Evaluation of Windows and Energy Performance
Case-Study: Colored Building, Faculty of Architecture (EMU)

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ABSTRACT

The purpose of the current research is to make it possible to compare the energy performance of different windows in a simple model. The net energy gain through windows depends both on the thermal transmittance (*U*-value) and the total solar energy transmittance (*g*-value). This fact makes it difficult to choose a window with respect to the energy performance in a given case. To be able to compare several glazing and windows combinations in an easy way, a dynamic simulation tool have been used, giving the net energy gain of *U*-value and *g*-value which are based on the orientation and specific latitude of the windows. In addition, each single simulation shows the net energy gain in an educational building which makes it possible to evaluate the energy performance of different glazing with regard to solar radiation and heat loss for the Colored Building located in Eastern Mediterranean University. The simulation tool, WINDOW7.2, provides an easy way for comparing different advanced windows and giving the optimum alternative for Cyprus climate.

The method is not only useful for comparing window products so to replace the existing ones, but is also valuable for handling the energy performance of windows in a general and realistic way, in the early phase of designing a new building, via considering local climatic conditions.

Keywords: Windows, Glazing, Energy Performance, Simulation Tools, Hot-Humid Climate.

ÖZ

Bu çalışmanın amacı farklı pencerelerin enerji performansını basit bir modelde karşılaştırmasinin mümkün sağlamaktir. Bir pencereden elde edilen net enerji kazancı hem termal geçirgenlik (U değeri) ve hem toplam güneş enerjisi geçirgenliğine (g-değeri) bağlıdır. Bu durum enerji performansı açısından pencerelerinin seçiminde verilen örnekte zor bir durumda bırakmaktadır. Kolay bir şekilde birkaç cam ve pencerelerin kombinasyonları karşılaştırmak için, dinamik bir simülasyon aracığiyla net enerji kazanımını U-değeri ve G-değeri kazanımını ki oryantasyon ve pencerelerin belirli enlemine bağlıdır. Ayrıca, Doğu Akdeniz Üniversitesinin Renkli Binasında, bir eğitim binasinin net enerji kazancını gösteren her bir tek simülasyon ki enerji performansını farklı cam değerlendirmesinin güneş radyasyon ve ısı kayıpları dayanarak mumkun saglamaktadir. Simülasyon araçları WINDOW7.2 farklı gelişmiş pencerelerin karşılaştırmasina, Kıbrıs iklim optimum bir alternatif olarak kolay bir yol sağlar.

Bu yöntem mevcut pencerelerin değiştirilmesi için pencere ürünlerinin karşılaştırılması ile ilgili olarak yararlıdır, aynı zamanda yerel iklim koşulları dikkate alınarak yeni binaların tasarımında erken dönemde genel ama gerçekçi bir şekilde pencerelerin enerji performansını işlemek için yararlı olabilir .

Anahtar Kelimeler: Pencereler, Cam, Enerji performansı, Simülasyon araçları, sıcak-nemli iklim.

To My Family…

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PREFACE

The difference between stupidity and genius
Is that genius has its limits.

(*Albert Einstein 1879-1955*)

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LIST OF SYMBOLS AND ABBREVIATIONS

ASHRAE	Society of Heating, Refrigerating and Air Conditioning Engineer
NFRC	National Fenestration Rating Council
LBNL	Lawrence Berkeley National Laboratory
SHGC	Solar Heat Gain Coefficient
VT / Tvis	Visible light Transmittance
U-Factor/Value	Thermal Transmittance
W/ m2 K	Watts per square meter Kelvin
(mm)	Millimeter
(nm)	Nanometers
(°C)	Centigrade

Chapter 1

INTRODUCTION

In general, buildings are responsible for over 30% of the heat loss in the building envelop (Clark, 2007). Windows creates a sense of spacious for the room and provides natural lighting, view and ventilation for the interior space. It is important to consider windows with the highest rate of energy consumption in the building envelop, being five times more than the other elements (walls, doors, and etc.) in terms of transferring the overall heat (Bülow-Hübe, 2001).

In addition, proper selection of windows glazing and their design are effective strategies to minimize the energy consumption level (Haglund, 2010). Many studies have analyzed the impact of windows on energy consumption in the building envelop (Ihm et al., 2012; Karabay and Arıcı, 2012; Van Den Bergh et al., 2013; Persson et al., 2006). In many countries the use of single glazed windows has been abandoned due to the increasing heat loss and U-factor (Aydin, 2000). Another strategy which is beneficial to reduce heat transfer is using two or multiple pane and filling the windows cavity with low conductivity gases such as argon and krypton, or using an edge spacer instead of the conventional one (Muneer et al., 1997). Recently, technology in windows glazing has begun to change the amount of energy consumption. Low-E coating can perform to minimize U-value and SHGC while maintaining the high level of visible transmittance. In other words, it can extremely reduce heat loss, solar heat gain, and glare of the glazing and fenestration products which are useful for both cooling and heating demand of the building envelop (Arasteh and Selkowitz, 1989; Barry and Elmahdy, 2007).

Typically a window with Low-E coating saves roughly 40% of the energy consumption in most of the US climates. Low-E coating also reduces the U-factor while keeps high levels of visible transmittance (Arasteh et al., 2003). Thermal performance significantly determines solar heat gain for the minimum or maximum amount to be involved is based on weather conditions as well as the building orientation. Hence, different glazing material might be designed to prevent unwanted heat gain in a warm climate or give the permission to it for transmitting the solar radiation to the interior space in a cold climate (Gueymard and DuPont, 2009).

1.1 Aims and Objectives

Windows play significant role in building energy consumption and with proper glazing design, they may reduce a large amount of energy consumption through the building envelop. However, it is quite difficult to decide the best windows glazing for a building for it often requires considering many factors. Consequently, how glazing can be organized with optical and thermal properties will be highlighted. And as a result, the aim of this thesis is to find out the optimum alternative for glazing windows with different simulation to reach a balance between reductions of the level of heat loss through sufficient insulation as well as prevention of unwanted heating in summer time through using glass materials.

1.2 Problem Statement

Not only large part of windows provide an opportunity to let daylight penetrate into the interior space and provide a view to outside in typical buildings, but also it plays an important role and is responsible for the highest rate of energy consumption, roughly over 30%, in the building envelop.

Therefore, in order to optimize the role of windows glazing to reduce the level of energy usage, it is important to be aware of the design and therefore select suitable windows to achieve a better performance. In this regards, Colored Building which is covered by large windows has been examined in this study by means of overall heat transfer (U-value), solar heat gain coefficient (SHGC), and visible light transmittance (VT or Tvis).

1.3 Research Methodology

The methodology of the research is based on scientific journals and books to find out the importance of windows in terms of energy efficiency. After figuring out the problem of Colored Building which is covered with large windows, a simulation has been used to illustrate the amount of heat loss and solar heat gain in the building.

To calculate energy heat loss and solar heat gain in the building and compare them with alternative simulations in all four orientations, Lawrence Berkeley National Laboratory (LBNL) offers a windows simulation tool (WINDOW 7.2) to calculate the windows performance, providing the following parameters:

- It is calculate U-value, visible transmittance, Solar Heat Gain Coefficient of direct solar radiation for complete windows system or center of glass with ASHRAE SPC142.
- It is able to analyze any combination of glazing layers, gas filled between layers, frame with different material, and spacers in any building orientation and latitude.

Short overview of input and output of these simulation tools are as follows:

- **Input data:**

Glazing Layers
Glass Type
Frame Type and material
Gas layers and thickness

- **Output Data:**

U-value (W/m2K)
SHGC
Visible Transmittance

1.4 Limitation

Different types of windows perform to provide natural lighting, ventilation, view and etc. The limitation of this research is that it has only focused on vertical and fixed windows plates without any shading devices; how they will minimize the heat loss by improving the glazing material or replacing the glass material to block the infrared radiation and prevent unwanted heat gain in summer period, in the Colored Building of the Faculty of Architecture at Eastern Mediterranean University, North Cyprus.

In order to know how windows performs well so to achieve better results regarding the energy efficiency, it is essential to discuss about the solar radiation through glazing for optical properties as well as glazing materials for reducing the amounts of heat loss.

1.5 Organization of the Thesis

This thesis encompasses four chapters with the following details: Chapter 1 represents the introduction with aims and objectives, problem statement, research methodology, limitation and organization of the thesis. In chapter 2, literature review on importance of windows with physical, optical and thermal approaches have been investigated with regards to better energy performance in the building envelop. In chapter 3, Colored Building was analyzed with concerns to three parameters of overall heat transfer, solar heat gain and visible transmittance, by the help of WINDOW 7.2 Simulation tool and comparison to other simulations so to acquire the optimum alternative. And finally, conclusion of this study is in chapter 4, summarizing the final discussion and simulation results and coming out with some solutions as well as ideas for future research.

Chapter 2

WINDOWS AND WINDOWS PROPERTIES

2.1 History of Windows and Glass Component

Windows were just like a hole in the wall at first; little by little they were covered with wooden material, rags and animal fur. Since ancient time, humankind have been used glass materials in their buildings to benefit from solar radiation for providing daylight as well as heat in order to have a comfortable space for living or a working environment. In addition, glass materials help to protect against rain, wind, harsh weather and etc. The history of windows goes back to 4000-6000 years in history according to the following citation (Zerwick et al., 1980).

> "Who, when he first saw the sand or ashes ... melted into a metallic form ... would have imagined that, in this shapeless lump, lay concealed so many conveniences of life? ... Yet, by some such fortuitous liquefaction was mankind taught to procure a body ... which might admit the light of the sun, and exclude the violence of the wind ..."

What is more, the glass materials are mainly made out of sand or silica, and to be able to change the chemical substance of silica from solid to liquid there has to be an approximate increase of 1700 °C in the temperature. The second element of glass is soda ash which reduces melting temperature to near 800 °C and gives a flexibility feature to the glass. Overall, the glass composition consists mainly of 65% sand, 20% soda ash and 15% limestone (Flavell and Smale, 1974).

2.2 Importance of Windows

To design any building it is important to consider windows as an aesthetic satisfying view both toward outside and inside of the building, for daylighting, fresh air and even for the occupants' psychological aspect. These criteria, however, were considered as traditional purposes. By the popularity of windows glazing and their feature in building design, it was then vital to consider the other aspects beside these functions to achieve the best optimization.

Mostly windows are considered as the weakest point in building envelop which have negative impacts on the energy load. The cooling and heating demand in summer and winter respectively, should also be taken into account, which makes it not possible to reach optimization unless the designer is aware of the heat transfer mechanism through windows glazing in order to reduce the amount of heat loss in the building envelop.

Moreover, recent technologies, which enable the designer to add low-e coating on both or a single part of glazing surfaces, give an opportunity to transmit solar radiation and to have daylight and visible transmittance into the interior space. However, it is necessary to avoid unwanted heating in a warm climate or a hot season by using different glazing materials so to reflect the solar radiation into outer space (Jelle, 2013; Arasteh, 1994).

Furthermore, ultraviolet rays, visible transmittance, and infrared rays are three primary emissions which come from solar radiation. In what way the sum of solar transmission and reflection is up to the glazing material is later discussed in details. Besides, to reduce energy loss in building, it is important to know about the orientation and placement of windows and how they effect and help in minimizing the energy load (Selkowitz et al., 2004).

In addition, the percentage of windows to the exterior walls in building envelop is an important issue which has crucial effect on building energy flows as well as daylight. However, in this study, windows are considered only as transparent glazing area and there is no referring to opaque the layers or frames.

While it is acceptable to have the highest windows to wall ratio in a warm climate, in a cold climate, this percentage should be minimized to 40% or even less to have sufficient insulation. Moreover, it is possible to have a larger ratio where windows are created with low U-value to minimize the heat loss in winter or heat gain in summer. For instance, there is direct relationship between windows to wall ratio and the solar heat gain. When there is an increase in the windows to wall ratio, solar heat gain will increase accordingly (Su and Zhang, 2010; Inanici and Demirbilek, 2000).

Since solar radiation has a different performance for achieving sufficient light and heat regarding to different geographical locations (North or South hemisphere) and different seasons, it needs to be considered significantly and much attention should be put on it. For instance, when sun position is low in winter, the south orientation has different solar radiation achievement in comparison to summer time. This is consistent with east and west façade as well (Figure 1).

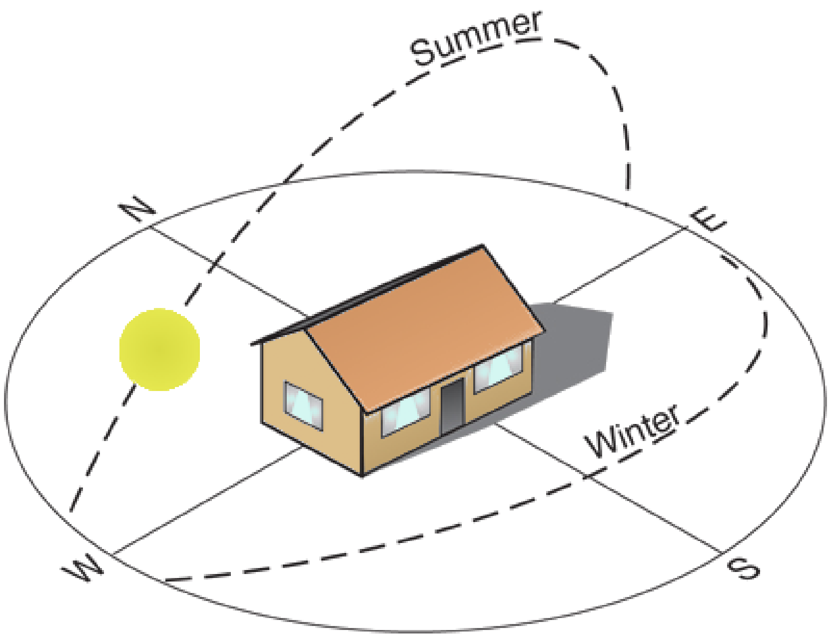


Figure 1: Sun Path In North Hemisphere
(http://www.nachi.org/building-orientation-optimum-energy.htm)

It is good to mention that North orientation achieves indirect radiation in both summer and winter periods (Persson, et al., 2006). Thus, glazing and windows material should be categorized according to the windows orientation, their light and heat requirement, so to have better performance. It should be somehow to prevent overheating in warm climate by different glazing material while optimizing the energy performance which will be discussed in the following sections.

2.3 Glasses and Glazing

As illustrated in Figure 2, windows include glazing, frame and spacer as its physical property and a large part of it is only glazing. Therefore, windows' glazing is a drawback for it lacks the sufficient insulating quality and leads to an increase in the energy consumption. However, to optimize the energy performance in windows glazing, the importance of gas filled, spacer, and glass material should be considered as well as the possibility of adding coating on glass surfaces for making better energy performance.

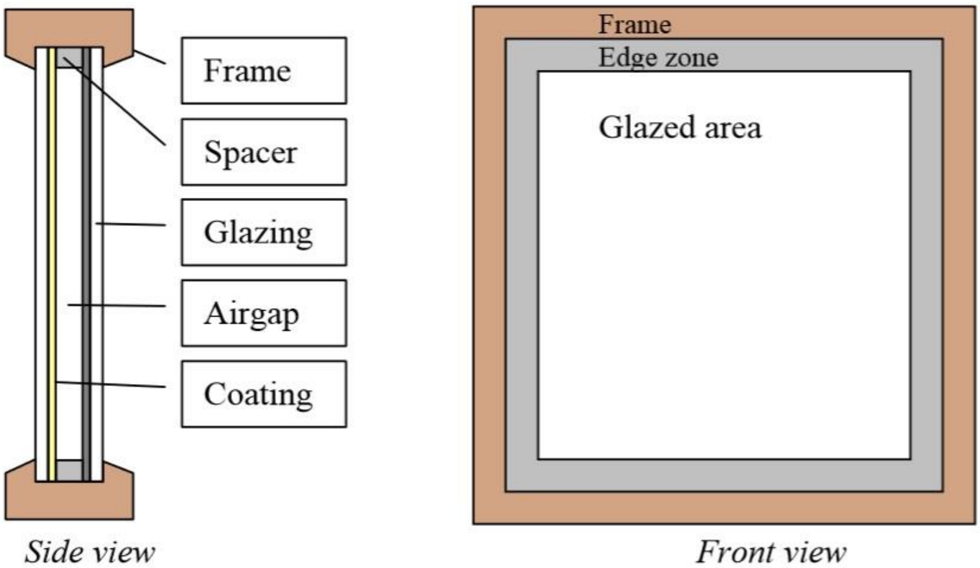


Figure 2: Physical Properties of Windows (Karlsson, 2001)

2.3.1 Glass Type

Glass transparency and their characteristic, whether leading to transmit solar radiation through glazing or reflect, is due to its material and its components. For instance, a single clear glass has the highest amount of solar transmittance in terms of both light and heat, while reflective low-e with tinted gray glasses go with the minimum transmittance. Hence, it is important to design the building function according to the occupants' needs as well as the climate conditions.

2.3.1.1 Clear Glass

Traditionally, clear glasses have been made for most windows glazing in buildings to provide daylighting and view to outside, with lack of privacy for the occupants. However, glass material has direct impact on the rate of solar transmittance in glazing. For instance, in (Figure 3) ordinary clear glasses with 3mm thicknesses transmit the highest solar radiation , roughly 90%, which hits the surface of the glass; only 8% of it reflected and the rest is absorbed and converted into heat (Bülow-Hübe, 2001).

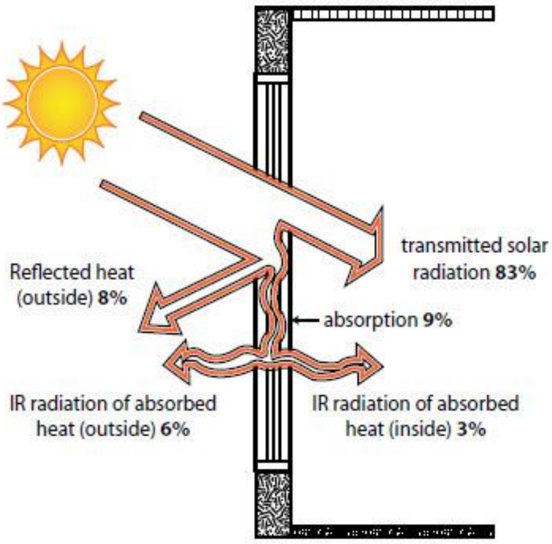


Figure 3: Clear Ordinary Glasses with Highest Solar Transmission
(http://www.commercialwindows.org/shgc.php)

2.3.1.2 Tinted Glass

Tinted glass refers to the type of glass which has balance between the visible light and solar heat gain. It has two sorts and the traditional one minimizes visible transmittance as well as heat gain with two gray and bronze colors in the market.

What is more, tinted glass has initially been formulated to increase the level of heat absorption. Visual privacy and daylighting has been increased by it, while the amount of glare, shiny and bright light, which is not suitable for human eye, has been reduced. Although, tinted glass absorbs large amounts of solar heat and the glass temperature rises, but the level of transmittance is minimized by it at the same time. In addition, to be successful with this trade-off, glass manufactures have released a new type of tinted glass by changing the chemical substances to the float glass process which absorbs a large part of near-infrared radiation. Furthermore, it is possible to work and joint with Low-E.

Moreover, there is a well-known spectrally selective tints glass with blue and green colors which gives opportunity to transmit more daylight and reduce solar heat gain.

2.3.1.3 Laminated Glass

Laminated glass refers to a type of glass which consist Polyvinyl Butyral (PVB) and bond with two or more sheets of tough interlayer plastic material like a sandwich which occurs under heat and pressure. Since the chemical process and sealed will be finish, it acts as single normal glass and provides multifunctional benefits, resolving many design problems such as aesthetic appearance and durability. It minimizes the amount of noise transmission, and protects against disasters such as earthquakes and explosion which makes it safer than conventional glasses (Bülow-Hübe, 2001).

Moreover, it is possible to apply patterns and reflective coating on the laminated glass sandwiches and assemble it together. Hence, by placing double pane laminated glass and Low-E coating, the effect will be optimized where facing air space (Alvarez et al., 1998).

2.3.1.4 Low-Emissivity (Low-E) and Coated Glasses

In the next part of this study, solar radiation through glazing will be highlighted. Understanding solar radiation advantages for reducing energy consumption in building envelop has brought a new technology in windows and glazing (Smith et al., 1998).

After discussing about clear, tinted and laminated glasses with their advantages and disadvantages in windows glazing, recently Low-Emissivity or (Low-E) coatings are coming to the market and are designed to reduce the thermal conduction amount (U-Factor). Typically, coated glass’s range is divided into two main categories which refer to “low- emissivity” and “solar control” coatings for different weather conditions and can be applied into clear, tinted or laminated glasses. In addition, the low-E coating, for instance in warm climate coated, can be applied on the outside of the pane to keep the heat out, and in cold climate coated, it can be applied on the inner side of the pane to keep the heat in (Figure 4). Low-e products are categorized into “soft” and “hard" coatings.

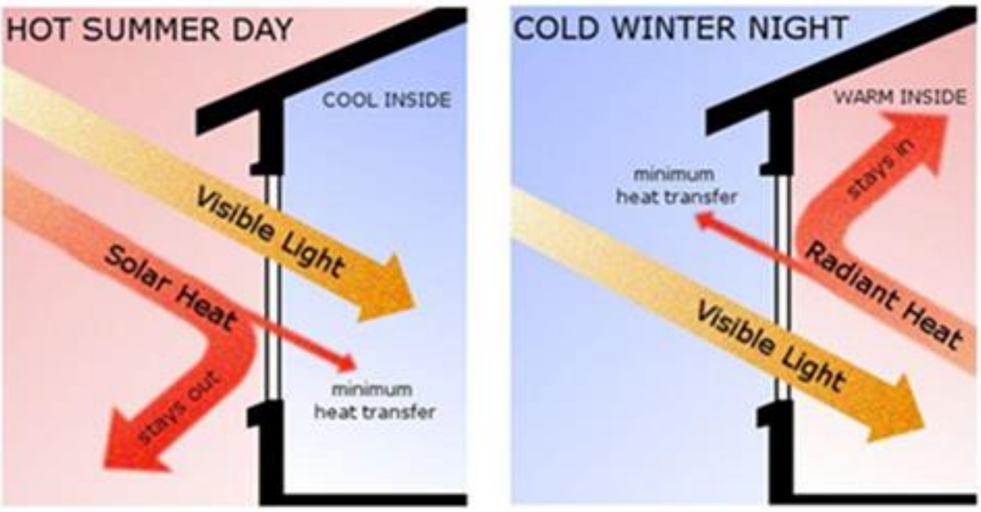


Figure 4: Solar heat and Visible Transmittance in Low-E Coated Glass (http://www.replacementwindowsnj.org/a-synopsis-of-low-e-glass-with-argon-why-its-so-energy-efficient/)

Hard coating is based on tin oxide material whereas soft coating is usually made out of thin layers of silver. Soft coatings have high levels of infrared reflectance and can reduce solar transmittance intensify compared to hard coatings (Pfrommer et al., 1995).

