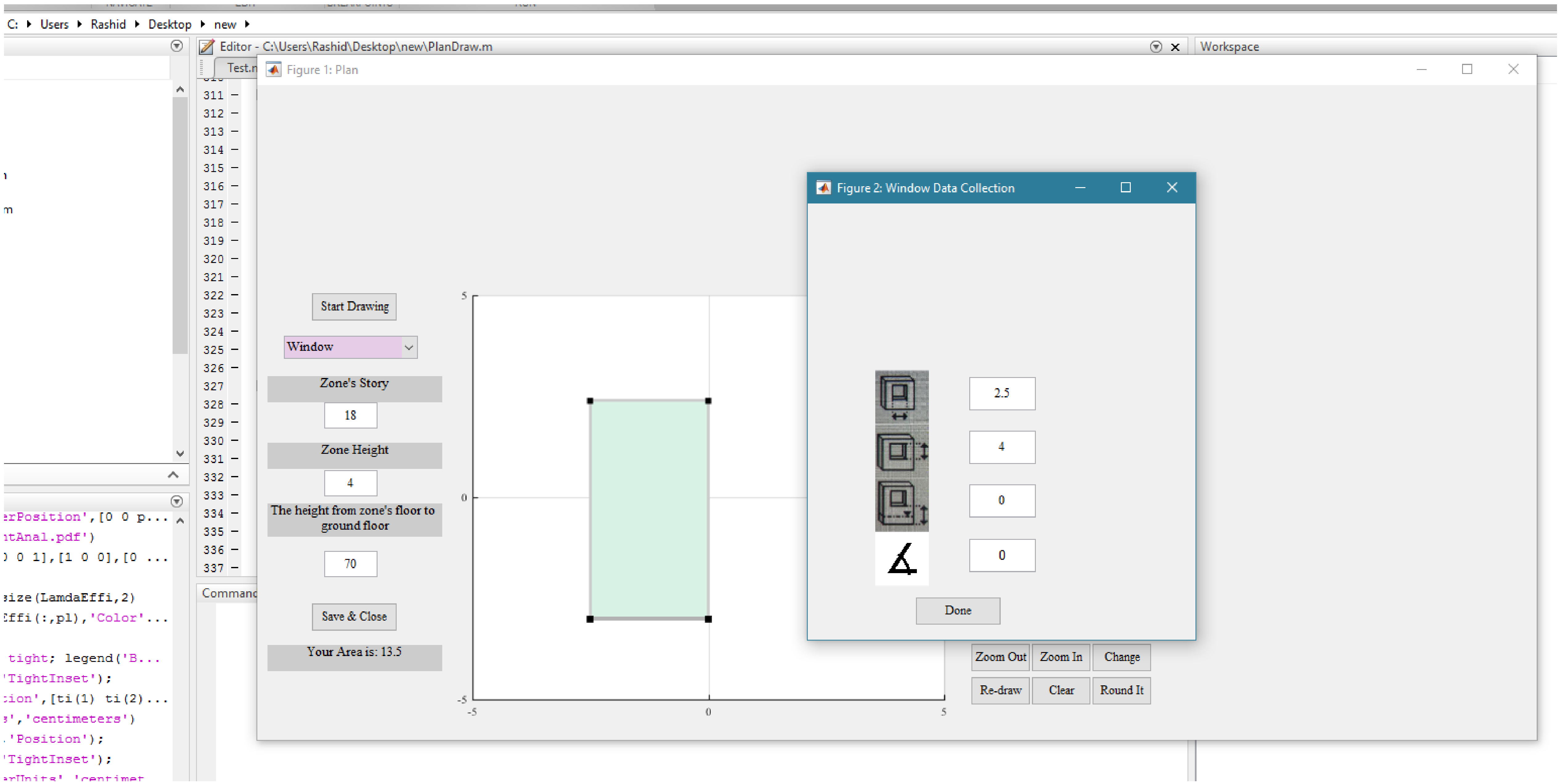

Figure 2.4. First sample drawing in smart window design tool

Appendix-2. (continues) Graphics

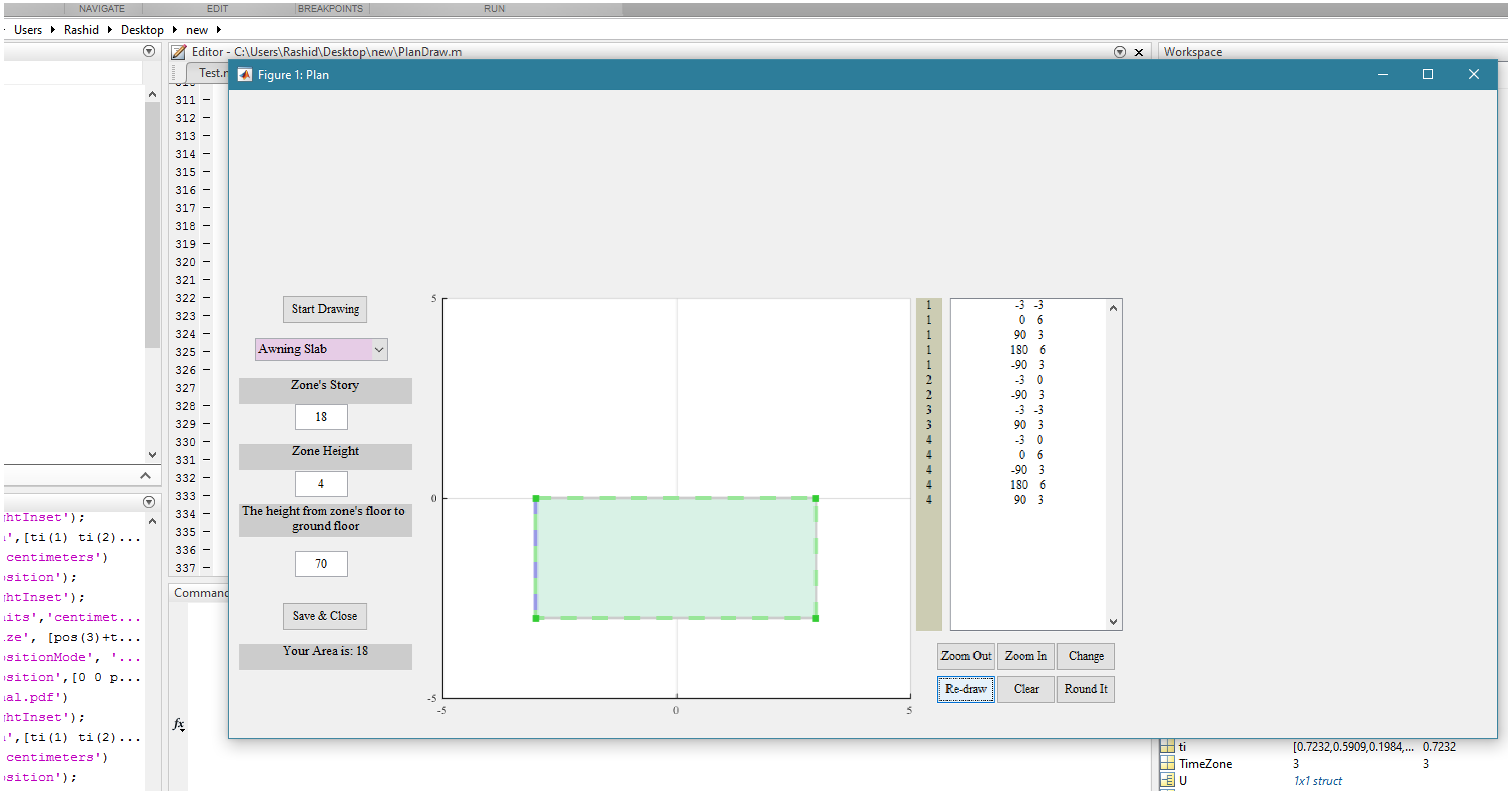

Figure 02.5. Second sample drawing in smart window design tool

Appendix-3. Algorithms

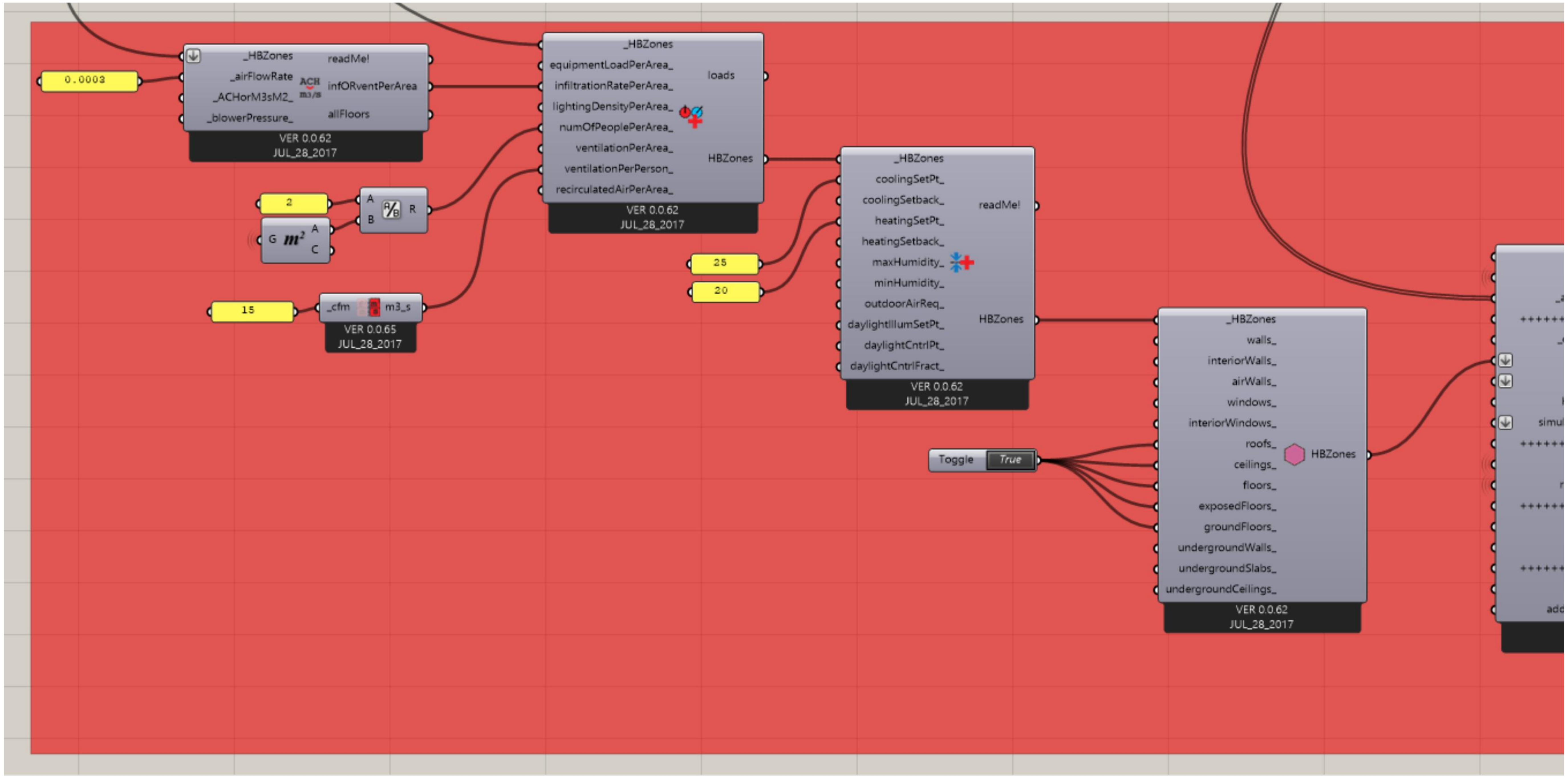

