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Investigation on the Physical Conditions of Façade Systems of Campus Buildings by Infrared Thermography Tests

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Abstract—Campus buildings are educational facilities where various amount of energy consumption for lighting, heating, cooling and ventilation occurs. Some of the new universities in Turkey, where this investigation takes place, still continue their educational activities in existing buildings primarily designed for different architectural programs and converted to campus buildings via changes of function, space organizations and structural interventions but most of the time without consideration of appropriate micro climatic conditions. Reducing energy consumption in these structures not only contributes to the national economy but also mitigates the negative effects on environment. Furthermore, optimum thermal comfort conditions should be provided during the refurbishment of existing campus structures and their building envelope. Considering this issue, the first step is to investigate the climatic performance of building elements regarding refurbishment process. In the context of the study Kocaeli University, Faculty of Design and Architecture building constructed in 1980s in Anıtpark campus located in the central part of Kocaeli, Turkey was investigated. Climatic factors influencing thermal conditions; the deteriorations on building envelope; temperature distribution; heat losses from façade elements observed by thermography were presented in order to improve strategies for retrofit process for the building envelope. Within the scope of the survey, refurbishment strategies towards providing optimum climatic comfort conditions, increasing energy efficiency of building envelope were proposed.

Keywords—Building envelope, IRT, refurbishment, non-destructive test.

I. Introduction

PUBLIC buildings cover a large part of the existing building stock after residential buildings in Turkey. Considering public buildings, educational buildings generate the largest group by 30% [1]. These are the building types where optimum interior comfort conditions have to be maintained as students and academicians with different ages over 17 spend most of the daytime to get and give education. Existing public educational facilities comprise a high rate among the public building stock. Especially university campuses are the prototypes of suburbs where many types of energy consumption is generated as different types of buildings with variety of functions of research as academic facilities, administration, sport centers, auditorium and dormitory, etc. are included. These settlements create a direct pressure on national economy and environment because of the amount of energy consumption and waste production during usage of laboratories, classrooms, offices and other facilities.

In Turkey in last decade, public and private university numbers has dramatically increased as a government policy. The rate of university facilities which started educational activities in existing facilities are much more than newly built sustainable, green campuses which are also expected to have a mission of being role models of a live laboratory for trainings, new technologies, implementations in sustainability for the negative impacts on environment. Sustainable campuses must decrease their energy consumption and emissions, refurbish their government of waste and material. Unfortunately some of new universities continue their activities in the existing buildings which have been converted to campus buildings by merely functional changes, most of the time without consideration of appropriate micro climatic conditions for educational and other activities. These kinds of campuses also have to decrease their energy consumption and emissions. Decreasing energy consumption and increasing the usage of renewable energy resources in these campus structures contribute to the national economy and mitigate the negative effects on the environment caused by the usage of primary energy resources. Besides, the refurbishment of existing campus structures enables students to continue their educational life in better spaces providing better thermal, visual and acoustical comfort conditions.

In educational buildings, 69% of total energy is consumed for heating spaces as the heating period is longer than the cooling period in most of the climatic districts in Turkey [1]. Energy consumption for heating can be decreased primarily by precautions implemented on the building envelope. Building form and orientation are important design parameters effecting thermal comfort and energy conservation which cannot be changed in existing buildings. So changing facade materials with materials having appropriate optical and thermo-physical properties is an important passive strategy. Mostly heat losses occur through building envelope from the openings, and opaque surfaces by conduction and convection and radiation. Interior air temperature and mean radiant temperature are the most important interior climatic elements which effect climatic comfort conditions. Interior surface temperatures which generate interior air temperature and mean radiant temperature reach to specific values by the effects of the

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amount of heat which the volume gains or losses by different heat transfer.

