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Energy efficient mobile building design

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Abstract

Mobile buildings consume less energy compared to traditional stable buildings in pre-construction, construction, occupancy/maintenance and recycling stages in terms of lifecycle. The reduction of the energy consumption of the houses during their lifecycle is going to play an important role in the decrease of fossil fuel consumption. The purpose of this study is to develop a model to guide designers in terms of designing mobile buildings for the production of energy efficient buildings that do minimum harm to the environment, are suitable for climatic data, use renewable energy sources and are flexible for user needs that grow or decrease in size. The proposed mobile building is a single story energy efficient house in Istanbul for four people, which is developed by examining modern mobile building models. The building's design process was examined in detail including general design decisions and the effective use of energy, water, and materials. The building envelope alternatives created during this process were analyzed with Autodesk Ecotect Analysis 2011 software and according to the data obtained from the simulation program the final building envelope that decreases energy consumption has been identified. This final building envelope's energy loads are designed to be met with solar energy systems like photovoltaics and solar panels. Decreasing the energy consumption of houses during their lifecycle with energy efficient mobile building design was the aim of this study.

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Keywords
Mobile building, Energy efficiency, Dwelling.

1. Introduction

Resource requirements such as land, building material and energy are increasing as communities develop economically and this increases the impact of architectural activities on the global ecosystem (Smith, 1997).

A significant amount of energy is spent on generating buildings. The construction sector is responsible for a large part of the total energy consumption in the world. Therefore, minimizing the amount of energy consumption during the production phase of buildings is very important to reduce the amount of fossil fuel consumption. Buildings should be examined not only during production phase but also the lifecycle to reduce the amount of consumed energy throughout their life.

The building's life cycle is composed of four stages: the pre-construction stage, construction stage, occupancy/maintenance stage, and recycling stage.

Considering all these stages, mobile buildings consume less energy during the pre-construction, construction, occupancy/maintenance and recycling stages compared to traditional stable buildings. The tests that were conducted in the last few years have shown that mobile buildings are 67% more efficient on average than traditional stable buildings (Url-1, 2013).

Mobile buildings can be carried by a vehicle or be the vehicle themselves. These buildings are preferred because of being mountable and easily movable, having the ability to grow with additional connections when they needed, having a lower margin of error compared to other housing production techniques, and being economical.

Currently, mobile buildings serve the purpose of closed space needs by quickly creating shelter in case of disaster, accommodation in holidays, an infirmary for medical services, and short-term work offices in the field. They are often used as mobile housing to meet shelter needs.

Mobile buildings save energy in the pre-production phase because all the materials and systems of mobile buildings are pre-produced in factories and brought to the site. They consume less transportation energy due to loading on vehicles in portable size modules. Mobile buildings prevent the energy consumption of new buildings' production by responding to user needs when they are changed with the addition or removal of units. They are easily removed in the recycle stage and this also provides energy savings.

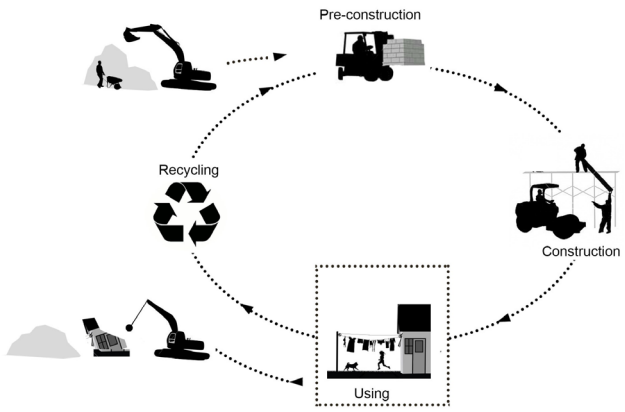

Figure 1. *Energy efficient building's lifecycle.*

The aim of this study is to develop a model for mobile housing that leads the designers to produce energy efficient mobile buildings that cause minimum harm to the environment, consider climatic data, use renewable energy sources, allow flexible use according to user needs and can grow or shrink on demand.

