RESPONSIVE FACADES; ARCHITECTURAL FEATURES OF RENOVATED TRADITIONAL BOSPORUS MANSIONS' WOODEN WINDOWS WITH SOLAR CONTROL SYSTEMS, A CASE STUDY

[1]CAGLA KELES, [2]FATIH YAZICIOGLU

Istanbul Medipol University, The School of Fine Arts, Design and Architecture, Istanbul, Turkey Istanbul Technical University, Faculty of Architecture, Istanbul, Turkey
E-mail: [1]ckeles@medipol.edu.tr, [2]fyazicioglu@gmail.com

Abstract - Throughout history, the need for meeting performance requirements has caused designers to improve new components and devices for the glazing parts which can respond to changes of exterior conditions by moving physically according to user's needs. In years, these improvements have been evolved to smart technologies and innovations that it is entitled as responsive facade today. The working principle of responsive facade is basically adapting to needs of people according to changes of exterior environment conditions by moving manually or dynamically. It is mostly used in hot and temperate climates, such as Istanbul city. Istanbul is one of the most historic cities in the world. Especially, it is specialized with its water-way called Bosporus dividing the city half as European and Asian sides. In historic residential buildings on Bosporus coastal-line, called Bosporus Mansions, window systems were designed with traditional wooden shutters in order to establish comfort conditions inside by responding to sunlight changes. After renovations, these window systems have been changed into contemporary devices and designs. The aim of this paper is to analyze historic Bosporus Mansions' window systems and review them as responsive components. After comprehensive literature review and providing a classification approach about responsive facades, six residentials in Asian coastal line of Bosporus are selected and their windows' system details areprovided along with their working principles. Their suitability levels to responsive facades and further researchesare discussed in results.

Index Terms - Responsive facades, Solar shading devices, Traditional Bosporus Mansions, Window systems.

I. INTRODUCTION

Throughout centuries, Istanbul has been a homeland for many historic civilizations like the Ottoman Empire, Byzantine Empire, and Roman Empire etc. [1]. The most important aspects of Istanbul are that it is divided by a water-way called Bosporus and categorised as European and Asian sides of the city. Bosporus coastline is unique with the historic buildings in the region [2]. Today, the historic residential buildings of last century's Ottoman Empire has stillbeen existing in the Bosporus region. Whereas small amount of buildings continues to exist without any change, the majority of these dwellings havebeen maintained through restoration or reconstruction [3]. There are several approaches for the reconstructions of historic buildings; two of them are; reanimating all historic features and changing the invisible parts to a modern system while keeping the visible parts with the original features. Today in the Bosporus region examples for both alternatives may be found (Fig. 1). When the windows of those dwellings are analysed, it is found that there are traditional wooden shutters that are used for solar control. Today, some dwellings have been renovated with keeping the traditional wooden shutters, whereas the others have been through renovation in accordance with the window's original feature, but modern roller shutters were added as a solar shading system instead of the wooden shutters [5]. Some of these wooden shutters can move uniaxial and some others can move biaxial. These wooden shutters can be controlled manually to change illuminance level and solar gain; that's why, they can beaccepted as traditional responsive facade units. Responsive facades are moveable, operable, manually or automatically controlled elements which can adapt to the needs of people, by changing the comfort conditions of interior environment [6]. The facade responds to the user, exterior environment or a computer operating system by changing its physical behaviour.



Fig. 1. A Bosporus Mansion located Asian coastal line of Istanbul [4].

In order to reduce the solar load on facade, the most effective way is keeping direct radiation before it reaches the glass of window [7]. That's why, it is more reasonable to make use of responsive facade units since this will improve the comfort level of the occupants and it will have positive impact on the energy consumption. In Central Europe, because of the moderate climate, the traditional methods of construction for window ventilation and exterior sun

protection caused this technology to evolve. Today's double-skin facade has been developed from the folding shutter of windows which is creating a thermal buffer between the glass and the shutter at night [8].

Wooden shutters are traditional components of building envelopes. They function for reducing solar gain and regulating indoor illuminance level. Today, these components have been transformed with new innovations and technologies. There are several studies in literature about the effect of solar shading devices. The related studies are presented at Table 1. Despite of many studies about solar shading devices, there are limited studies about Bosporus with its original and historical urban texture. The climate of Istanbul is different from many other regions where the studies about solar shading devices were conducted before. It is affected by climates of Black Sea, Mediterranean and Marmara, which means the climate of Istanbul is hot and dry in summer, mild and rainy in winters, and it is under the influence of north winds [2]. Based on this information, the solar control systems will be more effective under this climate condition. Therefore, the aim of this paper is to analyse renovated Bosporus Mansions' window systems by evaluating them as responsive components.

II. METHODOLOGY

This paper consists of four main parts; the first part introduces a literature review about the history of responsive facade components from wooden shutters to automated solar control elements along with providing the classification approach of responsive facades, second part provides a comprehensive framework about architectural features and details of window systems of Bosporus region. This part introduces case studies of Bosporus Mansions' window systems. Six different window systems with solar shading devices have been chosen and reviewed as a traditional responsive facade elements. The detail drawingsand architectural features of selected cases' window systems have been presented. In fourth part, their suitability levels according to features of responsive facade elements are described and presented in table. Finally, the paper introduces a conclusion of traditional Bosporus Mansions' window systems.

