Eurasian Journal of Civil Engineering and Architecture
EJCAR, Vol. 3, Issue 1, pp. 56-69, June 2019

ISSN 2602-3865, TURKEY
Research Article

AN EVALUATION OF THREE SOLAR ARCHITECTURE HOUSING PROJECTS USING THE ANALYTIC HIERARCHY PROCESS (AHP)

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Received: 03/05/2019 **Accepted:** 12/06/2019

ABSTRACT

Negative effects stemming from global warming all over the world, depletion of fossil fuels, technological developments and transformation of building living spaces have not only increased the need for energy but have also enhanced the need for new energy resources. Within this framework, continuous, clean and renewable energy resources need to be expanded along with their effective utilization. To provide maximum profitable architectural methods, energy from the sun needs to be exploited across the four seasons in Turkey and worldwide.

Three student groups designed a two-story building project using the passive solar energy methods to experience the architectural methods providing solar gain. The Analytic Hierarchy Process (AHP) was used to determine which one of three different building projects conducted to benefit from solar architecture used these architectural methods most effectively.

Keywords: *Solar architecture, Solar energy system, Decision, AHP (Analytic Hierarchy Process*

1. INTRODUCTION

The energy crisis caused by globalization, and ever-increasing consumption of conventional energy resources and reserves has focused attention on the use of the constant solar energy that serves as the source of life. Making correct decisions about settlement, direction, construction form and elements seen in global practices – with regard to energy gain – facilitates the process for the architects who conduct the implementation process, construction groups and users in the long term (Şimşek, 2009). Accordingly, contemporary designers design the internal and external areas of buildings using methods that could provide energy saving in a way that enables users to perform any activities they wish. Considering the fact that energy losses in buildings take place indoors, it is important to create designs which can ensure that the majority of the energy consumed indoors is gained directly from the sun and that the gained energy is stored without losses.

A two-story building project was designed by three student groups to use passive solar energy systems integrated with the architecture as part of the Solar Architecture course run by the Department of Architecture in the Faculty of Architecture at of Erciyes University. Architectural methods that are regarded as aesthetic, that enable longer-term use with minimum costs and ensure that the building is used as long as possible were preferred when using the passive solar energy systems. Cold climate data indicated that it would be important to gain solar energy for warming-related purposes within the solar architecture building projects that were conducted in cold climate regions. In this regard, for the relevant projects, it was necessary to settle on south-facing slopes or fields, direct the main spaces towards the south, use construction elements and materials providing solar gain, and perform detailing that ensured that the acquired heat was stored

Only architectural methods were employed in this study, and projects were assessed in accordance with architectural criteria. Therefore, annual energy consumption was not evaluated. Roof pools that were preferred for cooling-related purposes were not employed because passive solar energy methods with higher warming performance were preferred for the cold climate regions in this project. In addition, active systems were not preferred as they are related to an area of expertise other than architecture, and calculations in which solar panels were used for water heating were avoided.

Deciding which of the projects that were conducted as a result of the designs met the expectations was not easy, as each method used was determined after a number of successful attempts.Thus, the choice between the alternative solar architecture projects with multiple decision criteria was made using the Analytic Hierarchy Process (AHP) – the primary multi-criteria decision-making model. The reason why AHP was preferred while making decision was that it facilitates the conversion of verbal assessments to digital values and ensures that inconsistent decisions still remain within reasonable limits.

2. ARCHITECTURAL METHODS PROVIDING SOLAR GAIN

Solar energy is used in buildings for the purposes of heating, cooling, illumination and electricity generation. Considering the fact that one-third of the energy consumed in buildings is used for heating, using solar energy helps reduce environmental problems and protect fossil fuels and contributes to the economy.

There are two solar energy system types used in architecture: passive and active. The systems, in which solar energy is used with constructional elements (walls, flooring, roofs, clarities, etc.) for heating spaces, are called passive solar systems. The systems in which energy is collected, stored and transferred through technological means are called active solar systems. The solar energy systems used in architecture are integrated into the buildings.

2.1. Passive Solar Systems

Passive solar systems can be used for heat gain in winter and for natural ventilation and cooling in summer. Passive systems are formed and used through the planning decisions made in the design stage and in the materials used. These systems, which are economical and reliable, do not have an initial investment cost. As the system is activated at the construction design stage, no additional expertise other than architecture knowledge is needed. The solar rays reaching the buildings' walls, windows and roof elements are collected, stored and transferred indoors through transmission, convection or radiation. Passive systems are evaluated in three groups as direct systems, indirect systems and isolated systems.

2.1.1. Direct systems

Regarding the direct systems, the building is designed to receive maximum sunlight and to transfer it indoors without any additional means. The system consists of walls and roof windows that are directed towards the south.

South clarities: With this design, the solar rays pass through the glass surfaces into the building, and they are transformed into heat, stored and later transferred (Fig. 1). For the purpose of obtaining an advantage from this system, glass surfaces directed towards the south, and surfaces in other directions should be kept limited. Measures should be taken to prevent overheating on hot summer days, and heat loss on cold winter days.