To develop this proposal, literature research was conducted and the historical processes of mobile buildings were examined. People used mobile buildings for the first time in history to protect themselves from other people and natural conditions, to ensure privacy, and to create a safe environment when on the move. Initially, shelters were temporary shelters built with local materials in the area they were located and came apart when they were moved. Then they reached an architectural design that was small and light enough for nomadic communities to pack and carry with them, durable enough to resist the harshest climate conditions and comfortable as a home (Kronenburg, 1995).

Since the second half of the 20th century, mobile building design that was inspired by ancient cultures has been reinterpreted to include the features of nomad settlements such as lightness, portability, and flexibility as an essential component while maintaining the continuity that is a need of the same discipline as a model.

Today, designing energy efficient mobile houses is gaining importance and many examples are available around the world. These buildings are aimed to be houses that take their entire energy from the sun, are low cost and are based on good engineering analysis.

In particular, the Solar Decathlon student competition organized by the US Department of Energy draws attention to this issue effectively. All the projects that participated in the competition, use passive considering the efficient use of energy. The renewable energy sources are also used as active systems.

2. Design process

The design process consists of four stages: the general design decisions, and effective use of energy, water, and material (Parlak, H. H., 2013).

2.1. General design decisions

The first stage of the design process is to take decisions on the general design of the building. At this stage, variables are determined such as the function, user number and climate zone where the building is located.

The building is designed as a mobile house for a four-person family in Istanbul, situated in the temperate humid region of Turkey.

Mobile building with the area of 73.5 m2 consists of living space, kitchen, children's bedroom, master bedroom, bathroom and mechanical room. As shown in the plan in Figure 3, the

Figure 2. *Mobile building overview.*

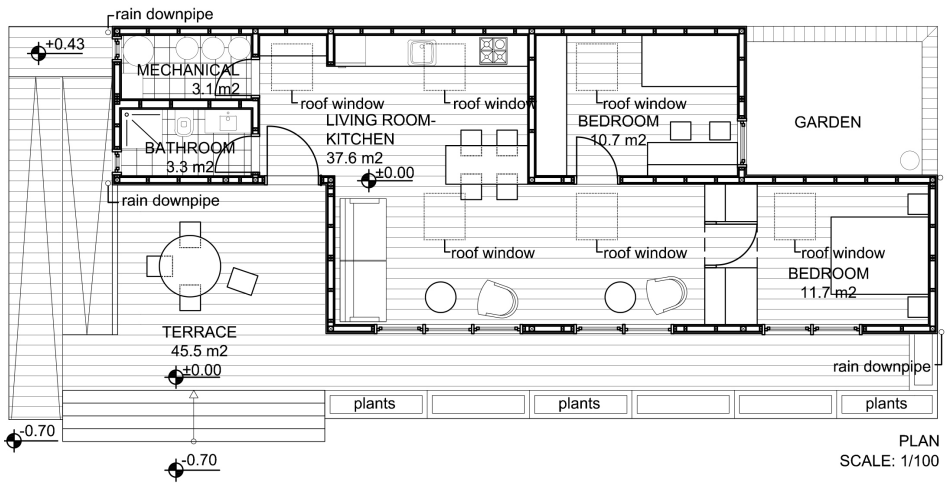

Figure 3. *Mobile building plan.*

building's entrance is located on the south. Transitions to the mechanical room and bathroom are provided from the entrance. Living space and kitchen are used together. The bedrooms can be reached from the living space, which consists of living and working areas.

2.2. Design process in terms of energy efficiency

The methods that can be applied to ensure the efficient use of energy are defined as passive and active systems and the designed house is evaluated through these systems.

The passive systems that are discussed in the building are listed as building orientation, room organization, building form, building envelope, natural ventilation, and natural lighting; while active systems are listed as the use of renewable energy, energy efficient appliances, and intelligent building automation systems.

- Passive Systems Used in the Building

The building is oriented to the east-west axis and the long facade is directed to the south to take maximum advantage of the sun.

Living room and master bedroom are facing south and children's bedroom is facing east. The open plan kitchen is designed as a continuation of the living room and benefits from direct solar radiation that comes from the south direction. Bathroom and mechanical room are facing west.

The building form is designed in as complex form considering the features of temperate humid climate.