III. LITERATURE REVIEW

There are several studies conducted to find solutions to the problems created by physical environmental conditions like daylight, thermal, optical, air-flow etc. These studies are evaluated in terms of the system affecting the physical environmental conditions, factors defining relevant physics, tools used for getting results of studies, methodology approach, as well as authors and years. Table I summaries the related studies.

A. History of Responsive Facade

Taking precautions against external environmental conditions is one of the fundamental objectives of architecture. Precautions can vary as the external environment conditions change. Therefore, as technological advancements are enhanced, new innovations that could adapt to the external environment over time have been developed.

Historically, "the box-type" window, commonly found in Eastern Europe, is the first examples of responsive components of facade. It is made up of double windows to keep interior environment on comfort conditions in winter. It works as small-scale double facade. Another historical example is wooden shutters, which intercept direct radiation to prevent solar gain and provide night insulation when needed in Mediterranean and tropical climates. These mentioned historical facade elements are operated by manual actions of the user [24].

Le Corbusier developed a concept of "brisesoleil", meaning sun blocker [24]. He tried to apply this concept to several projects. The main purpose of the concept was creating a climatically active facade that can adapt to exterior local climate [25].

In 1973, the residential house of Steve Baer in New Mexico, USA was built with the concept of a wall made up of oil barrels filled with water to store heat by using greenhouse effect in daytime [26]. In the night, the exterior covers are closed, and interior covers are opened causing the stored heat to be discharged into the room.

During the last decades of 20th century, mechanically operated facade designs have begun to spread around the world. Arab World Institute in Paris, built in 1987, is considered the first example of highly mechanized responsive envelopes [21]. The design concept depends on 240 photo-sensitive modules with 30,000 motorized diaphragm apertures between two layers of glass that is mechanically open and close in response to different conditions of sun over day [27].

The logic of mechanically operated facade units caused new concepts and designs to be evolved. For example, in the Council House 2 (CH2) building, the traditional external shading components are improved by a computer controlled hydraulic system causing shading device to open in the morning and slowly close up with the movement of sun [28]. Besides, in some projects, such as Showroom Kiefer Technic building, the control mechanism is left to the user for manual operation [21]. In 2012, this concept was applied for the first time on a high raised building, Al Bahar Office Towers. Its facade is controlled by a computer system to respond to the movement of the sun by changing its triangle element's form in order to reduce solar gain and glare. In the evening, all screens are closed [29].

The most recent innovation of responsive facade concept is integrating smart materials and robotics to the facade element which responds and adapts to the exterior physical environmental changes [24]. For

instance, Media-TIC buildings' each facade is composed of different air cushions of ETFE material. Each facade is controlled by sensors measuring heat, temperature and angle of the sun and the material is changing to provide shade and prevent solar radiation [28]. Another recent innovation is phase change material that is integrated to the glazing of AlterswohnenDomat Ems building's facade. It is in liquid form in the day to store heatfrom the sun, and when temperature drops, it changes its phase from liquid to solid form by giving the stored heat back to the interior space [21]. The first algae-powered building in the world, BIQ House, has another innovative facade technology. The facade has bio-reactor units containing algae that grows faster in the sunlight by providing shading, as well as capturing solar thermal heat [30].

Table I. Summary of different studies about adapting exterior climate conditions

Reference Number	Author and Year	Observed System	Observed Performance	Method
[9]	A. Tzempelikos and A. Athienitis, (2007).	Shading devices	Cooling, Lighting	Simulation
[7]	A. Palmero-Marrero and A. Oliveira,(2010).	Louver shading devices	Thermal, Energy	Simulation
[10]	E. Alawadhi, (2012).	External window shutter, Phase change material	Thermal	Theoretical
[11]	F. Yazicioglu, (2013).	Traditional wooden shutter, Aluminum roller shutter	Embodied and operational CO^2 emissions	Inventory analysis
[12]	R. Loonen, M. Trčka, D. Cóstola and J. Hensen, (2013).	Climate adaptive building shells	-	State-of-art review
[13]	F. Favoino, F. Goia, M. Perino and V. Serra, (2014).	Multifunctional facade module	Thermal, Energy	Experimental
[14]	J. Yao, (2014).	Movable solar shades	Energy, Thermal, Illuminance	Case study, Simulation
[15]	J. Yao, (2014).	Manually controlled solar shades	Energy	Case study, Stochastic model construction, Simulation
[16]	A. Freewan, (2014).	External shading devices	Thermal, Daylighting	Experimental, Case Study, Simulation
[17]	T. Silva, R. Vicente, F. Rodrigues, A. Samagaio and C. Cardoso,(2015).	Window shutter, Phase change material	Thermal, Energy	Experimental
[18]	F. Favoino, F. Goia, M. Perino and V. Serra, (2016).	Multifunctional facade module, ACTRESS	Thermal, Energy	Experimental
[19]	Z. Nagy et al, (2016).	Adaptive solar façade prototype	Heating, Cooling, Electricity	Simulation, Experimental
[20]	E. Alawadhi, (2016).	Exterior window shutter	Thermal, Illuminance	Experimental
[21]	M. Koyaz, (2017).	Adaptive facade	-	State-of-art review
[22]	M. Iommi, [2018].	Smart and adaptive facade prototype, phase change material, high insulating material	Thermal, Energy	Experimental, Simulation
[23]	S. Al-Masrani, K. Al-Obaidi, N. Zalin and M. Aida Isma, (2018).	Solar shading systems	-	Review

B. Classification of Responsive Facades

Different responsive facade classification approaches in the literature are reviewed and interpreted (Table II).

