Refurbishing for Thermal Comfort:
The rehabilitation of an abandoned village school building

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ABSTRACT: This paper presents details of a refurbishment project carried out on an abandoned school building, in a Turkish village, that was converted into a multipurpose facility for the Kerkenes Eco-Center, to hold workshops and university courses, and to house the participants. The refurbishment was aimed at maximizing thermal comfort conditions and reducing energy loads by using solar energy for water and space heating. To this end thermal insulation was added to the roof and to the part of the wall facing north; solar water heaters were installed; and a sunspace was built along the southern façade. This space was divided into three areas: solar drying of fruits and vegetables on one end; a greenhouse for growing vegetables on the other end; and a dining area in the middle. Funding for the refurbishment project was provided by the local government and the university students were involved in its construction. Temperature and humidity data were recorded before renovations, after refurbishment, and after adding the sunspace; while the building was also modelled to simulate its energy consumption. All collected data were analysed and the results show that the building has become thermally comfortable after refurbishment and its performance has increased further after adding the south facing sunspace.

Keywords: building refurbishments, sunspaces, energy consumption, heating loads, building simulations

INTRODUCTION

Buildings are responsible for nearly 40% of the overall energy consumption (EREC, 2010) and also for 36% of the total greenhouse gas emissions in Europe (Meeus et al, 2012). In view of the fact that constructing new buildings is not always a viable option in Europe, only 11.5% of building stock consists of new buildings (Vieites et al., 2015). Hence, refurbishing and retrofitting of the existing building stock can prove to be beneficial in terms of energy savings; greenhouse gas emission reductions (Meeus et al., 2012; Vieites et al., 2015); cost effectiveness (Guertler and Smith, 2006); enhancing thermal comfort for occupants and attaining sustainability goals (Tagliabue et al, 2012) and improving esthetics of the refurbished buildings (Bećirović and Vasić, 2013).

We also know that 48% of the total energy consumed in the EU is used for meeting space heating demands (EREC, 2010) therefore, efforts to reduce building heating loads through energy efficient refurbishments gains great importance (Stevenson, 2013). Improving the quality of a building envelope as a barrier between the indoor and outdoor environment can have a significant impact on reducing the energy consumption of the building (Ardente et al, 2011 and Pomponi et al 2015) as well as increasing the thermal comfort within (Shameri et al, 2011).

BENEFITS OF REFURBISHING

With regard to the option between refurbishment and replacement of existing decrepit buildings, various studies have shown that refurbishing is a more beneficial option when compared to demolishing and rebuilding (Power, 2008). The Sustainable Development Commission (2005) recommends that in order to achieve cost effectiveness, existing properties should be upgraded to high environmental standards rather than replacing the rundown buildings with new ones. Further, increasing energy efficiency of the buildings and enhancing environmental sustainability (Konstantinou and Knaack, 2011 and 2013), especially by assisting in the reduction of CO_2 emissions (Waide, 2006) are benefits worth mentioning. Furthermore, integration of renewable energy sources and technologies during refurbishment interventions can help to reduce the demand for toxic energy sources (Eicker et al., 2015); even if the technologies adopted to meet the desired goals are not expensive state of the art brands (Matic et al, 2015).

Different refurbishing strategies are possible to integrate to the existing building depending on the scope and objectives of the refurbishments. Strategies can range from simple thermal upgrade of the building envelope to increase energy efficiency, to more complicated solutions that incorporate renewable energy options (Konstantinou and Knaack, 2013). Moreover, various factors, such as specification of the project, current status of the building, budget, preferences of clients and designers and availability of the strategy for each specific project influence the type of refurbishment to be undertaken (Konstantinou and Knaack, 2011). Additional factors which need to be considered are thermal comfort, combined with a reduction in energy demands (Richarz and Schulz, 2013); payback time, durability, aesthetics, functionality and maintenance properties; negative environmental impacts of the materials used; and sound insulation (Kaklauskas et al, 2005).

Examining and analysing the current situation of the building in order to identify the problems constitutes the first step in every refurbishment project (Konstantinou and Knaack, 2011). In this regard, location and orientation of the existing building are substantial parameters which can influence the choice of refurbishment strategies (Konstantinou and Knaack, 2013). Considering energy efficiency as one of main objectives of refurbishment, the retrofitting strategy should improve a building in such a way that its heating, cooling and ventilation can all be affected positively by incorporating passive solutions to offset the detrimental climate conditions prevailing on site (Richarz and Schulz, 2013).