Due to being mobile, the building is designed with minimum dimensions to facilitate movement and provide material savings.

The roof is designed as a gable roof to ensure high efficiency of solar collectors and photovoltaic solar panels.

External walls, ceilings, floors, and windows are discussed as the building envelope. The building envelope is formed by considering the recommended U values for Istanbul in TS 825 and Uwalls=0.52 W/m2K, Ufloor=0.56 W/m2K, Uroof=0.37 W/m2K and Uwindows= 2.4 W/m2K were taken. The building envelope detils given in

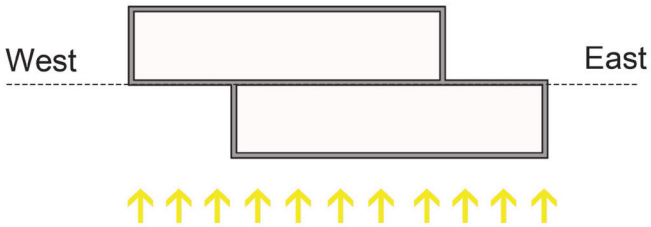

Figure 4. *Building orientation diagram.*

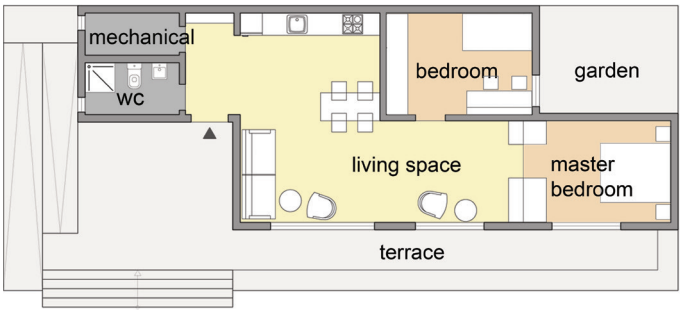

Figure 5. *Space organization diagram.*

Table 1 is formed with values close to those given in TS825 (TS825, 1998). Transparency ratios are created at different ratios in the facades facing different directions by taking into account the direct solar radiation gain. The transparency ratio on the western facade is 7%, on the southern facade it is 56%, on the eastern facade it is 12% and on the northern facade it is 0%.

The air taken through the windows is circulated and removed from the roof windows to provide an effective air circulation in each room of the building.

Windows and skylights are designed to receive the maximum amount of

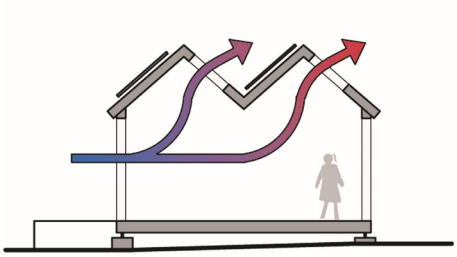

Figure 6. *Natural ventilation diagram.*

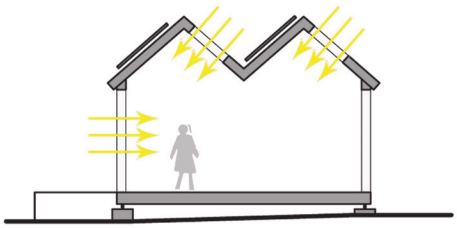

Figure 7. *Natural lighting diagram.*

Table 1. *Data related to mobile building envelope.*

	Material	Thickness (m)	Thermal conductivity coefficient (W/m°K)	U value (W/m2°K)	Recommended U value in TS825 for İst. (W/m2°K)
Wall	1. Wooden cladding	0.025	0.20	0.52	0.60
	2. Vertical air gap	d=0.02 d/λ='0.16			
	3. Thermal insulation (Rock wool)	0.04	0.034		
	4. Vertical air gap (inside 100 mm construction)	d=0.10	d/λ='0.17		
	5. Plasterboard	0.015	0.25		
	6. Plaster	0.02	0.52		
Ceiling	1. Metal cladding	0.008	113	0.37	0.40
	2. Water insulation	0.004	0.19		
	3. Thermal insulation (Rock wool)	0.7	0.034		
	4. Plywood	0.012	0.13		
	5. Horizontal air gap (inside 100 mm construction)	d=0.10	d/λ='0.16		
	6. Plywood	0.012	0.13		
	7. Wooden cladding	0.025	0.20		
Floor	1. Wooden cladding	0.025	0.20	0.56	0.60
	2. Wooden blind floor	0.03	0.13		
	3. Horizontal air gap (inside 18mm construction)	d=0.08	d/λ=0.21		
	4. Plywood	0.012	0.13		
	5. Thermal insulation (Rock wool)	0.03	0.034		
	6. Water insulation	0.004	0.19		
	7. Plywood	0.012	0.13		
Window				2.4.	2.4.