Figure 03.1. First part of the algorithm of Thermal analysis in Grasshopper

Appendix-3. (continues) Algorithms

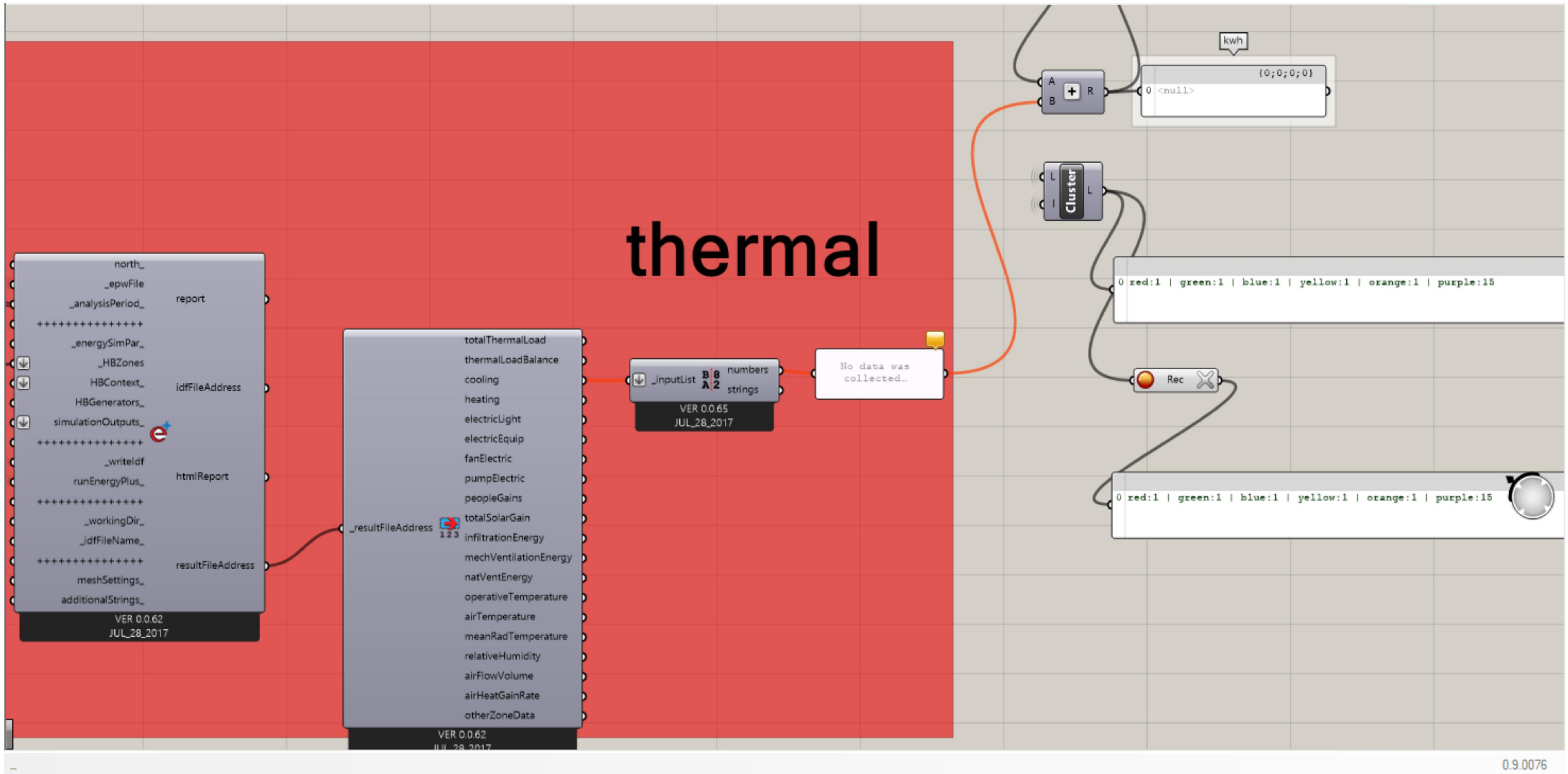

Figure 3.2. Second part of the algorithm of Thermal analysis in Grasshopper

Appendix-3. (continues) Algorithms