In some refurbishment projects there is an opportunity to reorganize the building layout also by taking into account various energy efficiency aspects (Richarz and Schulz, 2013) to upgrade the energy behavior of the building and improve the thermal comfort as a result (Gonzalo and Habermann p101, 2006). Given that the building envelope plays an important role as a barrier to external condition, it is responsible for many of the problems related to low environmental performance of the buildings (Konstantinou and Knaack, 2013). Integration of envelope insulation, application of appropriate coatings, and carrying out window retrofits, have been indicated as the key steps towards improving the energy efficiency of building envelopes (Ferrante, 2012).

BENEFITS OF SUNSPACES

Sunspaces are useful additions which can have a good potential for reducing energy consumption, particularly in existing buildings (Baker, 2009 p64). Attaching a sunspace to an existing envelope reduces the heat losses through that part of the envelope and gains heat by harvesting solar energy; thus, the building benefits from solar energy in terms of the reduction of winter energy demand for the adjacent space (Hestnes, 2000). Additionally, the extension of usable space increases the utility of a semi-exterior space that has acceptable thermal conditions for the occupants (Baker, 2009 p65; Hestnes, 2000). The efficiency of the sunspace is directly dependent on the geometry of the existing building and that of the sunspace, due to their influence on the possibility of solar gains (Baker, 2009 p65).

The most common type of sunspace is attached partially or fully to the exterior wall of an adjacent building, which has glazed windows and a connecting door between the two spaces; it is usually completely surrounded by a glazed envelope that admits solar radiation during the day and traps solar heat in the sunspace (Mihalakakou, 2002). The solar radiation transmitted through the glazed façade is partly absorbed by the opaque wall, partly transmitted to the adjacent building areas through the fenestration and some is lost to the outside through the glass façade (Oliveti et al, 2012).

Since heat gain in solar spaces is only through its transparent surfaces, the proportion of window surface area becomes vitally important in terms of improving its energy efficiency. In addition to window surface area, orientation of the openings affects the amount of heat gain and penetration of daylight as well as heat loss in winter (Richarz and Schulz, 2013). Hence, the area and orientation of the transparent surfaces should be determined carefully for each project (Richarz and Schulz, 2013).

This paper presents just such a project where a sunspace was designed as part of the building refurbishment interventions in order to reduce the heating energy requirements and to enhance the indoor environmental quality and facilities.

CLIMATE DATA

The building for the refurbishment project is located in the Yozgat province of Turkey within the village of Şahmuratlı, a typical Central Anatolian village. The climate of the Anatolian Plateau is a steppe climate thus, there is a great temperature difference between day and night. Climate data i.e. temperature, solar radiation, humidity and precipitation were obtained from the Yozgat meteorology station for the year 2015. Examined hourly temperature data shows that during winter months, i.e. December, January and February, maximum recorded temperature is 16.5C° in February, while minimum temperature is -17.7C° in January. During summer months, i.e. July, August and September, the highest and lowest temperatures are recorded in July as 35C° and 8.6C° respectively. Maximum and minimum temperature values for each month during year 2015 are presented in Figure 1.

According to the hourly solar radiation data obtained from meteorology for the year 2015, the highest monthly average solar radiation amount is 62.1kwatt/m^2

gained in June while in December and January the least amount of solar radiation gain is 10.7kwatt/m^2. Maximum amount of solar radiation for each month together with average values for each month are given in Figure 2.

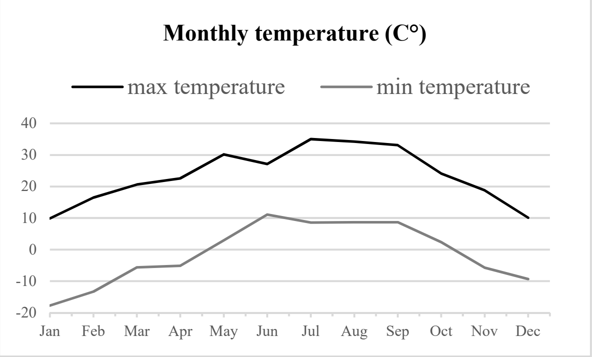

Figure 1: Monthly maximum and minimum values of temperature. (Data source: TSMS)