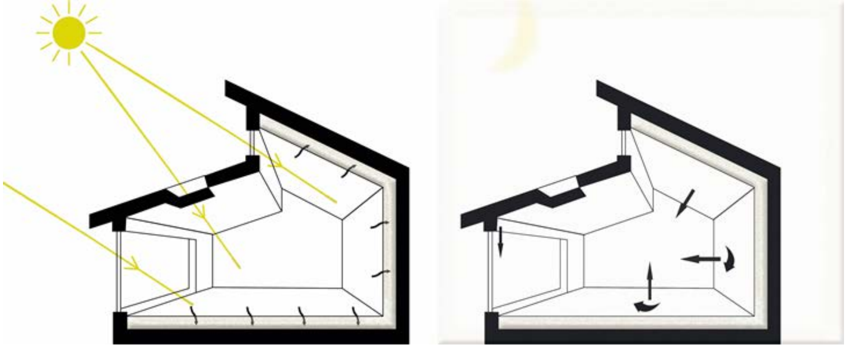

Fig. 1. South Clarity Systems (Yüre, 2007)

2.1.2. Indirect systems

Regarding the indirect systems, the collectors and storage components are designed as part of the constructional elements or sections that are outside the building but still integrated with it. This system consists of the active use of solar walls (trombe walls), water walls (jerry can walls), roof pools and solar rooms (greenhouses).

Trombe walls (solar walls) are made of a thermal mass that is positioned on and behind a glass surface that is directed towards the south and that stores energy. This mass can be black concrete, adobe, solid brick, water or stones. In this system, the heat stored in winter is transferred indoors, while the heat stored in summer is discharged through chimneys or windows without being transferred indoors (Demircan et al,2015) (Fig. 2).

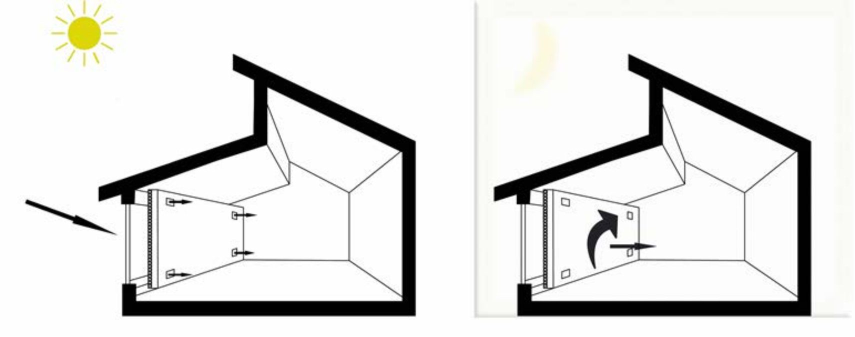

Fig. 2. Trombe wall (url 1)

Greenhouses (solar rooms) can be defined as collectors that facilitate a transition between the indoor areas and outdoor areas, provide heat, fresh air and moisture to the building, and serve as a habitable place (Alpaslan, 2010) (Fig.3). Greenhouses can serve as heat collection units or storage elements when designed to gain benefit from solar radiation in passive solar systems to a high degree. Greenhouses, like south clarities, require precautions to prevent overheating or heat losses due to the difference between summer and winter, or between day and night**.**

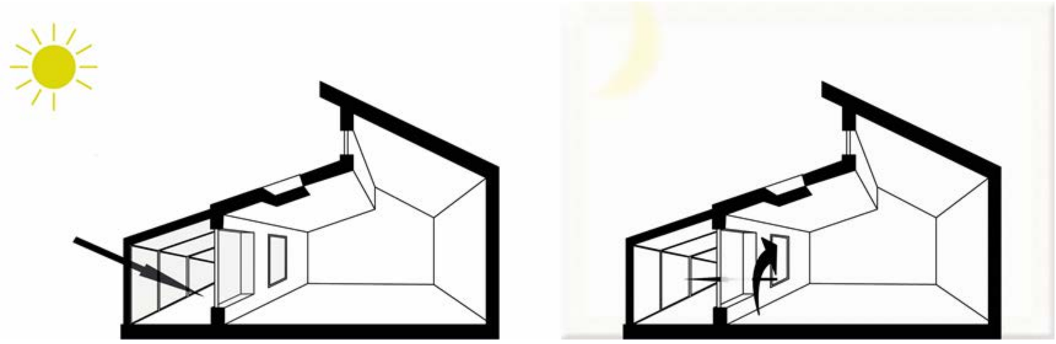

Fig.3. Greenhouse system (Alpaslan, 2010)

Roof pools: Pools or plastic bags filled with water and positioned on the roof of the building constitute a heat source transferring the stored heat to the building at night. In addition, collapsible insulated lids are positioned over the pools. These lids are opened for solar heating during the daytime and closed to prevent heat loss during night time in winter. The negative effects of solar energy are prevented by closing the lids, and these lids are opened for cooling purposes by ensuring a heat transfer from indoors to outdoors in summer (url3).Roof pools are preferred particularly for hot and dry climate regions as they provide high cooling performance, but these pools do not display the same amount of performance in cold climate regions where the heating-related needs are more significant.