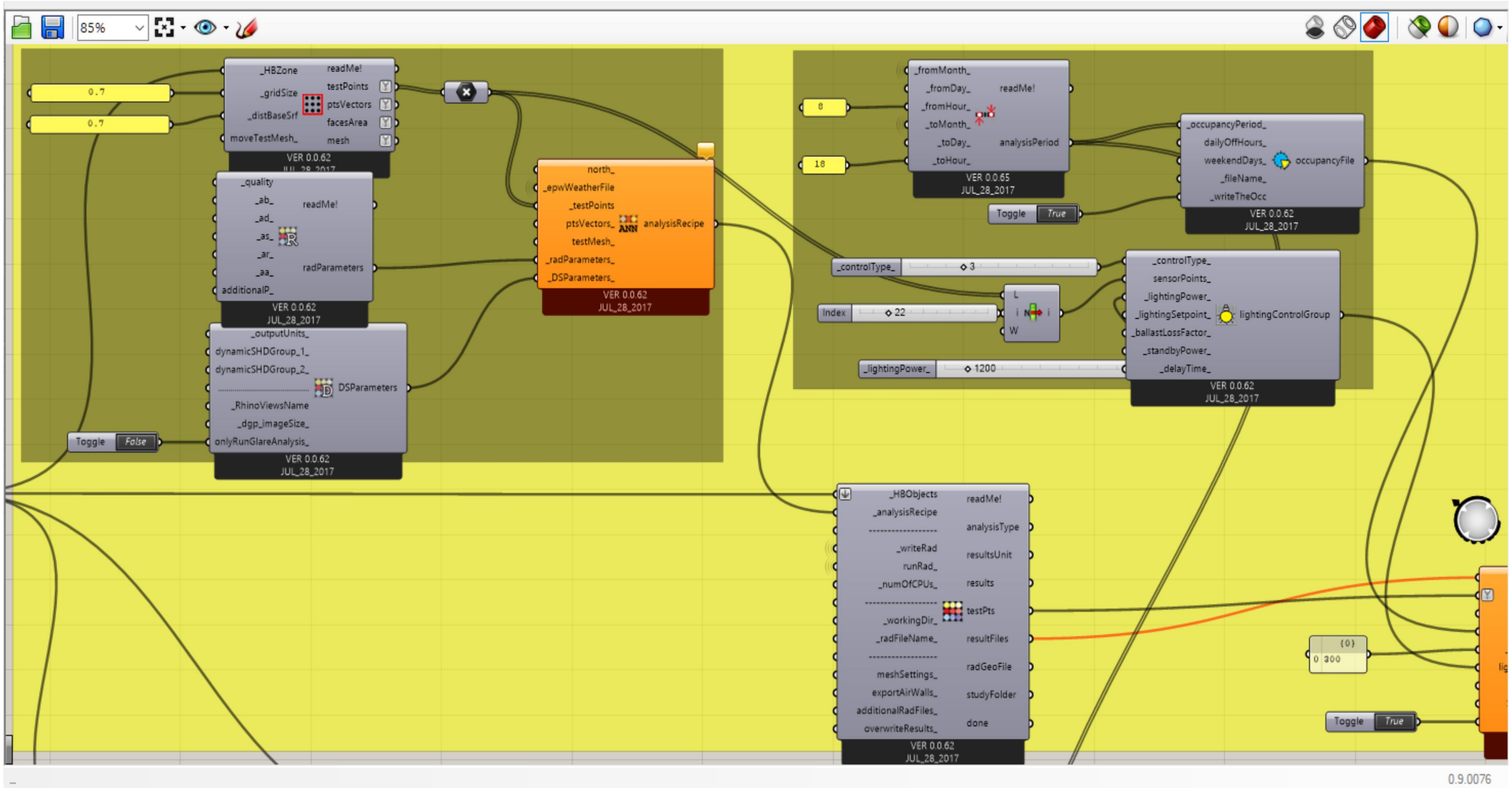

Figure 3.3. First part of the algorithm of lighting analysis in Grasshopper

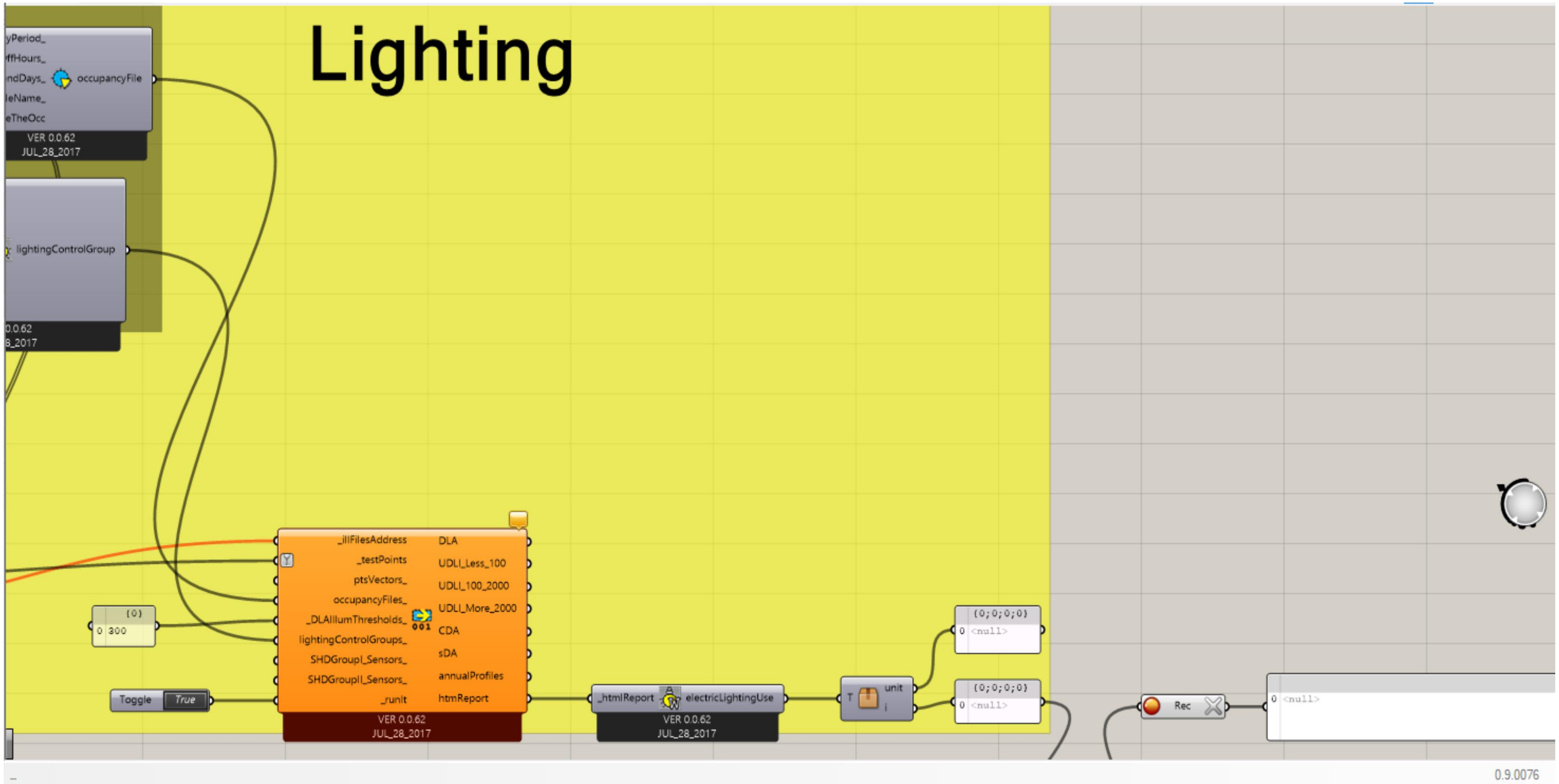

Figure 3.4. Second part of the algorithm of lighting analysis in Grasshopper

Appendix-3. (continues) Algorithms

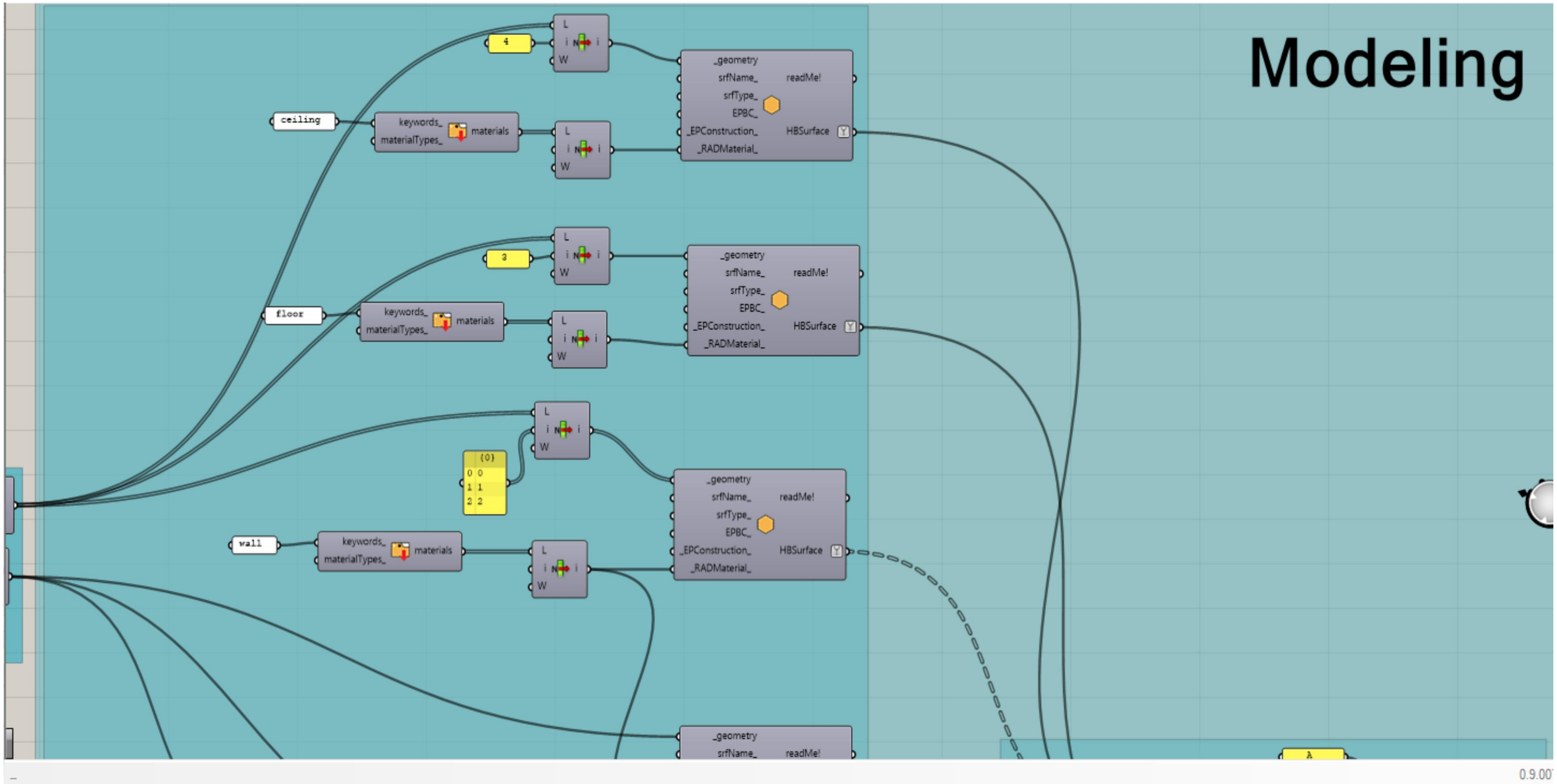