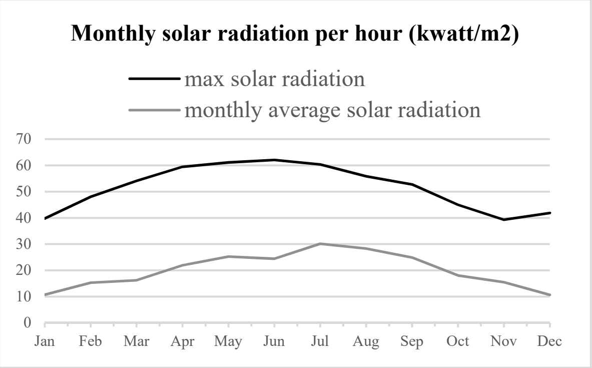

Figure 2: Monthly maximum and average values of solar radiation. (Data source: TSMS)

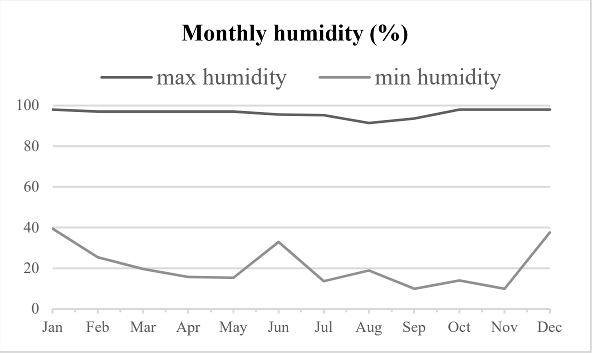

Figure 3: Monthly maximum and minimum values of humidity. (Data source: TSMS)

Analysing hourly humidity data shows that the annual average humidity is 66.8%. The highest humidity value is recorded in October, November, December and January rising to 98% while the lowest humidity value is recorded in September and November falling to 9.9% (Fig. 3).

Obtained precipitation data represent the average amount of precipitation for each month. As it is shown in Figure 4, the most amount of participation is recorded in December as 76.2mm and the least amount is in August as 8.9mm. The main wind direction is North-East and average wind speed is 2.4m/sec (Yozgat Governorship).

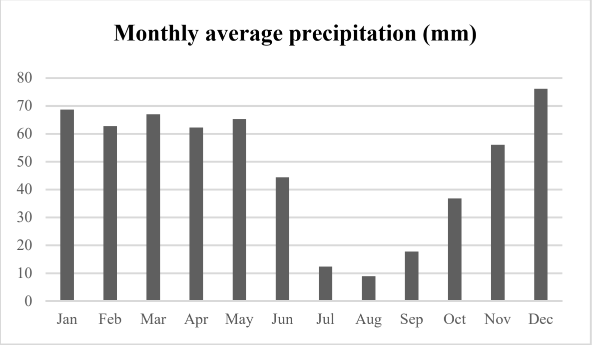

Figure 4: Monthly average values of precipitation. (Data source: TSMS)

METHODOLOGY

The refurbishment project was carried out on an abandoned school building (Fig. 5). The building has an east-west orientation such that its longest façades are facing north and south directions.

Figure 5: The abandoned village school before being taken over by the Kerkenes Eco-Center.

The school was converted into a multipurpose building to hold workshops and university courses, and to house the participants (Fig. 6). These courses are run by the faculty members of the Architecture department of a leading Turkish university, who are also running the Kerkenes Eco-Center in the same village. The village school refurbishment project was aimed at maximizing thermal comfort and using solar energy for water and space heating. To this end thermal insulation was added to the part of the wall facing north and under the ceiling, a solar water heater was installed on the roof; the floor was covered with laminated wood flooring; the single glazed wooden windows were replaced with air-tight double glazed PVC windows; and a sunspace was designed to be constructed along the southern façade of the building (Fig. 7). The sunspace was divided into three areas: solar drying of fruits and vegetables on one end; a greenhouse for growing vegetables on the other end; and a dining area in the middle for use by the course students. The building was painted inside and outside according to the villagers' tastes. The funding for the refurbishment project was provided by the local government and the university students were involved in its construction.

Figure 6: The village school building after renovations.

Figure 7: A solar space was added to the south façade of the school and a solar water heater was installed on the roof.