2.1.3. Isolated (separate) systems

These systems, in which solar energy is collected and stored outdoors, and then transferred indoors in a controlled manner, are called isolated systems (Mazria, 1979) (Fig. 4). Storage elements that consist of water and pebbles are used to transfer and store heat. Pebbles are the most frequently used element. These systems are more suitable for inclined land (Demirbilek, 1999). The sunlight received by black glass is transformed into heat, stored by the storage elements under the place to be heated, and transferred indoors through vents in the inclined area that is next to the building and that faces south. In these systems, the indoor flooring is always warm, and the indoor area that needs fresh air is always ventilated through windows (Şimşek, 2009).

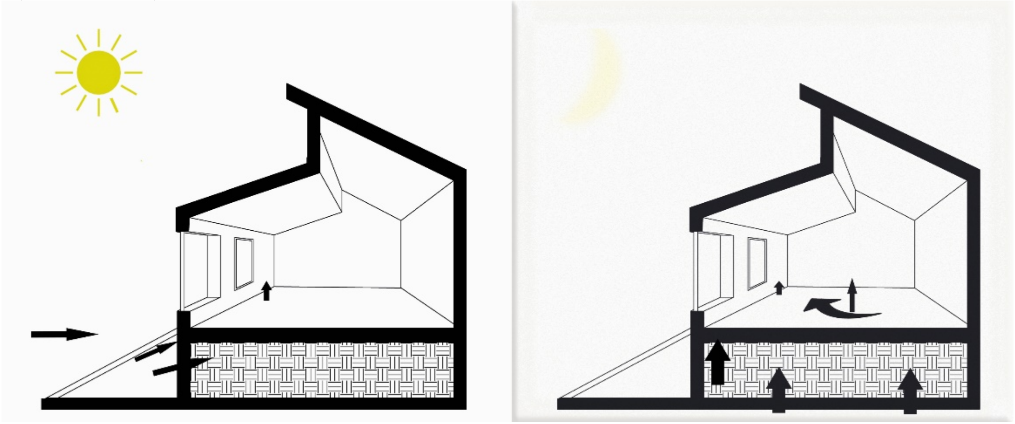

Fig. 4. Isolated Systems (url 1)

2.2. Active Solar Systems

These are the systems in which mechanical tools and instruments are used to benefit from solar energy for the purpose of heating, cooling and generating electricity. As active systems require expertise and expenditure outside the architectural domain, passive systems with more architectural content were preferred for these solar energy building projects.

Solar collectors (panels) are used to meet the hot water needs of buildings (Fig. 5). The solar collectors ensure that cold water flowing through the system works on the principle of collecting and intensifying the solar radiation (Özdoğan, 2005).

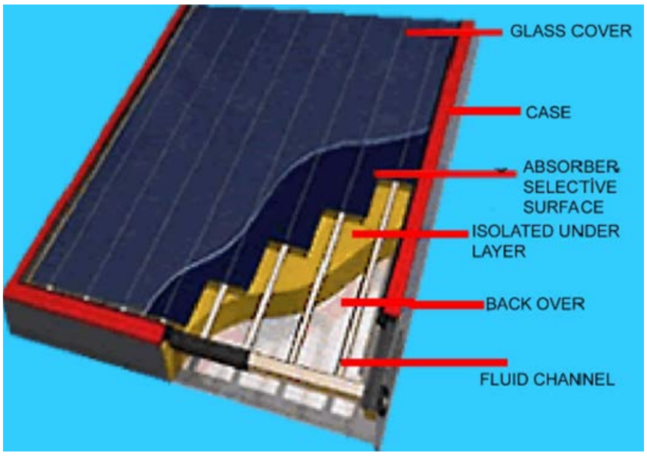

Fig. 5. Solar panel (url 2)

This study includes the architectural evaluation of three building projects that provide solar energy gain by benefiting from passive solar systems. Solar gain systems that display good heating performance and that can be used in cold climate regions were preferred. AHP, a multiple-criteria decision-making method, was used to determine the architectural success of the projects and the passive energy systems used.

3. THE ANALYTIC HIERARCHY METHOD

This method, which was first proposed by Thomas L. Saaty in 1977, constitutes the basis of multiple-criteria decision-making methods (Saaty, 1980). AHP is a mathematical method that considers the priorities of groups or individuals and holistically assesses the quantitative and qualitative variables (Dağdeviren et al.2004).

AHP consists of four steps (Toksarı, 2011):

Step 1. AHP forms the criteria that set initial target and affect the choice in regard to this target. The criteria are taken into account to determine the potential alternatives. A hierarchical structure is formed to make a final decision (Dağdeviren and Eren, 2001).

Step 2. A paired comparison matrix is formed as the second step of AHP. After forming a hierarchical structure, the degree of relative importance is calculated for each criterion (Chandran,2005). Following the structure formed in Step 1, alternatives should be compared for each criterion, and the resulting criteria should be compared with one another. The ratio scale criteria presented in Table 1 are used for the comparison.

Step 3. Normalization of the relationship matrices is performed in this step. Elements of each matrix column are divided into the total for that column. The line total of the value is calculated and divided into the number of elements in this line total.

Step 4. The order of priority regarding each alternative is found by multiplying the importance weights of the criteria with the importance weights of the alternatives. The alternative that obtains the highest value is the best alternative for the decision problem.