Since coating process applies to the glazing pane whether one or multiple, it changes the material and also optical properties of windows glazing and the incident angle of solar radiation accordingly (Karlsson and Roos, 2000). For windows coating design, it is important to consider the optical properties and the theory of thin films which depends on the quality and composition of glass substances (Hardy and Perrin, 1932; Rubin, 1982; Pfrommer et al., 1995; Berning, 1983).

In addition, in most western countries, there is a new standard for building regulation and that is to use coated low-e glazing in their products. That is why manufacture procedures have been increased (Wegener, 1997). Since 1980, the coating glass technology has been developed and extremely improved windows performance which is available in the market (Nilsson and Roos, 2009; Lampert, 1981). Recently another coating type has been released to the market known as switchable coating (Lee et al., 2006)

2.3.1.5 Reflective Coatings

If more reduction is required in solar heat gain coefficient, reflective coatings are applied on glazing surfaces. They can be used on clear or tinted glass with variety color such as silver, gold, bronze, and etc.

In addition, when solar radiation is emitted from the sun and hit the glass surface, it is limited to reflect high level of infrared radiation, depending on its thicknesses and material component, so to change the optical properties in the creation process (Smith et al., 1998; Berning, 1983; Johnson, 1991; Robinson and Hutchins, 1994).

Consequently, the coating acts as a mirror to reflect solar heat gain and unwanted heating to become useful for warm climates. However, the amount of visible transmittance and daylighting it keeps is able to transmit through glazing as illustrated in Figure 5. Moreover, it helps in reducing heat loss through glazing in the building envelop (Glenn et al., 2009; Balcomb, 1992; Mohelnikova, 2009).

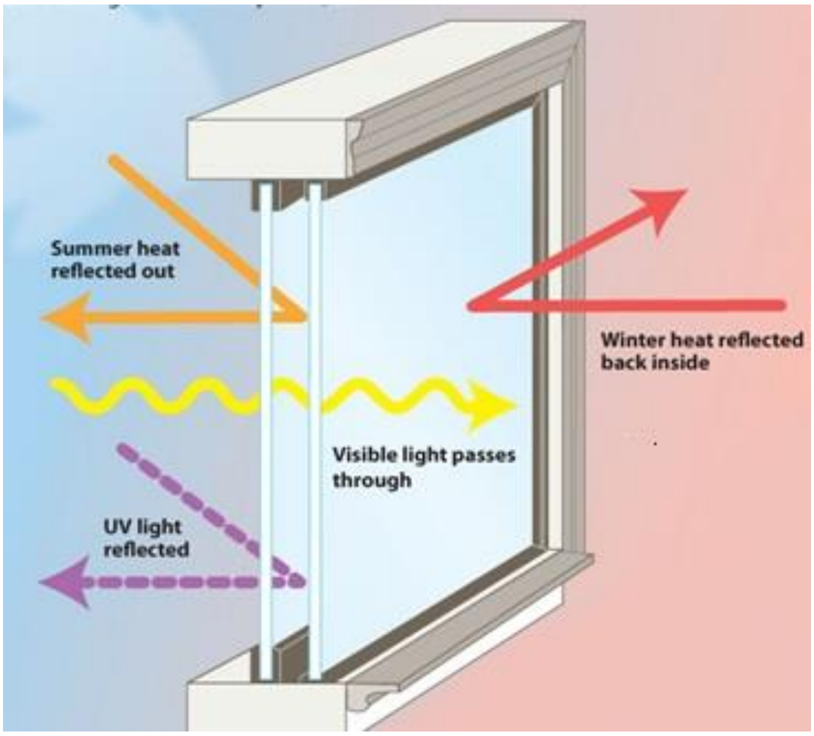


Figure 5: Low-E Coating and Solar Heat Gain Reduction (http://myimageglass.com/wp-content/uploads/2011/12/innerglass-low-e-illustrati.jpg)

2.3.2 Windows Frame Material and Spacer

After discussing the importance of glass and glazing, it should be mentioned that frames and spacers play a significant role in reducing the amount of heat loss in windows glazing (Gustavsen, 2001; Asif et al., 2005). Frames represent 20 to 30% of the total area of windows (Gustavsen et al., 2005, Gustavsen et al., 2008) which is crucial when considering the heat transfer rate by making a high insulated frame as well as a U-value reduction in the overall windows (Gustavsen et al., 2011). Also it is important to focus on design, dimension, size, and shape of the frame to reduce heat transfer in windows. The common materials for windows frame are aluminum, wood, PVC and fiberglass which are explained below in details and also different window frames are illustrated in Figure 6.

2.3.2.1 Aluminum

Windows with aluminum frame has 160 W/m·K thermal conductivity which represents a poor insulating material. This high thermal transition probably occurs due to its natural material characteristic which helps in raising the temperature as well as increasing U-value in the glazing product.

Consequently, whenever there is a difference between the temperature outside and inside, the aluminum window frame becomes cold in winter time and just the contrary in summer period.

Thermal breaks or barriers are to prevent heat transition in aluminum frames by a separator material which is used in between inner and outer part of the frame to join them. Designers need to consider shape, size and even location of thermal break into the glazing product to decrease the amount of U-Value as low as possible (Ben-Nakhi, 2002; Duer et al., 2002).

Apart from the poor insulation, aluminum has flexibility which makes it possible to create complex shapes. Also its weight being light makes it easy to carry out while still being strong. It is further possible to airtight and seals it easily to avoid air infiltration and leakage against dust, rain and harsh weather. That is why aluminum frames are the most widely used in the industry with minimum maintenance.

2.3.2.2 Wood

The second windows frame is wood which is organic and has porous material which shows good insulation with 0.13 W/m·K thermal conductivity and has more thermal resistance which acts well enough in comparison to steel or aluminum. However, it needs to be treated regularly and painted or sealant against rot, thus requiring more maintenance compared to the others.

In addition, wood frame and its thicknesses influence thermal resistance. By increasing the wood frame thickness, more insulation is provided against temperature fluctuation and the rate of heat loss will decrease accordingly (Byars, and Arasteh, 1992).

2.3.2.3 PVC

The third windows frame which is going to be discussed is Polyvinyl chloride, also known as the PVC with 0.17 W/m·k thermal conductivity. These plastic materials prevent heat loss through frame and symbolize well insulating by reducing the energy load through easy maintainable glazing. Polyvinyl chloride is roughly comparable to wood materials in terms of U-value and amount of thermal resistance. However, there is a negative point and that is PVC not being able to perform well against temperature fluctuation.

However, the number of PVC frame used recently has increased due to its well-known heat resistance and good thermal performance, with the most energy efficient windows frame for the consumers that is available in reasonable prices in the market (Beck and Arasteh, 1992).

2.3.2.4 Fiberglass

The last windows frame under study is Fiberglass with 0.40 W/m·K thermal conductivity which is not good in insulating and has high thermal conductivity after aluminum. It requires high maintenance and has a low popularity among the other frames in market nowadays because of its cost (Gustavsen, 2001).

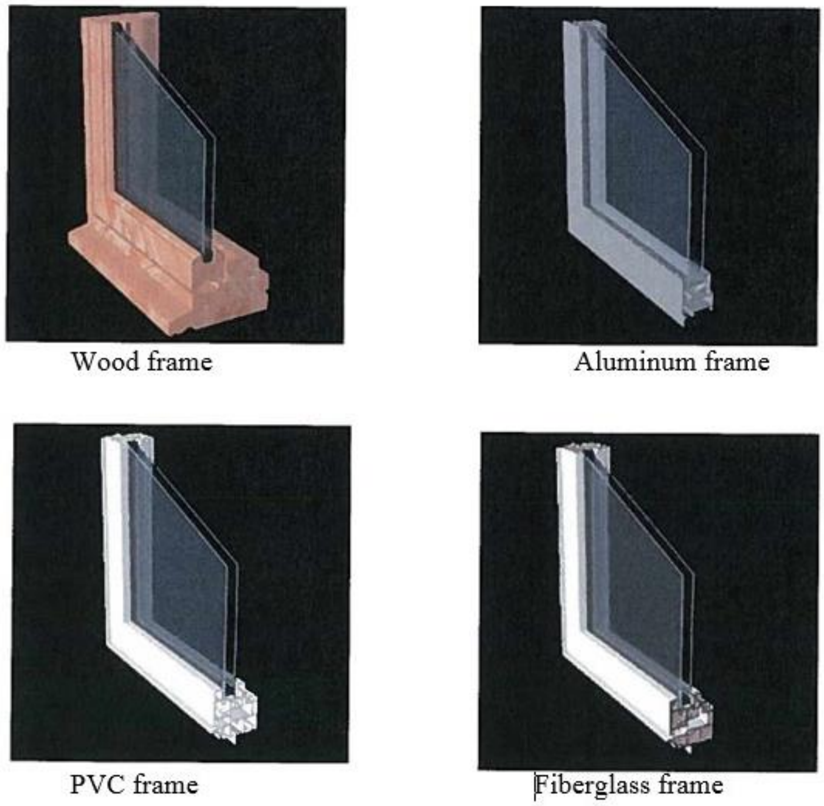


Figure 6: Windows Frame and Its Material (Linera & Gonzalez 2011)

2.3.2.5 Spacer

Spacers are acting as junctions between glazing and frame. They are typically made out of metal and aluminum which are lightweight but strong. Spacers are flexible and that make them able to form into different sizes and shapes, hence, more than single pane windows glazing separated via aluminum spacers to keep distance and create a kind of gap in between glazing to avoid thermal conductance. However, aluminum contributes to high levels of conductance and performs as a thermal bridge which helps to increase the amount of U-value roughly 0.2 W/m2K compared to warm edge technologies (Karlsson, 2001).

However, to have a better performance and decrease the level of heat loss for double glazing windows or multiple pane, warm edge spacer have been used in buildings to provide better results (Figure 7).

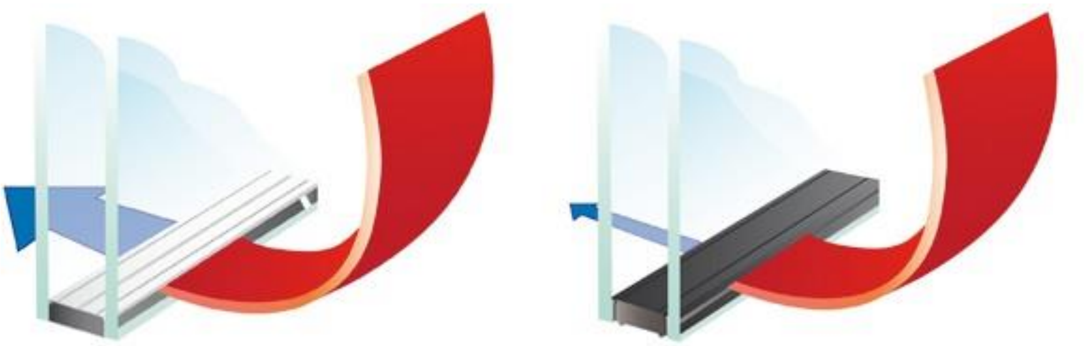


Figure 7: Aluminum spacers with high thermal conductivity (left side); warm edge spacer with low thermal conductivity (right side) (http://www.weatherproof-windows.co.uk/glazing.php)

It is also known as thermal break which is made out of fiber glass material and replaces the conventional aluminum. In addition, it helps to reduce thermal heat through glazing. Although it is more expensive than conventional aluminum but it is available in variety of colors in market (Song et al., 2007; Van Den Bergh et al., 2013).

2.3.3 Insulation

Since single glazing was improved to multiple glazing, the importance of gas filled in between the glazing, its gap differences and also the way to reduce the amount of air leakage for providing a better insulation are matters of importance.

2.3.3.1 Gas Filled

Typically, for multiple glazing it fills with different gas to provide better insulation and minimize the amount of current conduction and convection and even overall heat transfer (Ismail et al., 2008), for instance, air and argon gases are mostly common gas filled which is both of them are clear, nontoxic, odorless and nonreactive with considerable reduction in thermal conductance in between the glazing layers, hence, it has become favorable for manufacture to use it more and more in building construction, However, krypton has better thermal performance among air and argon (Weir and Muneer,1998) but it is more expensive to produce. Also, they can use pure or even mix between glazing layers to consider both its cost and thermal performance at the same time.

Furthermore, the mostly common gases filled between the glazing layers, which are air, argon and krypton, are illustrated in the graph below (Figure 8), and as can be seen, the optimum thermal performance occurs in between 10 and 15mm.

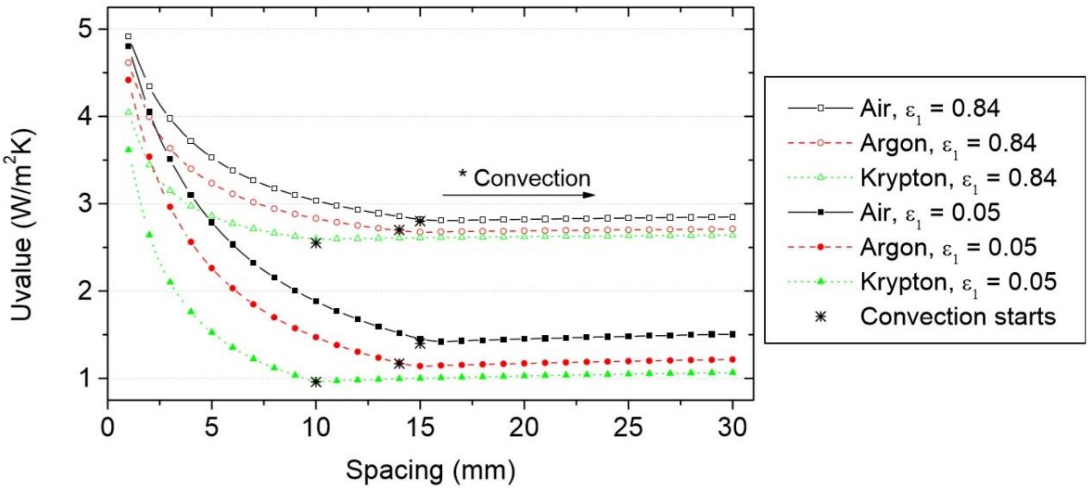


Figure 8: Spaces Gap in Between Glazing and Gas Filled with Thermal Conductivity Relationship (Karlsson, 2001)

2.3.3.2 Airtightness and Air leakage

Air flows through windows occurs due to difference in temperature and wind movement between inner and outer spaces which is often unwanted and is called air leakage (Figure 9). When air wants to penetrate into inner space, it is called 'air infiltration', whereas, when air tries to escape from the inner to outer space, it is called 'air exfiltration'. These movements of air allow the warm or cold temperatures to move out of building envelop, as a consequence of which, more energy is required to be loaded.

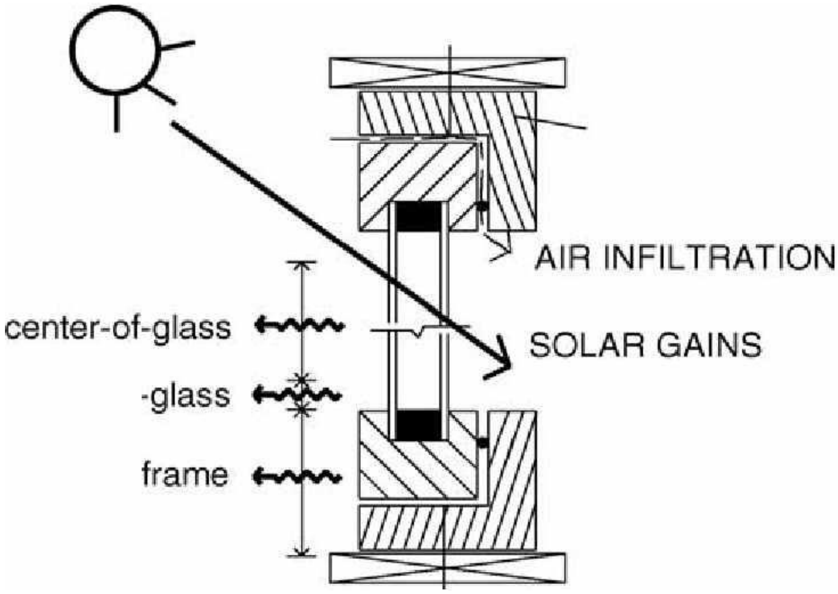


Figure 9: Air infiltration through glazing, (Bernier and Hallé, 2005)

The air movements might occur due to the lack of sealed gaps and even poorly joints in windows frame, its surrounding glass or its frame (Relander, et al., 2010). Also, operable windows have a desire to increase the level of air leakage rate and it is difficult to eliminate their frame gap to control them (Binamu, 2002). Hence, using fixed windows is an easier way to control the air movements. Fixed windows keep the air tight and air leakage will be minimized, that is why it is more effective than conventional operable windows (Hagentoft and Harderup, 1996).

Climate condition, temperature and wind speed as well as the building surrounding are the other parameters which have impact on the level of air leakage in windows products. Bearing in mind the energy loss rate in building envelops through windows due to uncontrollable air change and air leakage, it is important to consider airtightness.

In addition previous studies of Laverge et al. (2010) and Kalamees (2007) have shown the importance of airtightness through windows glazing in Belgium and Estonia respectively.

2.4 Optical and Thermal Windows Properties

In this part, the optical and thermal properties and their importance through windows glazing will be highlighted. Optical properties are defined as solar radiation and wavelength in spectrum which influence windows glazing (Roos, and Karlsson, 1994) by means of transmittance, absorbance and reflectance.

In next part, the importance of thermal properties which is in the same category with heat transfer mechanism will be talked of, as well as the ways to avoid heat loss and the importance of U-factor.

2.4.1 Solar Radiation and Spectrum

Solar radiation and electromagnetic of spectrum are divided into four main groups (Bube, 1983):

First of them is Ultraviolet (UV) with $\lambda<380$nm radiation which is not sensitive to human eye. Even though the level of this wavelength through glazing is very little, it can have a harmful effect on the interior furniture, decoration and even injury impacts on people and plants with minimum effect in balance of energy gain or loss. For better understanding of this issue please refer to the illustrations in Figure 10.

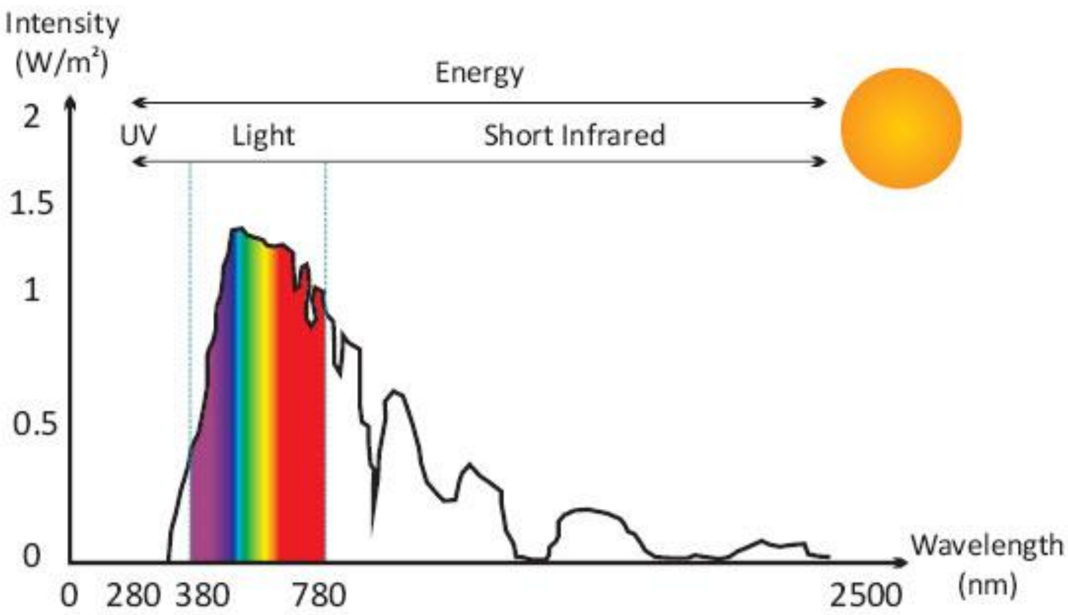


Figure 10: Solar Radiation of Four Wavelength in Spectrum
(http://www.jc-solarhomes.com/css/understanding-sunlight.html)

The second type of solar radiation goes to the visible portion with 380nm<λ<780nm. It consists 50% of the solar radiation and is vital to be considered as a wavelength interval. Also it is the only portion of this spectrum which is sensitive on human eye and humans interpret it as a light and illumination to use in their living spaces and building. Furthermore, it is interesting to know that an ordinary clear glass has the highest transmittance in this interval and with an addition of pane in the glazing the radiation will be absorbed and changed into heat.

The third interval of solar radiation is near infrared (NIR) with 780nm<λ<2500nm in between which is located above the visible radiation and therefore is not visible by human eyes. It consists approximately 40% of the solar energy which is transmitted to the earth.

The Infrared Radiation (IR-radiation) is the last type which has over 2500nm wavelength and most of this radiation is emitted from outside of the building into different directions. Although ordinary glasses absorb the radiation then reradiated into the outer space, energy is emitted in this interval. Hence, large amounts of heat loss might occur because of this mechanism (Bülow-Hübe, 2001).

