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The Role of Roof Shapes in Design of Green Building Systems (Case Study: Iran, Tehran)

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Abstract. Iran is recognized as one of the largest fossil fuels reserves resources in the world, but it is also suffer from mismanaged consumption. The consequences of this mismanagement have been considered in Iran during recent years and authorities have raised concerns about it. Identification of the optimized orientation and tilt angle for roofs in Tehran- The capital of Iran- in order to achieve the maximum daytime heat gain by photovoltaic cells and minimum energy loss at night in winter is the main purpose of this paper. So this paper makes a comparison in three types of roofs during December in Tehran (slab, 30-60^o and 45^o). The results show that the 30^o-60^o roof is the most efficient one in order to save energy during this month in Tehran.

Keywords: Green energy, roof shapes, energy consumption, photovoltaic panels.

1. Introduction

Nowadays, identification of new energy resources according to science, industry and technology developments, make a significant revolution in human life. Societies' dependence on fossil fuels, the crucial role of these resources in supplying world energy demand and the current irrational consumption of them which taking a long time to form beneath the earth's surface will obviously leads to the entirely vanish of these resources in near future. Considering the environmental impacts of this carbon based energy resource, the climate change and global warming they can cause, their increasing global cost and their scarceness and not renewability. Sun, the powerful clean source of energy, is become the focus of attentions.

Iran is recognized as one of the largest fossil fuels reserves resources in the world, but it is also suffer from the not managed consumption. The consequences of this mismanagement have been considered in Iran during recent years and authorities have raised concerns about it; yet, initiatives to develop energy efficient plans have been taken and in this case Targeted Subsidy Plan is one step toward this goal.

According to Iranian national building codes office declaration in 2002, constructions devote more than one-third of total energy use in this country to themselves; therefore, the major role of architecture in achieving energy efficient targets is undeniable. Investigations around alternative approaches for non renewable energy use by means of applying clean energy sources especially solar energy and taking advantage of new precise design trends for construction elements toward the best efficiency achievement is not only Iranian architecture deep need but also the world's architecture have to focus on that.

2. Research Questions and Inference Mechanism

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2.1. Research Aims

Identification of the optimized orientation and tilt angle for roofs in Tehran- The capital of Iran- in order to achieve the maximum daytime heat gain by photovoltaic cells and minimum energy loss at night in winter is the main purpose of this paper.

2.2. Research Questions

- What are the differences between slab roofs and gable roofs in heat loss at night?
- What are the differences between slab roofs and gable roofs in heat gain at day?
- What is the optimized tilt angle for gable roofs in Tehran for photovoltaic systems best efficiency during the days and minimum heat loss at night?

2.3. Research Method

Research approach is simulation and modeling and applied techniques are fabrication and calculation according to case study selection.[1]

3. Building Forms and Energy Consumption

Buildings can gain heat from several resources; the building occupants, the sun, lighting and illuminations, the heating equipments and other equipments which the consumed energy by them ends up to heat. The sun is clearly the most important resource. Solar radiations are received as direct, diffuse and reflected radiations. The amount of solar heat gain is dependent on the amount of received radiant and the destination of that. Local climatic condition, the sun position, the orientation and tilt of building external elements, the surface reflectance, the thermal capacity, the area of the surface must be considered in evaluating heat gain. This stored heat is distributed through the heat transfer modes of conduction, convection and radiation.

Solar technologies are developed today to enhance the exploit of solar energy in the form of passive and active systems. The passive systems includes passive solar heating, natural ventilation, daylighting, thermal mass storage and ground cooling. Passive solar heating employs the structural elements of a building to collect, store and distribute solar energy without or with minimal use of mechanical equipment.[2] In contrast, active systems make use of mechanical techniques to capture sunlight and convert it to a beneficial form. Integration of these two methods and applying unique building designs for the best efficiency of these two systems contributed to green echo-friendly buildings and societies.

4. Energy Lost at Night

4.1. Cases Study Selection

In Tehran, most architects use slab roofs for residential buildings. This case study is provided to estimate heat loss through 3 types of conventional roofs in Tehran and as a result to find the most appropriate roof shape for this city according to the minimum loss of energy at night. In order to obtain this goal, 3 buildings which all aspects including envelope, ceiling area, and used materials are the same and only different in the form of roof is assumed. The following is a description of the parameters used for calculations.