Table 1. Ratio scale criteria used for bi-directional comparisons (Saaty, 1980)

VALUE	**DEFINITION**
1	Equally significant
3	Moderately significant
5	Highly significant
7	Very highly significant
9	Definitely more significant
2,4,6,8	Intermediate values

3.1. Determining The Criteria

One of the first steps for evaluating the solar architecture building projects is the formation of the criteria. The criteria were selected from the solar energy systems that are believed to be efficient in cold climate regions. While performing evaluations in accordance with the criteria, the scoring performed by the decision makers in relation to the systems and design of the project is significant. Evaluation is performed in accordance to the criteria in Table 2.

Table 2. Evaluation criteria table

EVALUATION CRITERIA	
Facing south	The use of window and roof clarities that were positioned to predominantly face south
Aesthetically pleasing	Aesthetically pleasing systems that suit the project were preferred
Appropriate spatial organization	The relationship between the spaces and methods used in regard to heating
Climate-compatible design	Preferring methods used for heating in cold climate regions
Use of topography	Use of systems that benefits from the elevation

3.2. Solar Architecture Building Projects

The solar architecture building projects on different areas in the Kayseri-Talas locality were designed by students for three different families. Talas is situated to the southeast of Kayseri and the foothills of the Ali Mountain. Its geographical structure is rough. The climate in Talas is cold (terrestrial), hot and dry in summer, and snowy and cold in winter. The hottest months are July and August. Heating is generally needed in the months other than these two, and the sun is present for almost all of the seasons.The design criteria for cold climate regions have featured in the building designs. Accordingly, facing south, preferring the middle sections of sloping land, designing compact buildings, planting deciduous trees around the buildings, preventing the adjacent buildings from forming shade, preferring wind-protected surfaces, and construction elements and materials with strong thermal capacity were all been deemed to be significant. The targets to be met in the project design included the following:

- ensuring maximum solar gain
- storing the heat obtained from the construction elements and enabling the use of the heat when needed
- keeping heat losses to a minimum.

Solar architecture building project 1 (P1)[1] had a mechanism in which both passive system methods and solar panels were used together. Living environments on the south side of the building and terrace were heated through direct sunlight, and the secondary spaces on the north side were heated by water and additional heating from the solar panels.(Fig. 6).

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[1] Supervisor: S. Şimşek
P1: A. Kumaş, S. Kılınç

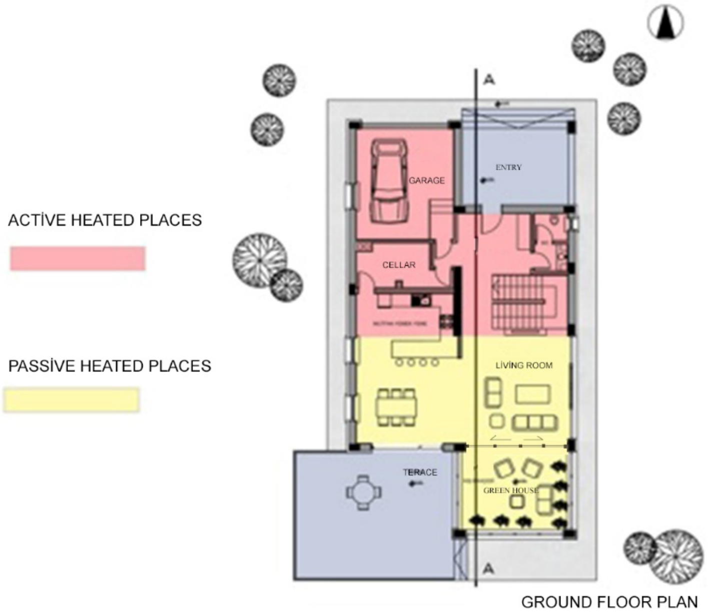

Fig. 6. Ground floor plan

Solar panels that helped meet the hot water needs were positioned on the roof of P1 facing south. There were system storage elements in the basement floor (Fig.7).