2.4.1.1 Solar Radiation through Window Glasses

Generally, solar radiation through glazing is transmitted, absorbed or reflected and the level of them depends on optical properties, which can be the wavelength of radiation or incident angle (Jelle, 2013).

Since radiation cannot pass through glazing surface or be reflected off, it may be absorbed. This energy may change into heat, raising the glass temperature and make it warm (Hass and Waylonis, 1961). In addition, no changes occur in glass color if they absorb infrared or ultraviolet radiation unless they absorb the visible light which makes them appear almost dark in surface (Wall, 1997). This change occurs based on the glazing material. For example, tinted glasses absorb large amounts of light while transparent clear glazing absorbs only a little (Jelle et al., 2007).

2.4.1.2 Visible Transmittance

The level of light transmittance through glazing in solar spectrum is called visible transmittance and it stands between 0 and 1 as numerical. Visible transmittance is based on the number of glazing, glass coating or etc. In addition, the concept of keeping the visible transmittance as much as possible is an important factor along with reducing the solar heat gain in warm climate. For instance, uncoated single clear glass represents the highest visible transmittance, roughly 90%. However, reflective tinted coating glass reaches only less than 10% which is important to be considered for occupants' necessity (Szczyrbowski et al., 1989).

2.4.2 Heat Transfer Mechanism through Glazing

The process of heat transferring through glazing is a complicated subject and is not easy to be calculated (Rubin, 1982) when windows glazing leads to a significant heat loss through the building envelop (Handbook, 1997). In the following part conduction, convection and radiation categories it will be discussed in details (Figure 11).

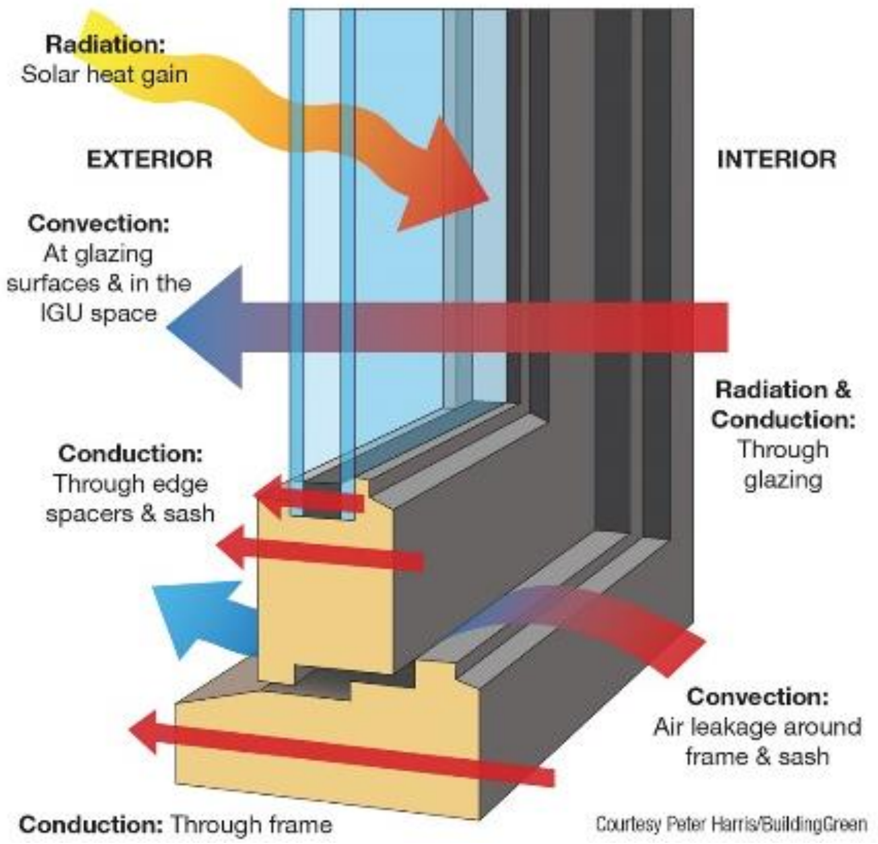


Figure 11: Heat Transfer Mechanism through Glazing
(www.homepower.com)

2.4.2.1 Conduction

Conduction is a kind of heat transfer process happening through objects when there is a direct contact between two sides of the object with different temperatures where atoms move freely as a group. The energy transfers by vibration of hotter molecules which are faster than their cooler neighbors. Wilson et al. (1998) have discussed about heat loss and how it can be decreased through well insulating the exterior part of the wall in buildings.

Generally heat loss occurs while there is a difference in temperature. When outside or inside is cold, heat transfers from the warmer section to the cooler one. For windows, on the other hand, frames and spacers are playing an important role in minimizing the conduction.

By using low conductivity materials such as wood and vinyl for the frame and warm edge spacers instead of current aluminum owns, the amount of heat loss in windows glazing will be reduced (Karlsson, 2001; Gustavsen, 2001).

2.4.2.2 Convection

This term defines the energy movement between molecules in fluids, such as air and water which carry something to another place. When warm air replaces its position with cool air, heat is raised upside and it helps to moderate the temperature inside the building.

However, in windows, air leakage with both infiltration and exfiltration as well as heat loss might occur due to the lack of sufficient materials for frame. The use of double-glazed and space gap which can be filled with variety of gas needs to be considered therefore to avoid convection.

2.4.2.3 Radiation

Typically, short wave radiation via emission of electromagnetic is transmitted through a transparent area. That means a large number of solar radiation is able to pass through glazing and gradually warm up the temperature and convert it into the heat energy. The number of transmittance or reflectance depends on the glass material and its component; that is why in opaque layers or walls it is absorbed or reflected off (Henderson and Roscoe, 2010).

2.4.3 U-Factor (Insulating Value)

The difference temperature between inner and outer space of glazing occurs heat loss (Wright, 1998) and the level of this conductance in glazing called U-factor and where there is a low heat transfer it means there is low U-value, on the other hand, to be able to measure resistance of heat loss through glazing called R-value (Arasteh et al., 2006; Presley and Christensen, 1997).

By increasing the number of glazing, pane type, air filled, spacers and size of windows the u-value will be improved while the amount of heat loss will be decreased (Jelle et al., 2007). Therefore, it is possible to achieve a thermal resistance optimization and be highly insulated through glazing. For instance, by increasing one more pane to a single glazing, the result roughly changes by halves from 5.9 to 2.9 W/m2K; and by adding one more glazing to triple it, the result will reduce again from 2.9 to 1.9 W/m2K (Karlsson, 2001).

The overall U-Value of windows contains both glazing and frame. In other words, there are three different U-values needed to be considered: glazing, frame and overall U-value of the window. The formula below shows how heat transfers coefficient calculation in the whole window including glazing and frame:

$$Uw = \frac{(Ag \times Ug \times Af \times Uf \times lg \times \Psi g)}{(Ag + Af)}$$

Here Ug refers to heat transfer coefficient of the glazing, Uf refers to heat transfer coefficient of the frame, Ψg refers to the linear heat transfer coefficient of the insulated glazing edge seal, Ag refers to the glass area, Af refers to the frame area, Aw refers to Ag+Af, and last one, lg, refers to the length of inner edge of the frame profile.

This value contains both frame and glazing as an overall value to demonstrate U-factor unit is Watts per square meter Kelvin (W/ (m2 K)) (Karlsson, 2001).

High insulating glazing units have U-value as low as 0.3-0.5 W/ (m2 K) within three layers of glass with low-e coating in both surfaces. High insulating frame have u value as low as 0.6 - 0.8 W/ (m2 K) and this reduction is caused by the low thermal conductivity material frame (Gardon, 1961).

2.4.4 Solar Heat Gain Coefficient (SHGC)

To evaluate energy performance of windows, it is important to be aware of the ability of the solar radiation through windows glazing. In other words, the solar radiation proportion which is able to transmit through glazing is called Solar Heat Gain Coefficient or SHGC (G-value in Europe) and its ranges are somewhere between 0 and 1 as a numerical. If this number is close to one, high solar heat transmission occurs which can be achieved with clear glasses or hard low-e locating, and is highly recommended for south facing facade in a warm climate., it is extremely recommend to use coating glass types to reflect solar radiation as much as possible so to avoid over heating in the summer season (Arasteh et al., 2006).

To have solar heat gain coefficient, two important factors are needed to be considered. First is the latitude of the specific region and second is the geographical location where the building is located in terms of its orientation. In the cold season, however, having a solar heat gain is beneficial for the building's interior temperature; while in a summer season, it makes overheating and causes discomfort for the occupants. To decrease this value as much as possible, the substantial material can be changed to add a low-E coating on a glazing surface. The average value of SHGC is lower than the center of the glazing where the amount of frame area has low SHGC in windows. Moreover, the radiation can be directly transmitted through the glazing into the interior space and some of it be absorbed by the glazing and frame indirectly while radiating later into the interior building. The number of pane, glazing type and also coated or uncoated layers impact solar heat gain (Arasteh et al., 1989). More than 80% of the solar heat gain can pass through glazing for uncoated clear glass glazing. For reflected coating glazing, most of the radiation will be reflected and only less than 20% of it is able to pass into the interior space.

Chapter 3

WINDOWS ANALYSIS OF COLORED BUILDING,EMU

3.1 Famagusta, Cyprus Climate

Cyprus is the third largest island in the Mediterranean Sea which is surrounded by three continents: Asia, Europe and Africa. It is situated on eastern part of the Mediterranean Sea with the 35° Latitude and 33° Longitude (Figures 12 and 13).

Figure 12: Cyprus in Eastern Part of Mediterranean Sea
(Google Earth, 2014)

Figure 13: Geographical location of Cyprus and Famagusta (http:/en.wikipedia.org)

Famagusta is located in eastern part of this island (latitude 35°7'N, 33°55'E) with hot and Mediterranean climate during summer (relative humidity is 61.6%) and cold with little rain in winter (Alibaba & Ozdeniz, 2011). The level of precipitation annually is 403.5mm with coldest month of the year being January (with 6 centigrade temperature), and hottest being July (maximum of 34 centigrade temperature) according to the Cyprus Meteorological and Famagusta report (Figure 14).

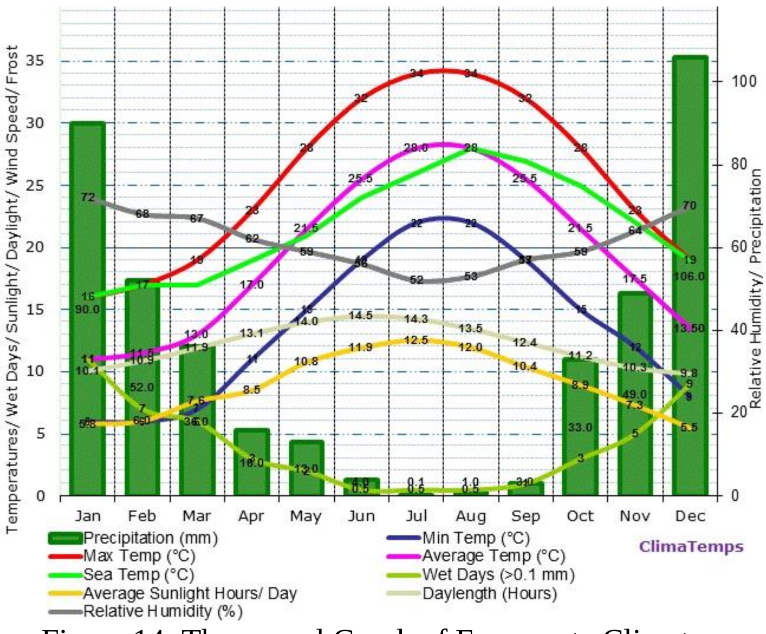


Figure 14: The annual Graph of Famagusta Climate (http://www.famagusta.climatemps.com)

3.2 Case Study, Colored Building, EMU

Colored building has three floors and a rectangular shape in plan which consists of studios, classes, a seminar room, a library and etc. (Appendix A) to perform as an educational building. It is part of the Faculty of Architecture at Eastern Mediterranean University, North Cyprus (Figures 15 and 16).

Figure 15: Colored Building as a Part of Faculty of Architecture,
(Taken by author, 2014)

Figure 16: Colored Building as a Part of Faculty of Architecture
Main Entrance (Taken by author, 2014)

3.2.1 Windows Glazing and Orientation in Colored Building

Poor design of windows glazing in this building has influenced the level of energy consumption. Energy consumption can get improved with good insulation to prevent high level of energy loss in both cold and hot seasons by adding more glazing panes, gas filled spacer material and etc. Colored Building has large parts of windows in four orientations (There are 16 types, please see Appendix C) which are made out of single clear glasses with 4 mm thickness and PVC frames with 50 mm thickness.

Hence, it is possible to apply different types of coating and films on windows configuration to change the material and optical properties of solar radiation so to reflect it and avoid overheating in hot seasons. To consider optical properties which are Solar Heat Gain Coefficient (SHGC) and Visible Transmittance, two important factors are required:

- Latitude region
- Windows orientation

The Colored Building is located approximately 30 degrees to the North (Figure 17) as can be seen in the image taken from Google Earth (Figures 18 and 19). Moreover, the current position of this building is simulated as a three dimensional image in Ecotect simulation program (Figures 20 and 21) to give a better understanding of the building orientation.

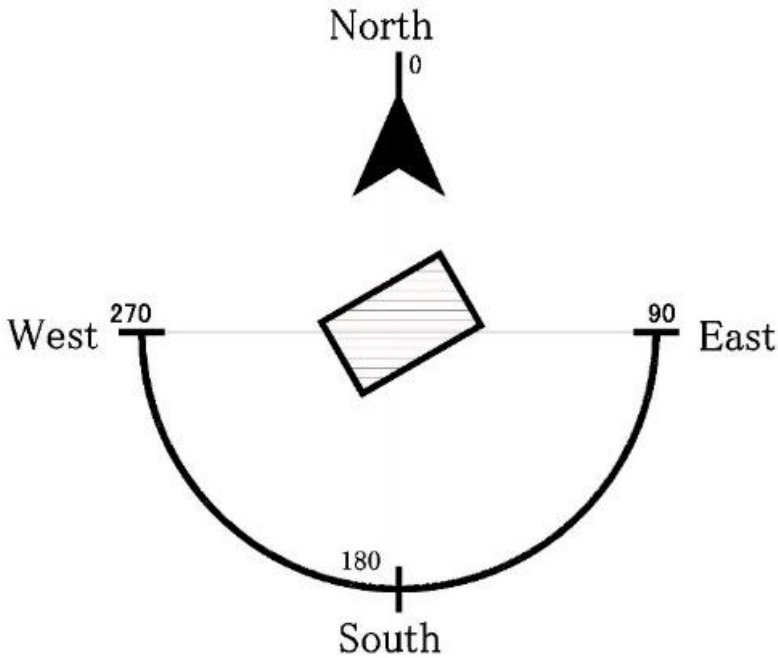


Figure 17: Current Position of Colored Building and its Orientation, (Drawn by author, 2014)

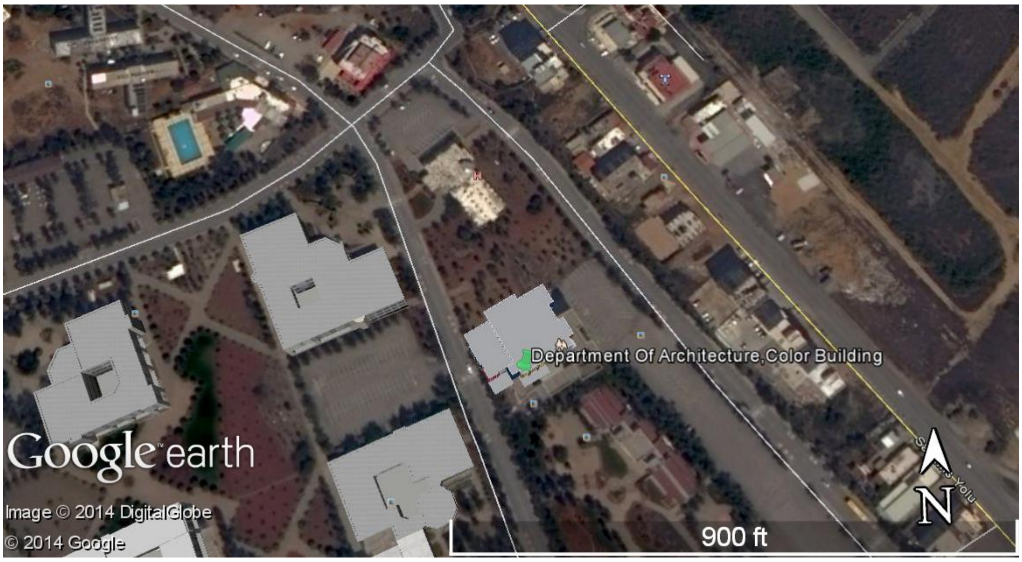


Figure 18: Site Plan of Colored Building with 30 Degree to the North, (Google Earth, 2014)

Figure 19: Three Dimension of Colored Building with 30 Degree to the North, (Google Earth, 2014)

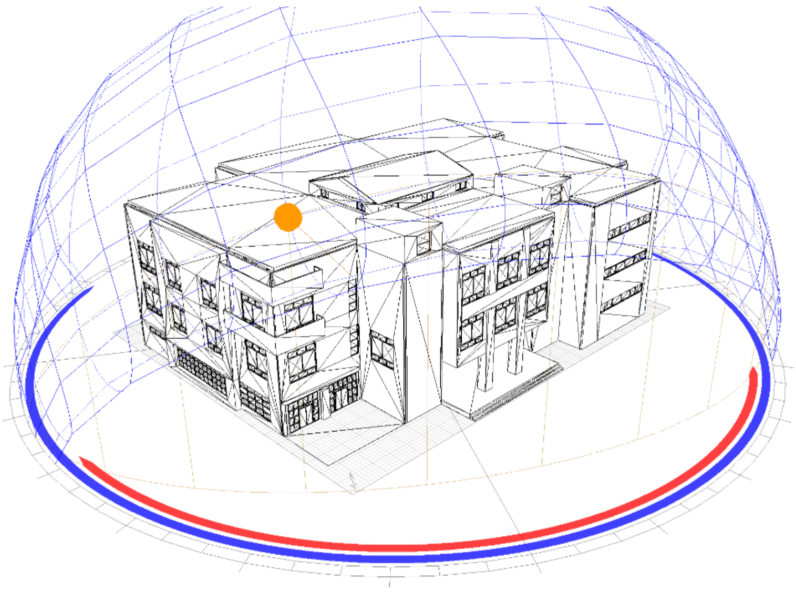


Figure 20: Colored Building 3D Model, South view, Ecotect Simulation Analysis (Drawn by author, 2014)

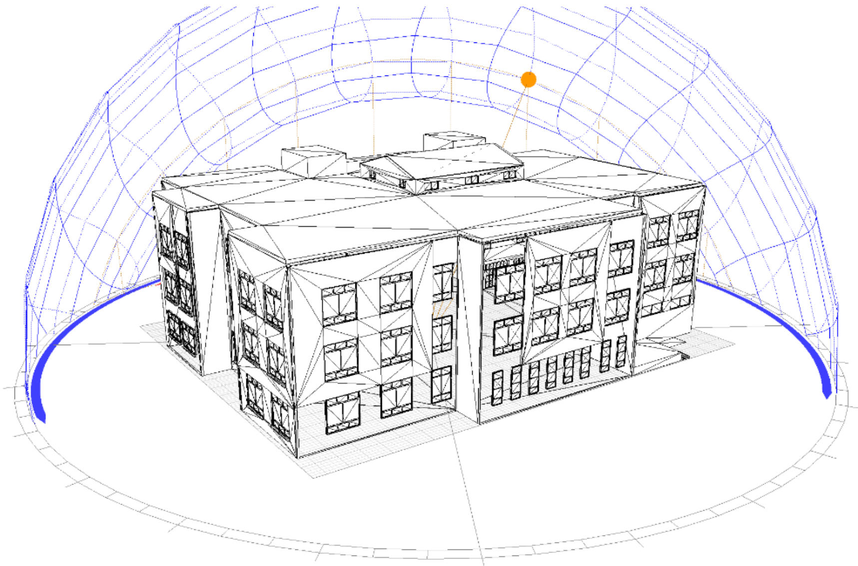


Figure 21: Colored Building 3D model, North view, Ecotect Simulation Analysis (Drawn by author, 2014)

3.3 Methodology, an Overview of WINDOW 7.2 Application

WINDOW 7.2 is the latest computer modeling program that has been released and is publicly available which can calculate and analyze the optical and thermal properties:

U-factor, Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) of frame as well as the glazing design of fenestration products (ASHRAE SPC142). It was developed by a group of scientific researchers in building technology at Lawrence Berkeley National Laboratory (LBNL) at the University of California (Figure 22).

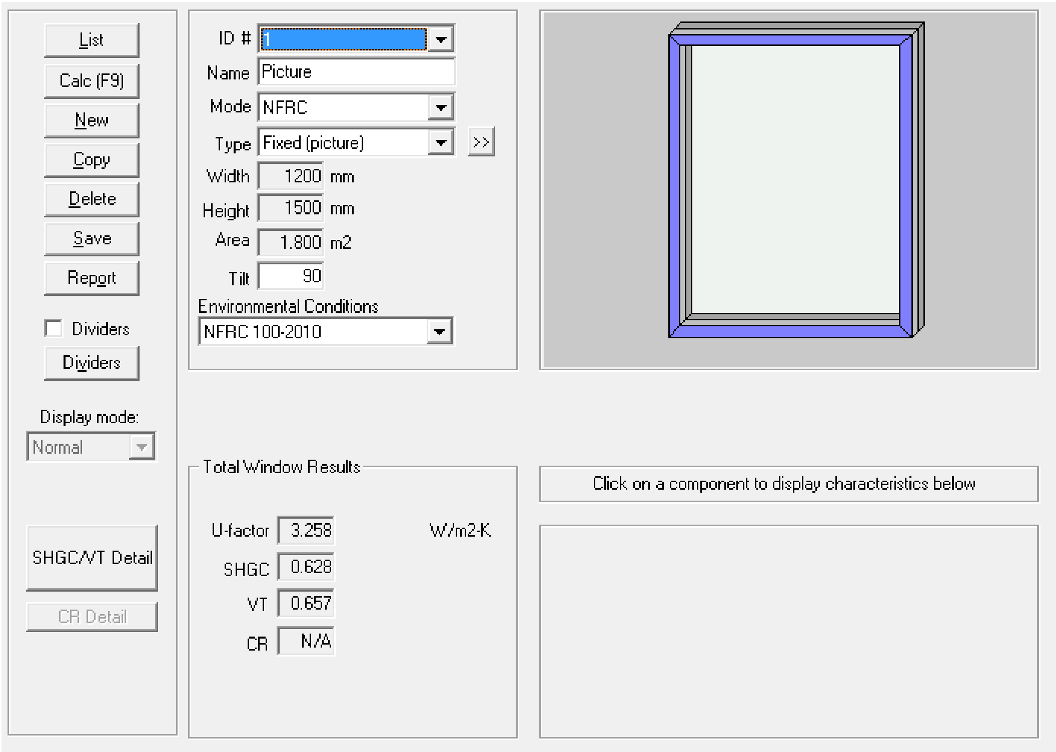


Figure 22: General Interface of WINDOW 7.2 Simulation Program, 2014

Also, WINDOW 7.2 offers following feature:

- It is able to analysis the fenestration of different combination of glazing layers, spacers, frame material and gas filled in between.
- The amount of heat loss, U-value through glazing and solar heat gain coefficient and visible transmitted for complete or center of glasses.
- The level of solar energy and visible light transmitted in both back and front surface in different latitude and building orientation.
- The level of solar energy and visible light reflected in both back and front surface in different latitude and climate condition.