daylight without compromising the visual comfort needs, and help to reduce the lighting energy consumption of the building.

- Active Systems Used in the Building

Photovoltaic solar panels and solar collectors are used in the building for electricity and thermal energy production. The electric energy generated from photovoltaic solar panels is used to cover the energy needed for lighting, equipment usage and cooling the building. Six grid connected photovoltaic panels are used in order to generate the required electricity for cooling the building. Thus, the energy produced by photovoltaic solar panels is used in the building when needed and given to the network if not needed. 250 W photovoltaic solar panels produced by the multi-crystalline silicon technology were selected.

Solar collectors are used to heat the domestic water and meet the energy needed for heating the building. The number of solar collectors can change depending on the number of people using the mobile building (one, two or four) so solar collectors are mounted on the roof surface. Eight solar collectors selected in closed loop system are vertical types of selective absorber surface plane collectors.

To reduce the operating costs in terms of energy, energy efficient compact fluorescent induction cooker, oven, refrigerator, dishwasher and washing machine are used. Addition-

ally, it is aimed to reduce energy consumption with the use of intelligent building automation systems that give information about heating, cooling, lighting and electric usage.

2.3. Design process in terms of efficient use of water

In the design process in terms of efficient use of water; rainwater collection, recycling and reuse, landscaping and use of water efficient appliances are provided. Rainwater collected on the roof surface of the building is transferred to water tank by grooves and rain downpipes. The rainwater collected in the tank outside the building is used for washing cars and irrigation. Assuming that the garden will be irrigated every day and the car will be washed once a week, the annual amount of water required (3285 l) is determined and a 50 l tank is made in the garden.

In the building, greywater from the bathroom sink and shower is purified and used for the toilet tank and washing machine. The water from the bathroom sink and shower provides 40% of daily water use. The water needs of the toilet tank and washing machine constitute 38% of the daily water need (Url-3, 2013). The grey water treatment system is installed in the mechanical room to treat this amount of water. In landscape design, plants that do not need more water and can be grown easily in a temperate humid climate are preferred. In addition to the small vegetable garden, edible plants are grown in pots placed on the terrace.

Aerator sink and shower faucets, motion sensitive faucets and dual-flow toilets are used in the building. Also, the washing machine and dishwasher are selected from water saving products.

2.4. Design process in terms of efficient use of material

In the design process in terms of efficient use of material; material-saving design and construction, the reuse of existing buildings, the use of recycled materials, and the use of local material are evaluated.

The minimum space measurements defined in Istanbul Building Regulations have been effective in identifying