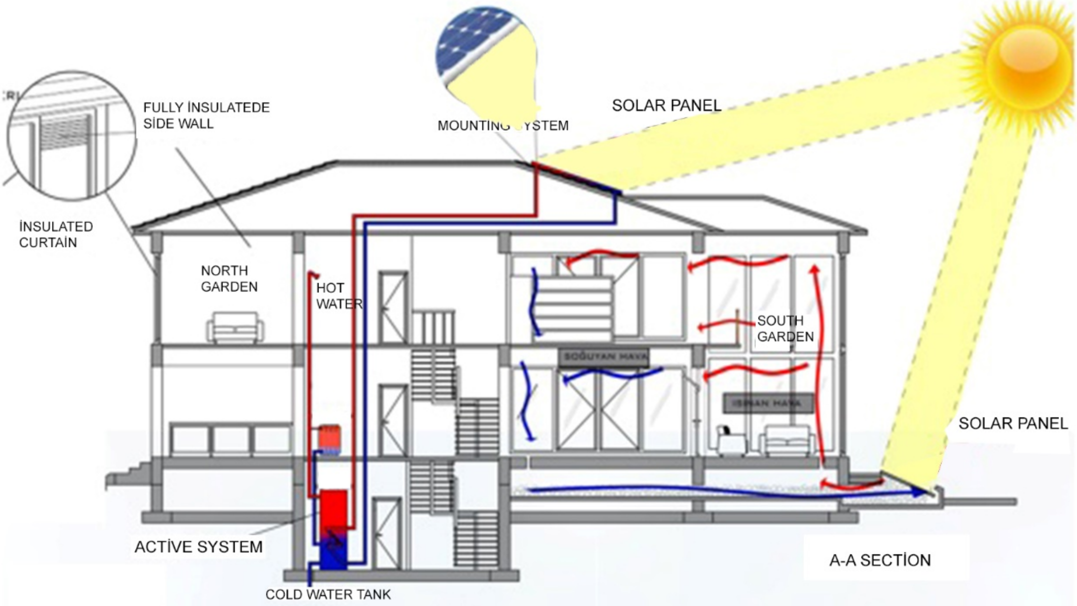

Fig. 7. A-A section

The southern facade of P1 has a transparent window system that will pass light but prevent heat loss. The largest facade clarities can be found pointing towards the south (Fig. 8).

Fig. 8. Southern façade

The details in Fig. 9 indicate that the heat reaching indoors through floor to ceiling windows warm the internal areas of the building via galleries and transparent spaces. The windows in the south are opened in summer and ensure integration with the garden. The heat-insulated windows can be used as sunshades when sunlight is not desired (Fig. 9). In addition, the panels positioned on the slope were used to ensure heating through the flooring.

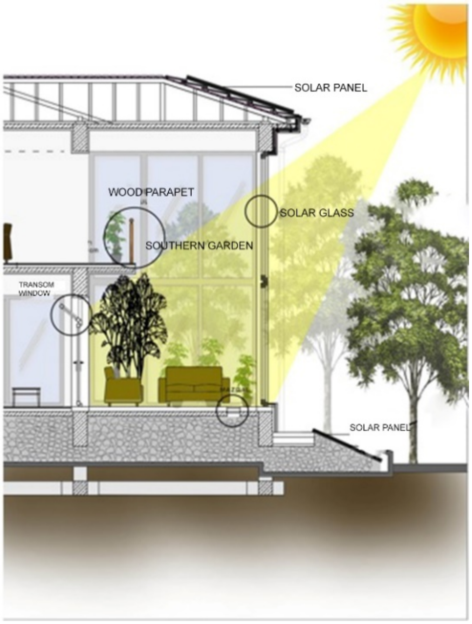

Fig. 9. Southern garden system section

As seen in solar architecture building project 2 (P2)[2] and P1, solar panels were used in north-facing areas such as the kitchen, guest room and dining room, where constant heating is not needed, and a passive system methods were used in the south-facing places, such as the living room where heating and sunlight were needed (Fig. 10).

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[2] Supervisor: S. Şimşek
P2: O. Boğa, İ. Yüksek

