FEASIBILITY STUDY OF A PASSIVE HOUSE: ANKARA CASE

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Abstract

The amount of residential energy consumption has a significant share over final energy consumption in Turkey which is increasing parallel to the rapid increase in population, economic growth and the number of houses. For this reason, energy savings in residential sector is of great importance in Turkey. In this study, technical feasibility study of a single detached Passive House located in Ankara, Turkey of which has cold and dry climate is investigated using building energy simulation software. House is designed to take advantage of solar radiation at maximum level with convenient shape, color and window/wall ratio. Model house has high insulation level and low air tightness. According to the simulations conducted, minimum space heating demand of the 3 bedroom, 120 m^2 single detached house located in Ankara, Turkey is estimated as 6,2 kWh/m^2-year, overcompensating the "15 kWh/m^2-year" Passive House target sufficiently. The primary energy demand is calculated as 30,8 kWh/m^2, marginally below the 120 kWh/m^2 target.

Keywords: - Passive house, Low energy buildings, Building Energy Simulation

1. Introduction

Energy consumption of residential sector is effected by many components such as socio-economic levels, behavior's, number of electrical appliances, cultural construction traditions, climate, HVAC equipment and ventilation habits of the nation. While planning the energy demand of residential sector, these components should be taken into account according to regions traditions, energy sources and availability of equipment's. There are many types of

[+] This paper has been presented at the ICENTE'18 (International Conference on Engineering Technologies) held in Konya (Turkey), October 26-28, 2018.

residential buildings designed and constructed by taking into account these components and therefore consume less energy compared to traditional buildings. These residential buildings are studied in the literature in order to decrease, minimize, set to zero or raise to positive the energy consumption and associated emission.

A major part of these studies are conducted by developing the energy consumption model of buildings and applying scenarios to the developed model to calculate the energy savings by using building energy simulation software's such as DOE-2 [1], EnergyPlus [2], eQUEST [1], TRNSYS [3] and ESP-r [4].

According to the existing terminology, there are many terms used with the purpose of expressing low energy buildings [5]. Some of the terms used are Low Energy Buildings, Zero Energy Buildings, Net Zero Energy Buildings, Net Zero Off-Site Energy Buildings, Net Zero Energy Cost Buildings, Net Zero Energy Emission Buildings, Zero Carbon Buildings, Approximately Zero Energy Buildings, Zero Emission House, Passive House, Plus Energy House, Net Positive Energy House and Hybrid Buildings. In newly built homes reaching passive house, net zero or net positive house standard get ahead of decreasing energy consumption. A newly built house should be designed with minimum energy demand, before supplying the energy demand of the home by renewable resources.

Passive Houses allow heating and cooling related energy savings of up to 90% compared to typical building stock and over 75% compared to average newly constructed buildings. The aim of 'Passivehaus' organization established in Germany is to design the most energy efficient homes. Passive House Database is a common project of the Passive House Institute, the Passivhaus Dienstleistung GmbH, the IG Passivhaus Deutschland and the iPHA (International Passive House Association) and Affiliates. According to Passive House Database there are 3558 newly constructed passive houses in world one of which is in Turkey [10].

There are two Certified Passive house buildings in Turkey one of which is newly build, other one is EnerPHit Retrofit. Both of the passive houses that own "Passive House Certificate" in Turkey are in Gaziantep [11]. Detailed information about these buildings is given in Table 1.

Table 1: Passive Houses in Turkey

Location	Gaziantep 1	Gaziantep 2
Year	2015 (*EnerPHit Retrofit*)	2011 (N*ew build)*
Exterior wall	U:0,149 W/m^{2}K	U:0,092 W/m^{2}K
Basement floor	U:0,169 W/m^{2}K	U:0,111 W/m^{2}K
Roof	U:0,201 W/m^{2}K	U:0,101 W/m^{2}K
Frame	U_f:0,79 U_w:0,81 W/m^{2}K	U_w:0,96 W/m^{2}K
Glazing	U_g:0,56 W/m^{2}K g-value = 39 %	U_g:0,56 W/m^{2}K g -value = 39 %
Door	U:0,89 W/m^{2}K	U_d:0,74 W/m^{2}K
Heating installation	Air Sourced Heat Pump Vitocal	-
Domestic hot water	Solar panel system	-
Heating demand	20 kWh/m^{2}a	7,23 kWh/m^{2}a
Primary energy	79 kWh/m^{2}a	95,81 kWh/m^{2}a

As it is clear from Table 1 that annual heating demands per unit area of the buildings estimated by PHPP are 20 kWh/m^{2}a and 7,23 kWh/m^{2}a respectively. The PHPP is an easy to use planning tool for energy efficiency for the use of architects and planning experts.

