# IMPACTS OF BUILDING FORM ON ENERGY EFFICIENT HEAT PUMP APPLICATIONS

Banu Erdim Gulten Manioglu
LEED Green Assoc. Assistant Professor
Faculty of Architecture, Istanbul Technical University
Taşkışla, Taksim, Istanbul, Turkey

**ABSTRACT**

One of the most important properties of a sustainable building is to provide thermal comfort conditions for users with a minimum heating and cooling energy consumption. Therefore, primary design parameters of building should be developed as providing the climatic comfort conditions and minimum energy consumption during the construction and use of the building. Building form is one of the important design parameters affecting the heating and cooling energy consumption in the building.

In this study; in order to provide energy conservation and climatic comfort in buildings, an approach which aims to control the energy consumption of heat pumps by controlling decisions related to building design parameters have been developed. For this purpose, two different building forms (L and rectangular) which have the same floor area, exterior facade area, volume and optical and thermophysical properties of building envelope were examined in Ankara, Turkey by using a building simulation program, eQUEST.

**Key Words:** Building Form, Heat Pump, Energy Conservation, Building Energy Simulation.

## 1. INTRODUCTION

Parallel to the population growth in the world, the energy demands increase and countries search for new methods of energy conservation. As a result of the need for supplying the climatic comfort condition, most of the energy is used for heating and cooling in buildings. Due to the depletion of natural resources, the increase in environmental pollution and its effect on human health, the energy consumption of heating and cooling systems in residential buildings should be minimized.

As a result of disadvantages of the non renewable energy resources (fossil fuel, oil, coal etc..) such as being fast depleting, expensive and harmful to the environment, renewable energy technologies such as solar panels, wind tower, photovoltaic systems should be successfully implemented with the application of passive design parameters through the management of energy consumption in buildings.

The most important design parameters which affect the indoor climate and give the designer basic design guidelines of energy efficient buildings are location of the building, building form, orientation of the building and optique and thermophysical properties of the building envelope (Yilmaz 1998). All these factors are related to each other and the optimum value of each factor should be determined in correlation with the other parameters.

*The location of the building*; including the slope of the plot, vegetation, facing the direction is a design parameter that effects in preventing air pollution and climate control. At the same time, it helps minimize the need and energy consumption for supplementary heating and air conditioning (Berkoz et al. 1995).

*The building form*, which is one of the most important passive design parameters affecting indoor climate, affects the total heat loss and gain through building envelope. Building form can be defined by basing on the shape factor (the ratio of building length to building depth), height and roof type. It is possible to determine a lot of building forms that yield same volume, but different facade area. As is known, total heat loss change with building form even if the floor area is constant for a building, façade area of the building may change due to the change in the building form. Moreover, bigger façade area may require bigger window area from daylighting point of view and consequently heat loss through glazing increases. Therefore building form is considered an important factor affecting total heat loss and thermal comfort (Yilmaz 1988).

*The orientation of building form* is the indicator of the amount of heat gained from solar radiation through building envelope. Accordingly, the intensity of solar radiation which affects the surfaces facing in different directions will be different (Yilmaz 1988).



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Therefore, the amount of heat gained from solar radiation in building volume is a function of the direction where the building envelope is oriented to.

*Optical and thermophysical properties of the building envelope* is one of the most important parameter which separates the indoor space from the external environment and in this way, modifies or prevents the direct effect of climatic variables. Therefore according to its storage capacity and its insulation resistance, the building envelope modifies also the effect of the heating system in the space (Manioglu 2002). Optical and thermophysical properties affecting the heat transfer through the building envelope are;

- Overall heat transfer coefficient
- Transparency ratio
- Decrement factor and time lag
- Optical properties, such as absorptivity, transmissivity and reflectivity