The combined effect of these phenomena generates the climatic conditions of interior zones. Building envelope, with opaque and transparent surfaces, is the most important building element where the effects of all phenomena described occur. The refurbishment process on facade system in order to decrease the heat losses in the coolest period would also decrease energy consumption for heating. Refurbishment strategies for facade can basically implemented by changing the windows and wall layers by materials with appropriate thermos-physical and optical characteristics and thicknesses. It is the first step to get information on performance of existing building elements in order to determine where, how and what kind of refurbishment activities will be suggested for the outer wall system.

The existing physical conditions of the buildings have to be examined particularly. The effective micro climatic conditions have to be examined and also the existing performance of building facade should be monitored and observed also by consideration of changes and interventions performed previously in energy refurbishment studies. It is possible to obtain realistic data on building envelope and the physical conditions of interior ambient by preliminary and comprehensive research on existing buildings by slightly destructive and non-destructive tests. The tests as infrared thermography technique which provide getting information on physical conditions without effecting building elements and preferred for determination of invisible deteriorations on especially existing buildings would present data on the outer skin on thermal bridges, deteriorations, cracks and sometimes hidden parts, different material layers which helps as guideline map for energy refurbishment process conducted for the wall system.

In the context of the study Kocaeli University, Anıtpark campus located in the central part of Kocaeli, Turkey is investigated. There are four buildings, one of which belongs to the "*Faculty of Architecture and Design*". The main building focused in the context of the research is an existing building built in 1980s. Until today, it had faced different kinds of interventions on building envelope. Exterior and interior physical climatic factors influencing thermal conditions, the deteriorations on building envelope caused by physical environmental factors; temperature distribution, heat losses from opaque and transparent façade elements by thermography as a non-destructive test method in order to improve strategies for the retrofitting process for the building envelope is presented.

Within the scope of the obtained data, refurbishment strategies towards providing optimum climatic comfort conditions increasing energy efficiency of building envelope are suggested.

II. Energy Refurbishment Process

Building retrofit comprises energy refurbishment, structural and aesthetic recruitment activities. Energy refurbishment in existing buildings has a great importance regarding to the consumption of energy increase which has become a typical problem for all countries. Decreasing energy consumption also reduces the pollution of environment. Energy refurbishment provides partial or normal changes to existing building systems, one of which is "façade retrofit" process in order to lower energy consumption and energy requirement and improve the energy performance of the building [2].

Energy refurbishment process is comprised of main five periods, respectively; collection of data, diagnosis, producing strategies as solution, and evaluation of strategies. Diagnosis process provides realistic information on the existing physical properties of buildings.

The diagnosis of energy losses and deteriorations caused by physical environmental parameters can be detected by non-destructive test methods by which investigation processes are conducted by consideration of exclusion of unwanted physical effects on buildings. American Society for Non-destructive Testing (ASNT) defines test methods, which provide opportunity for investigation of a building material or structural elements and their physical properties without giving harm to building itself as non-destructive test methods (NDT). The term is generally used with nonmedical investigations of material integrity including non-invasive medical diagnostics. X-rays, ultrasound and endoscopes are used by non-destructive testing [3]. Diagnosis techniques by non-destructive test methods for architectural purposes can be conducted by infrared thermography (IRT), measurement by monitoring techniques, measurement techniques for determination of the thermal transmission properties of opaque façade elements by the heat flow-meter measurements (HFM), moisture and thermal conductivity values on site, ultrasonic velocity measurements (UVM), psychometry, video endoscopy. These test methods all present the existing physical conditions of the building which provide information for improving strategies on partial, normal or total interventions for existing building systems in order to achieve more energy efficiency. The comparison of energy conservation amount, economical benefits, opportunity for enhancement of thermal comfort conditions of strategies developed for energy refurbishment process have to be evaluated by energy analysis simulation processes conducted by realistic data as input obtained by diagnosis process.

III. Energy Losses and Deteriorations on Facade

Enhancement of energy efficiency and thermal comfort conditions of existing campus buildings provide benefit to national economy and environment. Energy consumption in buildings with different functions occurs by heating, cooling, and air conditioning, as well as lighting demands, and all these consumption types are directly related to the performance of façade where heat transfers actualize continuously under the effect of different physical environmental parameters.