Due to the low HDD (Heating degree day) of Gaziantep compared to Ankara [12] it is more possible to achieve passive house heating demands standard in Gaziantep whereas CDD (Cooling degree day) of Gaziantep is higher than Ankara that increases cooling demand.

In addition to constructed passive houses there are two theoretical studies conducted to develop a passive house in Turkey. In scope of a master's thesis completed at the Department of Architecture of Istanbul Technical University the application of passive house assessment for Ankara, Turkey is investigated. In this thesis a model house is developed in computer software environment. Heating demand is estimated as 13 kWh/m^2, the cooling demand is estimated as 10 kWh/m^2, and the primary energy demand is calculated as 54 kWh/m^2. Insulation thickness which provides the passive house standard is calculated as 27 cm for Ankara [13]. Another master's thesis is conducted in Izmir Katip Celebi University to evaluate passive building design parameters for Izmir city by modeling a 12 storey residential building in Ecotect Analysis and Revit software [14].

2. Methodology

In this section data used and methods followed during development of a passive house model in Ankara climate are described in detail.

In this study a single detached house with 120 m^2 heated area is planned to achieve passive house standard in which four people reside. Electricity consumption of the house is estimated based on mandatory electrical appliances required in a house. Heating demand of the house is estimated by energy demand model of the house developed in eQUEST building energy simulation software. Heat gains of the house are also calculated and subtracted from heating demand.

This research study uses simulation and theoretical data to achieve passive house status through envelope improvement and energy star appliances in Ankara, Turkey.

2.1. Model Development

Heating demand model of the house is developed in eQUEST building energy simulation software to estimate the energy consumed for heating and cooling by using climate data of Ankara, construction data of the building and internal heat gains.

2.2. Heat Gain

Heat gain from electrical appliances, lighting and people cause an increase in the ambient temperature therefore should be added to the model. Heat gain is classified as sensible, convective or latent. Sensible heat gain (SHG) is added directly to the conditioned space by conduction, convection, and/or radiation (convective plus radiative). Latent heat gain (LHG) occurs when humidity is added to the space [15]. The sources of internal heat gains (IHG) include:

- People (SHG and LHG)
- Lighting (SHG)
- Electrical appliances
- Electrical plug loads (SHG)
- Processes such as cooking (SHG and LHG)

- People (SHG and LHG)

There are 4 people reside in house. Heat gain from people is calculated by using the heat gain activity in the ASHRAE catalog [15] given in Table 2 and equation (1).

$$HG_p = (HG_s \times N_p \times t) + (HG_l \times N_p \times t) \quad (1)$$

In this equation;

HG_p: Heat gain from people, Wh/day

HG_s: Sensible heat gain type, W

HG_l: Latent heat gain type, W

N_p: Number of people

t: Duration, hour

Table 2: Heat gain from people

Heat gain activity in the ASHRAE	Equivalent Activity	SHG (W)	LHG (W)
Theater seating	House seating	65	30
Sit at night in the theater	House seating	70	35
Very light work	Very light work	70	45
Active business environment	Active house cleaning	75	55
Standing, light works, walking	House cleaning	75	55
Light bench work	Major cleaning	80	80

- Lighting (SHG)

Heat generated by the LED lighting was calculated as 78.1% of the supplied power to the LEDs in a study [16]. Therefore heat gain from the lighting is calculated by multiplying the power values of the lamps with usage durations in a day and 0,781.

- Electrical appliances (SHG and LHG)

Heat gain from some of the electrical appliances is both sensible and latent heat gain (tea machine, steam iron, etc). Power values of A+ energy star electrical device are obtained from internet. Power of each appliance is multiplied by usage duration and sensible and latent load fraction of the appliances [17]. Load fraction differs for each device and fractions for the appliances are given in Table 3.