More recent researches appears to focuses on issues of heat gain and loss and thermal comfort as a basis for formulating building form utilizing passive strategies in different scale. Ratti, Raydan and Steemers are investigated "which building forms make the best use of land?" In order to find the answer they compared three different urban forms in hot arid region according to three parameters: surface to volume ratio, shadow density and daylight distribution. The first urban form is consists of building forms with courtyards. The first second two urban arrays are realistic pavilion types. The pavilion consists of replacing each courtyard of the first urban form with an urban block. The second pavilion consists of bigger urban block with less density. Dimensions of urban blocks are different in pavilion types. The results confirm that the best building form for hot arid regions is courtyard form by means of; their larger surface areas and high thermal mass, the daylight via the courtyard and shallow plan form and narrow spaces for shade and improved thermal comfort despite increased heat island. (Ratti et al.2003)

Yilmaz, Koclar and Manioglu discuss to determine building form which provides minimum heat loss through the whole building envelope. Building form is described by the indicator A/V (the ratio of total façade area to building volume).The heat loss is determined related to U value of the building envelope. A building form which enables minimum heat loss with a calculated limit U value is taken as a reference building form (A/V ratio). The revised U values related to reference building form are expressed with charts which help designers to revise building envelope U value for opaque component in order to achieve heating economy without changing other design parameters. Results confirm that especially in cold climate building form should be selected as close as the reference building form. (Yilmaz et al. 2000)(Yilmaz et al. 2003)(Yilmaz et al. 2002)

Okeil was interested in developing a systematic comparison and an evaluation of the relationship between urban building form and energy efficiency of three generic forms: two conventional forms and one proposed energy efficient form. The energy efficiency is evaluated with solar exposure in winter and reduced heat gain in summer via the support of strategies for mitigating the urban heat island effect. The investigation shows that the approach can produce building forms that allows the maximum potential of passive utilization of solar energy in buildings to be reached and the new developed building form support strategies for mitigating the urban heat island effect through increased airflow, the promotion of marketable green roofs and the reduction of transportation energy. (Okeil 2010)

When indoor climatic comfort of the users is satisfied without any mechanical heating and cooling in a building, this building can be considered as a passive heating and cooling system. However, climatic comfort conditions cannot be met by only passive heating and cooling system in a particular period of the year and in order to reach the required climatic comfort conditions, supplementary heating and cooling systems become necessary. (Yilmaz 1998).

The use of energy sources such as fossil fuels in heating and cooling systems is not only inadequate and expensive but also harmful to human health and the environment. As a result of this, the use of active systems using alternative energy sources such as solar, wind, biomass and environmental energies became a necessity to minimize the energy consumption in buildings with passive design strategies.

Heat pumps are energy efficient systems which use renewable energy of the building's surroundings to provide heating and cooling in buildings. They are classified by their heat sources such as; air, water and ground. Energy conservation in buildings can be achieved through heat pump systems by means of variables such as air temperature, mean radiant temperature, air movement and air humidity (Erdim 2010).

This study measures not only the impacts of energy efficient design parameters on energy consumption, but also the energy consumption of the buildings which incorporates renewable energy systems. For this purpose, a methodology which aims to control the consumption of heat pumps by controlling decisions related to building design parameters has been developed. The study aims to evaluate the impact of the building form on energy-efficient heat pump applications. In this study, the annual heating and cooling energy consumptions for different building forms which have the same floor area, total exterior facade area, volume and, optical and thermophysical properties of building envelope are processed and the results are analyzed from the energy conservation point of view.

## 2. METHODOLOGY

This study aims to evaluate the performance of different building forms with the use of heat pump to provide climate comfort and energy conservation. For this purpose, the annual heating and cooling energy consumption of air source heat pump application were calculated for two different building forms which have the same floor area, total exterior facade area, volume and, optical and thermophysical properties of building envelope. The proposed methodology has been applied to Ankara which is a representative city of Turkey for temperate-dry zone. As a result of these calculations, the appropriate building form is proposed by comparing the annual heating and cooling energy consumption. The assumptions of the study and followed steps are given as follows;

### 2.1. The determination of design parameters affecting heating and cooling systems in the building

As the main design parameters are important for determining the indoor air temperature and the selection of heat pump systems, the decisions taken related to design parameters for energy efficient heat pump applications are given below;

- The buildings used in this application are assumed in a region without any slope, and the buildings are not shaded by the other buildings in Ankara, Turkey.

