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An Investigation into the Thermal Behavior of Courtyards

Tofigh Tabesh [a*], **Begum Sertyesilisik** [a, b]

[a] *Department of Building Science, Faculty of Architecture, Istanbul Technical University, TURKEY*
[b] *School of the Built Environment, Liverpool John Moores University, UK*

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ABSTRACT

Buildings have been recognized as major energy consumers. Courtyards, as significant architectural elements affecting lighting, as well as heating and cooling, can affect buildings energy consumption. This research aims to examine thermal performance of material type used on courtyard adjacent space. Following the literature survey, analyses will be carried out using DesignBuilder/Energyplus. In this simulation, different climates in Turkey have been taken into account. The research gives valuable feedback to professionals and academicians especially with respect to the effect of the courtyard adjacent spaces material on the energy performance. The findings are expected to help increase in energy efficiency and thermal comfort as well as decrease in CO_2 emission.

1. Introduction

The concerns over global warming and need for reduction of high emission of greenhouse gases, ever-growing energy consumption and higher global oil prices suggest the need for long-term demand for the utilization of strategies for indoor climate modification in promoting comfortable indoor environment(Givoni, 1994). Feng *et al.* (2009) expressed that the building

*Corresponding author (T.Tabesh). Tel/Fax: +90-5324575723. E-mail address: t.tabesh@gmail.com. © 2014. American Transactions on Engineering & Applied Sciences. Volume 3 No.2 ISSN 2229-1652 eISSN 2229-1660 Online Available at http://TuEngr.com/ATEAS/V03/0115.pdf.

industry is considered to be an important contributor to the total national energy consumption. It is expected that the proportion of building energy consumption in national energy consumption will keep rising in the coming years (Feng, *et al.,* 2009). Cai *et al.*, (2009) stated that due to the improvement of the living requirements and the rapid urbanization, there will be a dramatic increase in the amount of energy consuming appliances (such as air-conditioners) and urban building areas, which will result in more energy consumption. For instance, Steemers, (2003) highlighted that in the UK, buildings account for about half of all energy consumption, compared to 41% in Europe and 36% in the USA. Energy efficiency of built environment in urban areas is an important factor in reducing the challenges of climate change, resource diminution and wider environmental issues (Steemers, 2003). The modern day practice does not give due respect to passive and natural environment control measures in buildings. With modern materials and technology, the buildings of present architectural style results in high energy consumption, in an attempt to provide thermal comfort indoors.

Designing without taking into consideration proper design of building form, orientation, and envelope can lead to considerable increase in heat gains and energy usage. Givoni (1994) analyzed several specific issues related to adjacent outdoor spaces such as courtyards and internal patios. With some details, courtyards can provide a pleasant outdoor environment and also improve the indoor thermal conditions (Givoni, 1994). The courtyard can modify the climatic conditions of the ambient environment and thus improve the indoor climate by shading the walls, increasing the insulation value of the adjacent walls by dense and high shrubs and vines, and lowering the air temperature by evaporative cooling systems such as wetted pavement, wet walls, or a small pond with a fine spray (Givoni, 1994).

Currently, efforts are made to determine the influence of windows on the energy consumption and economy of high-rise buildings. The area and orientation of glazing have a great impact on building energy usage (Al-Sallal, et al., 2013).

Modeling energy usage in buildings is an important step towards designing and implementing policy measures related to energy savings in buildings. Simulation of buildings' thermal-performances is necessary to predict comfort of the occupants in buildings and to identify alternate mechanical control-systems for achieving better indoor thermal environments.

The primary focus of this study is to examine the influence of glazing type on window to wall ratio in different climates of Turkey on a developed model of courtyard building. The model was created in Design Builder which was used in this study as the simulation tool. The simulations were considered as a temporary file of Design Builder based on ASHRAE due to Energy Plus calculation.