3.3.1 Simulation Description

WINDOW 7.2 has been developed to calculate thermal and optical properties of glazing and windows which is useful for manufactures, engineers, architects and scholars. In the following simulations, vinyl frame has been set as a default (Figure 23) for it has a better performance among the others and has the most energy efficiency in a hot climate.

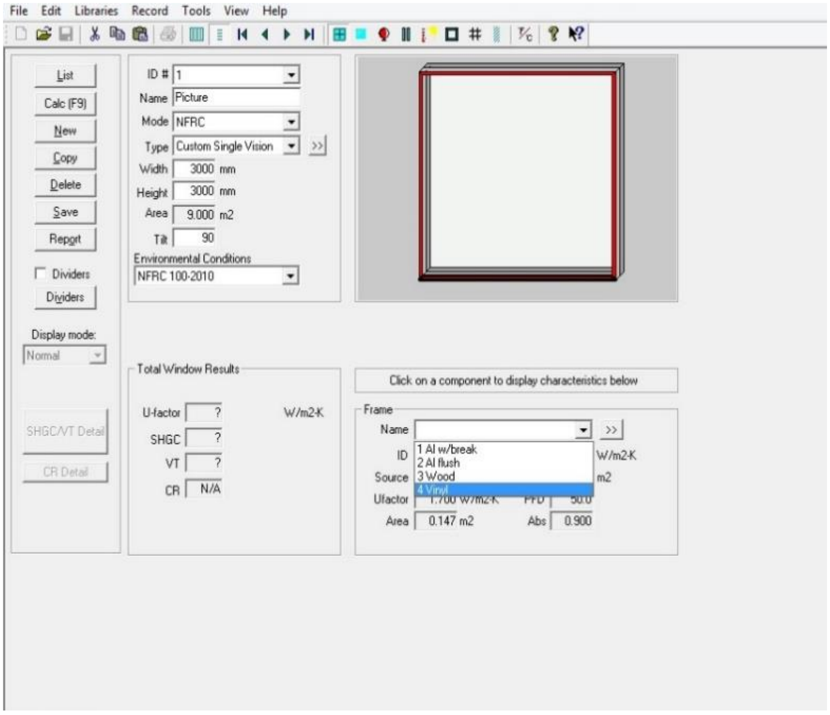


Figure 23: Frame Types in WINDOW 7.2 Simulation Tool, 2014

For the gas which is going to be filled with 10mm distance between glazing, air, argon and krypton have been chosen (Figure 24). They are enough to perform well in terms of thermal conductivity according to the literature review. In Figure 25, environmental condition is defined by National Fenestration Rating Council (NFRC-100-2010).

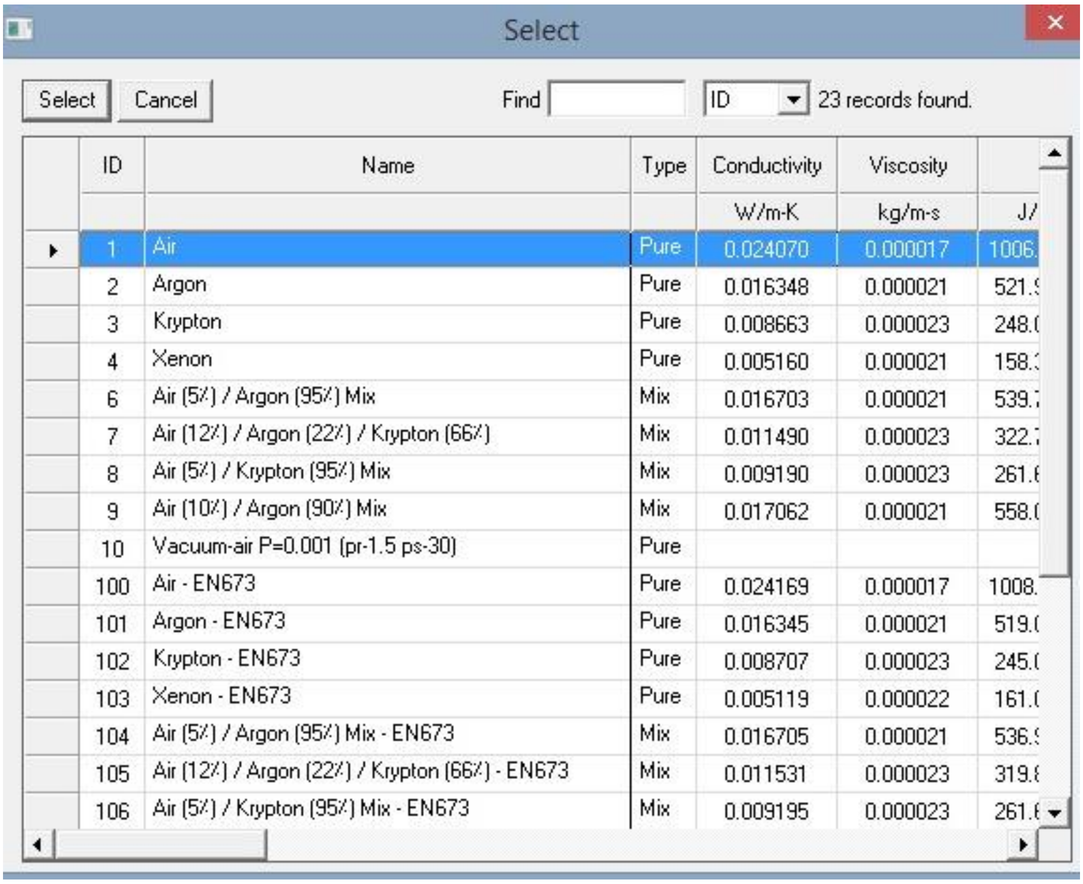


Figure 24: Gas Filled in WINDOW 7.2 Simulation Program, 2014

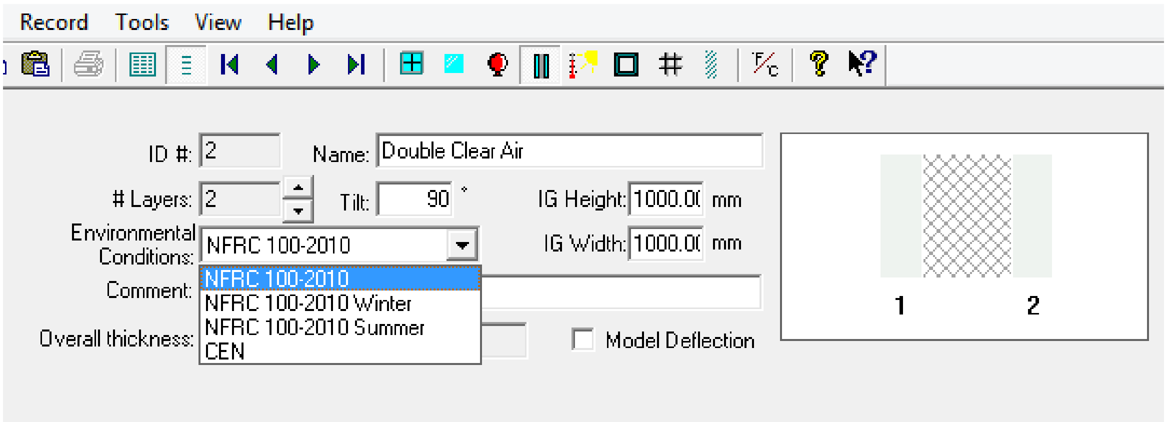


Figure 25: Environmental Condition in WINDOW 7.2, 2014

Different number of glazing with their dimension has been analyzed in this Colored Building (Appendix C). In all simulation ,solar heat gain coefficient and visible transmittance based on windows dimension 300*300 which they are available in all four orientation[1].For better understanding, windows to wall ratio in four orientation and windows sample are shown in Table 1 ,Figure 26 plus Appendix B.

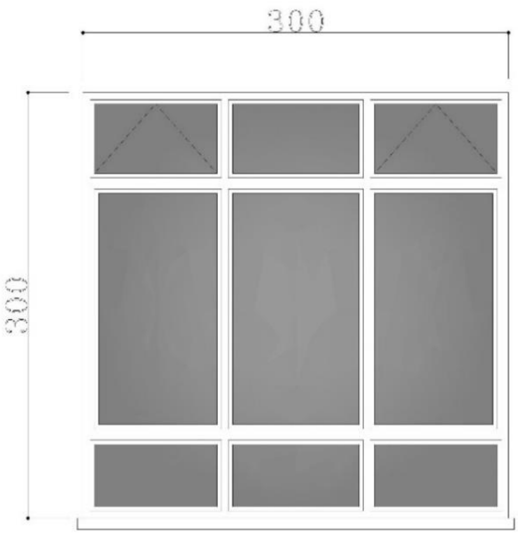


Figure 26: Windows Sample in Four Orientation of Colored Building With 300*300 dimension (Drawn by author, 2014)

Table 1: Windows wall ratio (WWR) in Colored Building (Drawn by author, 2014)

	North East Elevation	South West Orientation	South East Orientation	North West Orientation
Total Area (m2)	536	415	750	727
Windows Area(m2)	221.2	128.1	152.2	227
Windows Wall Ratio (WWR)%	41.3 %	30.8 %	20.2	31.2 %

[1]Windows orientation are defined with following icon : (If 0 is north)

North East is 60 degree 

South East is 150 degree 

South West is 240 degree 

North West is 330 degree 

3.3.1.1 Simulation No. 1: Existing Single Glazing with Clear Glass

In this simulation single clear glazing with 4 mm thicknesses and 50 mm PVC frame was consider as an existing model in colored building (Table 2 and Figures 27, 28).

Table 2 : Existing single glazing with clear glasses
(Drawn by author, Based on WINDOW 7.2 Simulation tool, 2014)

Input Data				*Output Data*		
Window Orientation	Width (cm)	Height (cm)	Area (m2)	U-value W/m2K	SHGC	Visible Transmittance
1.	300	300	9.00	5.156	0.808	0.840
2.	300	200	6.00	5.259	0.796	0.826
3.	400	200	8.00	5.290	0.802	0.802
4.	300	250	7.50	5.204	0.803	0.835
5.	200	300	6.00	5.096	0.795	0.826
6.	100	280	2.80	4.935	0.756	0.780
7.	100	300	3.00	4.918	0.757	0.782
8.	130	190	2.47	5.109	0.761	0.786
9.	530	100	5.30	5.420	0.769	0.794
10.	120	120	1.44	5.161	0.735	0.756
11.	200	70	1.40	5.286	0.715	0.732
12.	350	320	11.20	5.224	0.813	0.846
13.	300	110	3.30	5.359	0.765	0.790
14.	500	220	11.00	5.285	0.809	0.841
15.	570	220	12.54	5.294	0.811	0.843
16.	410	200	8.20	5.292	0.802	0.833

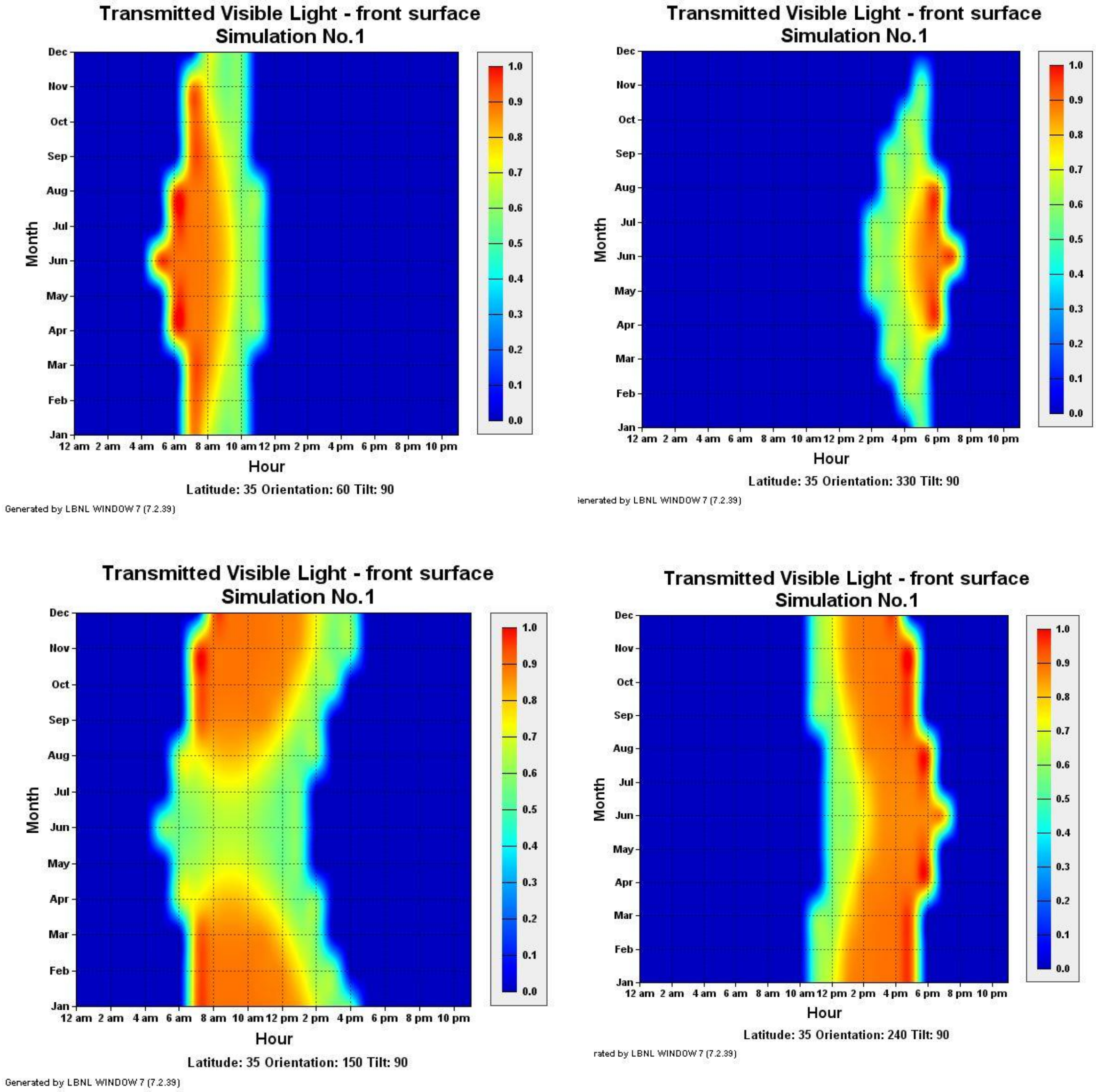


Figure 27: Transmitted Visible Light in Colored Building, Simulation No.1
(Modified by author, Based on WINDOW 7.2 Simulation tool)

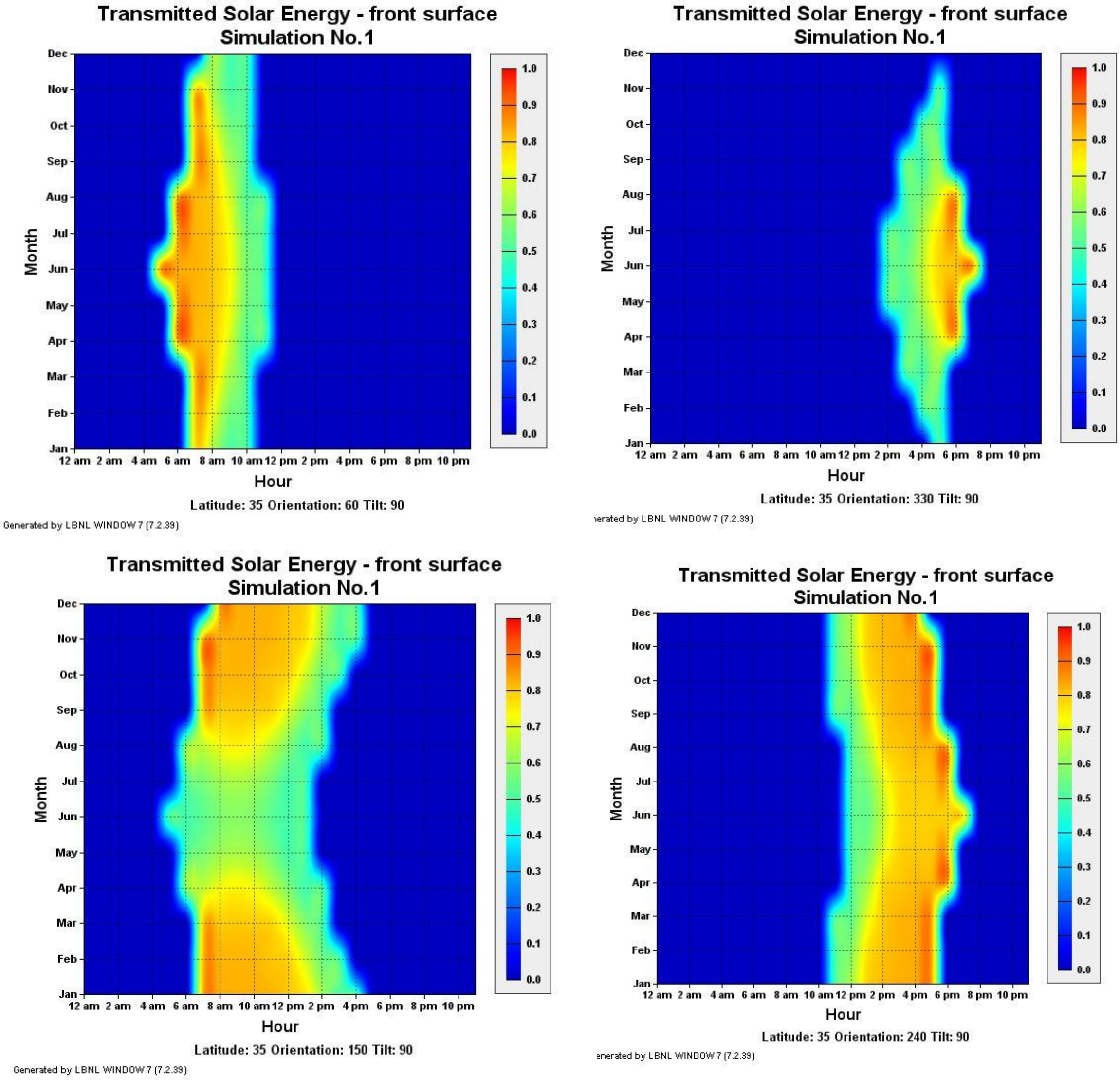


Figure 28: Transmitted Solar Energy in Colored Building, Simulation No.1
(Modified by author, Based on WINDOW 7.2 Simulation tool)

3.3.1.2 Simulation No. 2 Double Glazing with Clear Glasses

In this simulation, double clear glazing with 4 mm thickness with PVC frame and gas layers (Air10% -Argon 90%) with 10 mm in between was considered (Table 3 and Figures 29, 30).