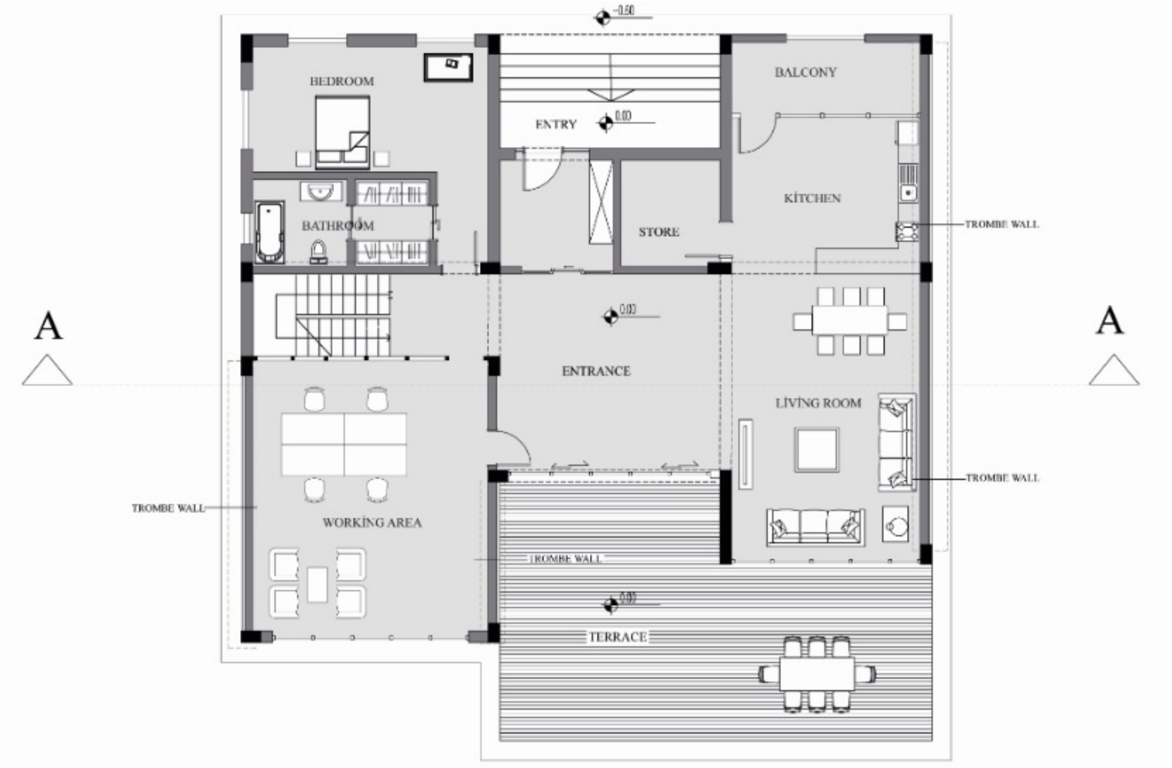

Fig. 10. Ground floor plan

As seen in the A-A section, the roof surfaces facing south side were expanded. The greenhouse with transparent coating ensured significant sunlight permeability for heating the upper floors (Fig.11). Fig. 11 presents the details of solar panels in the spaces to the north.

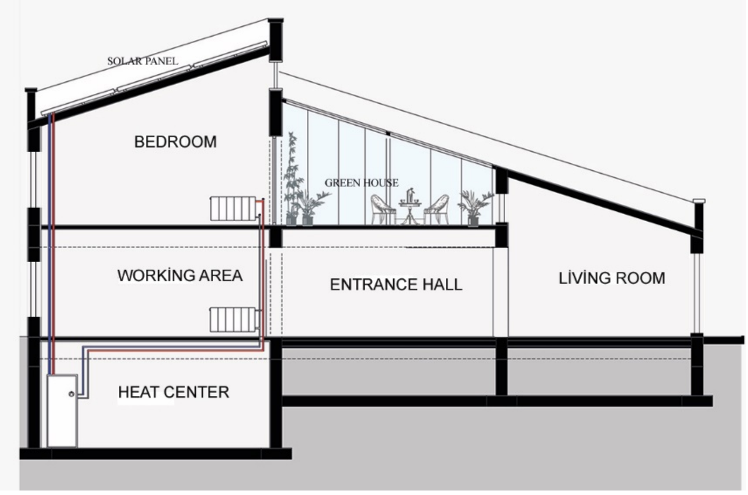

Fig. 11. A-A section

The southern view displays the transparent ground floors and greenhouse on the upper floor. The opaque surfaces used as trombe walls cover large areas, particularly on the ground floor (Fig. 12).

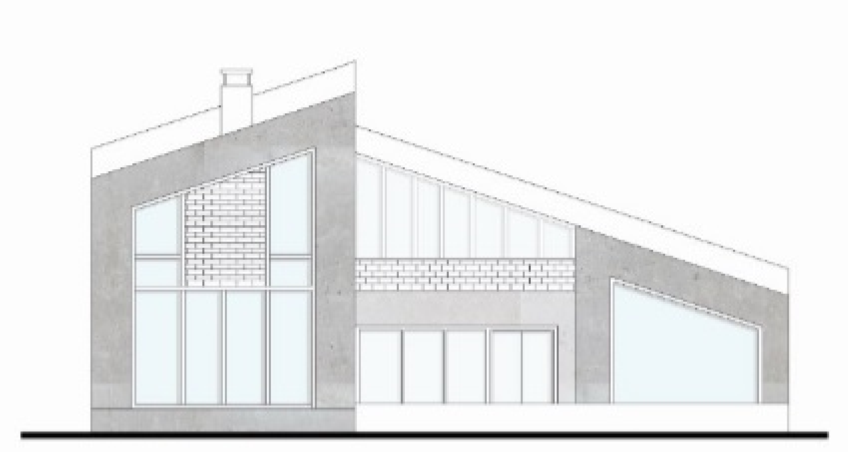

Fig. 12. View from the south

The opaque coverings on the transparent surfaces in the southern facade were used as trombe walls to obtain the maximum benefit from the sunlight. Figure 13 includes the section that displays the working principle of both the trombe wall and the greenhouse.