Physical environmental parameters as temperature, wind, humidity directly affect façade by heat transfers occurring among interior and outside wall and openings. Unwanted solar gains and losses can occur due to thermo-physical and optical characteristics of materials which generate the layers of a façade system during winter and summer conditions.

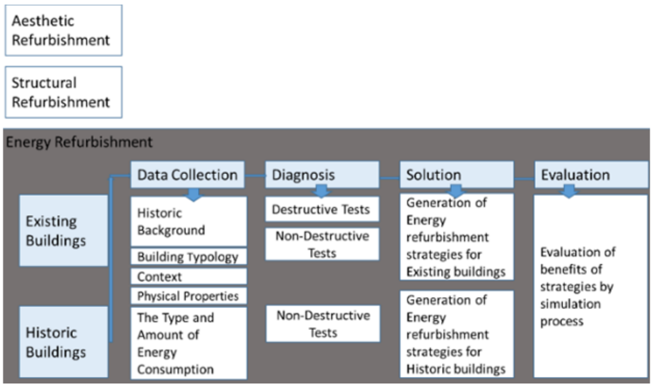

Fig. 1 Energy refurbishment process chart details and revised by the authors from [2]

The most important interior climatic parameters as interior air and mean radiant temperature is bounded up with interior surface temperatures, which are also directly affected by heat gain and losses through the façade system. The configuration of the façade system, generated by different layers with various materials and transparency ratios, creates different micro climatic conditions. The effect of forced convection stimulated by wind on outer skin, shortwave solar radiation acting on opaque and transparent façade elements; longwave radiation among the buildings and also among the building and the atmosphere, volume flow rates acting from openings; air infiltration from windows; heat transfer from outer skin to interior surface by conduction all creates combined effect on micro climate which also influence thermal sensation of occupants.

Buildings continue to serve under unfavorable conditions generated by movements caused by natural disasters as earthquake; material deteriorations, thermal bridges, cracks on building elements caused by climatic factors as snow, high and low temperature, daily temperature fluctuation, precipitation, relevant wind intensity, exposure to sun, relative humidity and conscious or unconscious interventions. These problems as shrinkage and expansion of materials, structural loading and material deficiencies may vary according to the selected façade materials.

The presence of cracks not only causes the decrease in material strength but also thermal conductivity and diffusivity of the materials, the main parameter of condensation and heat transmission from façade layers [4].

The presence of water on façade, which can be stimulated by infiltration from roof, pipes, capillary rise from the ground condensation, can cause degradation of façade materials [5]. Condensation problem on exterior and interior wall can occur if the capability of the materials to resist the periodical moisturizing and drying cycles to low temperature are not sufficient which causes corruption of the thermo-physical characteristics the outer wall system [6].

Existing buildings face this problem due to inappropriate material usage, sequence of materials. Especially insulation layers with moisture problem faces a dramatic increase in thermal conductivity which causes energy losses. Damp walls tend to create high interior relative humidity and mould growth on cold surfaces [5].

The problems caused by chemical and physical changes on materials and building elements by physical environmental parameters as surface losses, gaps, structural cracks, micro cracks, desquamation, cleavage, wall pointing gaps, incrustation, efflorescence, plant and mold growth, corrosion observed on building envelope are not only responsible for waste of energy from wall system but also inappropriate climatic conditions in enclosures which cause unhealthy environment for the occupants.

The effects and the causes of all these phenomena have to be investigated by especially non-destructive test methods in order to analyze problems and produce solutions to decrease energy consumption from the façade and also provide a healthy interior environment in the context of the energy refurbishment process.