Table 3 : Double glazing with clear glasses
(Drawn by author, Based on WINDOW 7.2 Simulation tool, 2014)

Input Data				*Output Data*		
Window Orientation	Width (cm)	Height (cm)	Area (m2)	U-value W/m2K	SHGC	Visible Transmittance
1.	300	300	9.00	2.540	0.717	0.761
2.	300	200	6.00	2.569	0.706	0.748
3.	400	200	8.00	2.570	0.712	0.754
4.	300	250	7.50	2.553	0.713	0.756
5.	200	300	6.00	2.539	0.706	0.748
6.	100	280	2.80	2.539	0.671	0.707
7.	100	300	3.00	2.535	0.673	0.708
8.	130	190	2.47	2.566	0.677	0.712
9.	530	100	5.30	2.620	0.683	0.719
10.	120	120	1.44	2.591	0.654	0.684
11.	200	70	1.40	2.626	0.637	0.663
12.	350	320	11.20	2.535	0.722	0.766
13.	300	110	3.30	2.610	0.680	0.716
14.	500	220	11.00	2.564	0.718	0.762
15.	570	220	12.54	2.564	0.720	0.764
16.	410	200	8.20	2.571	0.713	0.755

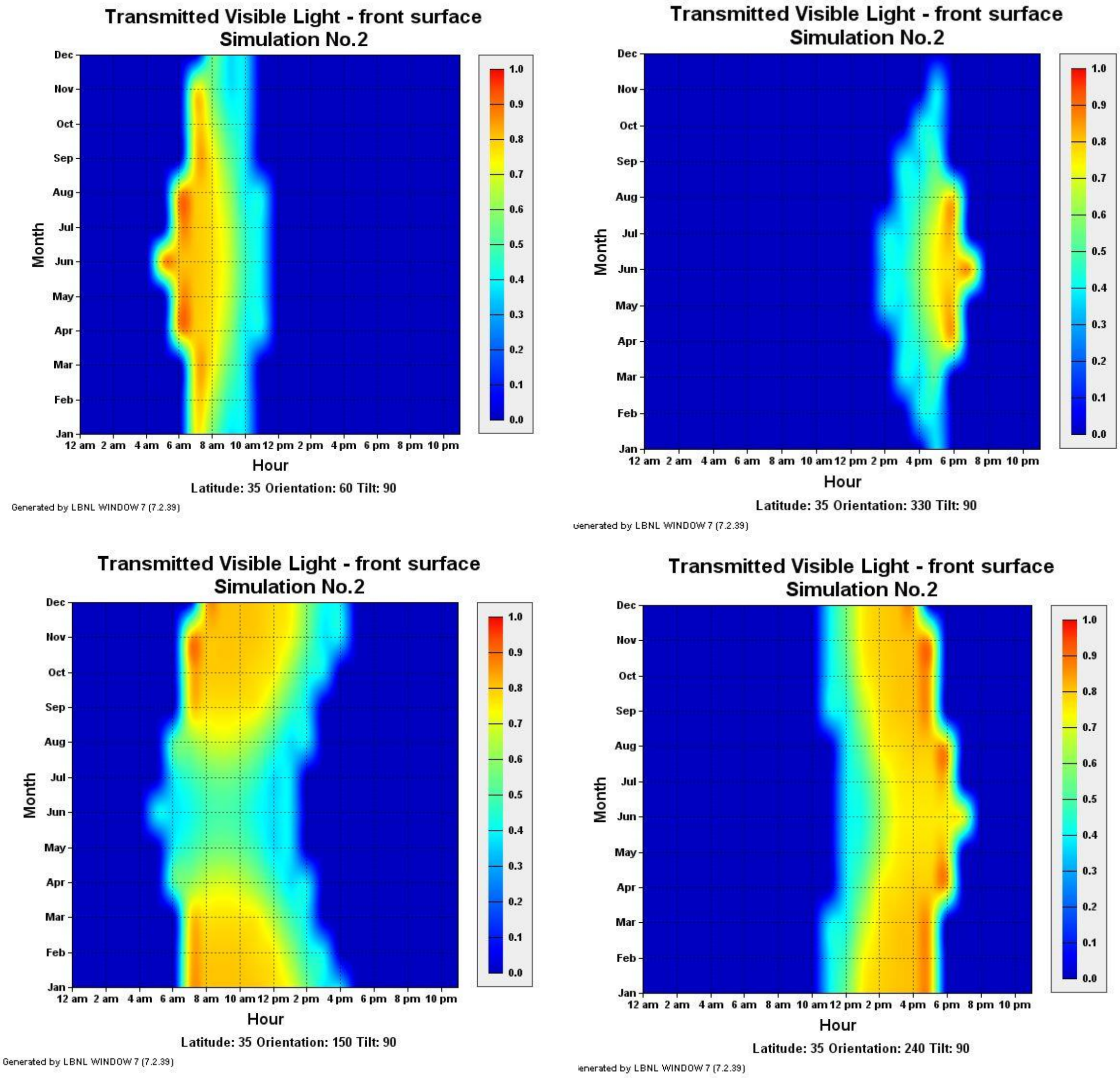


Figure 29: Transmitted Visible Light in Colored Building, Simulation No.2
(Modified by author, Based on WINDOW 7.2 Simulation tool)

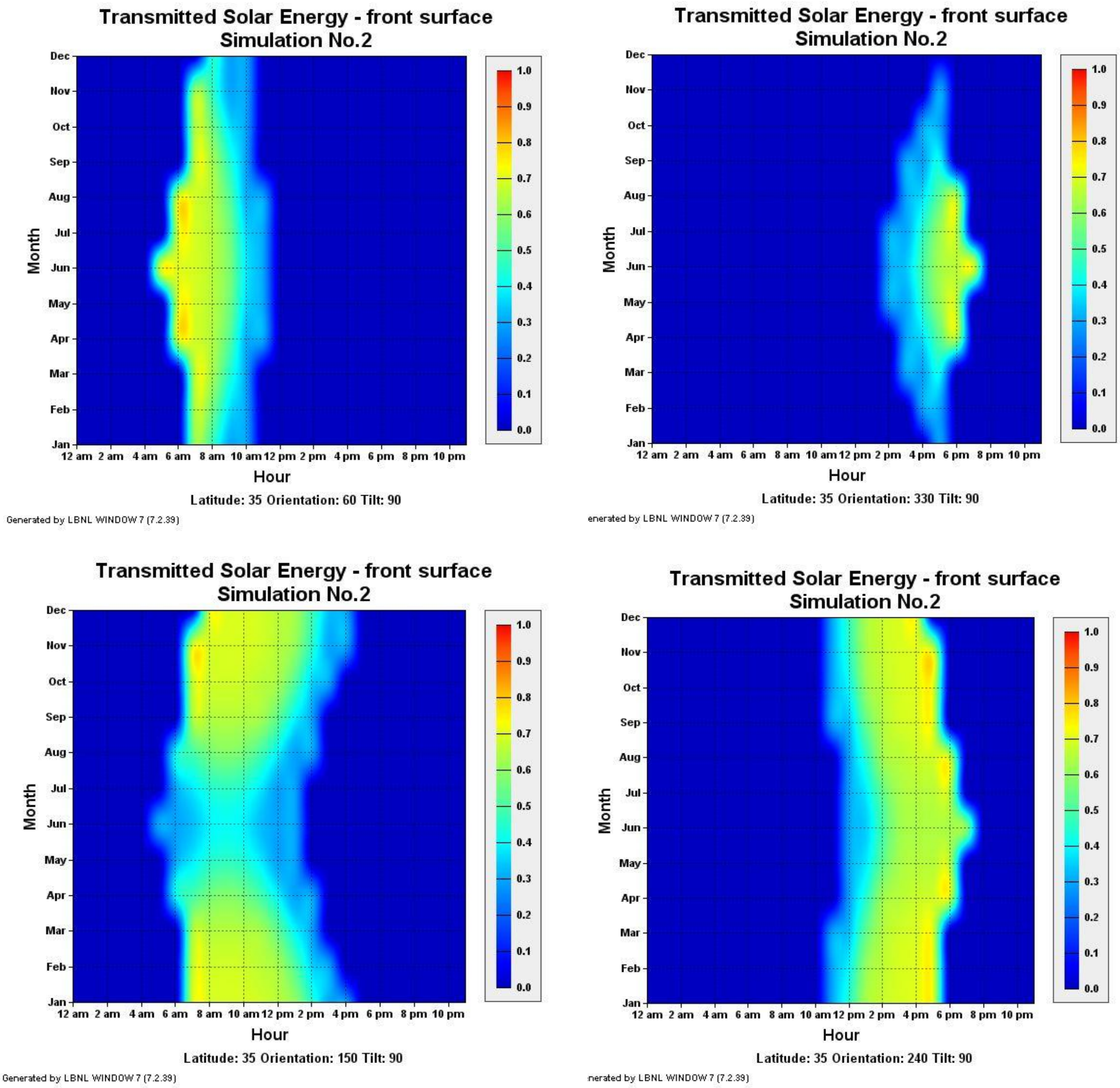
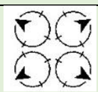


Figure 30: Transmitted Solar Energy in Colored Building, Simulation No.2
(Modified by author, Based on WINDOW 7.2 Simulation tool)

3.3.1.3 Simulation No. 3 Double Clear Glass with Low-E coating

In this simulation, double glazing with 4 mm thickness Low-E in outer space and clear glasses with 6mm thickness in inner space with PVC frame and gas layers air and krypton (Air 5% -Krypton 95%) with 10 mm in between was considered (Table 4 and Figures 31,32).

Table 4 : Double glazing with clear glasses+ low-E coating
(Drawn by author, Based on WINDOW 7.2 Simulation tool, 2014)

Input Data					*Output Data*	
Window Orientation	Width (cm)	Height (cm)	Area (m2)	U-value W/m2K	SHGC	Visible Transmittance
1. 	300	300	9.00	1.333	0.256	0.604
2. 	300	200	6.00	1.372	0.253	0.593
3. 	400	200	8.00	1.357	0.255	0.598
4. 	300	250	7.50	1.349	0.255	0.599
5. 	200	300	6.00	1.366	0.253	0.593
6. 	100	280	2.80	1.470	0.243	0.561
7. 	100	300	3.00	1.465	0.244	0.562
8. 	130	190	2.47	1.459	0.245	0.565
9. 	530	100	5.30	1.459	0.246	0.570
10. 	120	120	1.44	1.529	0.238	0.543
11. 	200	70	1.40	1.592	0.233	0.526
12. 	350	320	11.2 0	1.318	0.258	0.608
13. 	300	110	3.30	1.462	0.246	0.568
14. 	500	220	11.0 0	1.337	0.257	0.604
15. 	570	220	12.5 4	1.332	0.257	0.606
16. 	410	200	8.20	1.356	0.255	0.599

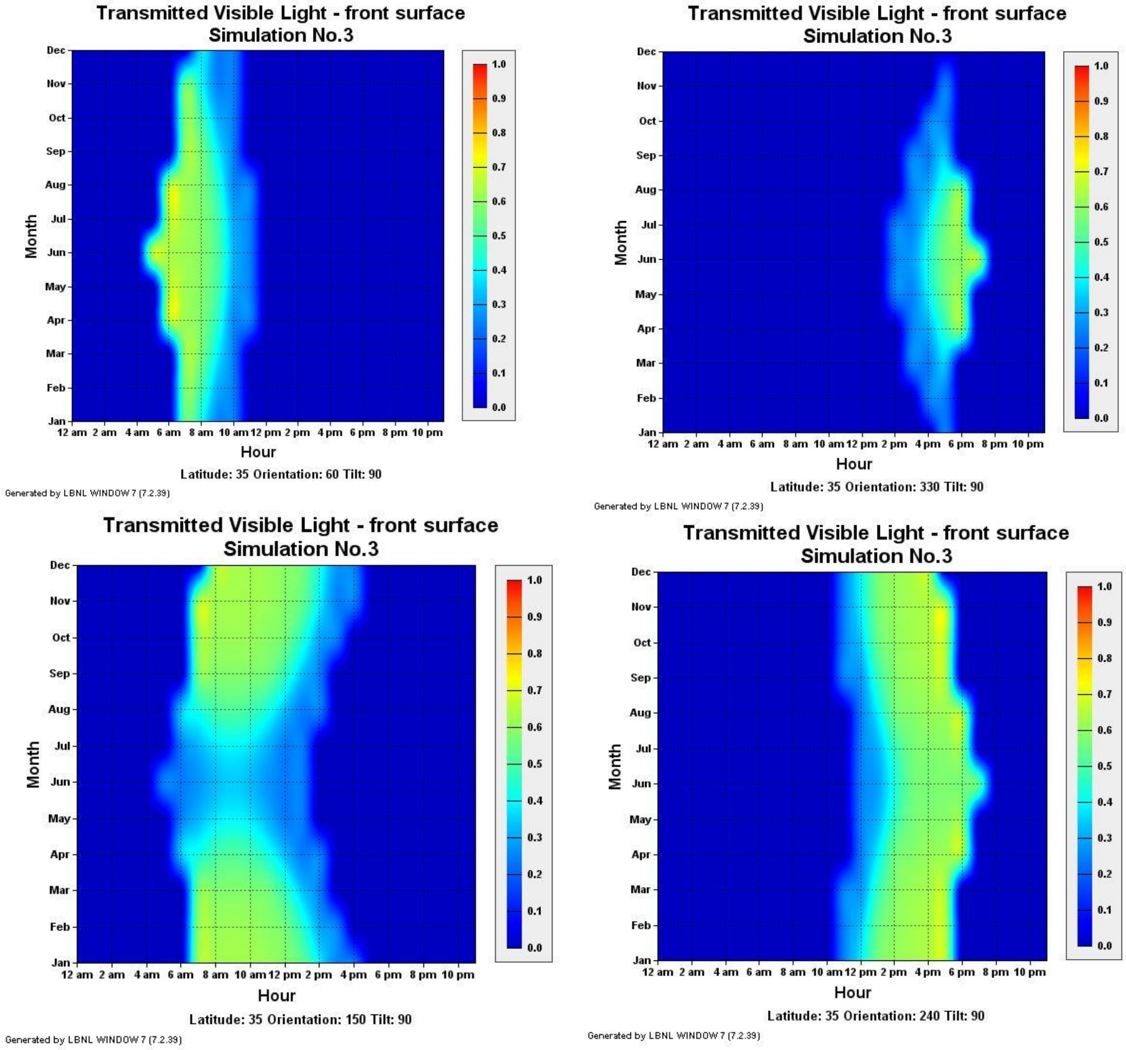


Figure 31: Transmitted Visible Light in Colored Building, Simulation No.3
(Modified by author, Based on WINDOW 7.2 Simulation tool)

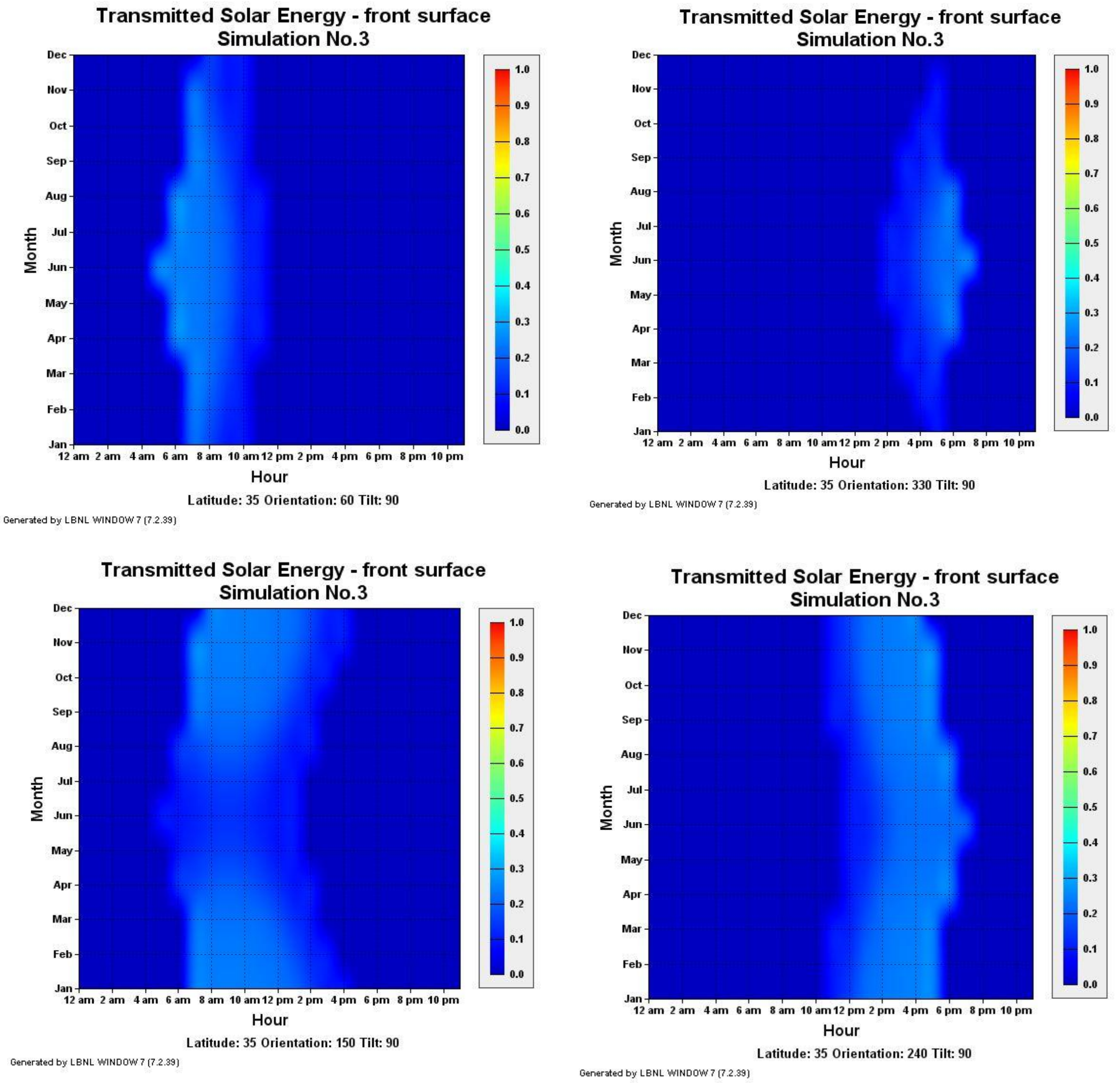
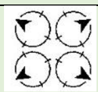


Figure 32: Transmitted Solar Energy in Colored Building, Simulation No.3
(Modified by author, Based on WINDOW 7.2 Simulation tool)

3.3.1.4 Simulation No. 4 Double Glazing with Low-E Glass

In this simulation, double glazing with 4 mm thickness Low-E in outer and inner space and with PVC frame and gas layers (Air 12%, Argon 22% and Krypton 66%) with 10 mm in between was considered (Table 5 and Figures 33,34).

Table 5: Double glazing with low-E glasses
(Drawn by author, Based on WINDOW 7.2 Simulation tool, 2014)

Input Data				*Output Data*		
Window Orientation	Width (cm)	Height (cm)	Area (m2)	U-value W/m2K	SHGC	Visible Transmittance
1. 	300	300	9.00	1.063	0.227	0.478
2. 	300	200	6.00	1.132	0.226	0.470
3. 	400	200	8.00	1.113	0.227	0.474
4. 	300	250	7.50	1.091	0.227	0.475
5. 	200	300	6.00	1.106	0.224	0.470
6. 	100	280	2.80	1.240	0.216	0.444
7. 	100	300	3.00	1.232	0.216	0.445
8. 	130	190	2.47	1.244	0.219	0.448
9. 	530	100	5.30	1.272	0.223	0.452
10. 	120	120	1.44	1.351	0.215	0.430
11. 	200	70	1.40	1.447	0.212	0.417
12. 	350	320	11.20	1.041	0.228	0.482
13. 	300	110	3.30	1.272	0.222	0.450
14. 	500	220	11.00	1.082	0.228	0.479
15. 	570	220	12.54	1.076	0.229	0.480
16. 	410	200	8.20	1.111	0.227	0.474

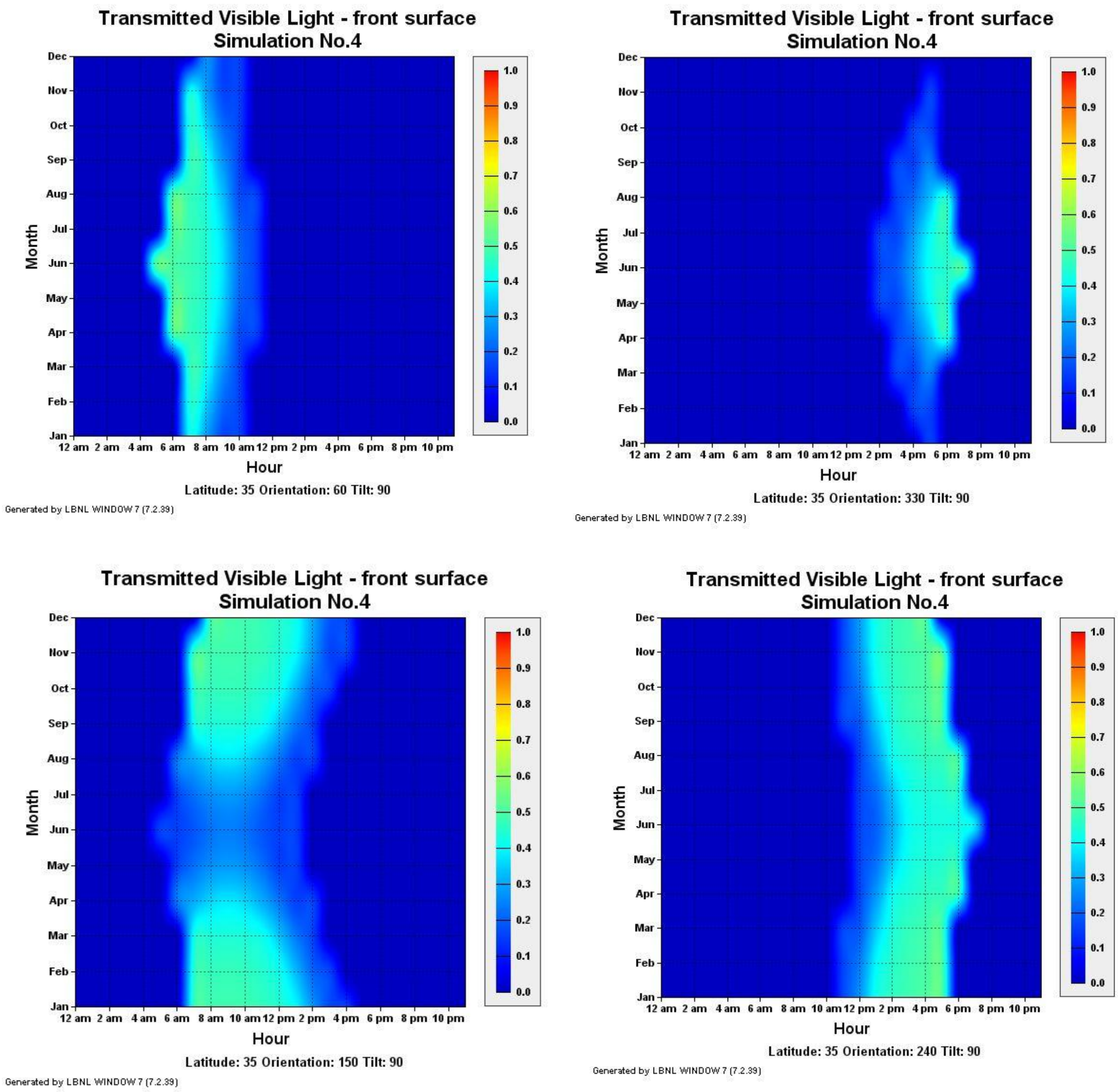


Figure 33: Transmitted Visible Light in Colored Building, Simulation No.4
(Modified by author, Based on WINDOW 7.2 Simulation tool)