Under the light of information gained, the following classification is related with type of use, relevant performance, control (actuator) type, and scale of response, that are mainly defined in the classification of responsive facade system.

- **Type of Use:** There are three systems that facade unit responds by changing its behaviour. The first one is passive system that no energy source is involved. The second one is active system that causes a dynamic change process by responding to the light and heat. Lastly, the third type is hybrid system that combines passive and active methods by integrating smart materials and innovative technologies [24].
- **Relevant Performance:** The main target of responsive facade units, both traditional and intelligent, is meeting a specific performance requirement of interior environment. Mainly these

performances are lighting, thermal comfort, ventilation or energy management [24].

- **Control (Actuator) Type:** In order to respond to the exterior environment, the physical change of facade units are actuated by a control mechanism. Traditional control mechanism is manually controlled systems that can be directly adjusted by the user. Another control mechanism is motorized controlled systems that are activated by motor sensors according to the user's act. The recent innovations are automatically (dynamic) controlled mechanism responding to the stimuli by supervisory control unit, and intrinsic control mechanismthat the facade component has a subsistent response to the change of the physical conditions [23].

- **Scale of Response:** Response of the facade can be a change or movement on the component of facade which can be defined as macro scale response, or the change can be directly within a material or component of facade which can be defined as micro scale response [21].

IV. CASE STUDY; TRADITIONAL BOSPORUS MANSION RESPONSIVE WINDOWS

The case buildings are located at Anatolian coastal line of Bosporus, Istanbul. They were originally constructed in 19th century or in the beginning of 20th century and renovated afterwards. They were built as seafront. The architectural plan is similar for all cases, it was designed as combining rooms opening to central sofa. All case buildings are protected by Council of Monuments of Turkey as first-degree cultural assets [5]. They show similar architectural features and views with horizontal eaves and sloping roofs. They are two or three stories high buildings with wooden frame structure system. They were originally built by traditional construction technic that is inserting wood laths in each two or three centimeters among timber frames of wall and covering it with plaster. In all cases, facades were covered with wood and painted. The size of windows is in 1/2 ratio which is 0.90 x 1.80 or 1.00 x 2.00 meters, therefore it seems as vertical shape [5]. Most of these mansions located at Anatolian coastal line were designed with solar control elements because of affected by direct sunlight from the West side.

These solar control elements differ with each case because some buildings' window systems have been changed with modern systems after renovation. The commonly used solar control elements are wooden shutters with movable panes, wooden shutters with fixed panes, sliding wooden panel, aluminum roller shutter, and windows in which both roller shutter and wooden shutters are integrated. After recent innovations, in some buildings, it has been kept or reused traditional wooden shutters, whereas in others; modern aluminum roller shutters have been chosen.

Table II. Summary of characteristics of responsive facades

Type of use	Passive system
	Active system
	Hybrid system
Relevant performance	Lighting
	Thermal
	Ventilation
	Energy management
Control (actuator) type	Manually controlled
	Motorized controlled
	Automatically (dynamic) control
	Intrinsic control
Scale of response	Macro
	Micro

A. Case A

The Mansion was built in 1895 as a three-storey building with a small pier in front of the facade facing to the sea. It was renovated between 1905-1910 [5]. Its architectural plan has been formed as sofa in the middle and the rooms opening to it.The building has wooden structure with showing neo-classic style features.It rises above a subbasement in the south-west [31].It has 11 rooms, 2 sofas, 3 kitchens, and 7 bathrooms. The height of the basement floor is 2,5 m, first floor is 3.5 m and third floor is 3.5 m [31]. It was determined by a cornice between the floors. Similar architectural elements were also included in the northwest facade. The roof has been constructed as hipped-gable roof and facades has been covered with wood painted as white.

On both floors, the windows have traditional wooden shutters with movable panes. In Fig. 2, the architectural details of elevations (a), section (b) and plan (c)are shown. Different parts of window system are marked with a number. Fixed shading system; 1a, creates upper part of solar control element and it cannot be modified to solar changes. Movable panes; 2a, areintegrated to vertical pivoted shading sashin lower part and its panes can be rotated by a switch according to sun's angle of incidence. Horizontal pivoted inner shading sash; 3a, can be opened and closed horizontally to allow fresh air to enter inside. Vertical pivoted shading sash; 4a, is located lower part of solar control element and it can be opened or closed according to user's needs. Number 5a and 6aare marked as glazing parts of the window system. Both upper ,5a, and lower ,6a, sashes of glazing pivot vertically by a sliding mechanism. This window system works as allowing fresh air to enter inside and hot air to go outside.