2. Literature review

One of the significant spaces in buildings is courtyard. Frequent utilisation of this space especially in hot-arid, hot- humid and cold climate reveal its importance in providing comfort to occupants. Edvards et al (2006) highlighted that courtyards are found in all climates and locations such as Iran, China and Middle East. They provide a private space for social and leisure activities, and modify local microclimate. Muhaisen and Gadi (2005) highlighted that the courtyard has been one of the most characteristic forms of residential architecture in warm climates. Sadafi et al, (2011) studied thermal performance of terrace housing by exploiting internal courtyard in tropical climate of Kuala Lumpur, Malaysia, using ECOTECT software as simulation software. The results from simulation analyses indicated that, applying internal courtyard in the terrace house improves natural ventilation and thermal comfort in spaces with openings to the outside environment (Sadafi et al, 2011). It has been shown that the zones adjacent to the courtyard with suitable openings in two sides can release the heat through natural ventilation resulting in better thermal condition (Sadafi *et al*, 2011). Sadafi *et al*, (2011) also highlighted that suitable shading devices as well as suitable materials for the internal courtyard's walls can diminish the influence of solar radiation penetration.

Dili *et al*, (2010) have conducted qualitative and quantitative analyses of the passive environment control system of vernacular residential architecture of Kerala, India. They highlighted that continuous heat exchange happen with the cooler surfaces and then the cooler air of the courtyard, as the air moves from outside to inside. They also indicated that due to cooler air settling at the bottom, lower part of the courtyard is the coolest part inside the building. They concluded that highly insulated building envelop for thermal protection of external walls from solar radiation and the pitched roof for protection from heavy rain together contribute to a passive environment control system in Kerala vernacular residential architecture.

*Corresponding author (T.Tabesh). Tel/Fax: +90-5324575723. E-mail address: t.tabesh@gmail.com. American Transactions on Engineering & Applied Sciences. Volume 3 No.2 ISSN 2229-1652 eISSN 2229-1660 Online Available at http://TuEngr.com/ATEAS/V03/0115.pdf.

Yang *et al*, (2012) developed a temporal 3D air and surface temperature model and simulated a courtyard located in Beijing to understand the energy exchanges in an ideal courtyard. The impact of design parameters such as the courtyard geometry, and thermal properties of building materials was studied to determine the relationship between these parameters and the micro-scale thermal environment of the courtyard (Yang *et al*, 2012). Yang *et al*, (2012) revealed that increasing courtyard height, thermal mass and material conductivity intensify the nocturnal micro-scale heat island effect in summer. Increasing thermal mass, surface reflection and conductivity efficiently reduce the peak temperature during daytime, which leads to a micro-scale urban cool island phenomenon in winter time. Yang *et al*, (2012) highlighted that among all 4 parameters (height, surface reflection and thermal mass as well as material conductivity) the height of the courtyard is found to be the most influencing whereas the surface reflection has found to have the least influence on the courtyard thermal environment.

Muhaisen and Gadi (2005) showed that changing the form's proportions in circular model significantly influences shading or exposure potential of the internal courtyard envelope and that shallow courtyards perform better than the deeper ones. Muhaisen and Gadi (2006a) used computer tool (IES) to carry out the effect of solar heat gain on the energy demand of courtyard building form with different proportions. They found that courtyards having deep forms require low energy for cooling in the summer. Muhaisen and Gadi (2006b) stressed that in polygon models deep courtyard forms with any geometry achieve maximum internal shaded areas in the summer whereas in winter, shallow forms provide sunlit areas. Muhaisen (2006) carried out a modeling study into the effect of rectangular courtyard proportions on the shading and exposure conditions on the internal envelope of the form in four different locations. The outcomes showed optimum courtyard height to obtain a reasonable performance in the summer and winter as three stories in hot humid climates, two-story in hot dry and temperate climates, and one-story in a cold climate (Muhaisen, 2006).

Aldawood (2006) highlighted that courtyard spaces are affected by the outdoor climate conditions more than any other spaces in the building because of the glazed materials used for courtyard walls' skylights. Al-Masri and Abu-Hijleh (2012) compared conventional and courtyard buildings by using computer simulation (Virtual Environment by Integrated Environmental Solutions) to determine the overall energy consumption, energy savings potential and available daylight levels. The simulation calculated effects of number of floors, type of glazing, wall thickness, and insulation type as well as insulation thickness on the performance of a courtyard type (Al-Masri and Abu-Hijleh, 2012). The result showed 11.16% reduction in the overall year-round energy consumption in optimized courtyard model compared to the reference conventional form building (Al-Masri and Abu-Hijleh, 2012). Assessment between the daylight performances of the two forms highlighted that the courtyard form provides more usable daylight without excessive glare (Al-Masri and Abu-Hijleh, 2012).