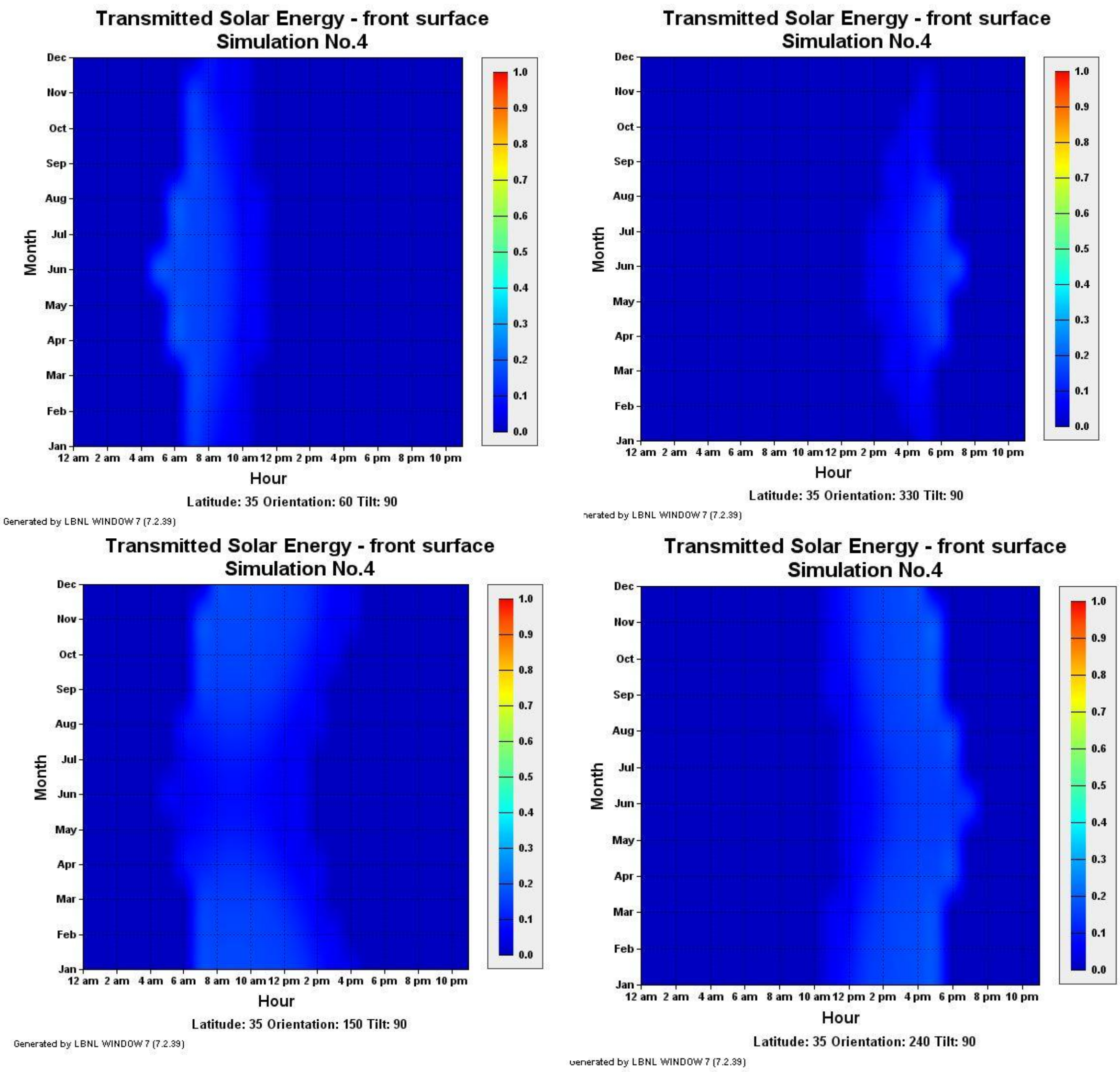


Figure 34: Transmitted Solar Energy in Colored Building, Simulation No.4
(Modified by author, Based on WINDOW 7.2 Simulation tool)

3.3.1.5 Simulation No. 5 Triple Glazing with Clear Glasses

In this simulation, triple clear glass with 4 mm thickness with PVC frame and gas layers (Air10% -Argon 90%) with 10 mm in between was considered (Table 6 and Figures 35, 36).

Table 6: Triple glazing with clear glass
(Drawn by author, Based on WINDOW 7.2 Simulation tool, 2014)

Input Data				*Output Data*		
Window Orientation	Width (cm)	Height (cm)	Area (m2)	U-value W/m2K	SHGC	Visible Transmittance
1.	300	300	9.00	1.758	0.643	0.693
2.	300	200	6.00	1.790	0.634	0.681
3.	400	200	8.00	1.781	0.639	0.687
4.	300	250	7.50	1.772	0.640	0.688
5.	200	300	6.00	1.778	0.634	0.681
6.	100	280	2.80	1.841	0.603	0.644
7.	100	300	3.00	1.837	0.604	0.645
8.	130	190	2.47	1.842	0.608	0.648
9.	530	100	5.30	1.856	0.614	0.655
10.	120	120	1.44	1.890	0.587	0.623
11.	200	70	1.40	1.937	0.572	0.604
12.	350	320	11.20	1.748	0.647	0.698
13.	300	110	3.30	1.855	0.611	0.652
14.	500	220	11.00	1.767	0.644	0.694
15.	570	220	12.54	1.764	0.646	0.695
16.	410	200	8.20	1.780	0.639	0.687

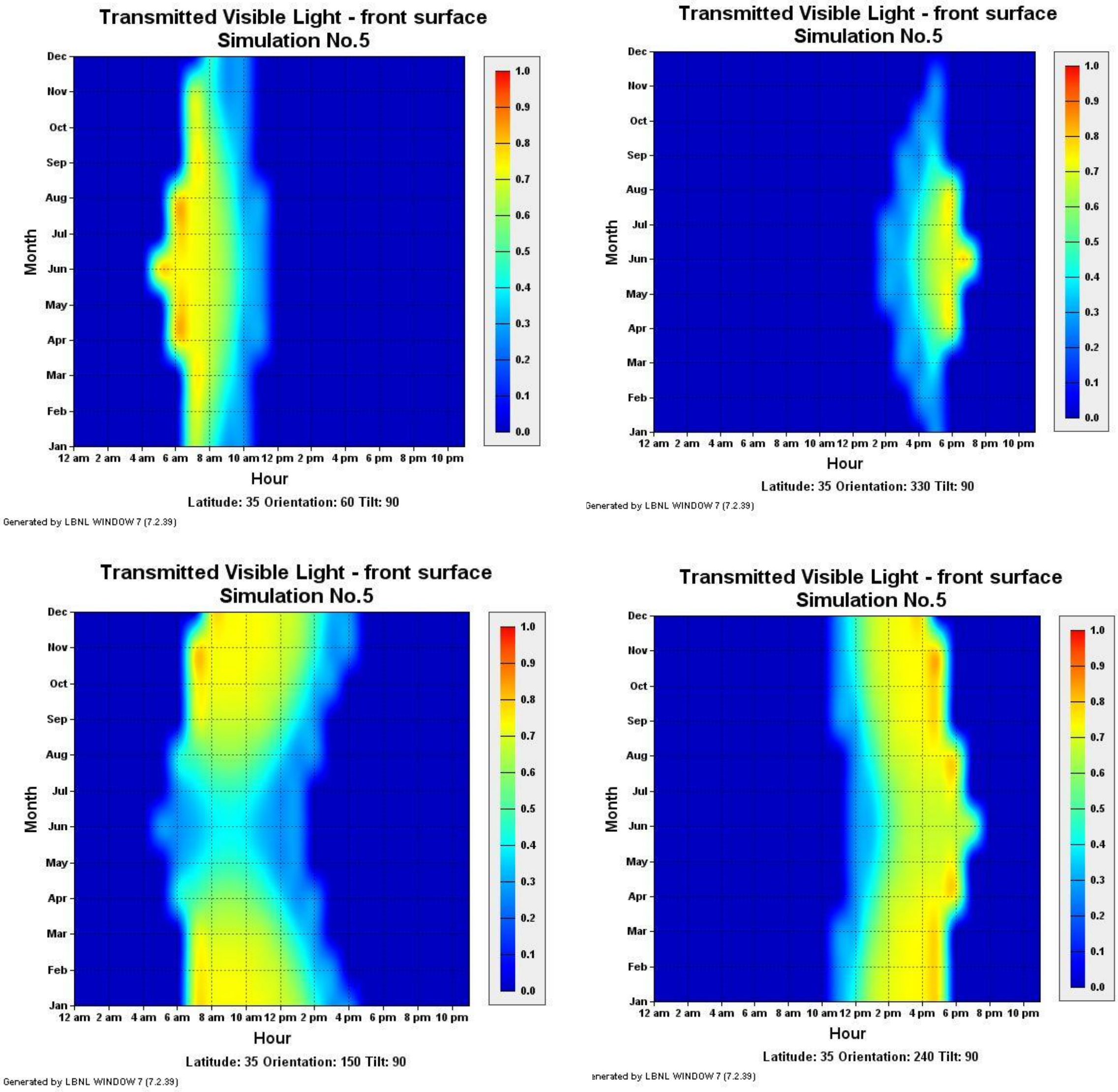


Figure 35: Transmitted Visible Light in Colored Building, Simulation No.5 (Modified by author, Based on WINDOW 7.2 Simulation tool)

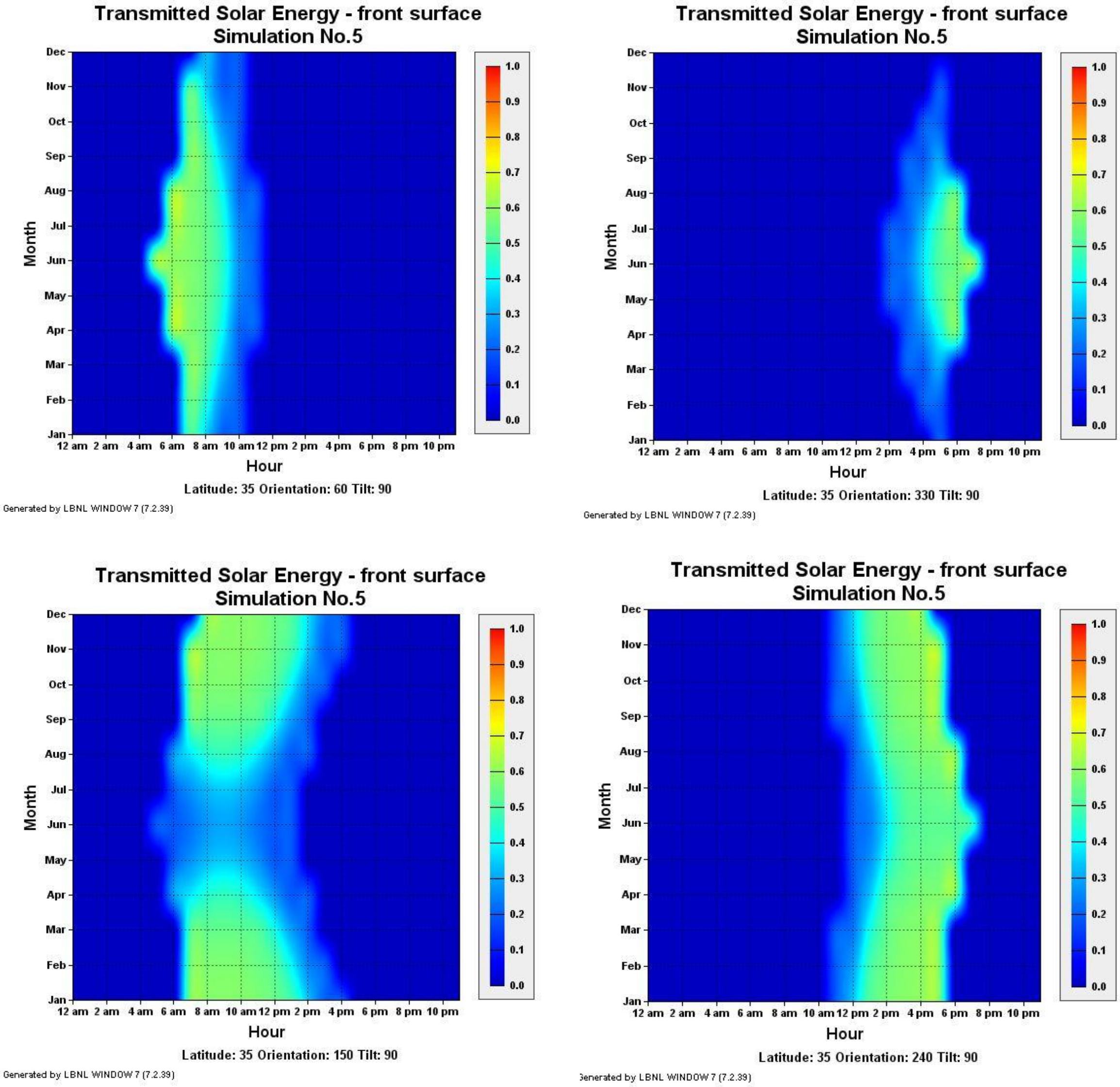
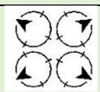


Figure 36: Transmitted Solar Energy in Colored Building, Simulation No.5 (Modified by author, Based on WINDOW 7.2 Simulation tool)

3.3.1.6 Simulation No. 6 Triple Clear Glass with Low-E Coating

In this simulation, triple glazing with 4 mm thickness Low-E in outer space and inner space and clear glasses with 6mm thickness in middle with PVC frame and gas layers air and krypton (Air 5% -Krypton 95%) with 10 mm in between was considered (Table 7 and Figures 37,38).

Table 7: Triple clear glass +low-E coating
(Drawn by author, Based on WINDOW 7.2 Simulation tool, 2014)

Input Data				*Output Data*		
Window Orientation	Width (cm)	Height (cm)	Area (m2)	U-value W/m2K	SHGC	Visible Transmittance
1. 	300	300	9.00	0.892	0.214	0.435
2. 	300	200	6.00	0.958	0.213	0.428
3. 	400	200	8.00	0.935	0.214	0.431
4. 	300	250	7.50	0.919	0.214	0.432
5. 	200	300	6.00	0.940	0.212	0.428
6. 	100	280	2.80	1.093	0.204	0.404
7. 	100	300	3.00	1.085	0.204	0.405
8. 	130	190	2.47	1.085	0.207	0.407
9. 	530	100	5.30	1.094	0.210	0.411
10. 	120	120	1.44	1.194	0.203	0.391
11. 	200	70	1.40	1.290	0.200	0.379
12. 	350	320	11.20	0.869	0.215	0.438
13. 	300	110	3.30	1.098	0.209	0.409
14. 	500	220	11.00	0.904	0.215	0.436
15. 	570	220	12.54	0.897	0.216	0.437
16. 	410	200	8.20	0.933	0.214	0.432

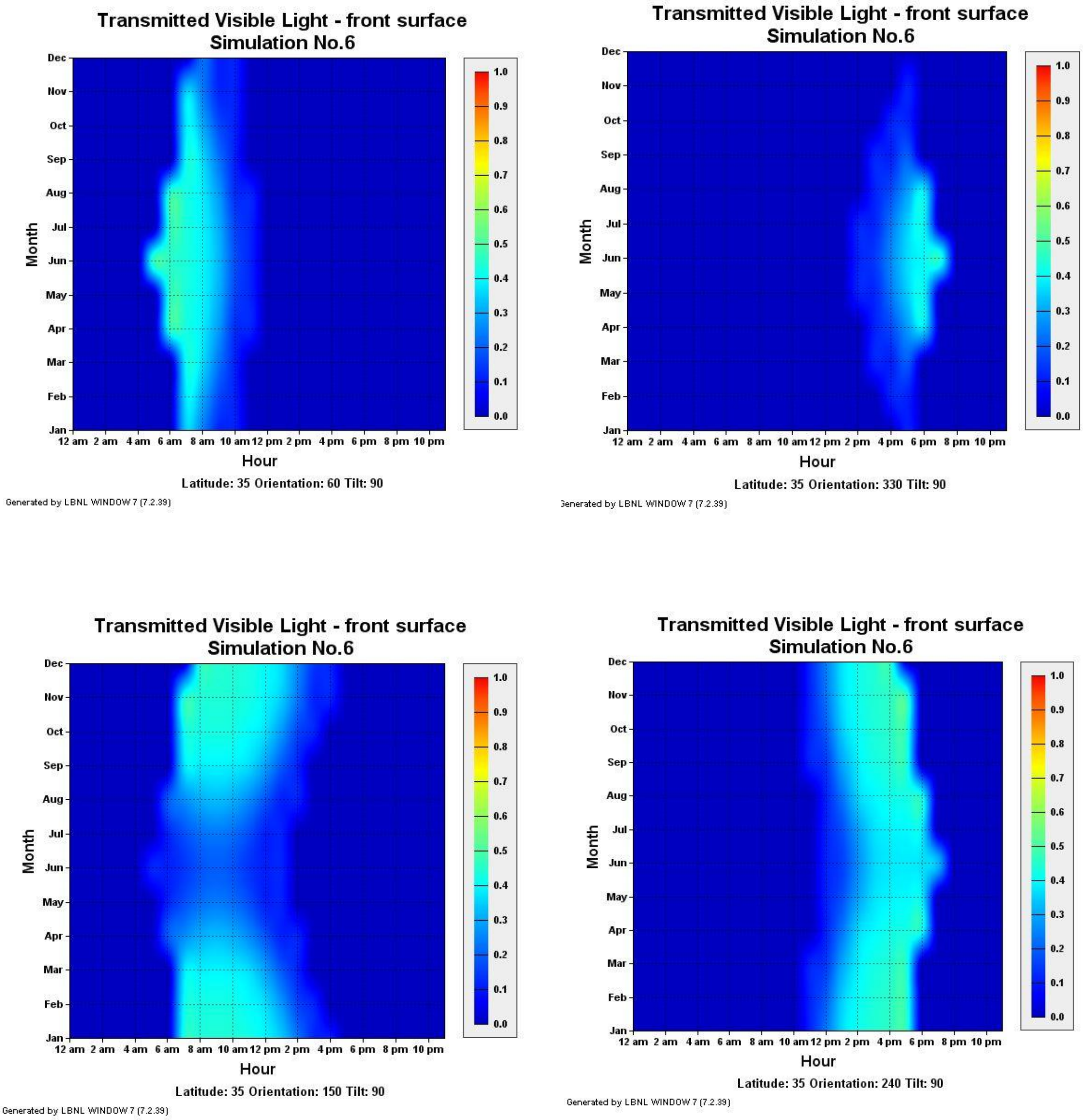


Figure 37: Transmitted Visible Light in Colored Building, Simulation No.6
(Modified by author, Based on WINDOW 7.2 Simulation tool)

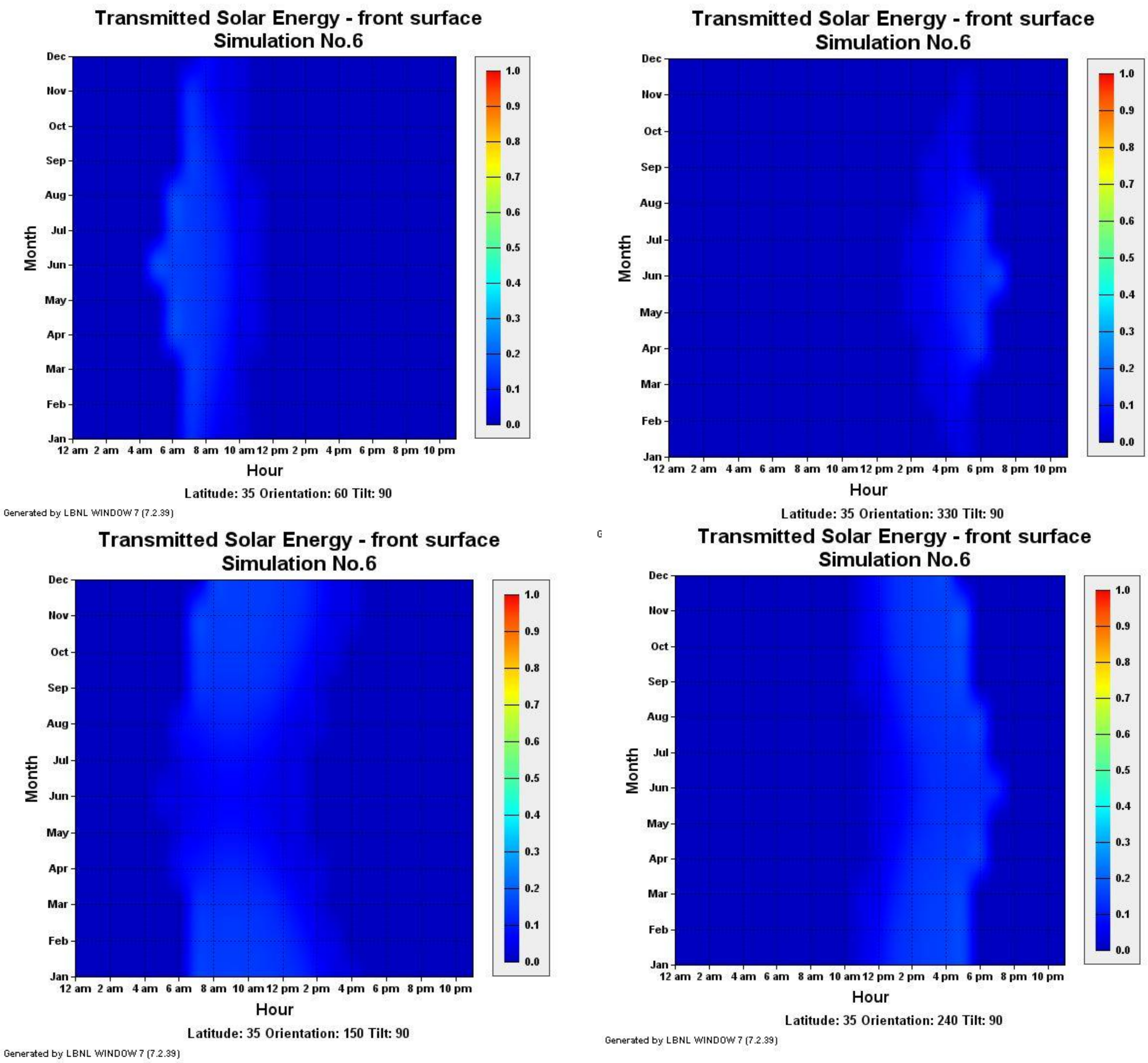


Figure 38: Transmitted Solar Energy in Colored Building, Simulation No.6
(Modified by author, Based on WINDOW 7.2 Simulation tool)

3.3.1.7 Simulation No. 7 Triple Glazing with Low-E Glasses

In this simulation, triple glazing with 4 mm thickness Low-E in outer, middle and inner space and with PVC frame and gas layers (Air 12%, Argon 22% and Krypton 66%) with 10 mm in between was considered (Table 8 and Figures 39,40).