Table 3: Load fractions of appliances

Appliance	**Sensible Fraction**	**Convective Fraction**	**Latent Fraction**
Miscellaneous loads (gas/electric house)	0,734		0,2
Television	1		
Microwave	1		
Stove and Oven gas	0,3		0,2
Refrigerator		1	
Washing Machine	0,4	0,6	0
Dish washer	0,51	0,34	0,15
Small Appliances	0,54	0,36	0,1
Lighting	0,78	0,1	

2.3. Climate Data

The normal climate data of Ankara is downloaded from the EnergyPlus weather data web site for Turkey in IWEC (International Weather for Energy Calculations) format. The IWEC data files are 'typical' weather files suitable for use with building energy simulation programs which are available for download in EnergyPlus weather format [18].

2.4. Physical Properties of the House

Model house is a highly insulated house. Details of exterior constructions are given in Table 4. In Table 4 Thickness (d), Thermal Conductivity (k), Thermal Resistance (Ri), Thermal conductivity (U) value of each Material in each Construction are given as ordered from outside to inside.

In addition to the construction properties given in Table 4, window/wall ratio for each side, window blind materials and open/close durations of the blinds, exterior shades and door location of the house are decided according to simulations conducted for each option. Final physical shape of the house is also decided at the end of simulations conducted for different house shapes.

It's clear from Table 1 and Table 4 that U values of exterior wall and roof of the passive house in Ankara is half of the passive house in Gaziantep which means thermal resistance of the passive house in Ankara is double of the passive house in Gaziantep due to higher HDD of Ankara compared to Gaziantep. As it is shown in Table 4, polyisocyanurate is selected as insulation material due to the high energy savings obtained compared to polyurethane and polystyrene conducted in a study for cold climates [19]. In addition, Polyisocyanurate increases value of a building due to its high resistivity to fire and humidity. It's also economic, easy to install and environment friendly. Insulation installed in exterior wall is 33 cm and in roof is 30 cm. Window glazing of the house is selected as triple glazing filled with argon gas. Window frames are aluminum.

In model house all rooms are kept at 20°C during winter, at 26 °C during summer.

Normally the ACH value varies from 0,5 ACH for tight and well-sealed buildings to about 2,0 for loose and poorly sealed buildings. For modern buildings the ACH value may be as low as 0,2 ACH [20]. In this study, airflow into the house by natural ventilation (ACH) is assumed as 0,4.

3. Results and Discussion

In this section results of heat gain and electricity consumption are given. Then model development and estimation by the simulation of the model are presented. Finally total energy demand of the house is given to show if the study reach passive house standard or not.

3.1. Heat Gain and Electricity Consumption

Before the development of model, heat gain and electricity consumption of the house is calculated by taking into account mandatory electrical appliances, equation [1] and Table 3. Daily heat gain from people is given in Table 5.

Table 4: Construction properties of the passive house

Construction	**Material**	**d, mm**	**k, W/m-K**	**R_i, m^2K/W**	**U, W/m^2K**
Exterior wall	Plywood	16	0,115	0,138	**0,057**
	Polyisocyanurate	305	0,020	15,11	
	E Wall Cons Material	NA	NA	0,980	
	Polyisocyanurate	25	0,020	1,254	
	GYPBd 1/2 in (GP01)	13	0,160	0,080	
	Total			17,48	
Roof (Ceiling)	Blt-Up Roof 3/8 in (BR01)	9	0,162	0,058	**0,055**
	Polyisocyanurate	305	0,020	15,11	
	Plywood	16	0,115	0,138	
	Roof Cons Mat 4	NA	NA	2,940	
	GYPBd 5/8 in (GP02)	16	0,160	0,099	
	Total	0	0,000	18,34	
Glazing	Glazing	6	1,000	0,006	**0,557**
	Argon gas	16	0,018	0,889	
	Glazing	6	1,000	0,006	
	Argon gas	16	0,018	0,889	
	Glazing	6	1,000	0,006	
	Total			1,796	
Door	Wood	40	0,220	0,027	**36,667**
Basement	Light Soil, Damp 12 in	6	0,862	0,354	**0,063**
	Concrete	305	1,724	0,177	
	Polyisocyanurate	305	0,020	15,11	
	Plywood 1 in (PW06)	305	0,115	0,220	
	Total	25		15,86	

Table 5: Heat gain from people

Activity	Hour, h	SHG, Wh	LHG, Wh
House seating	**0-8**	2080	960
Active house cleaning	**8-9**	300	220
Nobody at house	**9-18**	0	0
Sit at night in the house	**18-23**	1400	700
Very light work	**23-24**	280	180
Total, Wh		**4060**	**2060**

Table 5 shows that daily heat gain from people is 6,12 kWh/day. Daily electricity consumption and heat gain from appliances, lighting and people are given in Table 6.