Luis and Perez-Garci (2004) studied seasonal control of the solar gains on the roof apertures. Luis and Perez-Garci (2004) studied on refurbishment of an open courtyard by installing an innovative roof to maximize solar gains during the winter months and to minimize thermal loads in the summer.

Heras *et al* (2005) analyzed the energetic performance of a courtyard covered by saw tooth roof in the building of University of Almeria in Spain. Thermal evolution in typical summer and winter days and thermal comfort analyses showed a good thermal behavior in winter; stratification did not appear during all year and this fact produced overheating in summertime (Heras *et al*, 2005). Heras *et al* (2005)'s study revealed that around the noon an increase in the air velocity happens, consequently the chimney effect is greater during these hours and that the annual thermal loads required to obtain comfort conditions are lower in courtyard than in a conventional saw tooth roof.

There are series of details which have significant impact on thermal performance of courtyard building types such as climate conditions, building shape or height, orientation and internal loads, height of the building, window to wall ration, glazing type, the insulation levels, wind directions well as wind speed, impact of adjusting building characteristics on the buoyancy ventilation performance, the ventilation requirements and etc. It is evident that additional research is necessary to optimize the existing courtyard building systems and develop new ones.

3. Research Methods

This paper aims to examine the influence of glazing type on window to wall ratio in different climates of Turkey on a developed model of courtyard building. The model was created in the Design Builder which was used in this study as the simulation tool. Simulation packages for

*Corresponding author (T.Tabesh). Tel/Fax: +90-5324575723. E-mail address: t.tabesh@gmail.com.

predicting building performance in terms of energy and comfort are becoming increasingly important in the planning process. The analyses carried out within the scope of this research were based on two main building energy performance simulation tools, namely EnergyPlus and DesignBuilder. The EnergyPlus was used for calculating of total energy consumption of building by changing different glazing type on various windows to wall ratio in different climates. As EnergyPlus has been validated under the comparative Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs BESTEST/ASHARE STD 140, it is reliable (Henninger, and Witte, 2001).

DesignBuilder, as GUI (Grafical Usage Interface) for EnergyPlus, the DesignBuilder is the most comprehensive interface for EnergyPlus available today. Its current version (v3.2.0.008 beta) includes a simplified CAD interface, templates, wizards, and most compact air system configurations of EnergyPlus.

3.1 The Courtyard Model created within the scope of this research:

The courtyard model has been designed based on the criteria obtained from the literature survey. Courtyard thermal performance is mainly affected by the solar radiation penetration of the internal envelope, which is dependent on the courtyard geometrical parameters and the sun's position. Muhaisen and Gadi (2005) stressed that shallow courtyards perform better in winter time. Muhaisen and Gadi (2006b) highlighted that deep forms require low energy for cooling in summer.

The courtyard model has been designed to be located within an office building considering Perez-Lombard et al (2008)'s study. Perez-Lombard et al (2008) stated that offices and retail spaces are amongst the most energy intensive typologies in the nondomestic building sector. They alone account for over 50% of total energy consumption for non-domestic buildings. Perez-Lombard et al (2008) advised analysis of energy demand of the non-domestic building stock with office buildings. The reason which they stressed is not only the energy intensity of the office buildings but their constant increase in total floor area coupled with increase in lighting, IT and air conditioning. The other important reason which Perez-Lombard et al (2008) emphasized is office buildings are quite uniformly distributed across the buildings stocks in developed countries with three key energy end uses, HVAC, lighting and appliances, adding up together to around 85%.

This study tries to examine the influence of glazing type on window to wall ratio in different climate of Turkey on proposed model of courtyard building. In order to reach to aforementioned goal, two open central courtyard surrounded by adjacent spaces were modeled in Designbuilder. Four office areas face to the courtyard and circulation areas were located in the corners of the building. In terms of investigation three-story and six-story square shaped courtyards were modeled, see Figure 1. Each space was separated completely from any environmental thermal changes by four adiabatic walls from the out door. Central courtyard area was 400 m2, with 20 m length 20 m width. In the adjacent spaces floor to floor height was 3.50m and the depth of the office area was designed to be 10m. The internal environment of the four office spaces was modeled as fully conditioned.