Real-time Data Collection

In order to assess the indoor environmental conditions of the building, especially the thermal comfort, portable data loggers were used. These data loggers were installed inside the building and outside, to monitor the internal and external conditions just after the refurbishments were completed during the summer of 2013. Thermal data, i.e. temperature and humidity, were collected from July 2014 to December 2014. Data collection was continued after adding the solar space, in summer 2015, from August 2015 to date.

Data loggers were placed 50cm away from the external walls of each room at a height of 1.6m, and they recorded temperature and humidity readings every 15 minutes. In addition to ambient temperatures, surface temperatures from inside the exterior and interior walls were also recorded with surface sensors placed at approximately the middle of the walls at a height of 1.6m. The interior surface temperature data before adding the sunspace includes data from the middle of the south and north walls of the building; later more data were collected from the north and south walls of each room and east and west walls of the main building, together with temperatures from the north, east and west walls, and ceiling of the sunspace. A floor plan of the school building showing the location of the data loggers and the sensors is given in Figure 8. In order to record outside temperatures and humidity readings a waterproof data logger with a logging range of -40 to +85°C, was placed in a shaded location at a height of 3m from the ground.

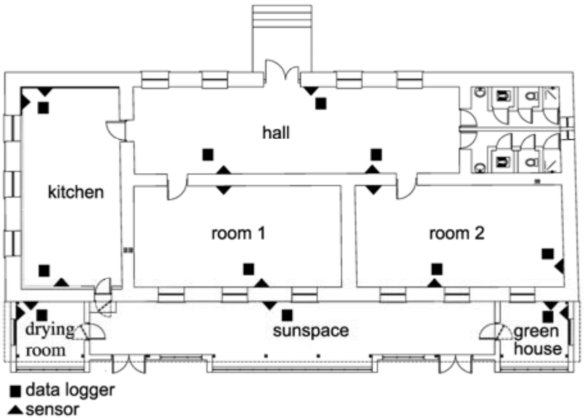

Figure 8: Location of data loggers and sensors.

Building Simulations

The building was modelled with DesignBuilder software for the three distinct stages; i.e. before renovations; after refurbishment; and after adding the sunspace. The simulation model of the original school building was prepared by using the actual specifications; i.e. 67 cm thick stone walls with cement plaster; 10 cm thick concrete floor slab; 10 cm thick concrete ceiling slab; a wooden pitched roof with clay tiles; single glazed wooden windows, and a steel entrance door. The refurbished model incorporated the actual interventions in the original building; i.e. an external door in the kitchen; laminated parquet flooring; gypsum plaster on the concrete ceiling; a 5 cm layer of AAC blocks inside the north kitchen wall; old windows replaced with double glazed PVC ones with 6 mm thick glass and 13 mm air gap. The third model has an additional sunspace with 25 cm thick unplastered AAC block walls; double glazed wooden fenestration; floor composed of 5 cm thick levelling concrete poured over a 5 cm thick bed of gravel; and a wooden roof with 25 cm AAC blocks sandwiched between two layers of chipboard and covered with 1 cm thick asphalt shingle roofing. The model is presented in Figure 9 below.

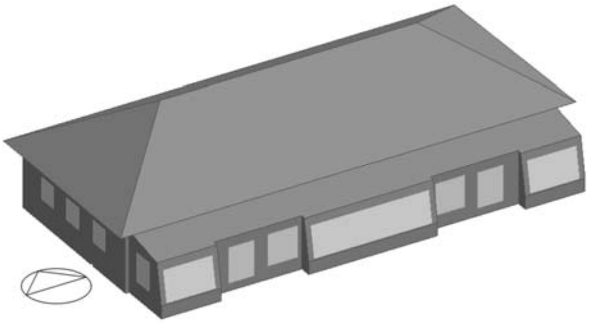

Figure 9: Simulation model of the refurbished school building with the south facing sunspace.

The educational/residential template for activity patterns and schedules was used for the simulations in DesignBuilder. Thus, occupancy density for bedrooms was 0.0963, kitchen was 0.0943, and the hall was 0.1100 people/m^2; while the occupancy schedule for each space also followed the template. The selected heating system consisted of a boiler and radiators, with set point and setback temperatures according to the individual spaces; i.e. for bedrooms they were 20°C and 10°C respectively; the set points for the kitchen and hall were 17°C and 15°C respectively; while the setback temperature for both these spaces was 12°C. All interior and exterior doors and windows were considered to be closed during simulations and no mechanical ventilation was considered.