3.2. Envelope Development

Firstly, envelope constructions and climate data are inserted to the model and then heating and cooling demands are calculated. Then window/wall ratio between 5-45% for each side is applied to the model and most efficient window/wall ratio for each side is decided. Finally different basement shapes are applied to the model to determine most efficient architectural drawing. Also, model is run for different envelope colors and basement types (earth contacting, open crawl space, over garage).

3.3. Calculation of Total Energy Demand

Heating and cooling energy demand of the house is calculated by using heat gain data and simulation of the model of the house in building energy simulation software.

Electricity consumption of the house is calculated by multiplying usage durations of the electrical appliances by power values.

Model house is developed for Ankara climate. In a study conducted in Konya daily energy consumption for hot water demand of a house is calculated as 4 GJ/year, 1 GJ/year-person with a solar domestic hot water system [21]. Therefore, in this study energy demand for hot water is assumed to be the same as the study conducted in Konya due to similar climate of Konya to Ankara.

Table 6: Heat gain and electricity consumption of the house

	Duration, h/day	Number	House Heat Gain, W			Heat Gain, kWh/day	Electricity Consumptio	Power, W
			SHG	CHG	LHG			
Refrigerator	24	1	38			0,91	0,90	38
Laptop	4	2	50			0,40	0,40	50
Charge App.	3	3	7			0,06	0,09	10
Vacuum Cleaner	0,10	1	840			0,08	0,12	1200
Washing Machine	0,50	1	166	250		0,21	0,21	416
Dishwasher	0,25	1	212	141	62,4	0,10	0,20	800
Cooking	1	1	1200			1,20	1,20	1200
TV	5	1	48			0,24	0,24	48
Lighting	6	5	19,5			0,59	0,75	25
People						6,12		
Total						**9,92**	**4,11**	

According to Table 6 daily total heat gain is calculated as 9,92 kWh/day, daily electricity consumption is calculated as 4,11 kWh (1500 kWh/year). Hourly heat gain is subtracted from estimated hourly heating demand. Hourly heat gain is shown in Table 7.

3.4. Model development

Heating and cooling demand of the passive house is estimated by the model developed in software. Model house is a highly insulated house as it is seen in Table 4. After the insertion of constructions to the model, heating and cooling demands are estimated by simulations. Then window/wall ratio between 5-45% for each side is applied to the model and most efficient window/wall ratio for each side is decided. Most energy efficient exterior door and window/wall ratio for each side are given in

Table 8.

Table 7: Hourly heating demand

Hour	**Refrigerator**	**Laptop**	**Charge App.**	**Vacuum C.**	**Washing M.**	**Dish washer**	**Cooking**	**TV**	**Lighting**	**People**	**Total**
1	38									380	**418**
2	38									380	**418**
3	38									380	**418**
4	38									380	**418**
5	38									380	**418**
6	38									380	**418**
7	38									380	**418**
8	38						600			380	**1018**
9	38										**38**
10	38										**38**
11	38										**38**
12	38										**38**
13	38										**38**
14	38										**38**
15	38										**38**
16	38										**38**
17	38										**38**
18	38									380	**418**
19	38	100	21				600	48	39	380	**1226**
20	38	100	21		208	88		48	39	380	**922**
21	38	100	21					48	39	380	**626**
22	38	100		84				48	39	380	**689**
23	38							48	39	380	**505**

24	38	39	380	**457**

Table 8 Energy efficient exterior door and window/wall ratio

Case	North	South	East	West
Door Direction	-	1	-	-
Window Percentage on Each Direction	5%	45%	15%	15%

As it is clear from

Table 8 45% of South wall, 15% of east and west walls and 5% of north wall are constructed of window. Most energy efficient window glazing type for Ankara climate is decided to be argon filled clear triple glazing. Low-E coated glazing may be effective in hot climates but it increased heating demand in Ankara where cooling load is very low compared to heating load.