Table 8: Triple glazing with low-E glasses
(Drawn by author, Based on WINDOW 7.2 Simulation tool, 2014)

Input Data				*Output Data*		
Window Orientation	Width (cm)	Height (cm)	Area (m2)	U-value W/m2K	SHGC	Visible Transmittance
1.	300	300	9.00	0.723	0.185	0.344
2.	300	200	6.00	0.787	0.184	0.338
3.	400	200	8.00	0.761	0.185	0.341
4.	300	250	7.50	0.749	0.185	0.342
5.	200	300	6.00	0.777	0.183	0.338
6.	100	280	2.80	0.949	0.177	0.320
7.	100	300	3.00	0.941	0.177	0.320
8.	130	190	2.47	0.930	0.179	0.322
9.	530	100	5.30	0.924	0.182	0.325
10.	120	120	1.44	1.044	0.176	0.310
11.	200	70	1.40	1.143	0.174	0.300
12.	350	320	11.20	0.699	0.185	0.347
13.	300	110	3.30	0.931	0.181	0.324
14.	500	220	11.00	0.728	0.186	0.345
15.	570	220	12.54	0.720	0.186	0.345
16.	410	200	8.20	0.759	0.185	0.341

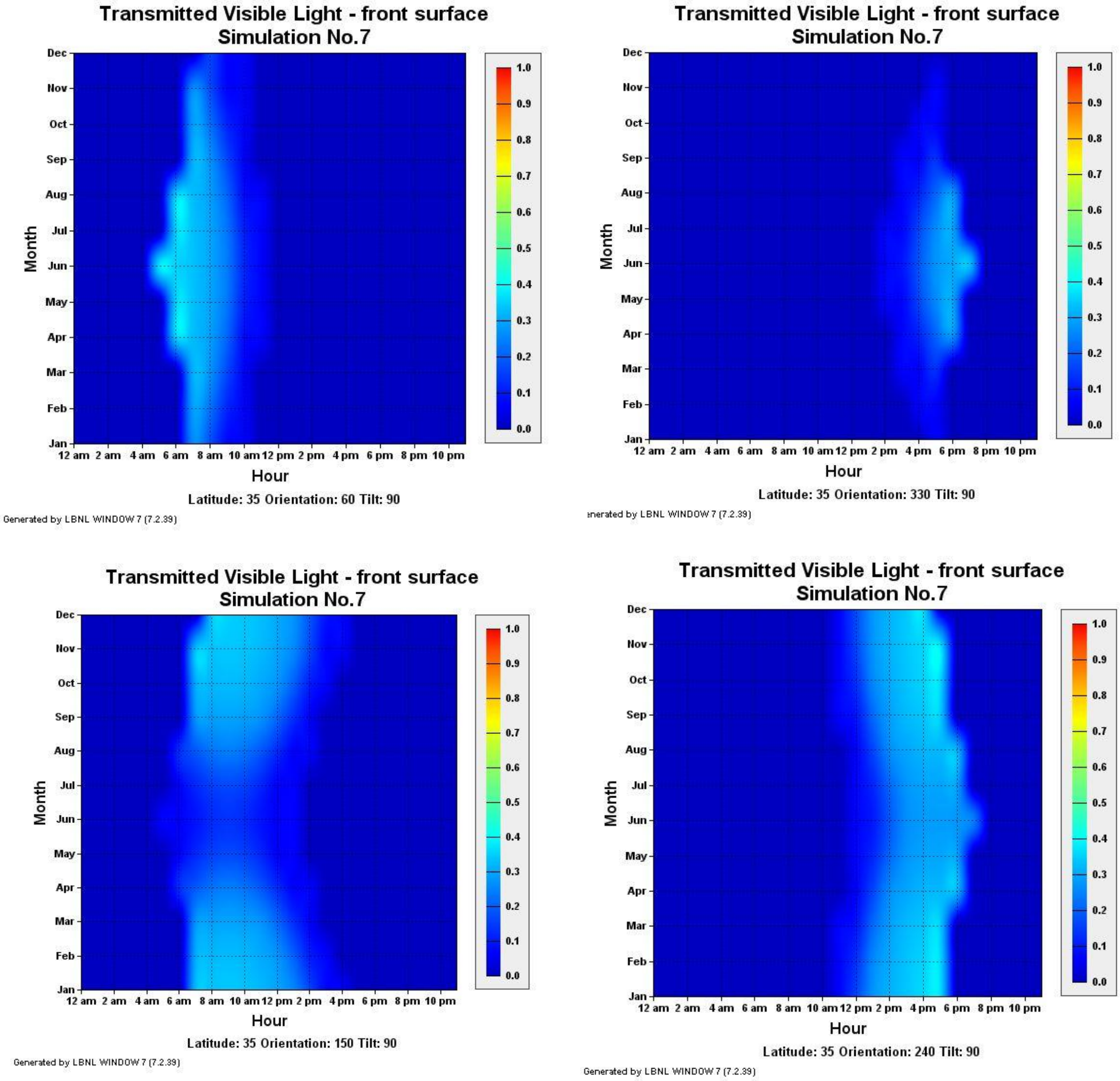


Figure 39: Transmitted Visible Light in Colored Building, Simulation No.7
(Modified by author, Based on WINDOW 7.2 Simulation tool)

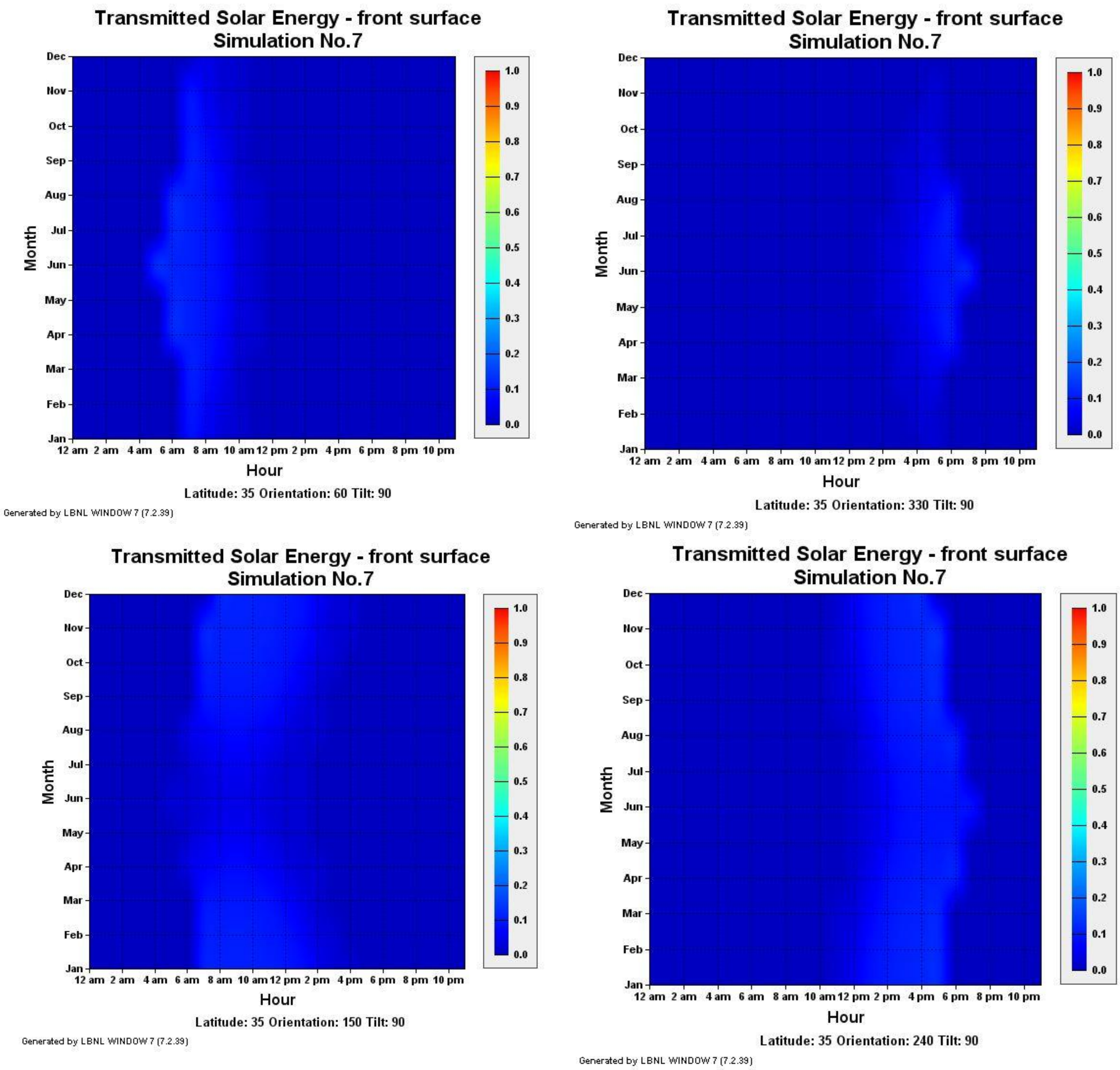


Figure 40: Transmitted Solar Energy in Colored Building, Simulation No.7
(Modified by author, Based on WINDOW 7.2 Simulation tool)

3.4 Discussion and Result

In this study, the energy performance of windows glazing was evaluated in the Colored Building with 7 simulations. The summary of all those simulations is demonstrated in in Figure 41, Table 9 also with the following explanations.

In simulation No.1, single clear glass which is the current windows glazing shows poor design in terms of thermal conductivity and solar heat gain, and contributes to the highest thermal conductivity (5.156) during summer and winter as well as unwanted heat gain (0.808) in summer time.

In simulation No.2, with adding one more pane to the single clear glass and gas layers (Air10%, Argon 90%), thermal conductivity became around half compared to the previous simulation (2.540). However, still there remains a high level of solar transmittance (0.717) which is due to the lack of low-E coating on glass surfaces.

In simulation No.3, double glazing with low-E in outer space were used and the gas layers percentages were changed to 5% Air and 95% Krypton. Here, thermal conductivity reaches to less than one third of simulation 1 (1.333). While the amount of solar transmittance significantly decreased to 0.256 which shows a large amount of unwanted heat has been reflect to outer space, there is only a minor change in visible transmittance (0.604).

In simulation No.4, double glazing with two low-e coating on both surfaces of the glass with a new combination of gas layers (Air 12%, Argon 22% and Krypton 66%) made the results to reach around one fifth of simulation 1, with thermal conductivity of 1.063. The amount of solar heat gain (0.227) was however close to the previous simulation.

In simulation No.5, triple clear glass with gas layers of 10% Air and 90% Argon proved a dramatic increase in thermal conductivity (1.758) and 0. 643 unwanted heat gain transmittance in summer period.

In simulation No.6, triple clear glass with low-E coating on two surfaces of the glass and one clear glass layer with combination of 5% Air and 95% Krypton in between reduced the amount of thermal conductivity and solar heat considerably to 0.892 and 0.214 respectively.

In simulation No.7, which was the last simulation, low-E coating had been placed on inner, outer and middle of the surfaces on triple glazing, and a mixture of 12% Air, 22% Argon, and 66% Krypton in between. It led to have almost one seventh of the simulation 1 results in terms of thermal conductivity (0.723) as well as reduction in unwanted heat gain (0.185) in summer time.

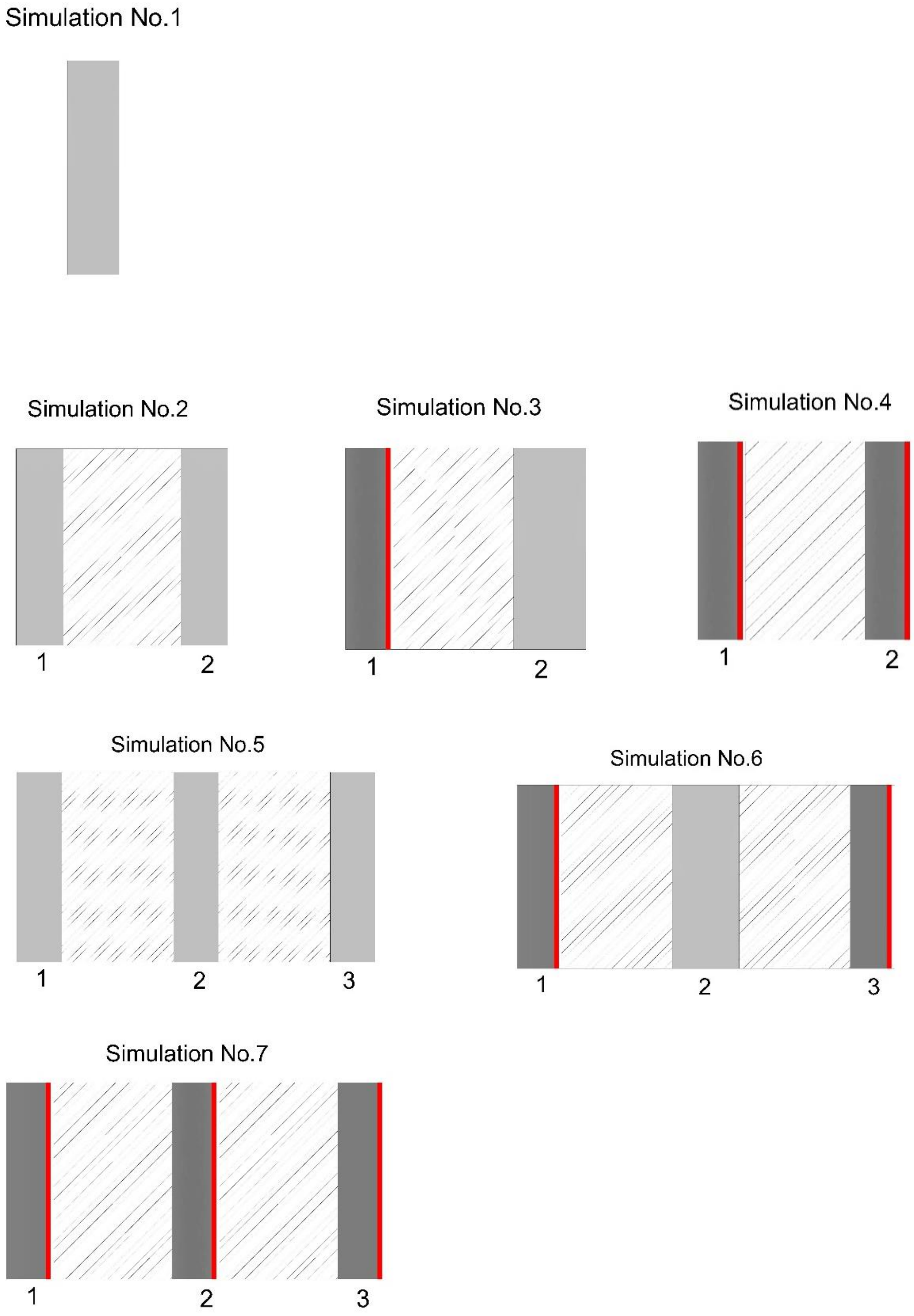
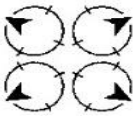


Figure 41: Low-E Coated Position And Its Combination with Clear Glasses in Seven Simulation (Drawn by author, 2014)

Table 9: Summary of seven simulations (windows 300*300 dimension) with thermal conductivity,solar heat gain coefficent and visible transmittance.
(Drwan by author,Based on WINDOW 7.2 Simulation tool, 2015)

	**Number of Pane**	**U-value W/m2K**	**SHGC**	**Visible Transmittance**
Simulation No.1	Single	5.156	0.808	0.840
Simulation No.2	Double	2.540	0.717	0.761
Simulation No.3	Double	1.333	0.256	0.604
Simulation No.4	Double	1.063	0.227	0.478
Simulation No.5	Triple	1.758	0.643	0.693
Simulation No.6	Triple	0.892	0.214	0.435
Simulation No.7	Triple	0.723	0.185	0.344

Chapter 4

CONCLUSION

The development of low emissivity over the past twenty years has brought advanced technology to minimize the long wave radiant and adjacent infrared wavelength. In addition, overall thermal resistance of windows glazing is based on using low conductivity gas to reduce both conduction and convection of heat transfer mechanism, insulating material of the frame, and thermal broken spacer through windows glazing. All of them contribute to help in optimizing the energy performance of windows and fenestration products. It should be noted that U-value is not the only factor for measuring the energy efficiency of windows and taking its transmitting properties into account. With comprehensive understanding of thermal and optical properties through windows, manufactures and designers are able to design and produce more efficient windows with advanced technologies.

Scholars and scientific communities all agree that energy efficient windows save more energy. However, coated glass technology is not sufficient and should be more widespread in order to increase this product popularity and develop windows energy rating into building regulation.

Researchers have found out where thermal conduction (U-value) decreases as low as possible, larger windows area might be used to collect more light. Furthermore, in buildings that are located in cold climates and heating demand is primary important, the amount of solar heat gain (g-value) should be increased, while in buildings that are located in warm climate and cooling demand is its primary issue, unwanted heat in summer time should be avoided and solar heat gain (g-value) needs to be decreased with maintained light transmittance.

The question of ‘how to select a high performance energy efficient window?’ always remains for a given building. Moreover, the energy demand in a building is highly grounded on proper selection of windows. Therefore, in order to simplify windows selection, it is highly recommended to use windows simulation tool whether on the early stage of design process of a new building or for replacement of existing windows for any regional, national, or global scale.

This study aimed to minimize the amount of heat loss and reduce the solar heat gain while maintaining the visible transmittance in windows glazing via WINDOW 7.2 application. Considering Cyprus having hot and humid climate with high cooling demand not only in summer time but most months of the year, the first simulation as an existing with single clear glazing in Colored Building was considered poor and far away in terms of energy efficiency.

According to the Colored Building orientation (30 degrees to North) for south-east, in May, Jun and July there is minimum solar transmittance and just the opposite is in January, February, March, September, October and November with maximum solar transmittance in the morning and noon time, almost between 7:00am and 2:00pm. In addition, for south-west orientation, maximum solar transmittance occurs in May, Jun and July approximately between 12:00pm and 7:00pm.

On the other hand, in May, Jun and July, early in the morning, between 4:30am and 7:00am, in north-east orientations, solar transmittance is the opposite for north-west in between 5:00pm and 8:00pm with maximum solar transmittance. Colored Building functions as an educational building which is extremely under usage between 8:00am and 4:30 in the afternoon, with south-east and south-west orientation.

Hence, it is highly recommend using double or tripling low-e coated glasses (simulations No.4, No.6 or No.7) to reduce the amount of heat loss as well as preventing the unwanted heat gain before penetration into the interior space for south-east and south-west orientations. In addition, for north-east and north-west using double or tripling low-e coated glasses (simulations No.3 or No.5) is required to reduce the amount of heat loss through windows glazing so to optimize the energy performance in all four orientations.

Finally, a window glazing is required to minimize heat loss while maintaining the visible transmittance to provide both light and heat for different months of a year, which consequently brings the fuel bills down and enhances the comfort.