Figure 3.5. First part of the Modeling algorithm of 1st sample in Grasshopper

Appendix-3. (continues) Algorithms

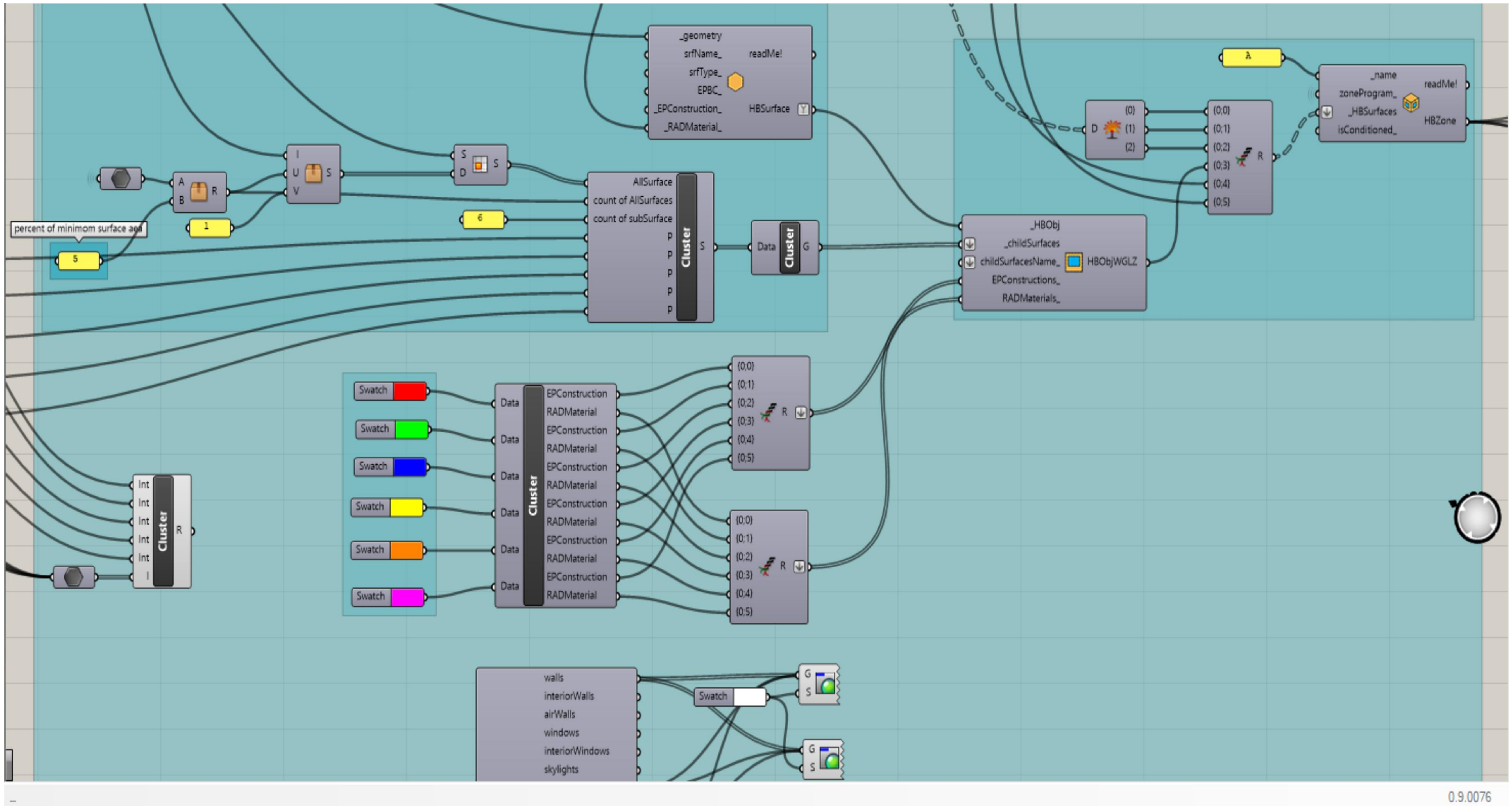

Figure 3.6. Second part of the Modeling algorithm of 1st sample in Grasshopper

Appendix-3. (continues) Algorithms