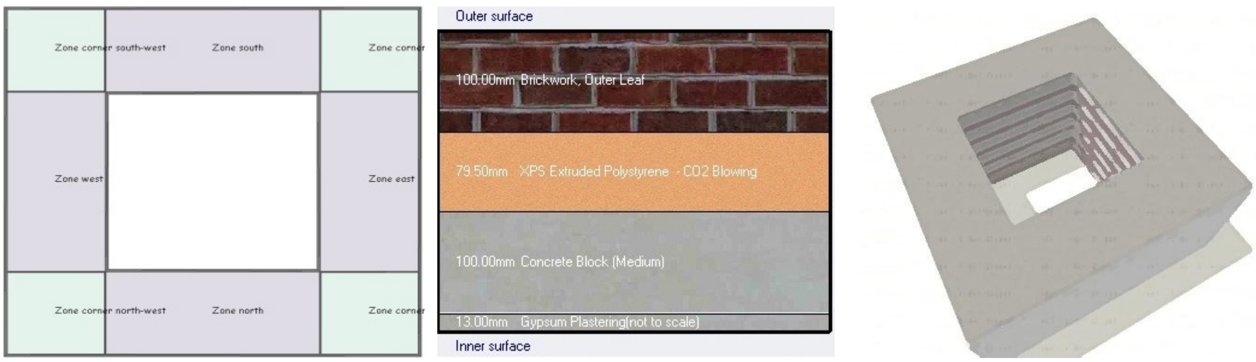

Figure 1: Model and courtyard used for simulation.

The spaces were set to a constant temperature of 24°C. All spaces were assumed to have recessed fluorescent with lighting energy. The type of artificial heating was selected as natural gas and electric for cooling system. All requirements including schedules such as lighting schedule, wall infiltration schedule, window infiltration schedule,daylight schedule and all design aspects needed to conduct the all adjacent spaces were assumed to be fully conditioned. For the purpose of analysing the influence of climate on the thermal performance of model and their different alternatives, three locations in the Turkey were selected. Each location represented a different climatic region. The selected locations were Erzurum for the cold climate, Diyarbakir for hot-dry climate, and Istanbul for temperate climate. Glazing percentage varied from 0 to 100% for the simulations. In order to understand differences in total energy consumptions of the modeled courtyard building clearly, simulations have been carried out for two types of glazing, namely: single and triple glazing (Table 1)

*Corresponding author (T.Tabesh). Tel/Fax: +90-5324575723. E-mail address: t.tabesh@gmail.com.

Table 1: Varied glazing percentages used in simulation

Abbreviation of glazing name		Triple glazing type	Single Glazing type
Sgl	Single pane	Triple LoE Film(33)Bronze 6mm/13mm Air	Single ref-A-L Clr 6mm
Dbl	Double Pane	Triple LoE Film(44)Bronze 6mm/13mm Air	Single ref-D Clr 6mm
Xmm	X= thickness of glass panes in mm	Triple LoE Film(55)Bronze 6mm/13mm Air	Single Ref-A-M Clr 6mm
Xmm/Ymm	X= thickness of glass panes, Y= gap Thickness	Triple LoE Film(66)Bronze 6mm/13mm Air	Single Ref-C-M Clr 6mm
Clr	All Panes are clear glass	Triple LoE Film(55)Clr 6mm/13mm Air	Single Ref-B-M Clr 6mm
Tint	One pane is tinted	Triple LoE Film(66)Clr 6mm/13mm Air	Single Ref-C-H Clr 6mm
Low Iron	Glass pane with low iron content	Triple LoE Film(77)Clr 6mm/13mm Air	Single Ref-B-H Clr 6mm
LowE	Low emissivity coating on one or more pane	Triple Clr 3mm/30mm air for mid-pane blind	Single Ref-D Clr 6mm
eX=Y	Low emissivity coating on pane surface X with emissivity Y	Triple Clr 3mm/13mm Arg	Single Blue Clr 6mm
Film(xx)	Coated polyester film with nominal visible transmittance of XX percent	4-12-4, coated, Argon filed	Single Grey Clr 6mm
Ref-x-y	One pane has a metallic reflective coating where: X=A: Stainless Steel Coating X=B: Titanium Coating X=C: Pewter coating X=D: Tin-oxide coating Y=L: low-transmittance coating Y=M: Medium-Transmittance coating Y=H: High-transmittance coating	Triple loE file (88)Clr 3mm/13mm Air	Single Bronze 6mm
		Triple LoE (e2=e5=0.1)clr 3mm/13mm Arg	Single Green 6mm
			Single Clear 3mm
			Single Low Iron 5mm
			Single LoE (e2=2)Clr mm
Air	Between pane gas fill is air		
Arg	Between pane gas fill is Argon		
Elec Ref	Electro chromic glass that darkness by becoming more reflective		

4. Results and Discussion

Six-story courtyard performed similar to three-story courtyard in terms of total energy consumption trend of the glazing types (Figures 2 and 3). Energy performance of “Sgl Rer-B-H Clr 6mm” and “Sgl Ref-D Clr 6mm” type glazings in Istanbul differed a little when the height of the courtyard changed (Figures 2 and 3). 40% and 60% of window to wall ratio has been found to be optimum in three-story courtyard whereas this ratio has been found to be 100% for six-story courtyard.