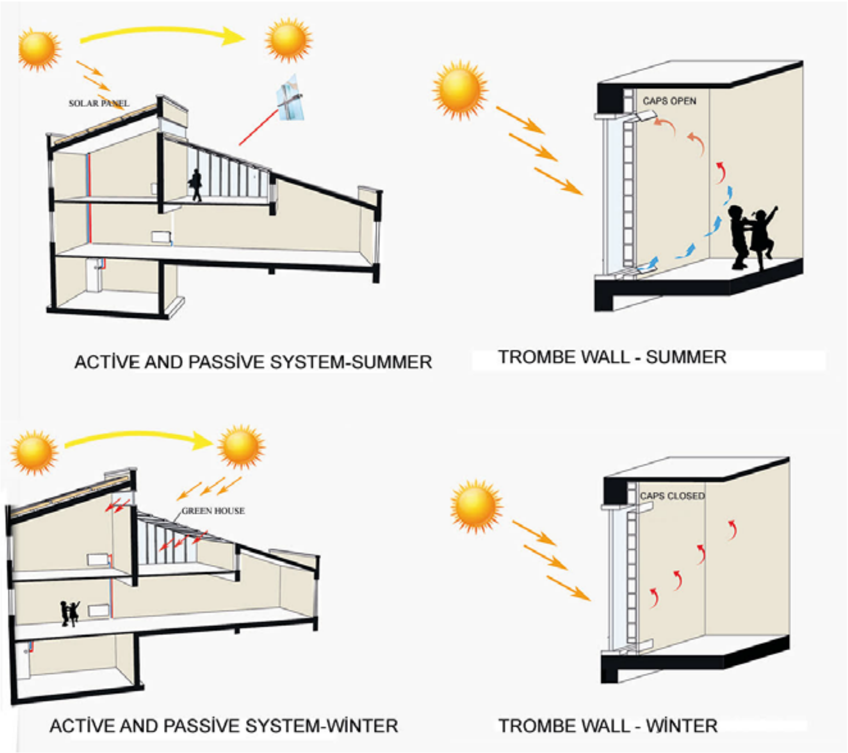

Fig. 13. Sections

The ground floor plan of the solar architecture building project 3 (P3)[3] indicates that the southern facade consists of large glass surfaces (south clarity), a trombe wall and a greenhouse, while the northern facade has rather more opaque surfaces (Fig. 14).

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[3] Supervisor: S. Şimşek
P3: Ş. G. Gediri, Ş. Çiltepe

Fig. 14. Ground floor plan

The trombe wall was separately designed for both floors on large opaque surfaces facing southwards. Isolated glass was positioned on the inclined slope facing the south side, so heating from the flooring was ensured. A greenhouse was constructed to increase the rate of sunlight reaching the living environment. Panels were positioned on the roof on the south side to heat the building (Fig. 15).

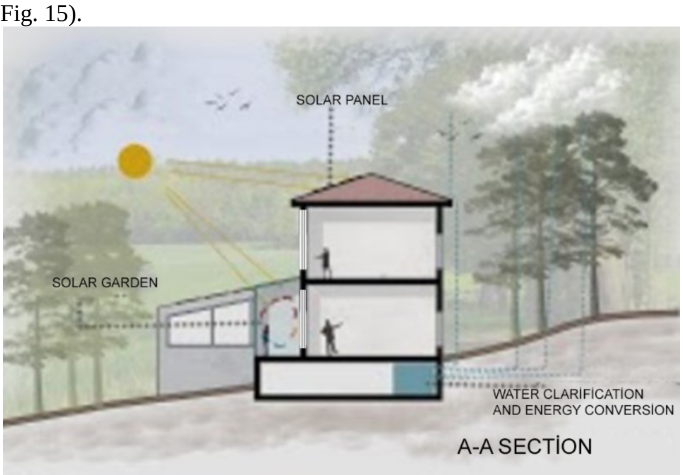

Figure 15. P3 section

Fig. 16 presents the details of the trombe wall separately designed for two floors. The heat is controlled with the lower and upper vents in the trombe walls working on the principle of convection (Fig. 16).

Fig. 16. System details of trombe wall

4. AHP IMPLEMENTATION AND RESULTS

Step 1. Comparison of the building projects: The projects were evaluated through verbal assessments with regard to the criteria in Table 2. These evaluations were transformed into the numerical figures in Table 1 and thus digitized (Table 3).

Table 3. Comparison of the projects by criteria

	A FACİNG SOUTH		
	P1	P2	P3
P1	1	5	7
P2	1/5	1	1/5
P3	1/7	5	1
	B AESTHETİCALLY PLEASİNG		
	P1	P2	P3
P1	1	1/5	1/7
P2	5	1	1/3
P3	7	3	1
	C APPROPRIATE SPATIAL ORGANIZATION		
	P1	P2	P3
P1	1	7	9
P2	1/7	1	3
P3	1/9	1/3	1
	D CLİMATE-COMPATİBLE DESİGN		
	P1	P2	P3
P1	1	9	9
P2	1/9	1	1
P3	1/9	1	1
	E USE OF TOPOGRAPHY		
	P1	P2	P3
P1	1	1/3	5
P2	3	1	7
P3	1/5	1/7	1

Step 2. Normalization of projects' value matrix: The total of the values was divided by each figure of the value matrix in the project (Table 4). The criteria were described with the codes A, B, C, D and E for facilitating the process.

Table 4. Normalization of the projects with regard to criterion A

	FACING SOUTH		
	P1	**P2**	**P3**
P1	35/47	5/11	35/41
P2	7/47	1/11	1/41
P3	5/47	5/11	5/41

Step 3-4: Determination of weighted ratios: Each value in the normalization matrix of the projects was used to determine the weighted ratios with regard to criterion A (Table 5).

Table 5. Weighted ratios of the projects with regard to criterion A

	FACING SOUTH			
	P1	**P2**	**P3**	**MEAN VALUES**
P1	0.7447	0.4545	0.8537	0.6843
P2	0.1489	0.0909	0.0244	0.0881
P3	0.1064	0.4545	0.1220	0.2276

The same process was conducted for each criterion, alternative projects were evaluated with regard to each criterion following the same order, and the results are presented in Table 6.

Table 6. Formation of projects' weighted matrix and determination of mean weighted values

	A	**B**	**C**	**D**	**E**	**MEAN WEIGHTED VALUES**
P1	0.6843	0.0738	0.7766	0.8182	0.2828	0.5271
P2	0.0881	0.2828	0.1549	0.0909	0.6434	0.2520
P3	0.2276	0.6434	0.0685	0.0909	0.0738	0.2208

The mean weighted values are presented in Table 7 after the alternative projects were evaluated.