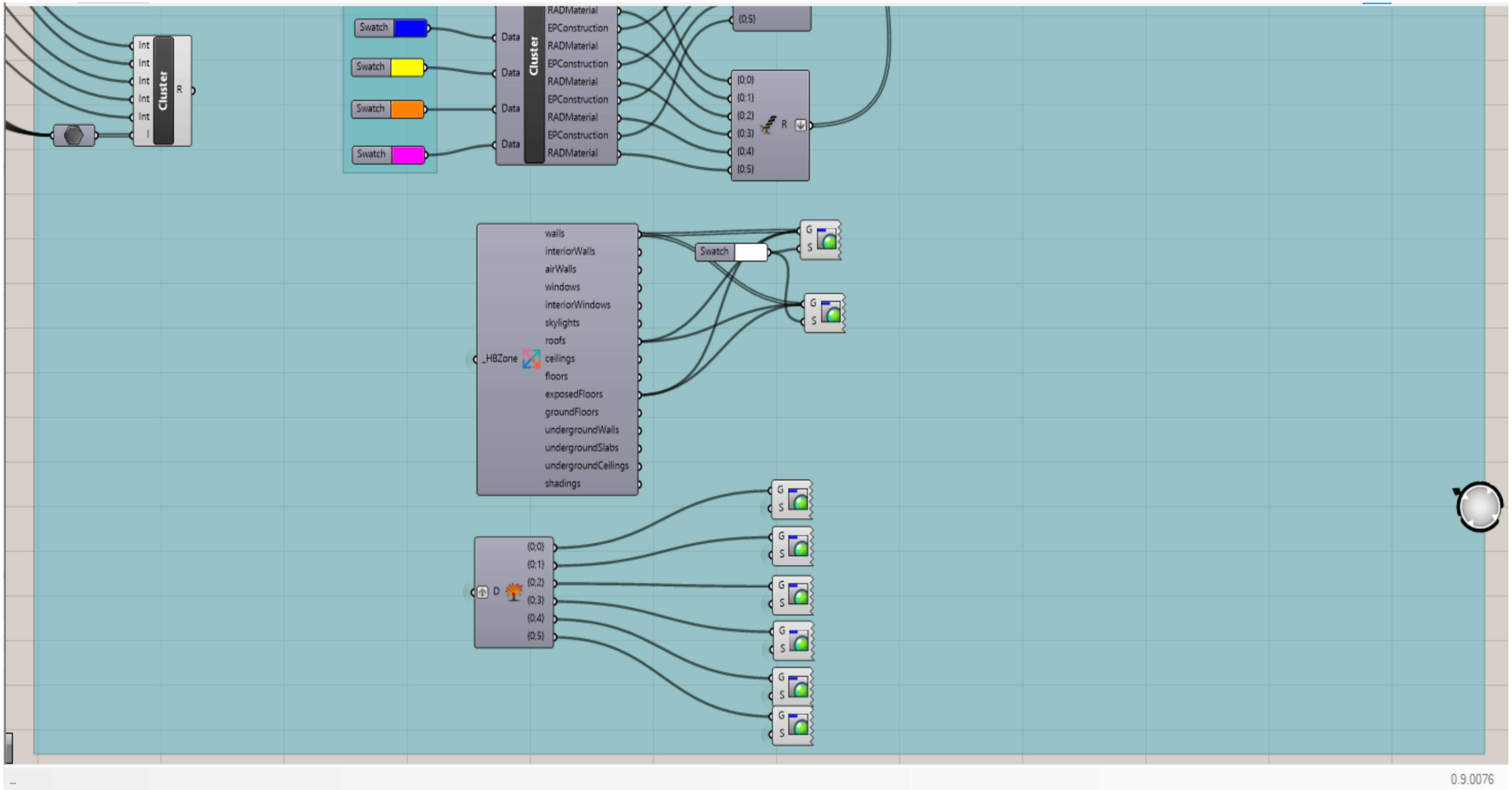

Figure 3.7. Third part of the Modeling algorithm of 1st sample in Grasshopper

Appendix-3. (continues) Algorithms

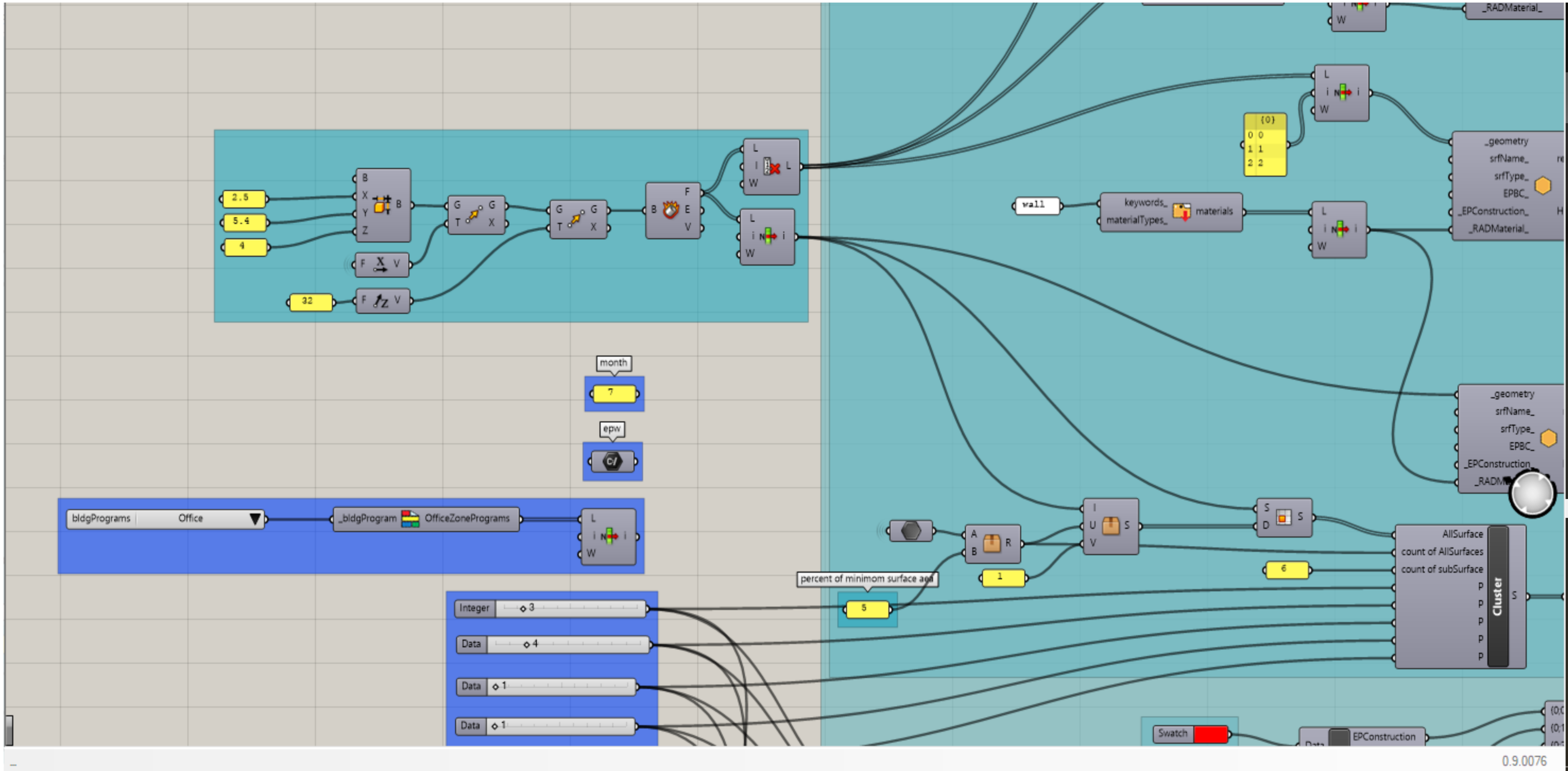

Figure 3.8. Forth part of the Modeling algorithm of 1st sample in Grasshopper

Appendix-3. (continues) Algorithms