The wooden shutter can respond manually to the differentiation of angles of sunlight by changing angles of panes. Controlling the angle of movable panes also causes illuminanceto keep at comfort levels. Even sashesare fully closed in intensive solar gain, the pivoted panes can let air exchange between inside and outside.

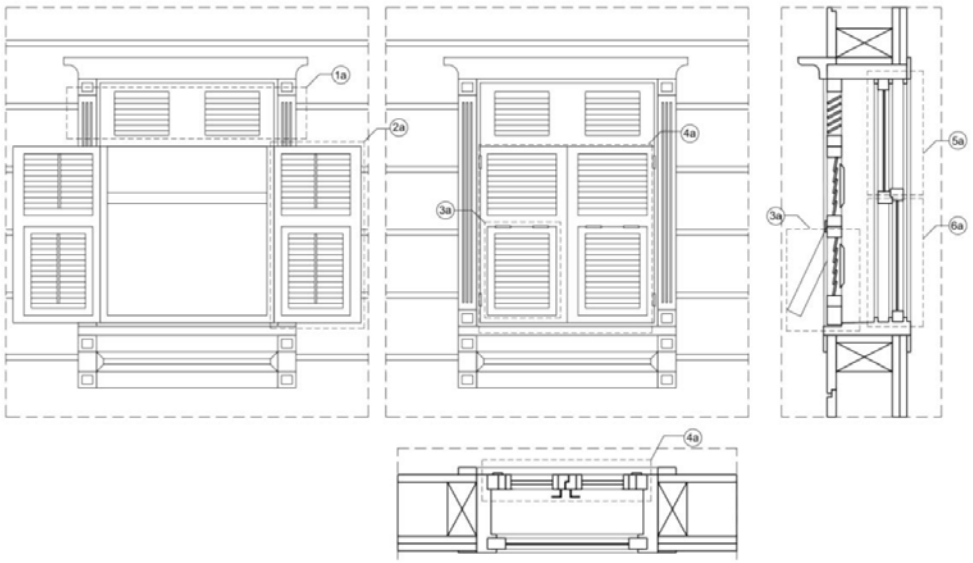


Fig. 2.(a)Elevations of the window system of Case A; (b) Section of the window system of Case A; (c) Plan of the window system of Case A.

B. Case B

The three-stories building is built in 1896 and renovated in 1990 [5]. There is a small pier in front of facade facing to the sea. Also, the building has a small attic in roof floor. There is a basement which is high in the sea side and disappearing as it goes to back. The sea facade's middle part is placed behind, therefore it creates iwan, and there are balconies in second and third floors. Integration of floors are determined by cornices. The roof creates eaves and has been constructed as hipped-gable roof. The facades of the building have been covered by wood and painted as white. The facade facing to the sea is directed to North-East. The windows in second and third floors are integrated with wooden shutters with fixed panes (Fig. 3). Unlike traditional wooden shutters with movable panes, these wooden shutters have been placed with a sliding mechanism because of the closeness of windows with each other. Each window has a rectangular pediment, and shutters were painted pink after renovation. The fixed panes; 1b, are integrated to the sliding shading sash, and it cannot be switched according to solar changes. Vertical sliding shading sash; 2b, can open and close by being folded on its hinge jointsaccording to the user's needs. The sliding mechanism; 3b, works as solar shading sash to be folded by the movement of integrated wheel in the mechanism. 4b and 5b creates glazing parts of window system. The upper part of glazing sash; 4b, cannot be opened or closed, whereas the lower part; 5b, can pivot vertically. The vertical pivoted glazing sash ,4b, can be opened to allow fresh air to enter inside. The sliding solar shading element can be opened and closed according to changes of solar angles throughout day. When solar shading element is closed,fixed panes of sashes block direct radiation to keep interior thermal conditions at comfort level. It also prevents glare by controlling illuminance level. The gaps between panes permits air circulation between inside and outside even if it is closed.

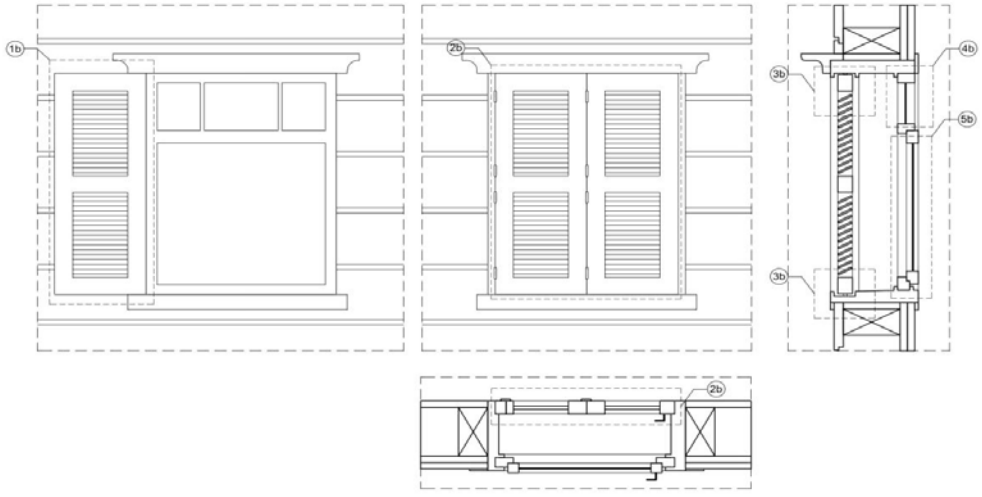


Fig. 3.(a) Elevations of the window system of Case B; (b) Section of the window system of Case B; (c) Plan of the window system of Case B.