Table 1: U-Values of the building components in the three simulation models

	Original Building w/m^{2}k	Refurbished building w/m^{2}k	Building with Sunspace w/m^{2}k
External Walls	2.336	2.336	2.336
Sunspace Walls	-	-	0.503
Building Floor	2.929	2.622	2.622
Sunspace Floor	-	-	2.600
Building Ceiling	4.736	3.990	3.990
Building Roof	3.602	3.602	3.602
Sunspace Roof	-	-	0.253
Building Windows	5.894	2.665	2.665
Sunspace Windows	-	-	2.716

The U-values of the building components used for the simulations of the three models are given in Table 1; i.e. Original building with 1.5 ach infiltration and the refurbished building with and without the sunspace, both having 1 ach each. Since the layer of 5 cm AAC blocks was applied to about 5% of the exterior walls only, the contribution to the U-value is negligible. Similarly, the additional 1 cm thick layer of parquet flooring and the 2 cm thick layer of gypsum plaster on the ceiling did not contribute much to lowering the U-values of the floor and the roof slab, respectively.

RESULTS AND DISCUSSION

All the recorded data were plotted on graphs to see the variations and trends during specified timetable thus it was possible to observe the performance of interior spaces compared to exterior condition. Also the data on U-values and energy consumption and heating loads that was obtained from the simulation of the three models was used for comparison in the following paragraphs.

Thermal Data

Due to abundance of collected data a selection had to be made for presentation in this paper. Hence, thermal data recorded after the refurbishment had finished, has been presented in the graph below (Fig. 10) for two adjacent rooms, one facing north (hall) and the other facing south (room 1) for the first week in December 2014.

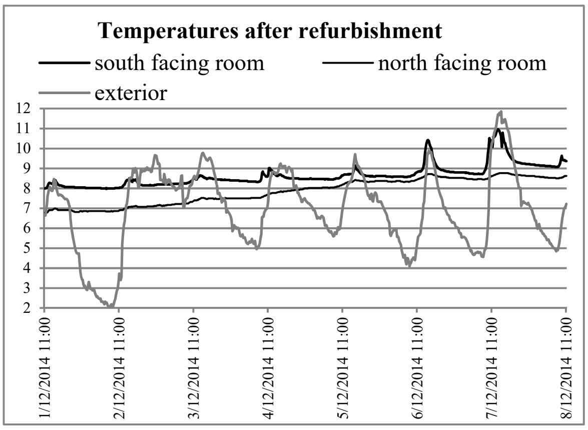

Figure 10: Exterior and ambient interior temperatures after refurbishment.

Data collected a year later for these rooms as well as the sunspace has been presented in another graph (Fig. 11) for the first week in December 2015.

An inspection of the graphical information given in Figures 10 and 11, it is understood that in the absence of the sunspace, the interior temperature of the room facing south has a fluctuation relatively similar to that of exterior temperature. The maximum difference between interior and exterior temperatures in this case was about 5ºC for the coldest day in December 2014. On the other hand, after adding the sunspace when the exterior temperature dropped to -6ºC on December 6, 2015, the temperature in the south facing room was almost 10ºC; thus giving a considerable difference of 16ºC between the internal and external thermal conditions. This is because the south facing room is adjacent to the sunspace and therefore absorbs heat from it during the day while the thick stone wall in between stores heat thus leading to relatively consistent temperatures during the night.

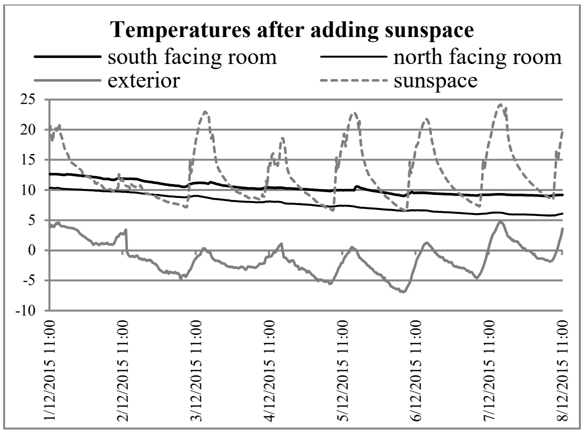

Figure 11: Exterior and ambient interior temperatures after refurbishment as well as addition of sunspace.