IV. Diagnosis of Energy Losses and Deteriorations on Façade by IRT

The objective of diagnosis is to identify the causes of deteriorations whereas refurbishment must define whether the consumption level is acceptable by analyzing the conditions of thermal behavior. IRT method, which measures infrared energy irradiated from the surface of building elements, is commonly used to detect and quantify heat losses and temperature variations through roofs and walls. IRT analysis maps, which present differences in surface temperature, can also be used to detect sub-surface details, such as the presence of embedded timber-frame members, voids, inconsistencies, and deterioration in timber members. It measures infrared energy irradiated from the surface of building elements used to detect and quantify heat losses and temperature variations through facade [7], [8]. Active and passive IRT techniques can be applied on existing and historical structures to detect anomalies [9]-[12].

Heat flow meter measurements conducted to investigate heat transmission and thermal conductivity values are not enough to get information on the physical conditions of a façade system most of the time because of the insufficient amount of measurement points. Diagnosis of deteriorations and heat losses by IRT techniques provides determination of problematical parts in building elements by monitoring heat losses, condensation problems and hidden parts. Instead of all parts of the façade, just focusing on these defined problematic areas by measurement processes with heat flow meters after monitoring process by IRT technique provides better solution in terms of saving time.

V. Visualization Results by IRT: Case Study

In the context of the research, Kocaeli University, Faculty of Architecture and Design building, constructed in the 1980s, was investigated. Kocaeli province, where Anıtpark campus is located in Izmit, is under humid-temperate climate conditions.

Lowest temperature period is defined among December and

March in which The lowest and average mean outside temperature is respectively -9.7°C, 7.4°C, and the mean temperature value of the lowest of all is 3.4°C, according to meteorological data for the last 10 years, obtained from the T.C. Prime Ministry Directorate of Meteorology. Prevailing wind acts from southeast and west- northwest orientations in the coldest period.

The building faced different kinds of interventions on the building envelope since it had been constructed. Existing problems such as thermal bridges, interior and exterior surface anomalies, moisture based deteriorations and insulation performances are examined by IRT methodologies.

A. Building Details

Kocaeli University, Anıtpark Campus currently comprises four buildings constructed in different years. In 1976, Kocaeli State Engineering and Architecture Academy was established with a single building, currently being used as a part of the Faculty of Fine Arts. At the beginning of 1980s another building was constructed which is focused on as case study in this research; these two buildings had been used as Yıldız Technical University Kocaeli Engineering Faculty in 1982. Two more buildings had been constructed until 1992. Finally, the fifth building, constructed in 1972 as “Commerce High School”, was converted to a faculty facility of Kocaeli University. This building was converted to High School again in 2005.

On 3 July 1992, Kocaeli University was established with aforesaid five buildings which started to serve as complex for Kocaeli University in Anıtpark Campus. In 1999, an earthquake with magnitude of 7.2 hit the city, and the six-story, currently used as the main building of Faculty of Fine Arts was damaged slightly. The top floor had been removed to preserve the safety of the structure in 2000.

In 2012, a steel-framed single story atelier was constructed in the campus area for design classes of Architecture. Four buildings and the recently constructed atelier became the city campus including Faculty of Architecture and Design, Faculty of Fine Arts and Conservatory (Fig. 2). The Faculty of Architecture and Design presented in Figs. 3 and 4 includes a conference hall, foyer, prototype and laser-cut laboratory, seven ateliers, eight seminar room, and 40 office rooms. The five-story building has two entrances from the south and west façade, and direct passage towards the Faculty of Fine Arts.

There are no documents to obtain information about the layers of the façade. The preliminary plans of the building without the technical detail, sections and elevations were obtained from the Construction Works office of Kocaeli University (Fig. 4). It can be observed that the south facade is generated by a weatherboarding system i.e. vinyl finishing while all the other facades are covered by cement plaster and painting.

All buildings in the campus are heated by central heating system during 08:00- until 17:00 during the week, with 22°C selected as the set-point temperatures for the winter period for all the zones in the buildings (Fig. 5).