- The proposed methodology has been applied for residential buildings which are used as a four-person housing units.

- The proposed methodology has been applied for 2 different buildings with different building form (L and rectangular building form). The selected buildings are considered as a 2 storey high, detached with flat or pitched roof.

- Each building floor area is 100 m², volume is 600 m³ and total facade areas of 348 m² .The dimensions, orientations, floor areas, the volumes and the total exterior façade areas of the buildings used in application are shown in Figure 1.

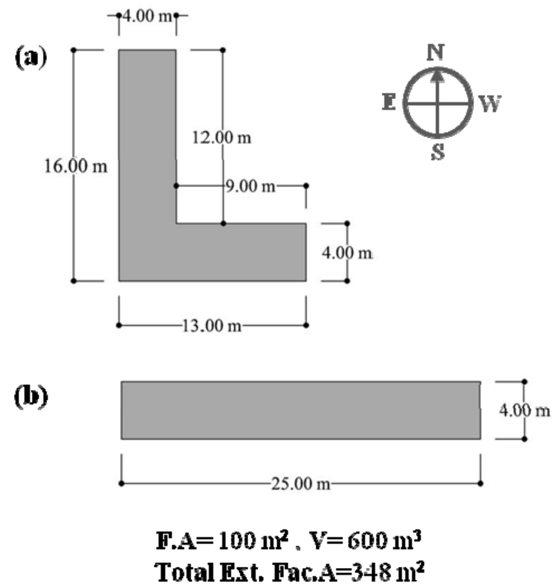



**Figure 1.** The dimensions, orientations, floor areas, the volumes and the exterior facade areas of the buildings used in application, (a) L shape, (b) Rectangular shape.

- In order to follow their thermal behaviors selected building forms (L and rectangular shaped buildings) are modeled with flat roof and pitched roof without overhang (Figure 2).

- The occupancy hours of the buildings used in the application are considered as 18:00 to 07:00 on weekdays, 24 hours on weekends. The simulation program takes into account the internal heat gain of the occupants, which comes from not only 4 person occupancy, but also the appliances, electronic devices and lighting.

- The external surfaces of the opaque components are painted in dark colors, with the solar radiation absorptivity of $a_o$= 0.70

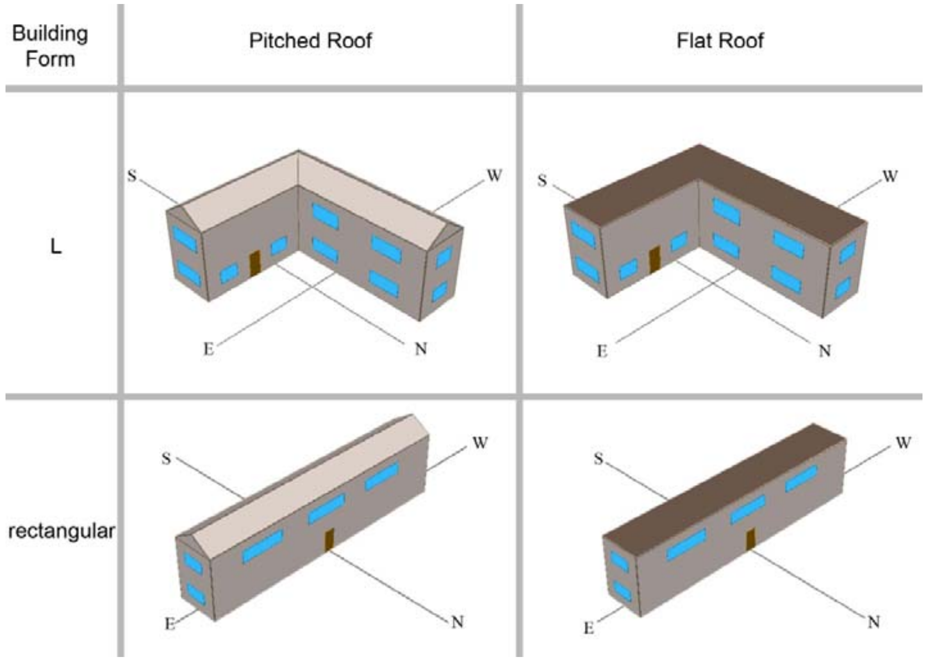



**Figure 2.** 3-D images of the buildings used in application

- The variation of the transparency ratios of the building envelope is as follows: North: %10, East: %20, South: %30, West: %20

- Window type is double glazed Low-E with wooden sash. Overall heat transfer coefficient of the transparent component is $U_{window}$ = 1.8 W/m²K.