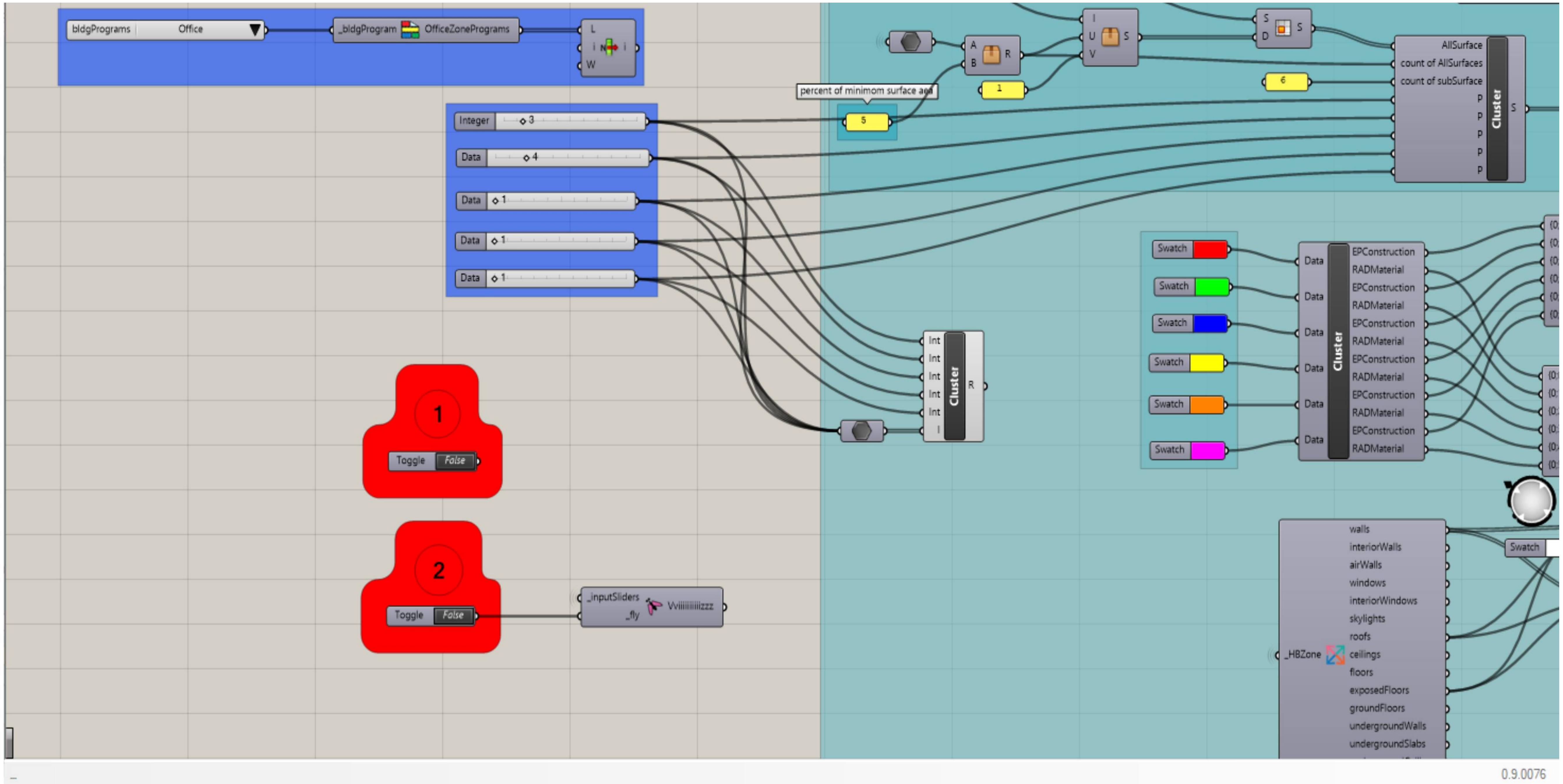

Figure 3.9. Fifth part of the modeling algorithm of 1st sample in Grasshopper

Appendix-3. (continues) Algorithms

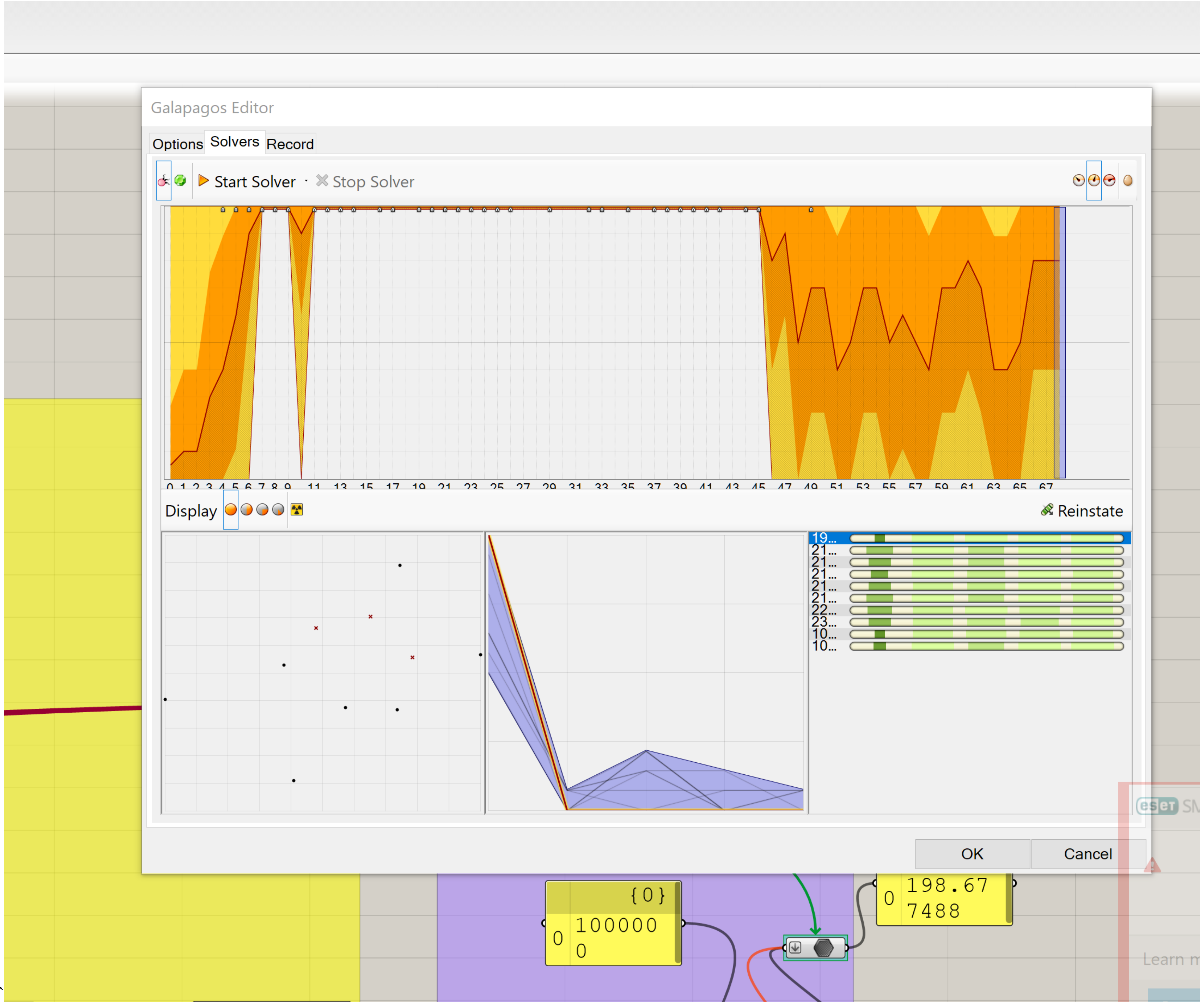

Figure 3.10 First sample optimization result in summer and total energy with Galapagos