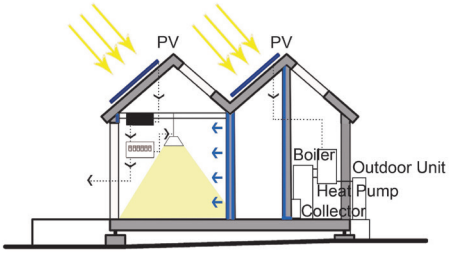

Figure 8. *The use of photovoltaic solar panel diagram.*

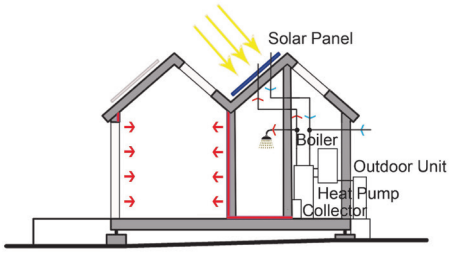

Figure 9. *The use of solar collector diagram.*

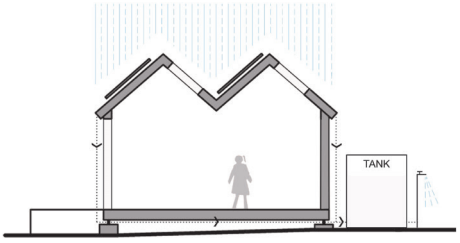

Figure 10. *Rainwater collection diagram.*

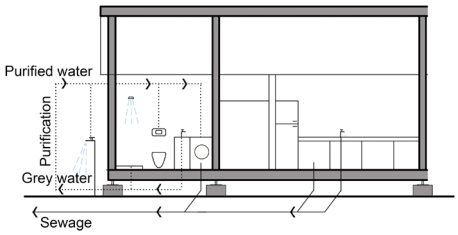

Figure 11. *Water reuse diagram.*

measurement of spaces in the building. The buildings should be able to produce solutions to the needs of the user without the need for much space with intelligent solutions in minimum areas.

Being pre-produced, mobile buildings save material by reducing the margin of error at the site. The destruction energy is removed by moving the building when it is old. In addition, due to the modular structure of the building, the building parts can be removed and used in other buildings. Thus, one building's waste becomes raw material for other buildings. The wooden material used as the general material for the designed building will not go through

the waste process because it is recyclable.

Using locally collected, processed, prepared and distributed materials considerably reduces the costs and the energy consumption required for transportation.

3. Evaluation process

In the evaluation process; the effect of decisions taken in the design process on heating, cooling and electricity loads of the building are evaluated. It is aimed to create an energy efficient building that uses a small amount of fossil fuel and reduces carbon emissions by meeting the energy loads from solar energy that is one of the renewable energy sources (Parlak, H. H., 2013).

In the evaluation process, the energy efficiency of a mobile building developed in the design process is assessed with the Autodesk Ecotect Analysis 2011 program (Url-4, 2011). The steps related to the evaluation process of mobile building are given below.

3.1. Modeling mobile building

The coordinates of Istanbul where the project will take place and climate data are considered and a 3D model is generated using Autodesk Ecotect Analysis 2011 program to perform the simulation.

All rooms are conditioned with the same properties so the building is considered as a single zone. The comfort value of indoor temperature is taken as 19°C for the heating period and 26°C for the cooling period for the building's heating and cooling energy calculations (Akşit, 2002).

In the simulation program, 0.60 clo for the insulation resistance of clothes, 60% for relative humidity and 0.50 m/s air infiltration values are assumed. General illumination level for the mobile building is identified as 200 lux and number of living people in the building is entered as four. House's design scenario is created for a couple, one is an employee and the other is not.

In addition to heat gain from the sun, heat gain from the people, lighting elements, and electrical appliances is also taken into account. In the selection of lighting elements, electricity use and effect on heating and cooling loads are taken into consideration. Accordingly, nine 18W compact fluorescent lamps are used in the building.

3.2. Calculation of the mobile building's energy loads

The building envelope is formed by considering the recommended U values for Istanbul in TS 825. The overall heat transfer coefficient for wall, floor, roof and windows are Uwall=0.52 W/m2K, Ufloor=0.56 W/m2K, Uroof=0.37 W/m2K and Uwindow= 2.4 W/m2K respectively. Annual heating and cooling loads of the mobile building with the building envelope determined according to these U-values are calculated with Autodesk Ecotect Analysis 2011 simulation program. According to simulation results, annual total heating load is 6742 kWh, annual total cooling load is 3073 kWh and annual heating and cooling load is 985 kWh.

The electricity requirements determined by using simulation program for the lighting system and equipments are; 97 kWh for annual total lighting energy requirement, 2043 kWh for annual total equipment energy requirement and 2141 kWh annual total electricity requirement.