In the case of the north facing room, it has a lower temperature compared to the south facing room; yet, it is always warmer than the exterior. The temperature in the sunspace follows the same trends as the outside temperature; however; the diurnal fluctuations in the sunspace are greater than that of the exterior.

The data presented in Figures 10 and 11 were collected when the windows between the rooms and the sunspace were closed; i.e. in absence of ventilation. In order to observe the effect of ventilation on interior temperatures for a limited period, from November 20th to 26th, the windows of the room adjacent to sunspace were opened during the day to allow harvested solar heat from the sunspace to enter the room interiors; but were kept closed during the night to retain the warmth inside the room.

As can be observed from the chart presented in Figure 12, between November 18th to 20th while windows between the room and the sunspace were closed, the temperature was relatively constant in the adjacent room; but from November 20th to 26th when the windows were left open for ventilation the interior temperatures were higher with fluctuations similar to exterior and sunspace fluctuations. Hence, more heat was transferred inside and the higher temperature made the room more comfortable.

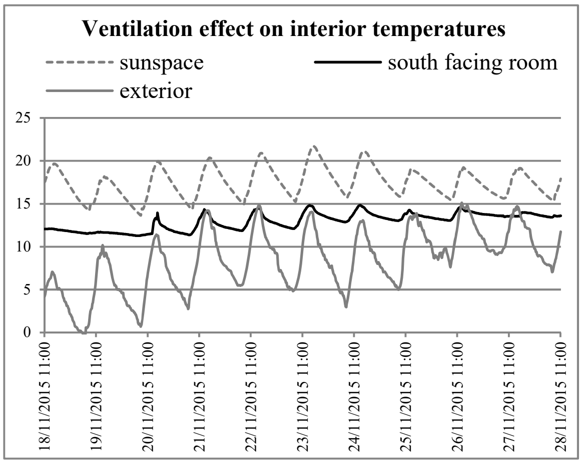

Figure 12: Effect of ventilation on temperatures inside the room adjacent to the sunspace.

Building Simulation

Since the objective was to assess the impact of adding the sunspace on energy consumption, the school building was simulated for space heating loads only. Domestic hot water was to be obtained from solar panels and a cooling system was not needed; while energy loads for electrical equipment and artificial lighting were deliberately ignored in the calculations. The pitched roof was defined as an unoccupied zone and the sunspace as an unconditioned zone. The simulations were carried out for the heating period only; i.e. from the 1st of November to the 30th of April. The energy consumption of the building and its heating loads before and after refurbishments; and after adding the sunspace are presented in Table 2 for comparison.

Table 2: A comparison of the energy consumption and heating loads of the school building before and after refurbishments and after adding the sunspace

	Total Heating Load[kWh]	Heating load / Conditioned area[kWh/m^2]
Original school building	41450.77	204.75
Refurbished building	34725.24	171.72
Building with Sunspace	32701.80	155.7822027
Energy Savings through refurbishment	16.22 %	16.13%
Addition savings from sunspace	5.82 %	9.28 %
Total Energy Savings	21.10 %	23.92 %

From Table 2 above we can see that simply by refurbishing the school building heating energy loads were reduced by almost 16.22%; while adding a sunspace brought further savings of 5.82% as compared to the refurbished building consumption. On the other hand the total energy savings achieved after refurbishing and adding the sunspace were an impressive amount of 21.1% as compared to the original building.

CONCLUSIONS

The real-time thermal data as well as the energy consumption data generated through simulations, before and after refurbishment interventions, have demonstrated that indeed the building has become thermally more comfortable after the refurbishment and its performance has increased further after adding the south facing sunspace. The project has demonstrated the feasibility of incorporating sunspaces into existing buildings located in cold regions, in order to harvest solar energy for passive space heating.

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REFERENCES

Ardente, F., Beccali, M., Cellura, M. and Mistretta, M., (2011). Energy and environmental benefits in public buildings as a result of retrofit actions. *Renewable and Sustainable Energy Reviews,* 15(1): p. 460–470.

Bećirović, S.P. and Vasić, M., (2013). Methodology and results of Serbian Energy-Efficiency Refurbishment Project. *Energy and Buildings,* 62: p. 258-267.