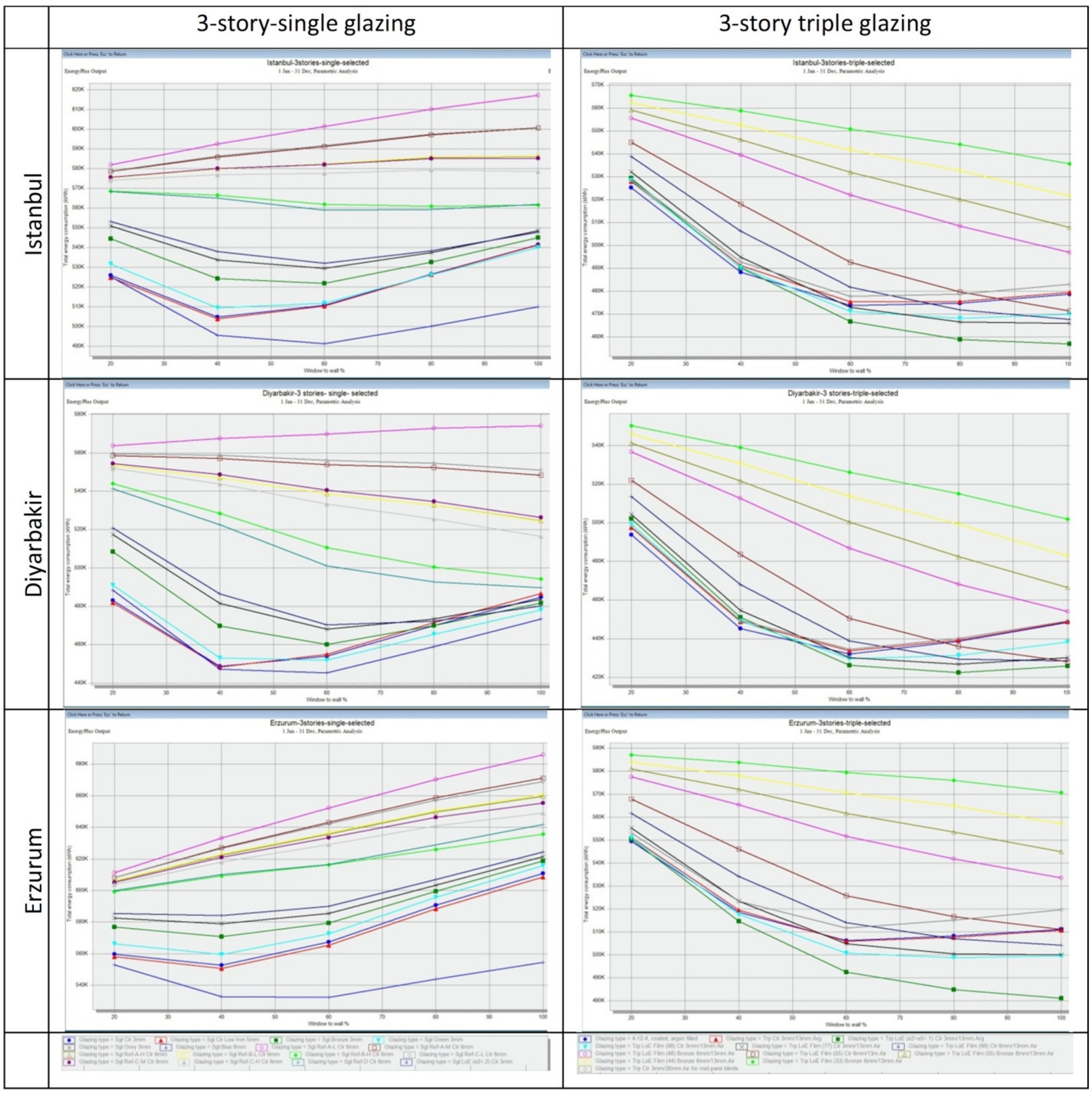

Figure 2: Simulation results for three-story courtyard.