C. Case C

The building, thought as the most original mansion in Bosporus, was constructed in 1825 and renovated between 1906-1916. There is no any entrance to building from the seaside. The two-stories building featuring neo-baroque characteristics was planned as oval sofa in the middle and rooms opening to it. It has 8 apartments and 26 rooms. One side faces the sea and the other side overlooks the garden. Of these, with a length of 30 meters along with the iwans, the top floor was completely made up of the roof without any bearing. It was originally built like a bellows with a hanger and was covered with an oval dome. However, because of damaging by fire, the roof has been built as hipped-gable roof[32]. The East facade of the building facing the garden and the West facade of the building facing the sea have a curved protrusion in the middle section parallel to the slope of the oval sofas. In addition to these formations which are designed to give mobility to the facade, there is a series of continuous windows designed on both sides of the plain. The window cage and railings, which constitute the only ornament of the facade, have the characteristics of late empire. The building was originally constructed as wood frame structure integrated with plaster laths and covered by plaster and wood.

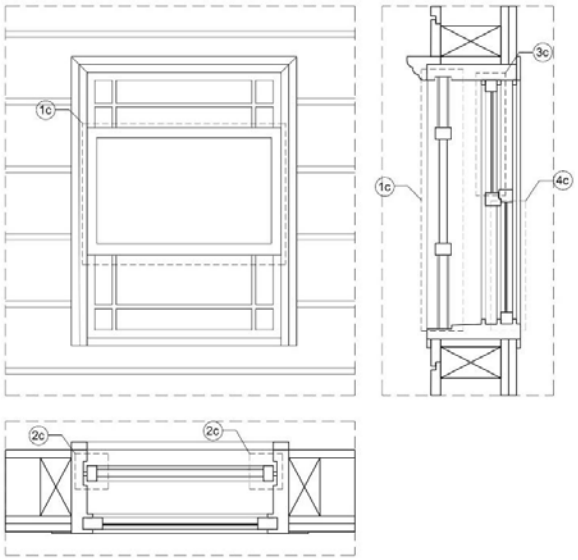


Fig. 4.(a) Elevation of the window system of Case C; (b) Section of the window system of Case C; (c) Plan of the window system of Case C.

In the second half of the 19th century, during the cage repair, the windows were raised as much as possible and the railings were lowered[32]. Because of the need for protection to solar radiation, solar control elements were integrated to windows. The system of solar control elements is made up of a wooden panel, which is half the size of window height, and a sliding mechanism (Fig. 4). Wooden sliding panel; 1c, can be moved up and down vertically according to the direction of sunlight. The sliding mechanism; 2c, is located vertical surfaces of window system and it allows solar shading panel to slide by the movement of integrated small wheels. The glazing part of window system consists of upper glazing sash ,3c, and lower glazing sash ,4c. Both of sashes can be pivoted vertically because of its sliding system according to the user's needs. The upper and lower vertical pivoted sashes of glazing cause air circulation between inside and outside. The sliding wooden panel can be moved with the movement of glazing sashes so that both blocking sunlight and air circulation can be achieved.

D. Case D

It is considered as it was built in the beginning of 1900's. There is limited information about the building in literature. There is a small pier and a garden in front of facade facing the sea. There are two wooden frame structure floors upon the basement floor, constructed as reinforced concrete, and an attic room under the triangular roof. The facade was covered by wood and painted beige colour.

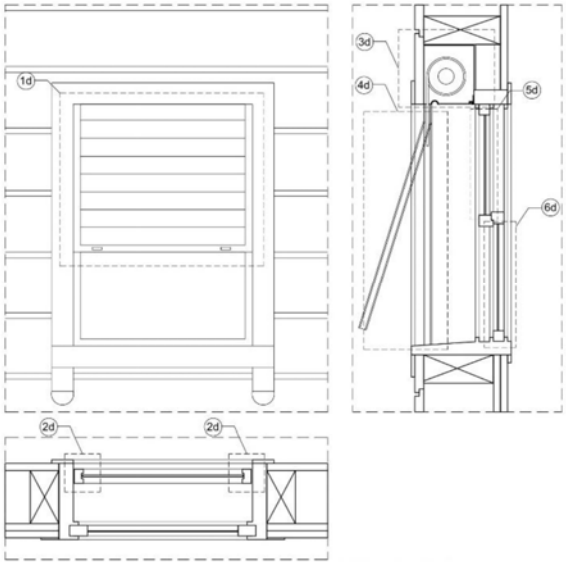


Fig. 5.(a) Elevation of the window system of Case D; (b) Section of the window system of Case D; (c) Plan of thewindow system of Case D.