- The overall heat transfer coefficients of opaque components are considered less than or equal to the limit values ($U_{wall}$=0.5 W/m²K, $U_{ceiling}$=0.3 W/m²K, $U_{floor}$=0, 45 W/m²K) suggested for Ankara according to TS 825 (Turkish Standards 1998). Opaque component alternatives were detailed from the building materials, which are produced and commonly used in Turkey to provide these overall heat transfer coefficients.

- In this study, same optical and thermophysical properties of the building envelope are carried out for all building forms. The details of opaque and transparent components (external wall, ceiling-flat roof and pitched roof- floor and window) derived for the applications are shown in Table 1.

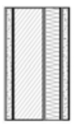
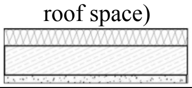
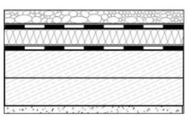
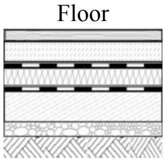
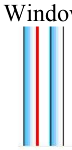
- Air source heat pump is used in the buildings for application because of its advantages such as low cost and ease of access to heat source.

## 2.2. Calculation of heating and cooling load for existing building

All calculations have been made under the terms of the real atmosphere in accordance with meteorological data, provided by the Turkish State Meteorological Service. Throughout the application study calculations have been made by using a building simulation program, eQUEST. eQUEST is a building energy use analysis tool derived from an advanced version of the DOE-2 simulation engine which helps the users to perform the building energy simulations by considering the state-of-the art building technologies (Web1). In addition, the energy spent for efficient operation of the system depending on the air temperature has been taken into account in the calculation. The comfort value of indoor temperature is taken 21°C for heating period and 26°C for cooling period according to international standards and Turkish Standards TS 825 (Turkish Standards 1998).

The comfort value of the indoor air temperature in all spaces of the buildings was supposed equivalent and thus, the effect of the internal walls and floors have been neglected. Thus, for heating and cooling loads calculations, the whole volume of the building was taken into account.

**Table 1.** The details of opaque and transparent components for Ankara

| Building Envelope Detail | Material No | Opaque Components | Thickness d [m] | Thermal Conductivity λ [W/m°K] | The overall heat transfer coefficient U [W/m²K] |
|---|---|---|---|---|---|
| Wall  | 1 | Lime mortar | 0,02 | 1 | 0,493 |
| | 3 | Porous light brick | 0,19 | 0,23 | |
| | 8 | Extruded polystyrene foam | 0,04 | 0,04 | |
| | 2 | Cement mortar | 0,02 | 1,6 | |
| Ceiling 1 (Pitched Roof-with roof space)  | 7 | Glass wool | 0,13 | 0,04 | 0,283 |
| | 4 | Concrete slab | 0,12 | 2,5 | |
| | 1 | Lime mortar | 0,02 | 1 | |
| Ceiling 2 (Flat Roof)  | 14 | Gravel | 0,05 | 0,7 | 0,291 |
| | 11 | Felt | 0,007 | 0,19 | |
| | 8 | Extruded polystyrene foam | 0,12 | 0,04 | |
| | 10 | Polymer Bituminous waterproofing | 0,007 | 0,19 | |
| | 5 | Light weight concrete for slopes | 0,8 | 1,65 | |
| | 4 | Concrete slab | 0,12 | 2,5 | |
| | 1 | Lime mortar | 0,02 | 1 | |
| Floor  | 12 | Wood | 0,02 | 0,13 | 0,413 |
| | 13 | Cement finish | 0,05 | 1,4 | |
| | 10 | Polymer Bituminous waterproofing | 0,007 | 0,19 | |
| | 9 | Polyurethane rigid foam | 0,06 | 0,035 | |
| | 10 | Polymer Bituminous waterproofing | 0,007 | 0,19 | |
| | 6 | Lean concrete | 0,10 | 1,65 | |
| | 15 | Rubble masonry | 0,15 | 0,7 | |
| | - | Ground | - | - | |
| Window  | Double glazed Low-E with wooden sash, gap of 16 mm | | | | 1,8 |