Fig. 2 The overview towards Anıtpark Campus and the investigated building (taller one)

Fig. 3 The overview towards Anıtpark Campus and the main building (taller one), [13]

A. Method

Degradations, cracks and active infiltration issue have been detected for the building, used as Faculty of Architecture and Design at 15:00-16:00, in the 14.02.2017 and 08.02.2017 winter period. The building envelope in terms of thermal bridge, insulation performance, and the state of decay regarding to moisture and hidden layers or building elements is detected by FLIR T640 which measures temperatures in the range of -40°C to +2000°C. The thermal and real images were obtained synchronically. Environmental conditions as outside air temperature, interior air temperatures, relative humidity values are recorded by Extech RHT 10 datalogger every 30 minutes.

Interior air temperatures were logged in the lobby of the ground floor and in the offices of both lecturers and administrative staff at the 3rd, 4th and 5th level. The survey is specifically conducted in the office where moisture induced degradations were noticed by direct investigations. The first measurement process was conducted on 08.02.2017 at all measurement locations. Average outdoor air temperature was measured as 18°C in the South garden and 17.5°C in the North garden. The sky was clear. During the measurement process on 14.02.2017, the sky was overcast and no direct radiation acted on the building. Average outdoor air temperature was measured as 5.5°C in the South garden and 4.5°C in the North garden. Average relevant wind velocity acting from South in the South garden of the campus was 0.78 m/s and 1.45 m/s from the Southeast. Maximum wind velocity value of 2.09 m/s was measured from the South. Average relevant wind velocity acting from Southeast in the North garden of the campus was 2.17 m/s and 1.95 m/s from the East. Maximum wind velocity value of 4.65 m/s was measured from the East. The images were obtained among the buildings via camera due to the available space (Fig. 6).

Two measurement points (2, 3) are located on various spots around the building. Measurement point 2, which is located on the sixth floor of a newly built hospital building, 200 m far away from the case study, provided larger visualization potential; measurement point 3 on the 3rd floor of the conservatory building was used in order to get images from the South façade, half of which is very near to the other block. Partial façade images were obtained as it was not possible to obtain data for the whole façade at one time.

Only the South and North façade of the building was observed by IRT technique. General views of the North and South façades of the building were obtained from the points 5 and 1. Partial views of glass entrance and the windows located on the South half of the building, which is not under the effect of solar radiation, are obtained from the point 4 and point 3. Point 2 was used to get images from the upper part of the North façade where the moisture problems could be detected. This method could not be implemented to the South facade as the trees prevented general visualization of the façade from the other buildings outside the campus.

B. Results

IRT captures executed on Faculty of Architecture and Design building help to assess thermal loss, thermal performance of building envelope, degradations and the transformation of openings on the façade. On 14 February 2017, interior ambient temperatures were logged simultaneously with IRT method. Interior air temperatures were similar in each of the offices at the 3rd, 4th and 5th floors and logged around 22°C; however, these values were measured as 10°C in the entrance; as 13°C in the lobby and 18°C at the office in the north-east office where anomalies were observed.

Moisture induced anomalies were also observed via IRT technique. Infiltration from the roof where staircase and the building connected in the north-east part building was observed. The insufficient downspout and rain drain influence hygrothermal conditions of the offices located at the top floor oriented to the North; efflorescence and biological growth were observed on the interior surface of the most North-east office of the building even by direct investigation (N-5-1 in Fig. 7). Outside surface temperature was logged between 4.5°C and 7°C on the outside surface; the highest value obtained on the envelope where radiator heats the zone, whereas interior air temperature was logged as 18°C. It is deduced that heat loss phenomenon occur with higher amount compared to other offices. The northern parapet of the roof display lower outside surface temperature with respect to other parts of the elevation; especially, the top level of the north-east area of the elevation is highly exposed to direct and wind-driven rain phenomenon. Contrarily, capillary rise based degradations were not detected on both elevations by IRT technique (N-G-1 in Fig. 7; S-G-1 and S-G-2 in Fig. 8).