In order to protect the interior from high temperatures caused by sunlight, it was used aluminum roller shutter that has a motorized mechanism and a sash opening and closing in limited angle (Fig. 5). The aluminum shutter; 1d, is connected to a motor sensor and opens/closes as it moves vertically on a sliding mechanism. Aluminum shutter moves vertically on a sliding path ,2d, which surrounds shutter both vertically and horizontally. Motorized mechanism; 3d, actuates the aluminum shutter to move vertically according to user's needs. Unlike the others, this mechanism functions by a motor systeminstead of manual actuator. Horizontal pivoted aluminum sash; 4d, moves horizontally on a certain angle, allowing air circulation between inside and outside even if it is fully closed. The glazing part of window system is

made up of upper vertically pivoted sash ,5d, and lower vertically pivoted sash ,6d. Aluminum shutter can block sunlight entirely in parts that it covers, creating shading inside and preventing overheating because of sunlight. It can respond to sunlight by closing certain percentages. When it is fully closed, the horizontal pivoted sash and lower part of glazing can be opened to take fresh air inside.

E. Case E

Two-stories mansion was built in 18th century and renovated in 19th century. It has been remained undamaged and survived thanks to frequent renovations. The architectural plan of building shows typical Bosporus Mansions' plan characteristics which is made up of sofa in the middle and rooms opening to it.It has 20 rooms, 2 kitchens, 6 sofas, 3 bathrooms and a Turkish bath [33]. The upper floor was placed on the walls without relying on any column. The roof system is hipped-gable roof type. The structure is wooden frame placed with laths and plaster, and the facade was covered by wood and painted white.

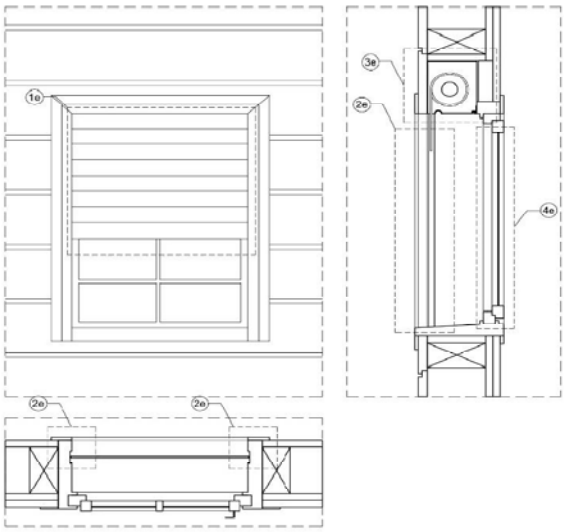


Fig. 6. (a) Elevation of the window system of Case E; (b) Section of the window system of Case E; (c) Plan of the window system of Case E.

During the renovations, aluminum roller shutters were integrated to windows in order to prevent solar radiation (Fig. 6). Aluminum shutter; 1e, covers the glazing by moving vertically according to the direction of sunlight.The sliding mechanism; 2e, is located vertical surfaces of window system, allowing aluminum shutter to slide in between. Motorized system; 3e, is actuator of the window system which activates the shutter.

The glazing part; 4e, is vertical pivoted sash of the window system. Aluminum shutter moves vertically to control interior thermal conditions and illuminance level. When it is fully closed, it is not possible for air circulation between inside and outside. It can be achieved only if both aluminum shutter and vertical pivoted glazing sash are opened.

F. Case F

The building was constructed in 1925 and demonstrates typical 20th century's Ottoman style mansion form. The building was renovated in 1990.There is limited information in literature about this case building. A small pier is found in front of the building. The mansion is two-stories in the south side, and three-stories in the north side. The sloped roof's eaves were decorated like lace motif. The facades were covered by wood and painted white. The west facade of the building is facing to the sea.

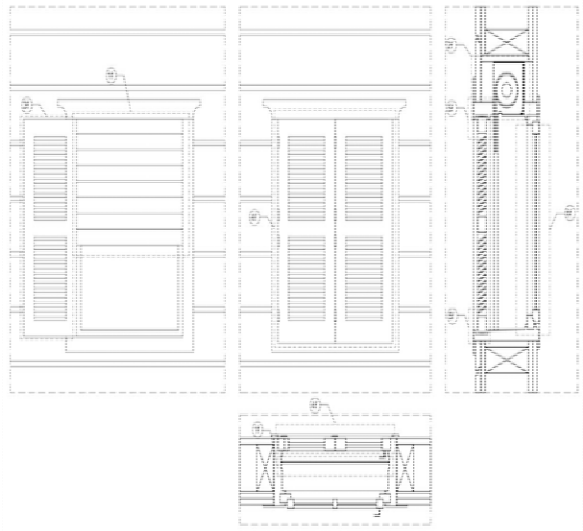


Fig. 7. (a) Elevations of the window system of Case f; (b) Section of the window system of Case F; (c) Plan of the window system of Case F.

Solar control elements were used to block direct sunlight. However, during renovations, modern aluminum roller shutter was integrated to windows additionally (Fig. 7).Aluminum shutter; 1f, moves vertically by its sliding system to block sunlight. The movement of shutter is actuated by a motorized system ,2f, which enables shutter to cover the glazing system at certain levels according to the user's needs. The vertical folding sash; 3f, can be opened and closed on its hinge joints. It is activated by a manual control. The fixed panes; 4f, is integrated to the vertical folding sash, and its rotation cannot be modified according to sun's angle of incidence. It moves vertically by folding within a sliding mechanism ,5f, which locates horizontal surface of window system. The glazing part; 6f, is vertical pivoted sash, allowing air circulation between inside and outside. When aluminum shutter is fully closed, the air circulation and illumination cannot be achieved inside. Aluminum shutter should be partly or fully opened to achieve these performances. The vertical sliding sash can achieve air circulation because of spaces between panes even if it is fully closed, as well as controlling illuminance level and overheating by blocking sunlight.