3.3. Determination of improvement alternatives for building envelope in order to reduce the energy consumption

According to energy load results of mobile building based on TS825, building envelope improvement alternatives intended for reducing the heating and cooling loads are identified as such:

- Alternative 1 is created by adding solar control elements to the mobile building.
- Alternative 2 is created by decreasing wall, roof and floor U-values of the mobile building.
- Alternative 3 is created by decreasing window U-values of the mobile

Table 2. *Mobile building envelope improvement alternatives.*

Mobile Building Envelope Improvement Alternatives					
(W/m2ºK)	U_D	U_T	U_t	U_P	Solar Control Elements
Mobile Building	0.52	0.37	0.56	2,40	-
Alternative 1	0.52	0.37	0.56	2,40	+
Alternative 2	0.20	0.21	0.19	2,40	-
Alternative 3	0.52	0.37	0.56	1,80	-
Alternative 4	0.20	0.21	0.19	1,80	+

building.

- Alternative 4 is created by adding solar control elements and reducing wall, roof, floor and window U-values.

3.4. Calculation of heating and cooling loads for the suggested improvement alternatives for the mobile building

The annual heating and cooling loads for the suggested improvement alternatives are calculated by the Autodesk Ecotect Analysis 2011 program. Calculation results can be seen in Table 3.

3.5. Comparison of heating and cooling loads of mobile building (the basic condition with the improved one)

The results of mobile building based on TS825 and improvement alternatives intended for reducing the energy loads are given in Table 3. According to these results, lower heating and cooling loads are obtained when improvement alternative 4 is used. In alternative 1, 21%, in alternative 2, 43%, in alternative 3, 5%, and in alternative 4, 77% reduce is provided in terms of total heating and cooling loads for the mobile building based on TS825. Therefore, the building envelope is formed based on alternative 4.

In alternative 4, Uwall=0.2 W/m2K, Ufloor=0.19 W/m2K, Uroof=0. 21 W/m2K, and Uwindow=1.8 W/m2K are used. Also, wooden solar control elements are used on the southern facade and curtains are used on skylights and all facades except the western facade.

3.6. Meeting the heating, cooling and electricity loads of alternative 4 with renewable energy sources

The heating, cooling and electricity energy needs of the building obtained from simulation results are intended to be met by solar power from renewable energy sources.

- Meeting the domestic hot water and heating energy needs

The required energy for domestic hot water and water used to heat the rooms to 19°C when the heating is required is provided by the solar energy system.

Table 3. *Heating and cooling loads of improvement alternatives.*

ALTERNATIVES / Annual Heating and Cooling Loads (kWh)	Heating	Cooling	Total
Alternative 1	4558	3248	7807
Alternative 2	4291	1351	5643
Alternative 3	6081	3107	9188
Alternative 4	2295	1447	3743

In the solar energy system for domestic water and heating support, thermosiphon combi type boiler, air to water air pump, outdoor unit and eight solar energy collectors for distribution of water to wall pipes are used (Interview with H. Boyalı, 2013).

The solar energy system designed with eight solar collectors meets 80% of the energy needed for domestic hot water and 50% of the energy needed for heating support. The rest of the energy needs are met by using the air to water heat pump. This calculation is made by selecting 21st December hourly values for T-Sol program (Interview with H. Boyalı, 2013).