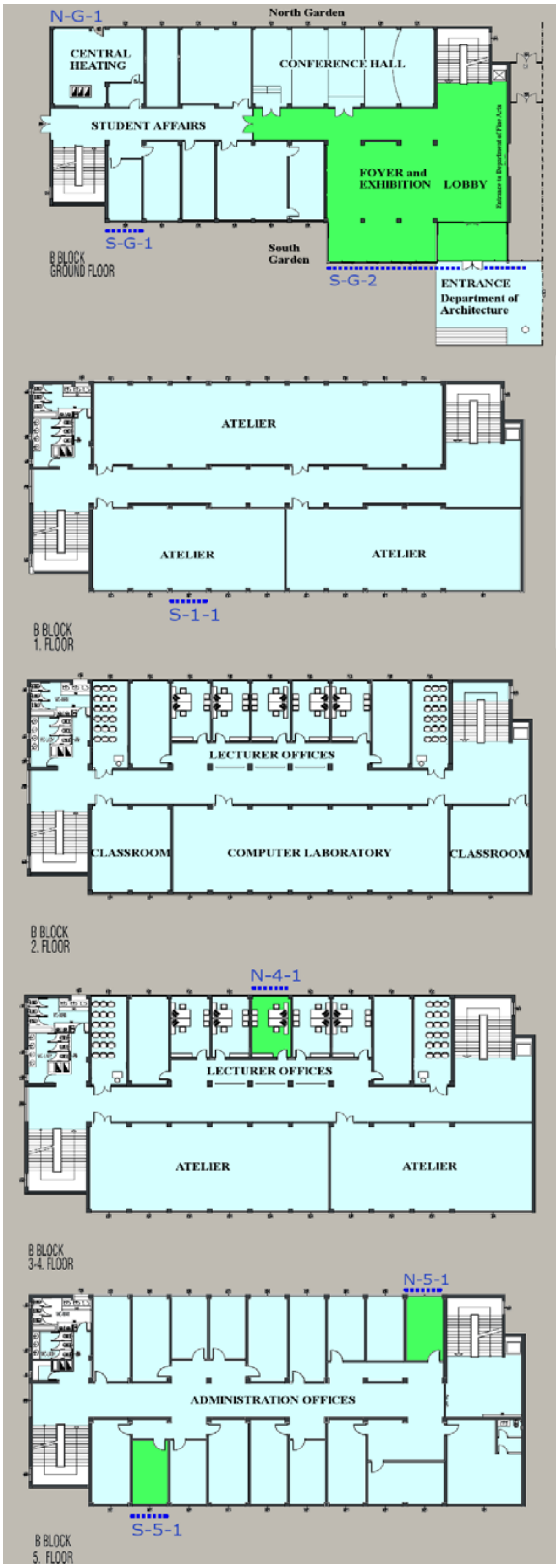

Fig. 4 Plans of Faculty of Architecture and Design building in Anıtpark Campus (taller one), [14]

Fig. 5 Heating system serving to four buildings in Anıtpark campus

Fig. 6 Visualization points with IRT in Kocaeli University Anıtpark Campus

On the other hand, South façade with vinyl finishing displayed better thermal performances compared to the North façade (Figs. 7 and 8). Active heating with heat losses were easily observed when the façade was examined via IRT captures. Outside surface temperature of south envelope for the S-5-1 was measured between 5.5°C and 6.5°C; concurrently interior ambient temperature was logged as 22°C. In spite of the better performance of the South façade, the patchy view and non-homogeneous surface temperature distribution was obtained. Additionally, close-up captures indicate that heat losses from window framings occurred in the South of building. It is proved that heat losses occur there as well (S-5-1 and S-1-1 in Fig. 8).

Closed openings and relatively new materials in the north elevation was noticed via IRT. Lack of insulation on both façade and higher heat losses enable to map these areas easily (N-4-1 in Fig. 7). It was also determined on the northern envelope that interventions on the openings of toilets were executed.