V. RESULTS & DISCUSSION

This paper analysis renovated Bosporus Mansion's window systems by evaluating them as responsive components. Based on the characteristics of responsive facade elements, the window systems of case A, case B and case C follow passive design approach because no energy sources are involved for function. Case C and case D are categorized as active design because of its motorized system, whereas the window system of case F functions with both passive and active system because of containing both aluminum and wooden shutters. All of cases are used to meet interior's thermal and lighting performances. However, for ventilation performance, only the window system of case E cannot achieve ventilation between inside and outside if it is fully closed. The window systems of all cases are not considered as managing the energy requirement. The systems are mainly used for shading needs against to the exposure of sunlight. The window systems of case A, case B and case C are actuated by manual action, whereas case D and case E are activated by a motorized system. However, the window system of case F is controlled by both manual and motorized actuator because the movement of its parts is maintained by manual and motorized actions. All of cases' window systems respond to exterior changes in macro scale. Table III summarizes the evaluations of all cases' window systems according to responsive facade characteristics. level of window systems, the window system of case A, which contains vertical pivoted solar control element with movable panes and vertical pivoted glazing sashes, has the maximum responsibility level among the others. It can respond to thermal, ventilation and lighting concerns as well as be modified to exterior environment by responding its switchable panes even when sashes are fully closed. Traditional wooden shutters and aluminum roller shutters have not been considered mainly for managing energy requirements. However, energy management is one of the fundamental qualifications for responsive facade systems, and case buildings consume lots of energy because it has not been taken precautions against thermal losses in envelope detail. Therefore, further researches should be conducted by considering case building's envelope details. The envelope should be reconsidered with its responsive components by calculating all energy requirements in long term with observing responses to exterior environment conditions.

CONCLUSIONS

This paper brings together responsive facade principles along with its development progress and historic Bosporus Mansion's facade elements. The Bosporus Mansions are one of the most unique buildings in Istanbul's architecture history. In order to maintain a comfortable environment inside, the window systems have been designed such a way that they can respond to changes of exterior physical environment by switching its physical behavior. Throughout years, this design approach has been evolved to intelligent envelopes that it isentitled as responsive facade today. Therefore, the window systems of Bosporus Mansions can be named as traditional responsive elements because of its responsive features. This paper analyzes the system details of Istanbul's historicBosporus Mansions' window systems by introducing its functions and performancesas well as providing a literature review and anevaluation framework aboutresponsive facade characteristics.

Table III. Summary of evaluation of window systems

Responsive Element Qualification		Case A	Case B	Case C	Case D	Case E	Case F
Type of use	Passive system	x	x	x			x
	Active system				x	x	x
	Hybrid system						
Relevant performance	Lighting	x	x	x	x	x	x
	Thermal	x	x	x	x	x	x
	Ventilation	x	x	x	x		x
	Energy management						
Control (actuator) type	Manually controlled	x	x	x			x
	Motorized manually controlled				x	x	x
	Automatically (dynamic) control						
	Intrinsic control						
Scale of response	Macro	x	x	x	x	x	x
	Micro						

REFERENCES

[1] D. Kuban, İstanbul, birkenttarihi: Bizantion, Konstantinopolis, İstanbul. Istanbul: TürkiyeEkonomikveToplumsalTarihVakfı, 1996.

[2] L. Yazicioglu, "Boğaziçikıyıyapıları: tarihselbiçimlenişleri, çağdaşbiçimlenişlerdetemelilkelerönerisi", Ph.D, Yıldız Technical University.

[3] "Boğaz'ınincisiyalılarzamanadireniyor", Habertürk, 2018. [Online]. Available: https://www.haberturk.com/bogaz-in-incisi-yalilar-zamana-direniyor-2005837. [Accessed: 05- Mar- 2019].

[4] https://www.eaglenews.ph/foreigners-snap-up-istanbuls-iconic-waterfront-mansions/. 2018.