Brown, N.W.O., Olsson, S. and Malmqvist, T., (2014). Embodied greenhouse gas emissions from refurbishment of residential building stock to achieve a 50% operational energy reduction. *Building and Environment,* 79(0): p. 46–56.

Eicker, U., Demir, E. and Gürlich, D., (2015). Strategies for cost efficient refurbishment and solar energy integration in European Case Study buildings. *Energy and Buildings,* 102: p. 237–249.

European Renewable Energy Council (EREC), (2010). *Renewable Energy in Europe, Markets, Trends and Technologies*. 2nd ed. London and Wahington DC. Earthscan, p. 17.

Ferrante, A., (2012). Zero- and low-energy housing for the Mediterranean climate. *Advances in Building Energy Research,* 6(1): p. 81–118.

Guertler, P. and Smith, W., (2006). Energy efficiency in the sustainable refurbishment of high-rise residential buildings: mapping out an integrated policy approach. *Energy for Sustainable Development,* 10(4): p. 37-44.

Hestnes, A.G., (1999). Building integration of solar energy systems. *Solar Energy*, 67: p. 181-187.

Kaklauskas, A., Zavadskas, E.K. and Raslanas, S., (2005). Multivariant design and multiplecriteria analysis of building refurbishments. *Energy and Buildings*, 37: p. 361–372.

Konstantinou, Th. and Knaack, U., (2011). Refurbishment of residential buildings: a design approach to energy-efficiency upgrades. In: *International Conference on Green Buildings and Sustainable Cities.* Bologna: Procedia Engineering, 21: p. 666-675.

Konstantinou, Th., Knaack, U., (2013). An approach to integrate energy efficiency upgrade into refurbishment design process, applied in two case-study buildings in Northern European climate. *Energy and Buildings*, 59: p. 301-309.

Matic, D., Calzada, J.M., Eric, M. and Babin, M., (2015). Economically feasible energy refurbishment of prefabricated building in Belgrade, Serbia. *Energy and Buildings,* 98: p. 74-81.

Meeus, L., Kaderják, P., Azevedo, I., Kotek, P., Pató, Z., Szabó, L. and Glachant, J.M., (2012). *How to refurbish all buildings by 2050. Report of EU's THINK project.* Florance: European University Institute, p. 1.

Mihalakakou, G., (2002). On the use of sunspace for space heating/cooling in Europe. *Renewable Energy*, 26: p. 415-429.

Pomponi, F., Farr, E.R.P., Piroozfar, P. and Gates, J. R., (2015). Façade refurbishment of existing office buildings: Do conventional energy-saving interventions always work? *Journal of Building Engineering,* 3: p. 135-143.

Power, A., (2008). Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability? *Energy Policy*, 36: p. 4487–4501.

Oliveti, G., Arcuri, N., De Simone, M. and Bruno, R., (2012). Solar heat gains and operative temperature in attached sunspaces. *Renewable Energy,* 39: p. 241-249.

Richarz, C. and Schulz, C., (2013). *Energy Efficiency Refurbishments: Principles, Details, Examples.* Munich: Institut fur internationale Architektur-Dokumentation GmbH & Co, p. 23-24.

Shameri, M.A., Alghoul, M.A., Sopian, K., Zain, M.F.M. and Elayeb, O., (2011). Perspectives of double skin facade systems in buildings and energy saving. *Renewable and Sustainable Energy Reviews,* 15(3): p. 1468–1475.

Stevenson, F., (2013). Reducing energy demand through retrofitting buildings. *Building Research & Information,* 41(5): p. 605–608.

TSMS (Turkish State Meteorological Service).

Vieites, E., Vassileva, I. and Arias, J. E., (2015). European initiatives towards improving the energy efficiency in existing and historic buildings. In: *The 7th International Conference on Applied Energy*. Abu Dhabi: Energy Procedia, 75: p. 1679 – 1685.

Waide, P., (2006). *High-Rise Refurbishment: The Energy-Efficient Upgrade of Multi-Story Residences in the European Union.* International Energy Agency Information Paper.

Tagliabue, L.C., Buzzetti, M. and Arosio, B., (2012). Energy saving through the sun: Analysis of visual comfort and energy consumption in office space. *Energy Procedia,* 30: p. 693 – 703.

Yozgat governership. Available:
http://www.yozgat.gov.tr/iklim [20 April 2016].