VI. Conclusion

Non-destructive tests as infrared thermography which provides getting information on physical conditions without affecting building elements and preferred for determination of invisible deteriorations, thermal bridges, hidden parts, layers help to diagnose current hygrothermal conditions of buildings. Besides, assessing thermal performance of public buildings is an essential in terms of sustainability and energy efficiency. Contextually, IRT technique was successful in order to detect heat loss and moisture based phenomenon on the elevations of Kocaeli University, Faculty of Architecture and Design in the winter time. The vinyl-coated South façade displayed better results than the plastered north façade; moisture based anomalies and the location of active radiators, were readily detected.

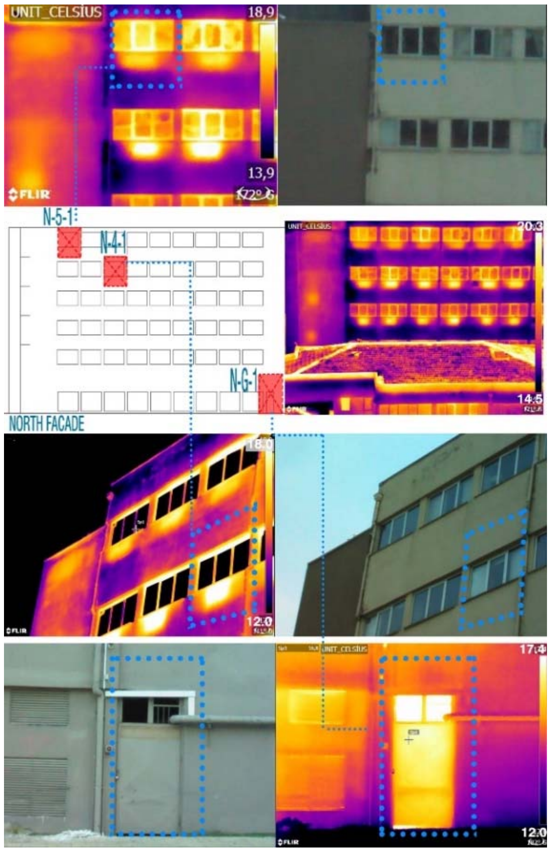

Fig. 7 IRT captures on North Elevation of Faculty of Architecture and Design

In consideration of the obtained data, refurbishment strategies towards increasing energy efficiency of building envelope are necessary. The insulation is required to prevent heat losses from the north façade. More detailed assessment need to be conveyed at the roof level. Rain drain and infiltration issue should be blocked since relative humidity level and mold growth influences the health of users. It is recommended that the vinyl coat and windows framing be changed in order to prevent heat losses. The enhancement of energy efficiency by adding insulation to the architectural composition would provide benefit to the building and the economy.

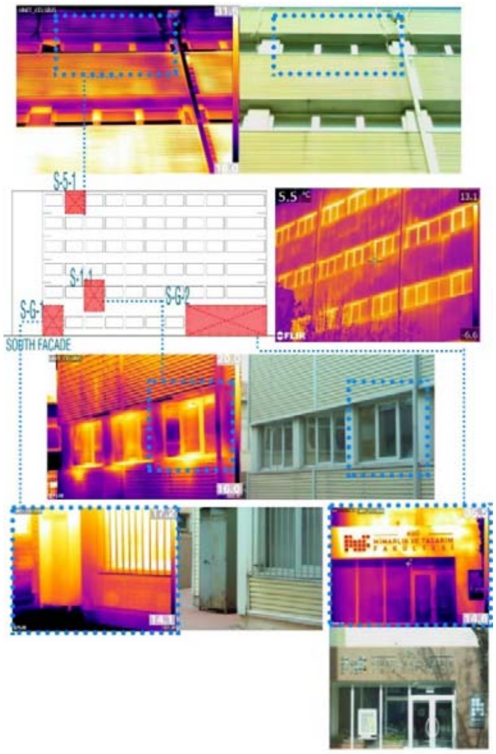

Fig. 8 IRT captures on South Elevation of Faculty of Architecture and Design

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[13] Source: Kocaeli University Baki Komsuoğlu Museum.

[14] Source: Construction works office of Kocaeli University.