Also, model is run for different envelope colors and most efficient envelope color is decided to be light brown with absorptivity 0,8.

Construction of basement is another significant factor in decreasing energy demand. According to the basement shapes applied to the model, most efficient basement is concluded to be earth contacting basement.

Finally, different architectural drawings are applied to the model by keeping heated area, constructions and window/wall ratio constant. As a result of these applications most energy efficient house shape is concluded to be triangle shape and the shape of the model house is shown in Figure 1.

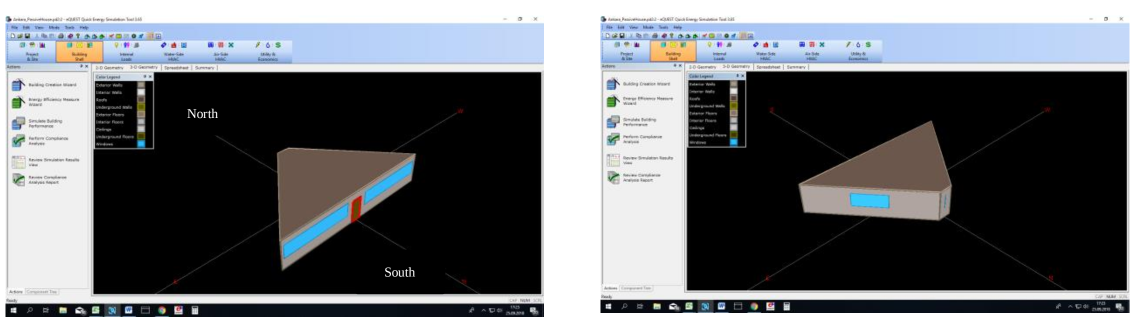


Figure 1. Most efficient house shape

Most efficient house shape shown in Figure 1 shows that as much as decreasing the wall on north side as possible decreases heating demand in cold climate due to the replacement the exterior wall in north side with the wall in east and west side. However an exact triangle shape is not always possible in real life. Heating demand for each building shape is given in Figure 2.

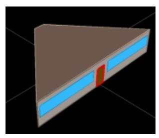
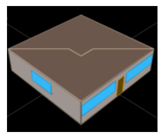
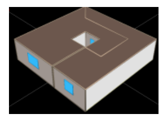
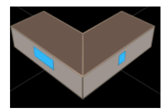
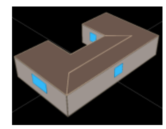
Heating demand, kWh/year	819	1049	1094	881	1089
Shape					

Figure 2. Comparison of heating demand of different building shapes

Figure 2 shows that heating demand for triangle shape house is 21% less then square shaped house.

3.5. Cooling Demand

After the construction, shape and color of the house are determined cooling and heating energy demand of the house is estimated hourly by simulation software. In model house all rooms are kept at 26 °C during summer. Cooling system has air cooled condenser and split system. In addition, house has exterior blinds as shown in Figure 3 which are closed during daytime of summer.

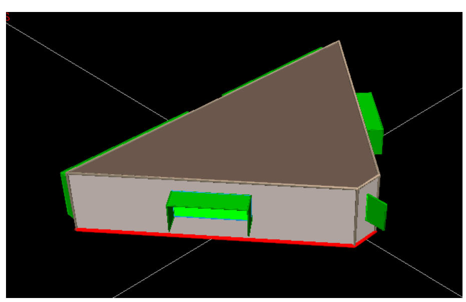


Figure 3. Exterior blinds of the house

Indoor blinds of the house are made of fabric drapes with light color. Indoor blinds are 60% closed when the house is occupied, 100% open when the house is not occupied. House is naturally ventilated during summer therefore heat gain is not taken into account. According to simulation results model house consumed 272 kWh/year energy for cooling between end of May and end of September. Daily simulation result is given in Figure 4.

3.6. Heating demand

Heating system of the house is designed as electric baseboard system and has air forced ventilation during winter. Total energy consumption of system is composed of Auxiliary end-use (pumps), heating end-use and ventilation fan end-use. Heating demand of the system is estimated as 1886 kWh/year. For each hour of the year, if the hourly heating demand is higher than heat gain, heat gain is subtracted from demand. If hourly heating demand is lower than heat gain, heating demand is assumed to be zero. By taking into account heat gains, net heating demand is calculated as 819 kWh/year. Daily heat gain, net heating demand and cooling demand are shown in Figure 4.