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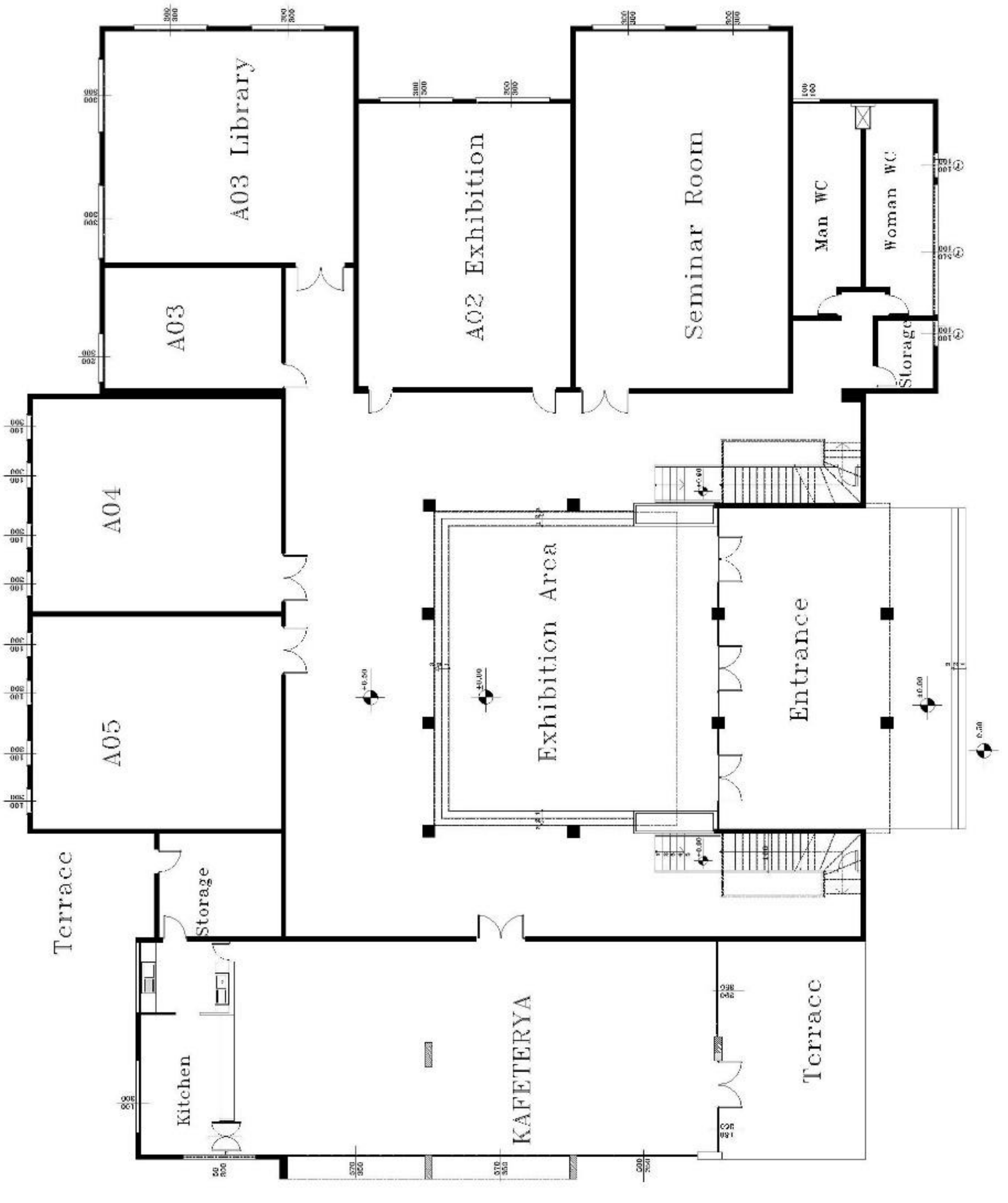
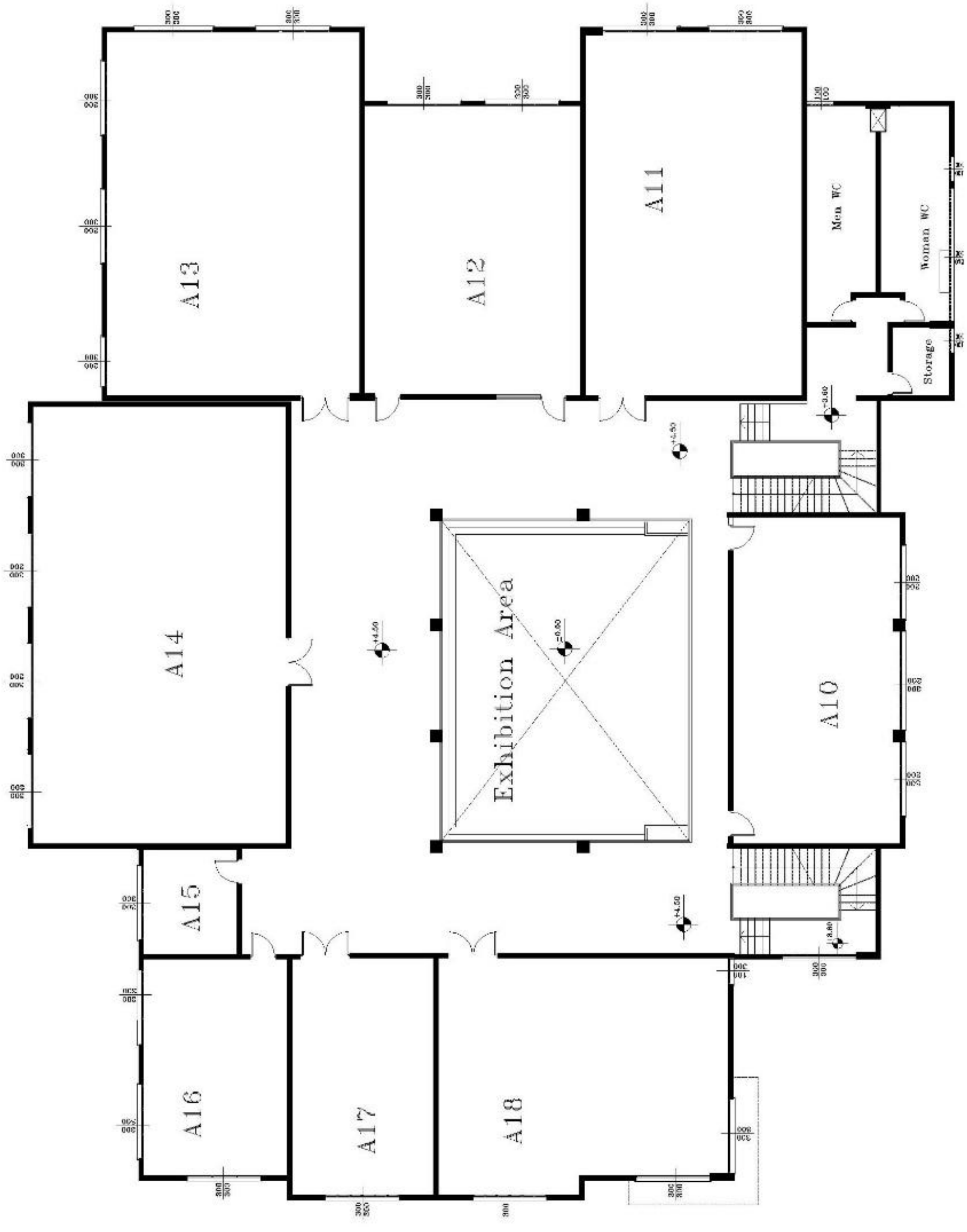
APPENDICES

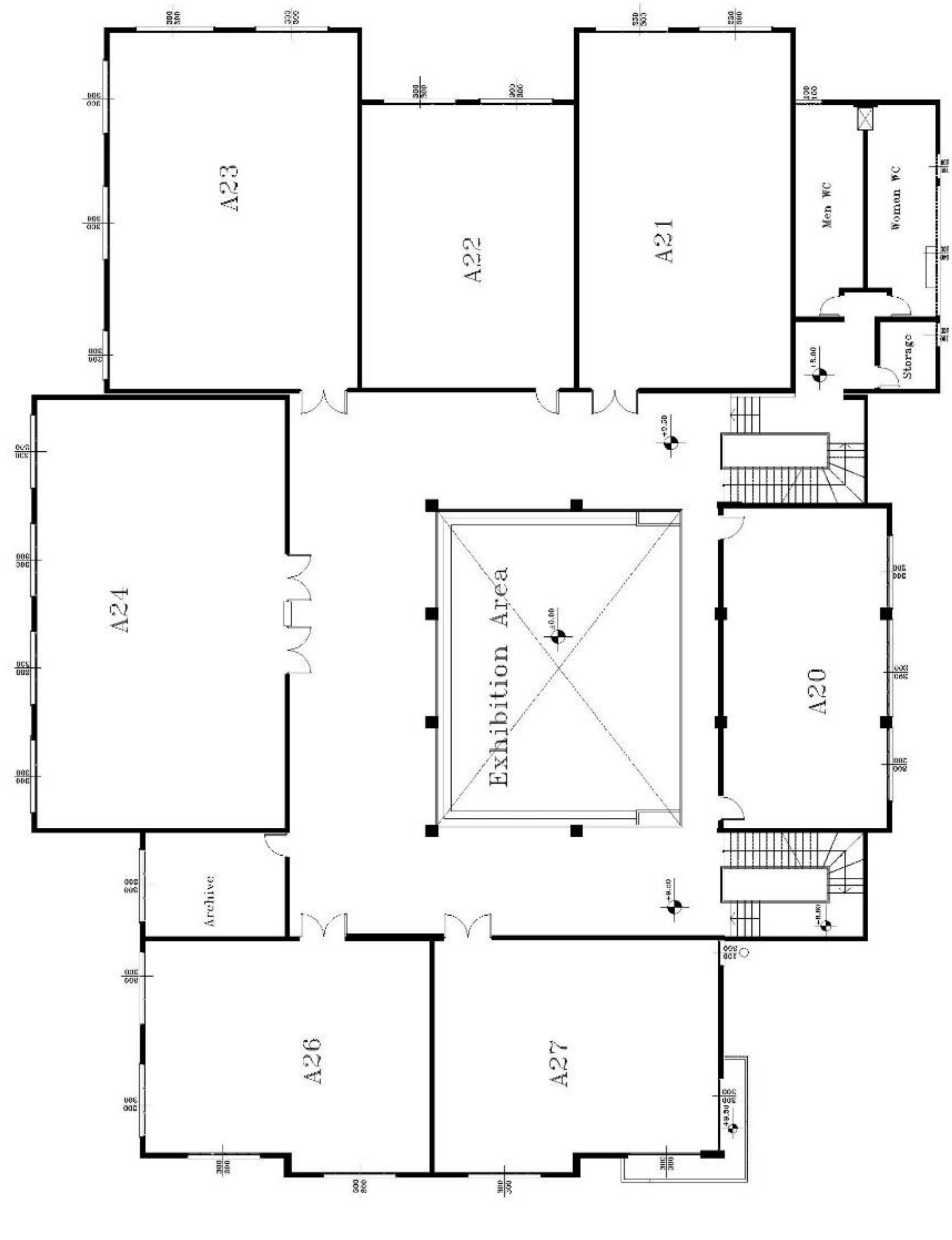
Appendix A: Colored Building Plans



Ground Floor Sc:1/100

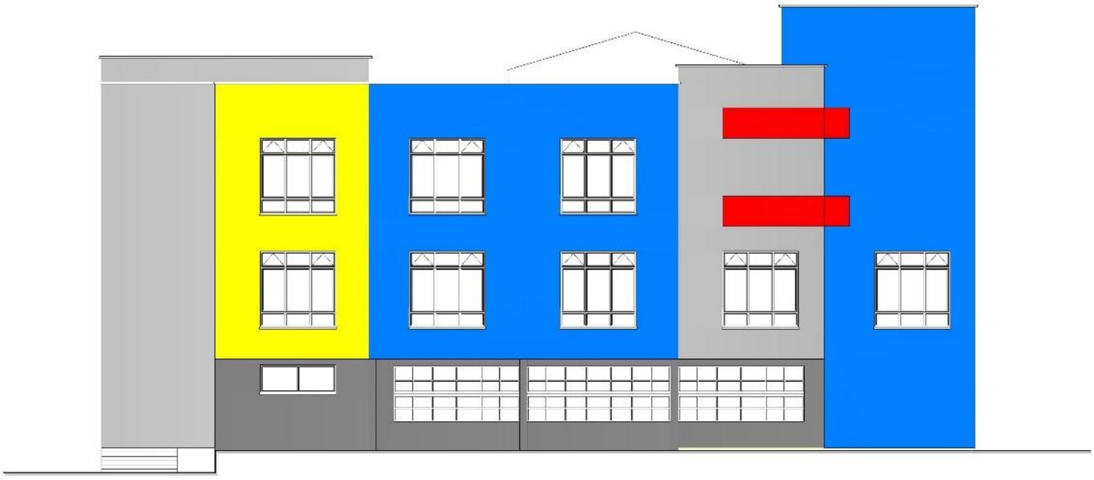


First Floor Sc:1/100

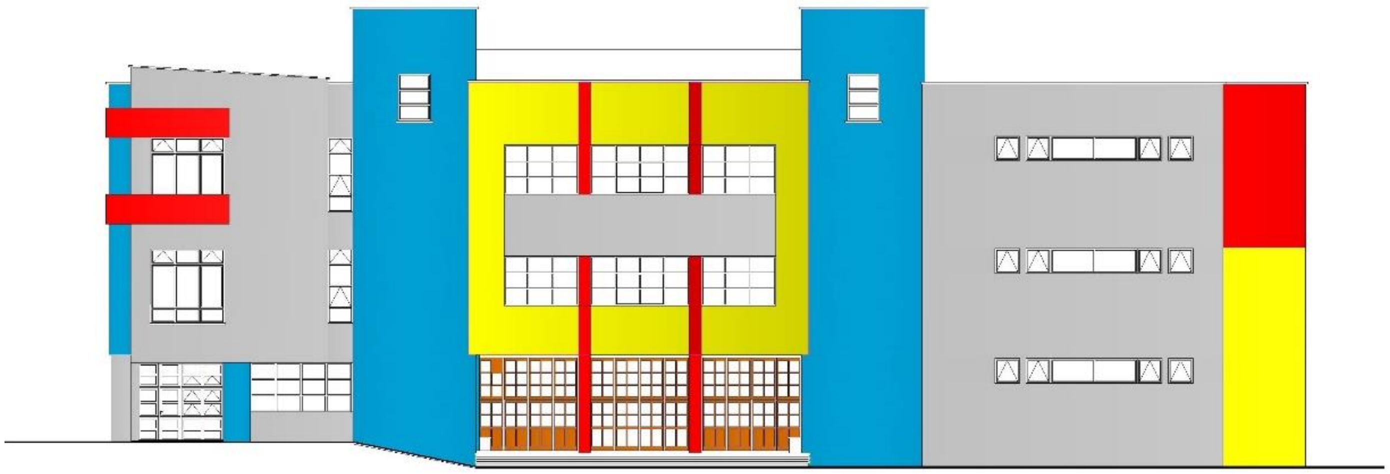


Second Floor Sc: 1/100

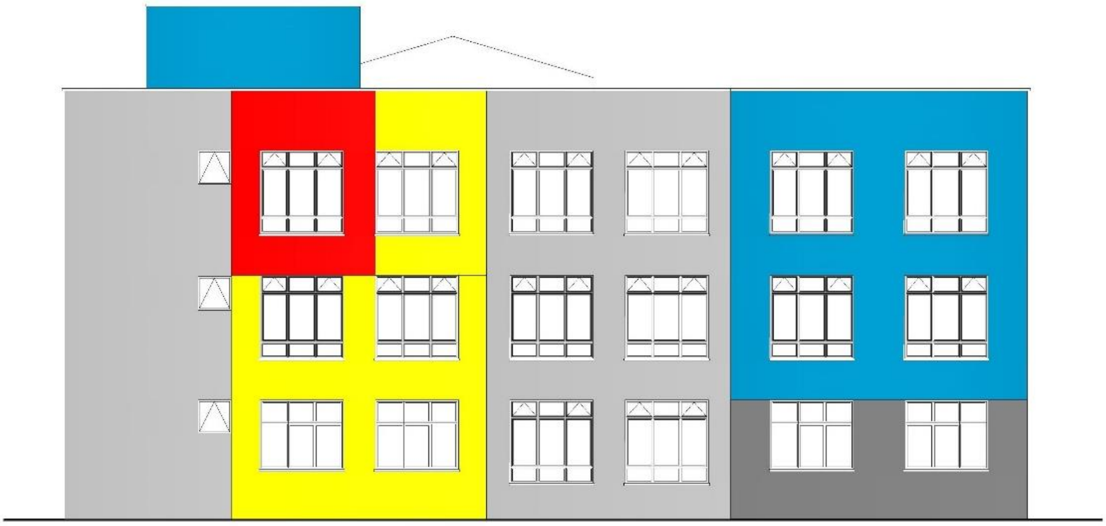
Appendix B: Colored Building Elevation



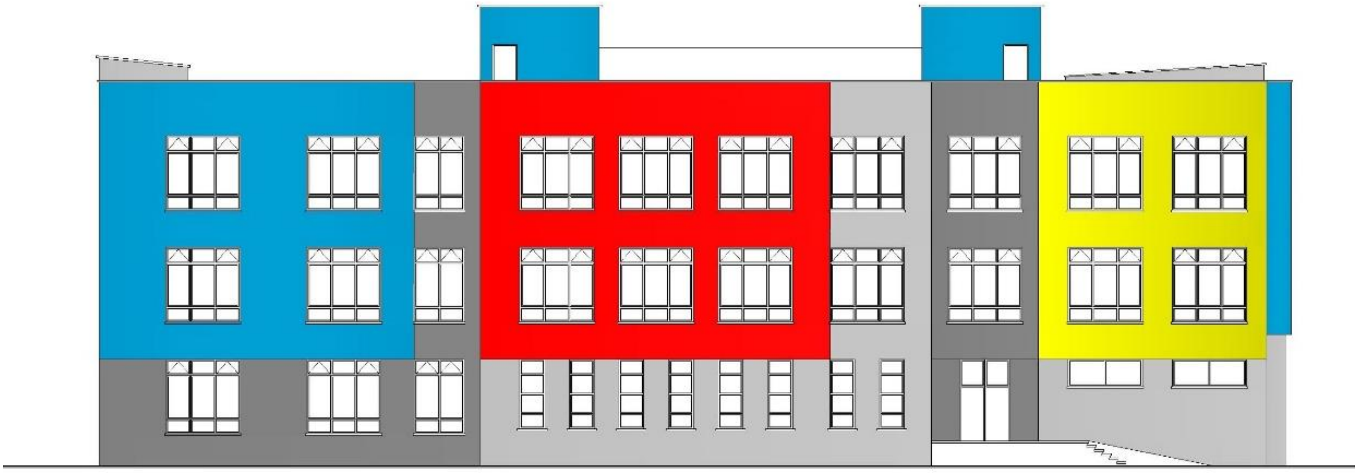
South-West Elevation



South -East Elevation

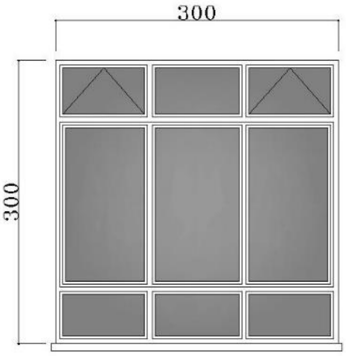


North- East Elevation



North-West Elevation

Appendix C: Windows Type in Colored Building



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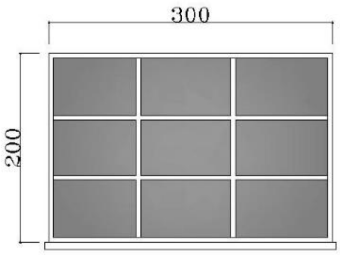
Studio Classes



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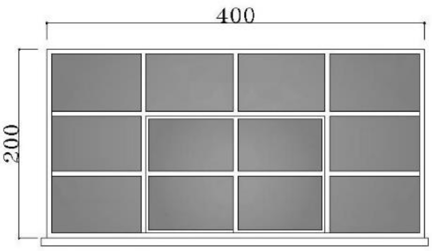

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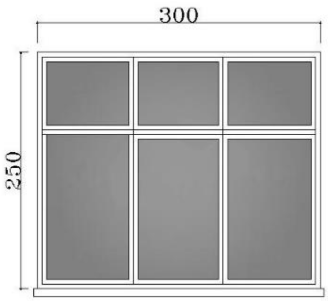

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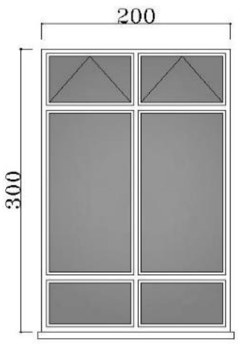

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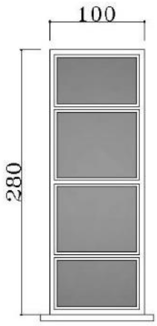

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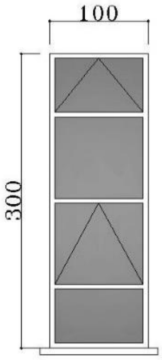

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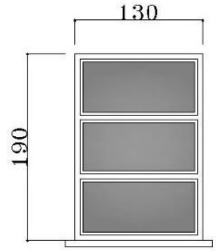
A-18



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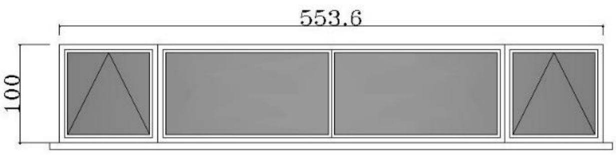

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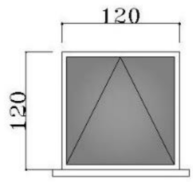
Woman Wc



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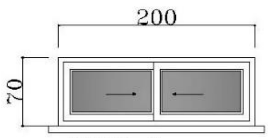

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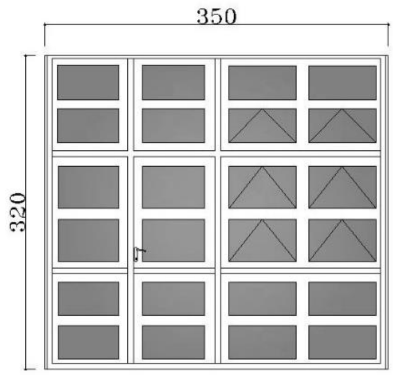

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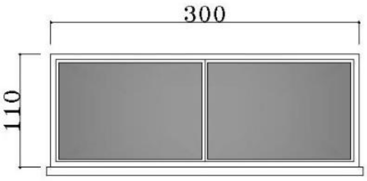

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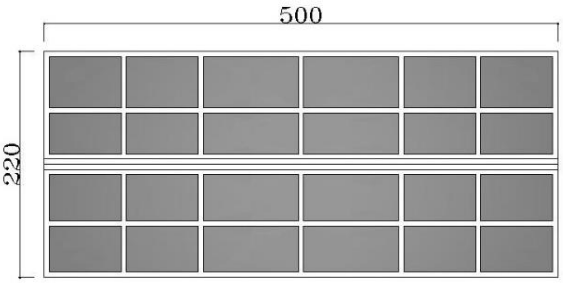

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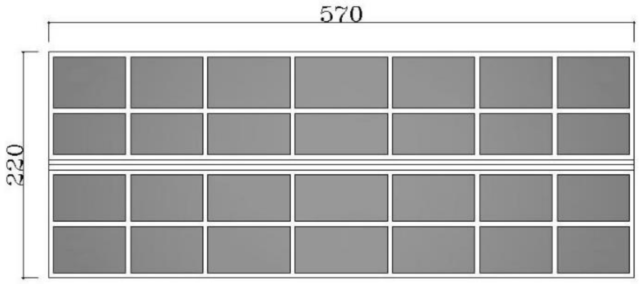

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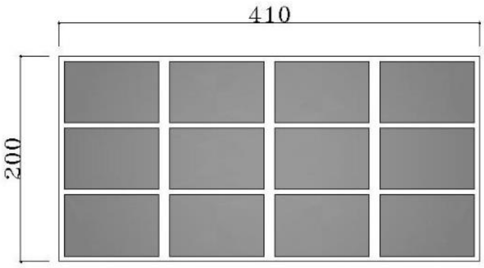

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