**3. RESULTS**

The monthly energy consumption of air source heat pump for each building form according to roof type is expressed in Figures 3 and 4.

The annual heating and cooling energy consumptions of air source heat pumps in L shaped and rectangular building forms for both flat and pitched roof are expressed in Figure 5 for the city of Ankara. The calculations are adjusted from monthly energy consumptions.

The annual heating and cooling energy consumption of air source heat pump in different building forms which have the same floor area, total exterior facade area, volume and optical and thermophysical properties of building envelope were calculated for the city of Ankara. By comparing the calculated values of heat pump applications for different building forms, the results obtained are summarized below.

- In all calculations, the energy consumption of rectangular shaped building form is % 9-10 less than the energy consumption of L shaped building form.
- The difference between the annual energy consumptions of L shaped building form and rectangular building forms which have the same floor area, total exterior facade area, volume, roof type and optical and thermophysical properties of building envelope are caused by having the same transparency ratio but different facade areas oriented in the same direction.

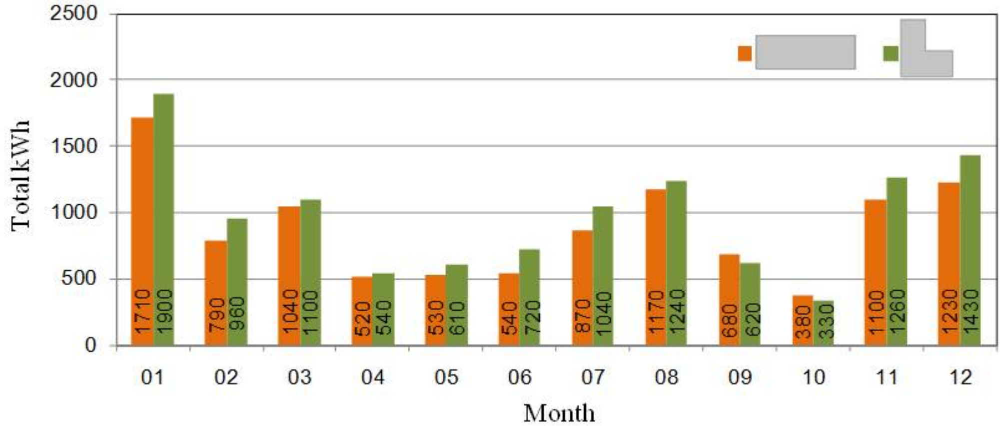



**Figure 3.** According to the use of pitched roof, the monthly energy consumption of air source heat pump

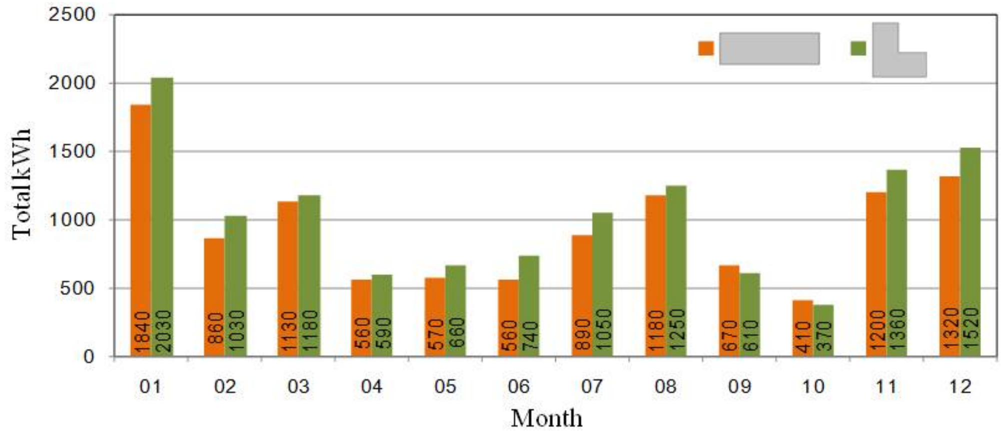



**Figure 4**. According to the use of flat roof, the monthly energy consumption of air source heat pump

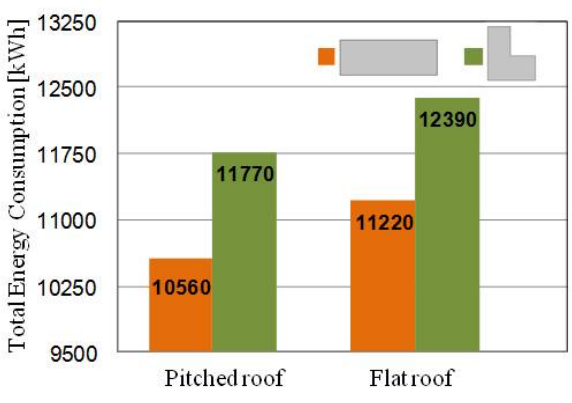



**Figure 5.** The annual heating and cooling energy consumption of air source heat pump in L and rectangular building forms

- Comparing the calculations of the pitched roof and flat roof application for the same building form, the annual heating and cooling energy consumption of pitched roof application is always % 5-6 lower than the flat roof application because the air layer at roof space works as an insulation layer.

**4. CONCLUSION**

Climatic comfort and energy conservation in buildings can be achieved along with the measures taken while the use of heating and cooling systems and with the help of the decisions related to design parameters to be taken during the design phase. The design parameters such as building form, building envelope and location of the building which have an important role on the energy consumption of the building should be taking into account during the energy efficient heat pump applications.

The method, which is introduced in this paper, has been used for controlling the energy consumption of heat pumps in different building forms which provide the climatic comfort conditions with the minimum energy consumption. The results of this study are summarized below.