[5] S. Yenigun, Boğazınincileriyalılar: AsyaYakasıBoğazYalıları. Istanbul: IIBB

KültürelveSosyalİşlerDaireBaşkanlığıKültürMüdürlüğü, 2008.
[6] M. Meagher, "Designing for change:The poetic potential of responsive architecture", Frontiers of Architectural Research, vol. 4, no. 2, pp. 159–165, June 2015.
[7] A. Palmero-Marrero and A. Oliveira, "Effect of louver shading devices on building energy requirements", Applied Energy, vol. 87, no. 6, pp. 2040-2049, June 2010.
[8] U. Knaack, T. Klein, M. Bilow and T. Auer, Façades - Principles of Construction: Principles of Construction, 2nd ed. Berlin: Walter de Gruyter GmbH, 2014, pp. 85-90.
[9] A. Tzempelikos and A. Athienitis, "The impact of shading design and control on building cooling and lighting demand", Solar Energy, vol. 81, no. 3, pp. 369-382, March 2007.
[10] E. Alawadhi, "Using phase change materials in window shutter to reduce the solar heat gain", Energy and Buildings, vol. 47, pp. 421-429, April 2012.
[11] F. Yazicioglu, "A Comparative Analysis of the Energy Performance of Traditional Wooden Shutters and Contemporary Aluminium Roller Shutters in Istanbul, a Case Study", Energy Procedia, vol. 42, pp. 483-492, 2013.
[12] R. Loonen, M. Trčka, D. Cóstola and J. Hensen, "Climate adaptive building shells: State-of-the-art and future challenges", Renewable and Sustainable Energy Reviews, vol. 25, pp. 483-493, September 2013.
[13] F. Favoino, F. Goia, M. Perino and V. Serra, "Experimental analysis of the energy performance of an ACTive, RESponsive and Solar (ACTRESS) façade module", Solar Energy, vol. 133, pp. 226-248, August 2016.
[14] J. Yao, "An investigation into the impact of movable solar shades on energy, indoor thermal and visual comfort improvements," Building and Environment, vol. 71, pp. 24–32, January 2014.
[15] J. Yao, "Determining the energy performance of manually controlled solar shades: A stochastic model based co-simulation analysis", Applied Energy, vol. 127, pp. 64-80, August 2014.
[16] A. Freewan, "Impact of external shading devices on thermal and daylighting performance of offices in hot climate regions", Solar Energy, vol. 102, pp. 14-30, April 2014.
[17] T. Silva, R. Vicente, F. Rodrigues, A. Samagaio and C. Cardoso, "Development of a window shutter with phase change materials: Full scale outdoor experimental approach", Energy and Buildings, vol. 88, pp. 110-121, February 2015.
[18] F. Favoino, F. Goia, M. Perino and V. Serra, "Experimental assessment of the energy performance of an advanced responsive multifunctional façade module", Energy and Buildings, vol. 68, pp. 647-659, January 2014.
[19] Z. Nagy et al., "The Adaptive Solar Facade: From concept to prototypes", Frontiers of Architectural Research, vol. 5, no. 2, pp. 143-156, June 2016.
[20] E. Alawadhi, "Effect of an incompletely closed window shutter on indoor illuminance level and heat gain", Energy and Buildings, vol. 110, pp. 112-119, January 2016.
[21] M. Koyaz, "Adaptabılıty level of facade systems regardıng facade performances", in Proceedings of Interdiciplinary Perspectives for Future Building Envelopes Conference, Istanbul, 2017, pp. 770-783.
[22] M. Iommi, "The Mediterranean smart adaptive wall. An experimental design of a smart and adaptive facade module for the Mediterranean climate", Energy and Buildings, vol. 158, pp. 1450-1460, January 2018.
[23] S. Al-Masrani, K. Al-Obaidi, N. Zalin and M. Aida Isma, "Design optimization of solar shading systems for tropical office buildings: Challenges and future trends", Solar Energy, vol. 170, pp. 849-872, August 2018.
[24] G. Capeluto and C. Ochoa, Intelligent Envelopes for High-Performance Buildings. Cham: Springer International Publishing AG, 2017, pp. 21-48.
[25] D. Barber, "Le Corbusier, the Brise-Soleil, and the Socio-climatic Project", Thresholds, Journal of MIT Department of Architecture, no. 40, pp. 21-32, 2012.
[26] T. Herzog, R. Krippner and W. Lang, Facade Construction Manual. Basel/Berlin/Boston: Walter de Gruyter GmbH, 2004, pp. 287-291.
[27] N. Gur, "A design support tool for variable building skins in the scope of sustainable architecture", Ph.D, Istanbul Technical University, 2007.
[28] B. Kolarevic and V. Parlac, Building Dynamics: Exploring Architecture of Change, 1st ed. New York: Routledge, 2015, pp. 70-87.
[29] K. Cilento, "Al Bahar Towers Responsive Facade / Aedas", Archdaily, 2012. [Online]. Available: https://www.archdaily.com/270592/al-bahar-towers-responsive-facade-aedas. [Accessed: 05- Mar- 2019].
[30] "The World's First Algae-Powered Building in Hamburg", Inhabitat, 2013. [Online]. Available: https://inhabitat.com/the-worlds-first-algae-powered-building-opens-in-hamburg/. [Accessed: 05- Mar- 2019].
[31] "PrensesRukiyeYalısı", EmlakAnsiklopedisi, 2013. [Online]. Available:http://emlakansiklopedisi.com//wiki/prenses-rukiye-yalisi/. [Accessed: 05- Mar- 2019].
[32] "HasipPaşaYalısı", EmlakAnsiklopedisi, 2013. [Online]. Available:http://emlakansiklopedisi.com/wiki/hasip-pasa-yalisi. [Accessed: 05- Mar- 2019].
[33] M. Tanman, "Fethi Ahmet PaşaYalısı", İslam Ansiklopedisi, 2019. [Online]. Available: https://islamansiklopedisi.org.tr/fethi-ahmed-pasa-yalisi. [Accessed: 05- Mar- 2019].

★★★