- Roof types:
  - Slab roof (Roof 0^o)
  - Roof $30^o\_60^o$
  - Roof $45^o\_45^o$
- Ceiling area: 200 m^2 (length is 20m and width is 10m)
- Air temperature under the roof : 25^oc (298.15^ok)
- Location : Tehran, Iran (latitude: 35.7^o north and longitude: 51.4^o east)

4.2. Determination of the Required Coefficient of Heat Loss (H)

The heat loss coefficient is the amount of heat flow through the different elements of a building because of 1^o c temperature difference. It can be determined due to relevant tables and equations provided in National building codes of Iran. The result is expressed in units of Watt (W) per Kelvin (K).

In order to find coefficient type, require thermal transmittance coefficient (U), which must be determined first according to the group of the specific building; the group must be distinguished in attention to the following parameters:

- Application of the building
- Geographical typology of annual cooling-heating need of the building location
- Infrastructure area of the building
- The city of the building placement

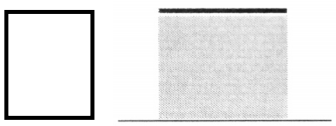
In this study, the application of the prototype is residential area with less than 1000m2 infrastructure. The building is considered to be in Tehran, which is categorized as a large city with moderate cooling and heating need; therefore the buildings in this study would be in class B (which is specific for moderate energy efficient buildings). The entry for U would be found in the relevant table in the column corresponding to class B and the row corresponding to slab or gable roofs which is **0.38 W/m^2. ^{o} k**. [3]

The mathematical model for calculating H is:

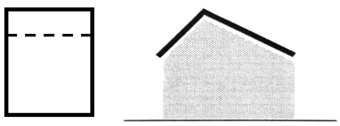
$$H = U \times A$$

Then the area of the roof surface must be calculated as the ceiling area is assumed to be the same.

1. **Slab roof :** A= 20×10 = **200 m^2**



2. **Roof 30^o _60^o :**
   A_1= (20 × sin 30^o) × 10 = 100 m^2
   A_2= (20 × cos 30^o) × 10 ≈ 173.2 m^2
   A_{Total} =273.2 m^2



3. **Roof 45^o_45^o :**
   A_1= A_2 = (10 × sin 45^o) × 20 ≈ 141.4 m^2
   A_{Total} =282.8 m^2

The temperature under the roof is assumed to be constant and equal to **25^{o}c = 298.15^{o}k**

Table 1: Total amount of heat lost at night for each roof, designed by authors.

Roof	A_{Total} (m2)	U (W/m^2. k)	H (W/ ^{o}k)	*Temperature* (^{o}k)	*Heat loss* (KW)
Slab	200	0.38	76	298.15	**22.65**
30^o _60^o	273.2	0.38	103.816	298.15	**30.95**
45^o_45^o	282.8	0.38	107.464	298.15	**32.04**

5. Photovoltaic Energy at Day

In this part the amount of heat gain for the three types of roofs is investigated to find out the most appropriate roof for installing photovoltaic arrays. The output from the arrays depend on the daily variation due to the rotation of the earth and the seasonal one, Location (the solar radiation available at the site), tilt and azimuth (orientation with respect to due south),shadowing and temperature. [4]

For unshaded installations the approximate monthly energy production of the system is calculated by following equation: [4]

$$E = S \times K \times L$$

- **S** = uncorrected daily output in KWh/day
- K = combination the loss due to temperature and a number of others such as dust, (assumes 0.9).
- L = losses in the other components (power conditioning unit, wiring, etc), (assumes 0.8).

The **S** parameter is calculated by following formula:

S = Array's Area × ***Module efficiency*** × ***Monthly average insolation of the surface***

The efficiency of Photovoltaic arrays is dependent to their type. Among ***monocrystalline silicon***, ***polycrystalline silicon*** and ***thin film silicon modules*** the monocrystalline one has the best efficiency about 12-15% under standard test conditions (STC).

To estimate the monthly average insolation on the roofs, as this parameter has different amounts for different tilt of a surface, 3 different calculations must be done. For horizontal surfaces this parameter could be derived from NASA information and for tilted surface due to the following formula it can be calculated according to the tilt angle. (Liu and Jordan.1963) [5]

$$\bar{H}_T = \bar{H}\left(1-\frac{\bar{H}_d}{\bar{H}}\right)\bar{R}_b + \bar{H}_d\left(\frac{1+\cos\beta}{2}\right) + \bar{H}\rho\left(\frac{1-\cos\beta}{2}\right)$$