• Even the buildings have the same floor area, total exterior façade areas, volume, roof type and optical and thermophysical properties of building envelope, the annual energy consumption of the buildings differs when the building form changes.

• The roof type which is a component of building form and the façade areas oriented in the different directions have an important impact on the annual energy consumption.

Therefore, in order to evaluate the impacts of building form on energy efficient heat pump application, the proposed methodology should be applied step by step for each different type of building even the building forms have the same floor areas, total exterior façade areas, volume and optical and thermophysical properties of building envelope and the building form which have the lowest annual heating and cooling energy consumption should be chosen.

As the main design parameters such as location of the building, building envelope and orientation of the building have effects on the annual heat loss and gain thereby the annual heating and cooling energy consumption , the most appropriate values for these main design parameters should be recommended in order to ensure energy efficient heat pump application for different building forms.

This study shows that energy efficient heat pump application is possible in different building forms with the developed approach. In this study, a limited number of alternative building form and the heat pump are discussed for Ankara region. This approach can be used for any type of building form and heat pump in any climate.

The author`s thesis includes studies done for the buildings which have the same floor area and volume but different total façade area. In addition to floor area and volume, 2 building forms which have the same total façade areas are examined in this study.

The suggestions about approach in order to contribute to future studies are as follows,

• The heat losses and gains through different exterior facades can be examined in more detail by simulating different dimensions of each building form.

• The approach can be developed by taking into consideration the parameters such as initial investment costs and life cycle costs.

• If renovation is made in an existing settlement, the approach can be applied to the existing building forms by proposing the appropriate values for the design parameters such as building envelope, roof type and heat pump type, thus it will be possible to assess the building's energy efficiency.

Consequently, it will be possible to design systems which use environmental energies, and provide climate comfort with minimum energy in buildings.

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