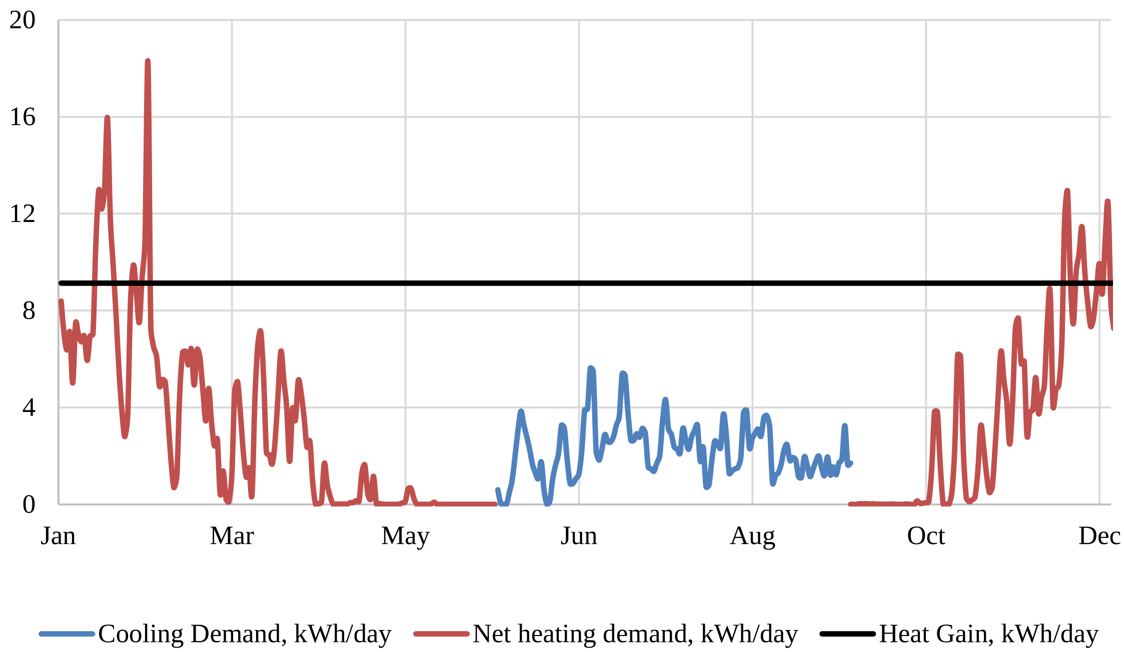


Figure 4. Daily heat gain, net heating demand and cooling demand, kWh/day

3.7. Total energy demand

According to the results shown in Figure 4 total heating and cooling demand of the house is estimated as 1092 kWh/day.

Electricity consumption of the house is calculated as 1500 kWh/year as given in Section III.A. Four people reside in the model house which results in consumption of 4 GJ/year (1111 kWh/year) energy for hot water demand. Finally primary Energy Demand of the house is calculated as 3703 kWh/year and 30,8 kWh/year-m^2. Heating Demand of the house is estimated as 819 kWh/year and 6,2 kWh/year-m^2 which overcompensate passive house standards.

Heating demand per unit area is half of the results obtained in a master's thesis completed at the Department of Architecture of Istanbul Technical University for Ankara climate which was estimated as 13 kWh/m^2. In master thesis primary energy need was calculated as 54 kWh/m^2 whereas it is calculated as 30,8 kWh/m^2 in this study which is also close to the half of the amount obtained in thesis. Main reason to obtain half of the results is to lower cooling demand by exterior blinds closed during summer and triangle shape of the house. Also insulation thickness is higher than the study conducted in Istanbul [13].

4. Conclusion

This study is conducted to investigate the feasibility of a passive house in Ankara climate. In order to reach the passive house target, the residential building is planned to have high insulation and low air tightness.

Minimum annual heating energy demand per unit area of the model house is calculated as 6,2 kWh/year-m^2 that overcompensate passive house standards in case of a triangle shape. Primary Energy Demand of the house is calculated as 3.703 kWh/year and 30,8 kWh/year-m^2 which shows its feasible and possible to build passive houses in Middle Anatolian region to minimize energy consumption from building sector.

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