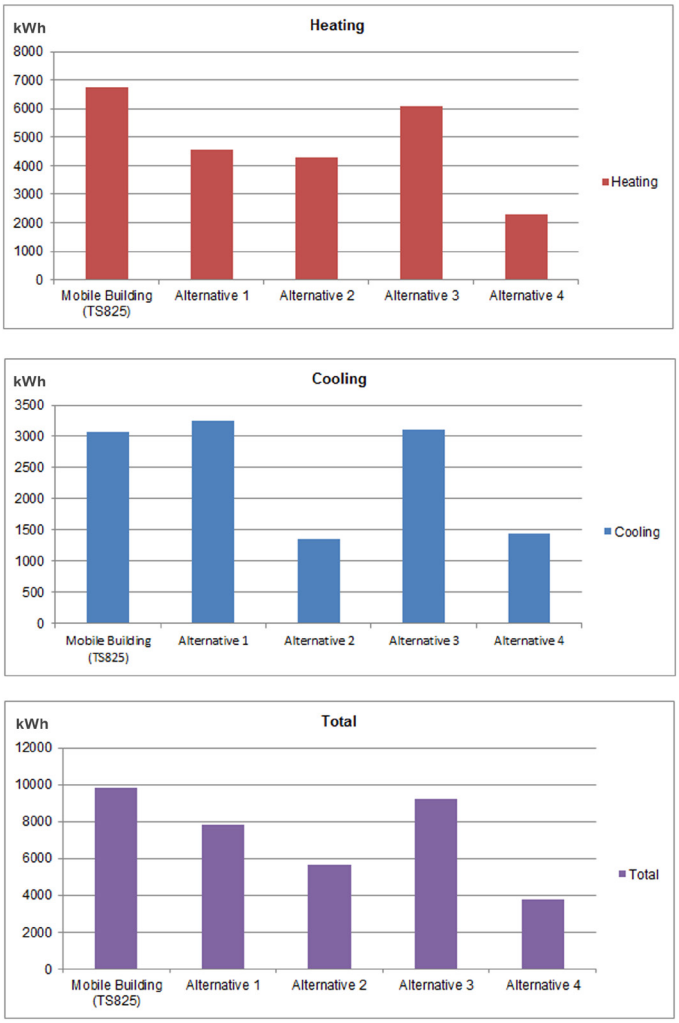

Figure 12. *The comparison of alternatives in terms of heating and cooling.*

Table 4. *Electrical energy needs for equipment usage and lighting system and energy generated from photovoltaic solar panels in alternative 4.*

	Annual Total (kWh)
Electrical Energy Need of the Building	2151
Electrical Energy Generation of the Building	2583
The energy obtained from 250W multi-crystalline silisyum photovoltaic solar panels which are mounted on roof at 41° angle in Istanbul	

- Meeting the cooling energy needs

The required energy for water used to cool the rooms to 26°C when the heating is not required is provided by the solar energy system.

In the solar energy system for cooling the building, thermosiphon combi type boiler, air to water air pump, outdoor unit and photovoltaic solar panels for distribution of water to wall pipes are used (Interview with H. Boyalı, 2013).

Six grid connected photovoltaic solar panels are used to generate the required electricity to cool the building. 250 W photovoltaic solar panels produced by the multi-crystalline silicon technology are selected. 50% of the annual total energy needed to support cooling is met with this system (Interview with H. Boyalı, 2013).

- Meeting the electricity needs

Photovoltaic solar panels, battery, inverter and charge controller are used to generate electricity with the solar energy system.

Electricity need changed due to shading device usage in alternative 4. Artificial lighting is used at noon when the heating system is not required and shading elements are used. For this reason, alternative 4's electricity energy needs are more than mobile building's electricity energy needs which has no shading elements.

The energy that can be obtained from photovoltaic solar panels that are mounted on the roof with 41° angles in Istanbul meet this energy need is given in Table 4 (Url-5, 2013).

4. Conclusion

Increase of energy consumption and decrease of existing resources with industrialization has brought the quest for renewable energy. The strategies that will be applied to energy efficiency in the construction sector have gained importance because the amount of energy consumed in the construction and occupancy stages represent a large part of the total energy consumed in the world. Therefore, the focus on energy conservation in housing interventions to close the deficit plays a major role in terms of energy problems.

Among the interventions to close the housing deficit, mobile building production that allows buildings to be obtained in a short time and to be developed in accordance with user requirements is important. The decisions to be taken at the design stage affect many buildings and users because of the mass production of mobile buildings.

The mobile building discussed in this study is designed as a single story dwelling unit for four people in Istanbul by considering energy efficient building design parameters. Different alternatives are developed to reduce the heating and cooling energy loads that cause an important amount of energy consumption in the mobile building designed according to TS825. The heating and cooling loads of each alternative are calculated and the alternative that provides the lowest heating and cooling loads is determined using the AutoCAD Ecotect Analysis 2011 simulation program in the study.

In this study related to meeting the energy needs of this alternative with solar energy it was discovered that 93% of energy used for equipment and lighting, 80% of energy used for heating domestic water, and 50% of energy used for building heating and cooling is met by using photovoltaic solar panels and solar collectors. These results indicate that energy efficient mobile building applications should be promoted in regulations.

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