- H_T: Monthly Averaged Insolation on a tilted Surface
- H : Monthly Averaged Insolation Incident On a horizontal surface (KWh/m2/day)
- H_d : Monthly Averaged Diffuse Radiation Incident on a horizontal surface (KWh/m2/day)
- R_b: The proportion of the beam radiation on a tilted surface to beam radiation on a horizontal surface. It's calculated through monthly averaged declination of sun and latitude of the location.
- β: Tilt of the surface in degree
- ρ : Ground reflectivity, assume an average value of 0.2
- Φ : latitude of Tehran which is 35.7 °

According to the NASA data, the following parameters are used in calculations for Tehran (latitude 35.7° and longitude 51.4°) in December. [6]

$$H = 2.38,\ H_d = 0.82,\ \delta = -22.8$$

It is assumed that the surface of roof which is covered with the photovoltaic arrays is sloped toward the equator and a 50m^2 monocrystalline silicon array (efficiency 15%) is applied. For achieving to R_b, firstly must calculate w_s and w'_s with the help of these equations:

$$w'_s = min\begin{cases}\cos^{-1}(-\tan\delta.\tan\Phi)\\ \cos^{-1}(-\tan\delta.\tan(\Phi-\beta))\end{cases} \qquad w_s = \cos^{-1}(-\tan\delta.\tan\Phi)$$

$$R_B = \frac{\cos(\Phi-\beta)\cos\delta\ \sin w'_s + \left(\frac{\pi}{180}\right)w'_s\ \sin(\Phi-\beta)\sin\delta}{\cos\Phi\cos\delta\ \sin w_s + \left(\frac{\pi}{180}\right)w_s\ \sin\Phi\ \sin\delta}$$

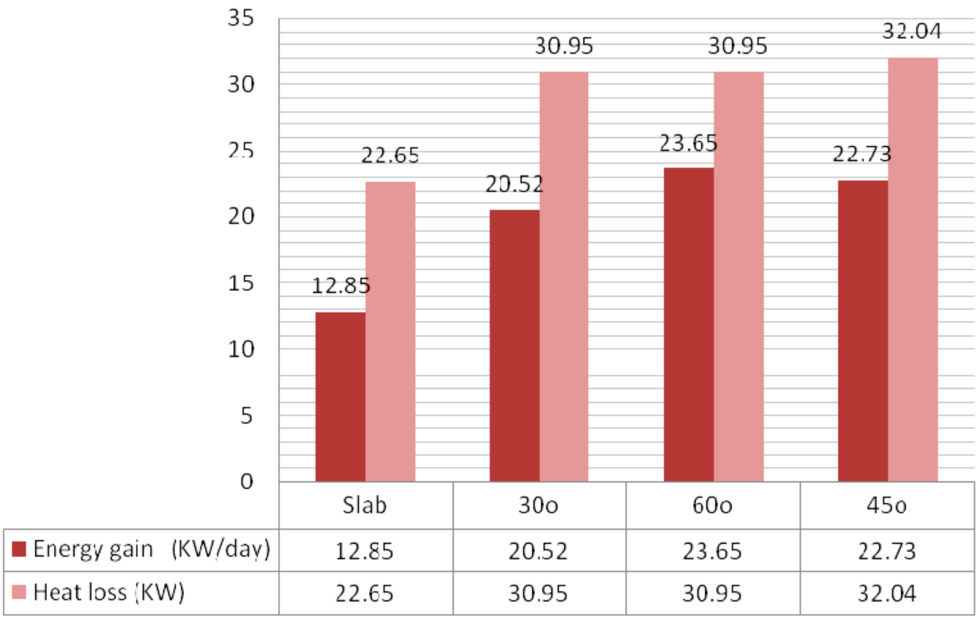
Table 2: Total amount of energy gain by each type of roof, designed by authors.

Roof	R_b	H_T (KW/m2/day)	S (KW/day)	K	L	E (KW/day)
Slab		2.38	17.85	0.9	0.8	**12.85**
30°	1.93	5.19	28.5	0.9	0.8	**20.52**
60°	2.34	6.05	32.85	0.9	0.8	**23.65**
45°	2.21	5.9	31.57	0.9	0.8	**22.73**

6. Conclusion

As a result, in order to find out which roof is the most efficient, a comparison of the results of heat loss and energy gain is represented in table 3.

Table 3: Comparison between heat loss and energy gain, designed by authors.



According to table 3, 30_60 degree roofs are the best case during December for Tehran in purpose of saving more energy. As the second option, it seems that two other types of roofs are similar in this situation.

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