*Corresponding author (T.Tabesh). Tel/Fax: +90-5324575723. E-mail address: t.tabesh@gmail.com.

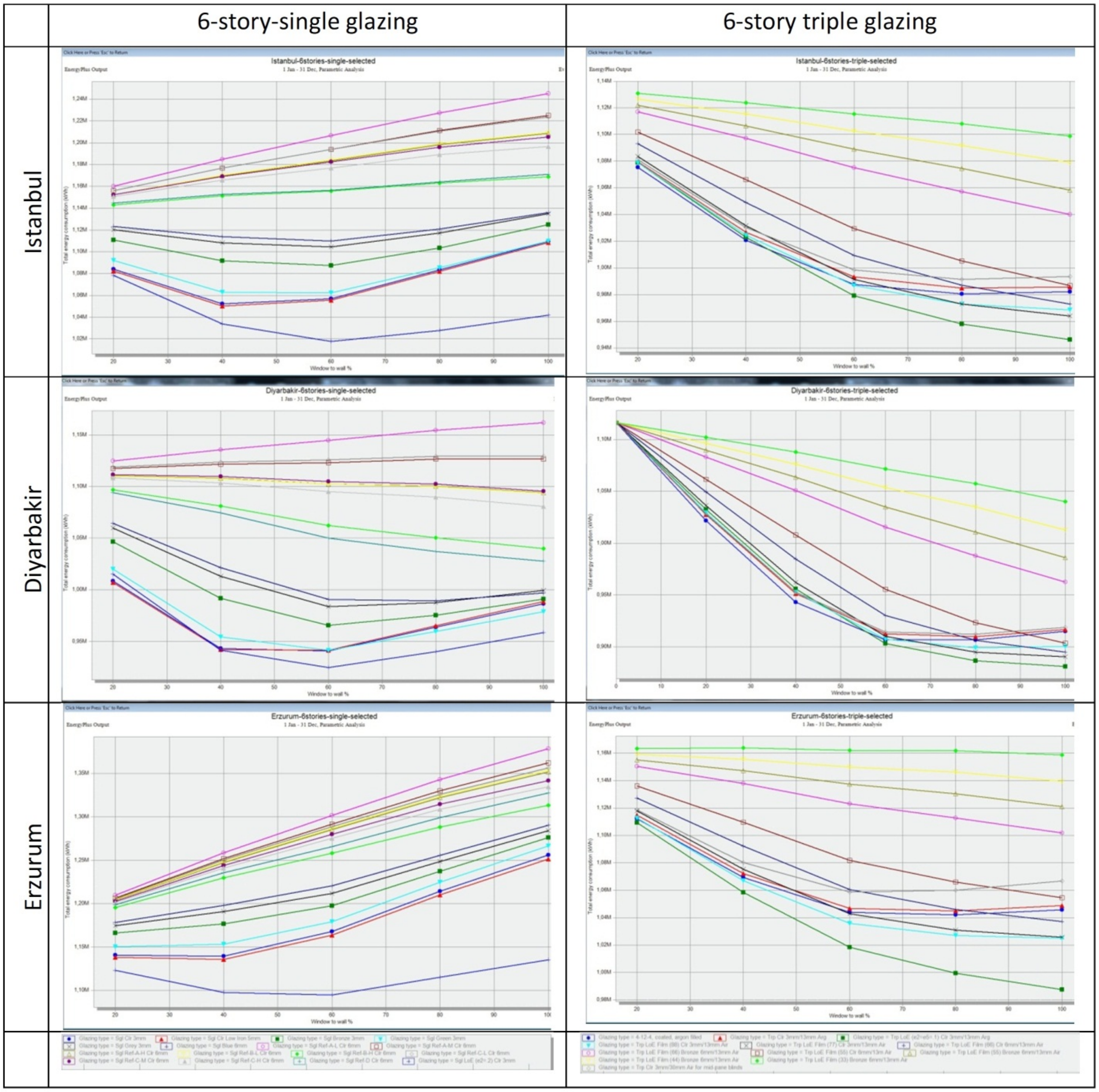

Figure 3: Simulation results for six-story courtyard.