Appendix-3. (continues) Algorithms

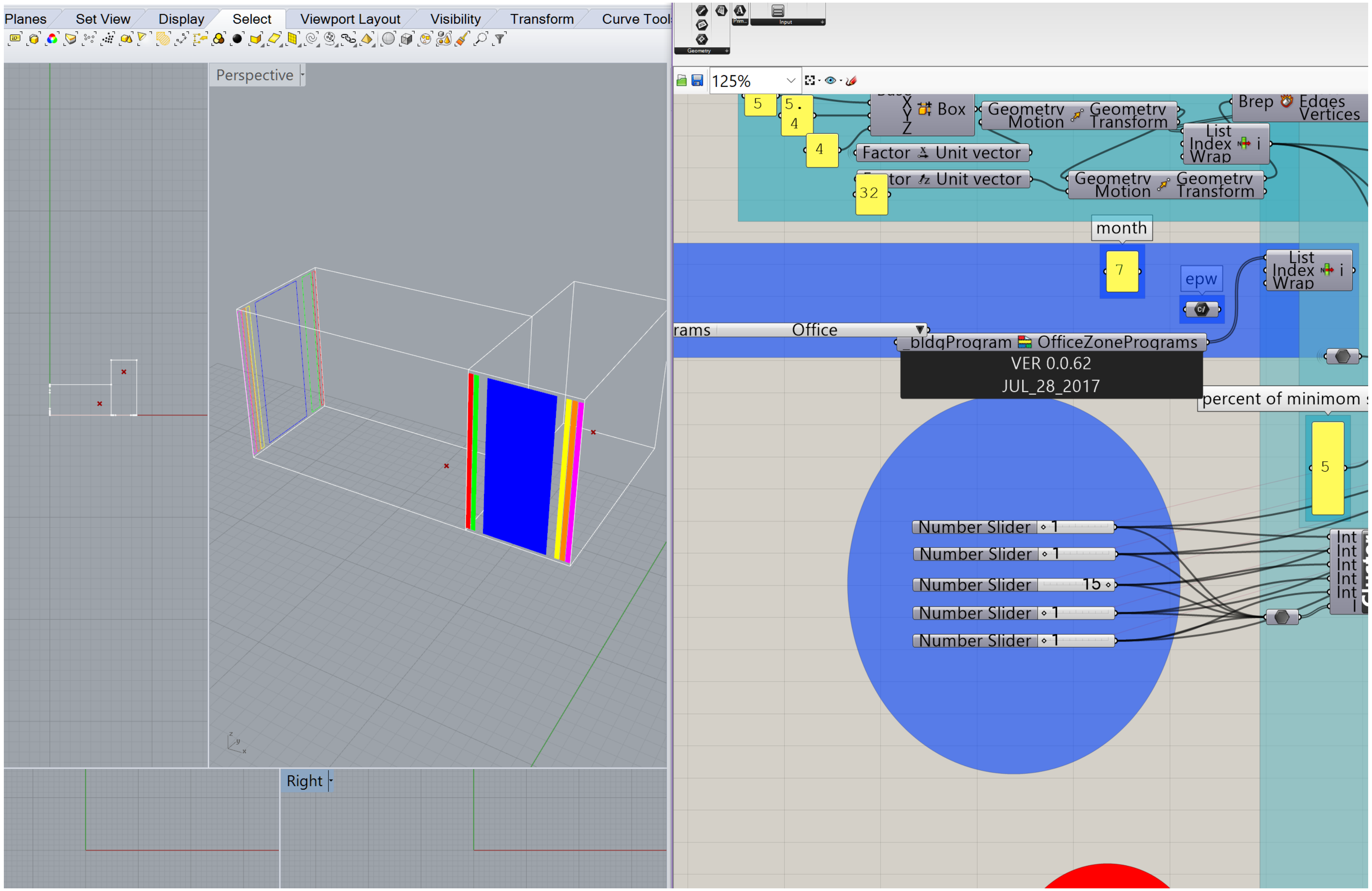

Figure 3.11. First sample optimization result in summer and CTFs optimal scheme

Appendix-3. (continues) Algorithms

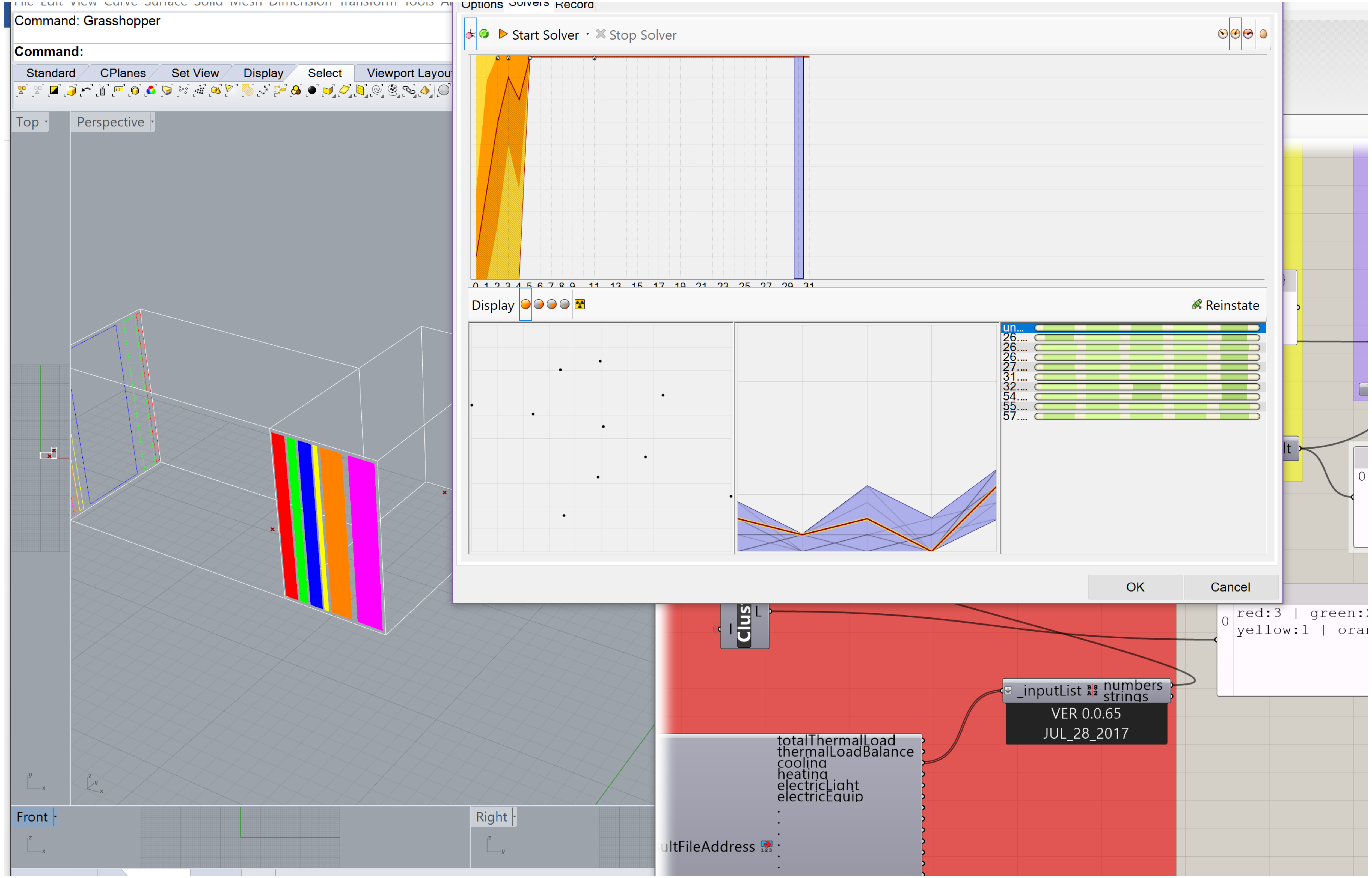

Figure 3.12. First sample optimization result in autumn-spring with Galapagos

Appendix-3. (continues) Algorithms

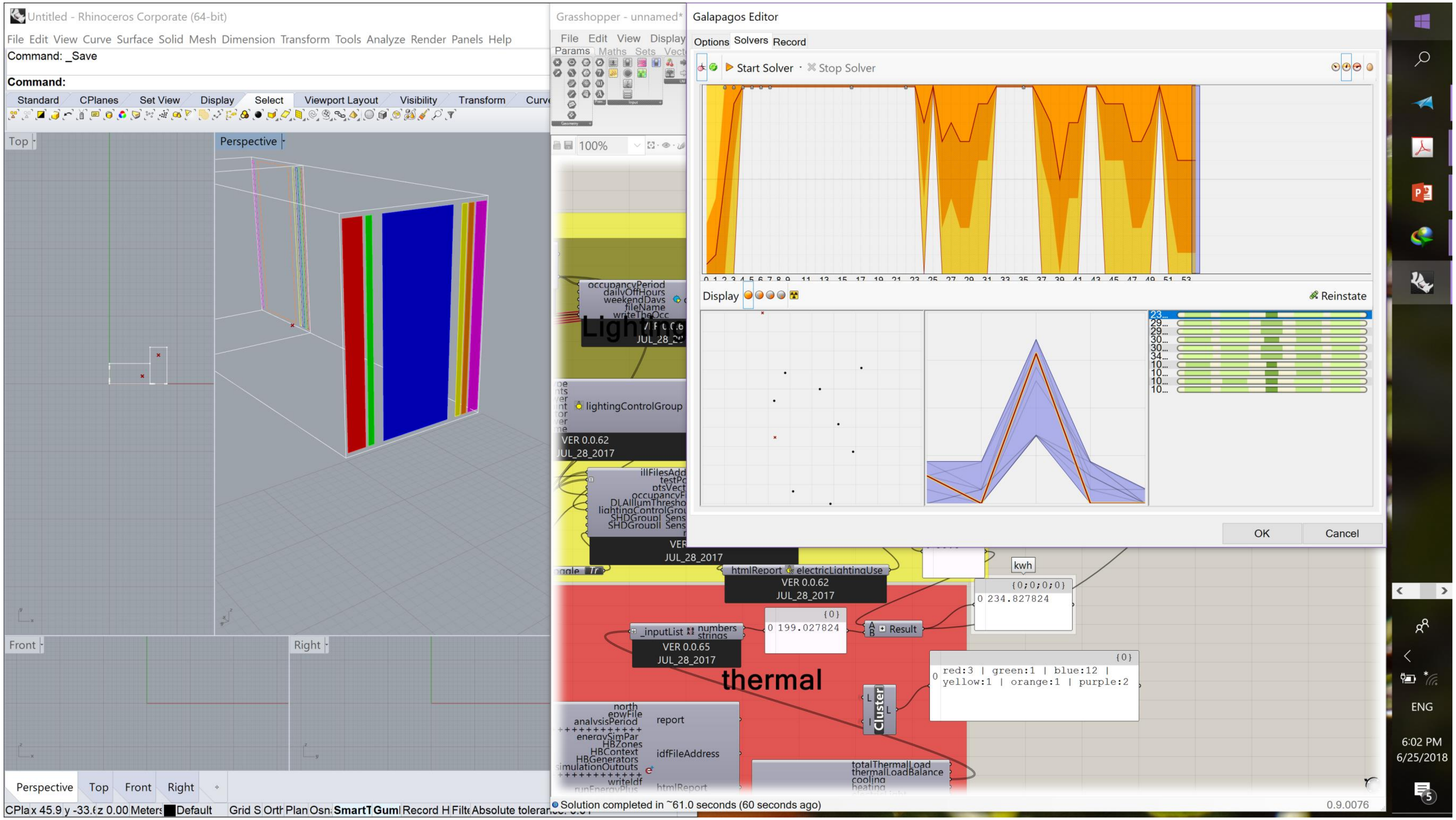

Figure 3.13. Second sample optimization result in summer and total energy consumption with Galapagos

Appendix-3. (continues) Algorithms

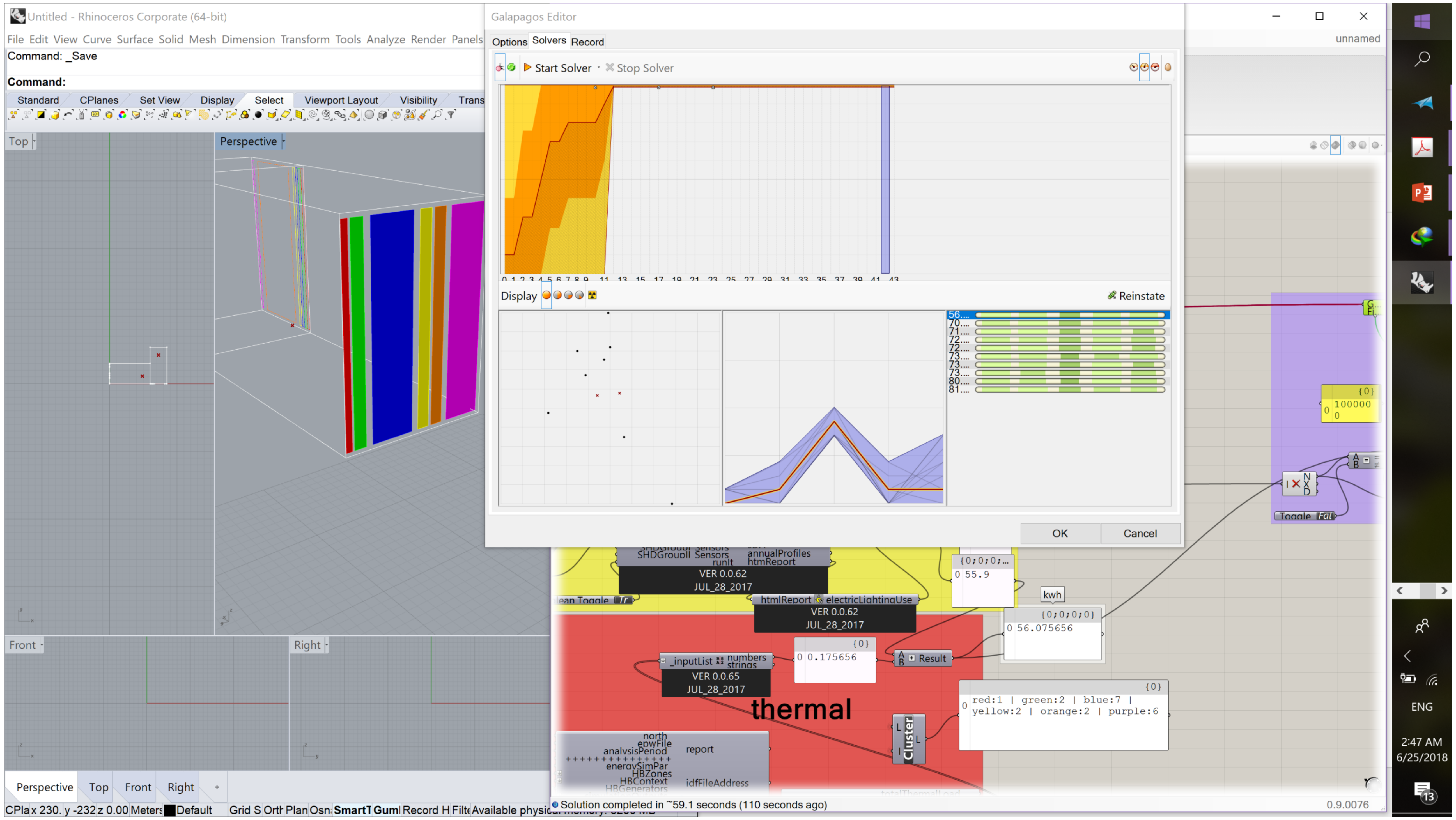

Figure 3.14. Second sample optimization result in autumn-spring and total energy consumption with Galapagos

CURRICULUM VITAE

Personal Information

Surname, name	: Sultan Qurraie, Bahar
Nationality	: Iran
Date and place of birth	: 27.04.1987, Tabriz, Iran
Marital status	: Single
Phone (Cell)	: 0 (539) 547 55 60
E-mail	: bahar.sultan.qurraie@gazi.edu.tr

Education

Degree	School / Program	Graduation Date
PhD	Gazi University/ Architecture	Ongoing
Master	Islamic Azad University / Architecture	2011
Bachelor	Islamic Azad University/ Architecture	2008

Professional Experiences

Year	Place of Work	Position
2010-2013	Islamic Azad University	Lecturer

Foreign Language

English, Persian, Turkish, Arabic

Publications

Sultan Qurraie, B, Beyhan, F. (2018). Using a shading tool to reform window designing due to solar radiation. *International Journal of Advanced Research in Engineering*, 4(1), 1-6.

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Sultan Qurraie, S., Pourafkari, Sh., Sultan Qurraie, B. (2013, December). *Deliberation of senses perceptions of blind in defining the location*. International Conference on Civil Engineering Architecture and Urban Sustainable Development, Tabriz, Iran.

Hobbies

Skating, Mountaineering, Swimming, Skiing, Chess, Calligraphy, Photography, Water-color painting.

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