Table 7. Weighted ratios of the projects

	WEIGHT	**RESULTS**
P1	52.71%	1
P2	25.20%	2
P3	22.08%	3

Step 1. Comparison of the criteria: The decision makers in this study compared the criteria with one another, and a value matrix was formed in accordance with the values they found. The results for the alternatives are shown in Table 8.

Table 8. Comparison of the criteria with one another

	A	**B**	**C**	**D**	**E**
A	1	5	3	7	5
B	1/5	1	1/3	5	3
C	1/3	3	1	5	7
D	1/7	1/5	1/5	1	5
E	1/5	1/3	1/7	1/5	1

Step 2. The normalization matrix was formed after the criteria were compared (Table 9).

Table 9. Normalization of the matrix values of the criteria

W	**A**	**B**	**C**	**D**	**E**	**W'**
A	0.5330	0.5245	0.6415	0.3846	0.2381	0.4643
B	0.1066	0.1049	0.0713	0.2747	0.1429	0.1401
C	0.1777	0.3147	0.2138	0.2747	0.3333	0.2629
D	0.0761	0.0210	0.0428	0.0549	0.2381	0.0866
E	0.1066	0.0350	0.0305	0.0110	0.0476	0.0461

The weighted ratios of the criteria in Table 10 indicate that facing south is first (46.43%), the appropriate spatial organization is second (26.29%), the aesthetically pleasing is third (14.01%), the climate-compatible design is fourth (8.66%), and the use of topography is fifth (4.61%).

Table 10. Weighted ratios of the criteria

CRITERIA	W'	RESULTS
A	46.43%	1
B	14.01%	3
C	26.29%	2
D	8.66%	4
E	4.61%	5

In conclusion, the weighted performance of the criteria and projects were multiplied, and the projects' weighted ratios and orders were determined (Table 11).

Table 11. Solar gain order of P1, P2, and P3 projects

	WEIGHTS	PERCENTAGE	RESULTS
P1	0.6161	61.61%	1
P2	0.1588	15.88%	3
P3	0.2251	22.51%	2

The evaluation in which AHP method was used to select the most efficient building project in regard to solar gain indicated that P1 project was first (61.61%), P3 project was second (22.51%) and P2 was third (15.88%). Facing south, A (46.43%), was first among the criteria. Appropriate spatial organization, C (26.29%), was second. Being aesthetically pleasing, B (14.01%), was third. Climate-compatible design, D (8.66%), was fourth and the use of topography, E (4.61%), was fifth.

5. CONCLUSION

P1 was regarded as the most efficient solar architecture project by a wide margin from the evaluation of the three building projects using AHP in regard to solar architecture. The fact that southern clarity (southern garden) continued for two floors from floor to ceiling was significant in rating this project first. Consequently, it ensured both floors passively benefited from solar energy. The rate of solar gain for the building increased as the window systems on the facade in the south clarity, which enabled plants to grow, were transparent to the sunlight and an insulator with regard to heat loss. . Appropriate spatial organization and the criterion of facing south were effective for ranking the P3 Project second. The locations and dimensions of the greenhouse and trombe wall in the south, and their relationships to the spaces were found to be successful.

Considering the weighted performances of the criteria used in the evaluation, facing south was determined to be the most significant criterion by a great margin. Facing south is necessary to benefit from the solar energy for direct heating purposes. Broad glass surfaces facing south can be successful if particular precautions are taken with the glass and window systems to prevent the loss of the heat obtained. Facing south was found to be successful for solar gain, which also increased the success of the projects that contained clarities on the south façade. The second most significant criterion was found to be appropriate spatial organization. This meant ensuring the relationship between the heating-related greenhouse, winter garden and solar room methods, and other spaces. Therefore, the heat reached other spaces and spreads out from there. The third significant criterion was being aesthetically pleasing. It represents the fitting, calibrated and proper appearance of the passive solar energy systems preferred for the project. Greenhouses, trombe walls, south clarities and solar panels were preferred for heating-related purposes, and these elements should fit the building rather than distorting its appearance. The fourth significant criterion was the climate-compatible design. Preferring the methods that meet the heating-related needs in the cold climate regions and performing more compact designs to retain the heat were deemed successful. The fifth (and last) significant criterion was the use of topography. Heat gain is ensured through isolated systems if the building is positioned on a slope. The heating-related needs of the building are met through the solar panels on the slope.

This study is important because it provides information about the ways to use solar energy in architecture and about how solar architecture building projects can be selected using architectural criteria.

ACKNOWLEDGEMENTS (*OPTIONAL*)

I extend my gratitude to İnanç Yüksek, Orhan Boğa, Ayşe Kumaş, Sena Kılınç, Şerife Gül Gediri and Şükrüye Çiltepe, who took the Solar Architecture course provided by the Department of Architecture in the Faculty of Architecture of Erciyes University in the 2018 to 2019 autumn term, for their contributions to the project study.

I also express my gratitude to Mechanical Engineer, Yavuz Şimşek, who provided technical support for the architectural decisions within this study.

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