Different single glazing types' performances have been analysed in different window to wall ratios (Figures 2 and 3). Accordingly, for both courtyards low total energy consumption occurred when "Sgl LoE (e2=2) Clr 3mm" glazing on 40% ratio has been used in Istanbul as well as in Erzurum. On the other hand, results show that in all climates "Sgl Ref-A-L Clr 6mm" glazing type caused high total energy consumption. It should be mentioned that for glazing types numbered from 9 to 14 in the Table 1, 40% ratio has been found to be optimum from the energy conservation point view in Erzurum. "Sgl Green 3mm", "Sgl Clear 3mm" and "Sgl Low Iron 5mm" glazings provided optimum energy performance in 40% ratio whereas "Sgl Blue 6mm", “Sgl Grey 3mm” and “Sgl Bronze 3mm’ in 60% ratio in Istanbul and Diyarbakir.

Usage of “Sgl Ref-B-H Clr 6mm” and “Sgl Ref-D Clr 6mm” glazing types and increasing window to wall ratio decreased the total energy consumption in Istanbul and Diyarbakir whereas increased rapidly in cold climate such as Erzurum (Figures 2 and 3). Increasing window to wall ratio in glazing types numbered from 1 to 8 in the table 1 increased the energy demand in Diyarbakir and Erzurum (Figures 2 and 3).

Using triple glazing types in courtyard building has lead to different behavior of building energy conservation in comparison with single ones. Increasing window to wall ratio in glazing types numbered from1 to 4 in the table 1 increased energy performance of the courtyards in all climates. It has been found that “Trp LoE (e2=e5=0.1) Clr 3mm/13mm Arg” requires minimum energy demand when window to wall ratio is 100% in Erzurum and in Istanbul whereas 80% for Diyarbakir. Maximum total energy consumption has been observed when using “Trp loE Film (33) Bronze 6mm/13mm Air” glazing type for three cities in all examined window to wall ratio.

5. Conclusion and recommendation

There is lack of a comprehensive strategy in terms of courtyards thermal performance under different conditions. Most study studies indicated that the characteristics of courtyards affect the indoor environment conditions and that incorporation of courtyards in buildings could increase the energy efficiency of buildings. There is still a lack of research in predicting the thermal behavior of courtyards like, radiation, air flow patterns, and humidity.

This research examined thermal performance of material type used on courtyard adjacent space. Following the literature survey, analyses have been carried out on courtyard modeled within the studied scope. The simulations have been undertaken using DesignBuilder/Energyplus considering different climates in Turkey, different glazing types and different window-wall ratios.

5.1 Summarized findings

- Glazing ratios have significant impact on total energy consumption of courtyard building.
- Total energy conservation happen in same window to wall ratio of single and triple group of glazing for two type of building (3 and 6 stories courtyard).
- Optimal energy conservation varies in different climates for most of the glazing.

*Corresponding author (T.Tabesh). Tel/Fax: +90-5324575723. E-mail address: t.tabesh@gmail.com.

5.2 Recommendations

The recommendations obtained from this research can be summarized as follows:

- Glazing type should be selected to minimize energy use, occupant comfort and to maximize daylight effectiveness while still meeting architectural objectives.
- The effective aperture target should be used to determine the range of desirable visible transmittances, based on window-to-wall ratio.
- Color, reflectance and UV transmittance influence should be considered in the glazing type selection.
- Sizing windows should be kept within acceptable limits.

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Tofigh Tabesh is a Ph.D candidate in Building Science division at Architecture Department of Istanbul Technical University, Turkey. He obtained both BSc and MSc in the field of Architecture from Islamic Azad University of Tabriz, Iran. He is cooperating with Islamic Azad University of Urmia, Iran. Tofigh's research interests are involved with architectural simulations related to energy efficient and energy retrofit as well as thermal behavior of the building.

Dr.Begum Sertyesilisik is a visiting professor in the School of Built Environment at the Liverpool John Moores University. She is working in the Architecture department of the Istanbul Technical University. She has been awarded a PhD in the field of construction contracts at the Middle East Technical University. She obtained an MSc in the field of Project Management at the Istanbul Technical University and an MBA at the Istanbul Technical University. She received a BSc in Architecture at the Istanbul Technical University. She has specialised in the areas of project management, sustainability, contract and dispute management. She is a member of the Chamber of Architects in Istanbul and of CIB.

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