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# Suitable roof constructions for warm climates—Gazimağusa case

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## Abstract

This research aims to find the suitable roof constructions for warm climates. The research has been carried out at Gazimağusa, North Cyprus. With the limited research budget 14 different roof constructions were selected and tested on a test house. These constructions included the types which are widely used in Cyprus and also the new ones. The roof constructions were tested under continuously air-conditioned and non-acclimatised regimes. They were also tested for the risk of condensation.

Most of the research on similar aspects were done in terms of energy loss and gain. This research has been designed to study the roof constructions in terms of thermal comfort of the users. Naturally, the roof constructions which have the highest thermal resistance will result in lowest heat gain and loose. In this study instead of finding the roof constructions which gain the least amount of heat during the hottest days of summer or the ones which loose the least amount of heat during the coldest days of winter, it was aimed to find how much they provide thermal comfort throughout the year.

In this respect, the roofs with thermal insulation showed the best performance. The location of the thermal insulation materials towards the inner surface of the section increased the performance. Inclined timber roof constructions on reinforced concrete ceiling save the buildings from solar bombarding in summer. However, to prevent the humidity accumulated, the attic space should be very well ventilated. On flat roofs, not only the thermal resistance of the roof section, but also the light reflectance of outside surface materials effected the thermal performance. Outside surface materials with very high light reflectance reduced heat gain in summer considerably.

In buildings which are air conditioned in summer, there is condensation risk. The defects due to this condensation can be avoided by the use of thermal insulation materials which are not effected from water. There is also condensation risk for winter. However, it was found that this condensation can dry if the building is ventilated.

*Keywords:* Warm climates; Flat roofs; Thermal comfort

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## 1. Introduction

In achieving thermal comfort in buildings the behavior of the external building elements is very important. Building elements are designed differently depending on the climatic conditions. Hot-dry, hot-humid, cool and temperate climates need totally different external building elements. There are vast amount of research in literature about the design of building elements in cool climates. However, there isn't enough research on the design of building elements in warm climates. This research aims to study the behavior of the roofs in a climate where the warm period is longer then the cool period.

The experimental study was carried out at the campus of Eastern Mediterranean University, Gazimağusa (35°7′N latitude and 33°57′ longitude). The climate of Gazimağusa is a transition between composite and hot-humid climates, thus it is a good representation of North Cyprus climate.

With the limited research budget 14 different roof constructions were selected and tested on a test house. These constructions included the types which are widely used in Cyprus and also the new ones. The constructions were selected as to test the contrasting features like:

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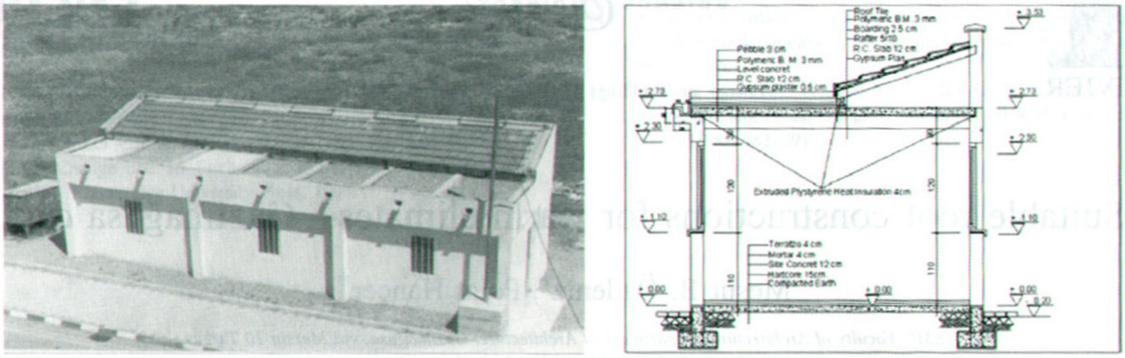


Fig. 1. Picture and the section of the test house.

Reverse flat roof versus conventional flat roof,
Inclined roof versus flat roof,
Ventilated inclined roof versus unventilated flat roof,
Inclined roof with the attic space inhabited versus inclined roof with the attic space uninhabited,
Thermal insulation on the inside of the roof section versus thermal insulation on the outside of the roof section,
Roof with thermal insulation versus roof without thermal insulation,
Accessible flat roof versus inaccessible flat roof.

Most of the researches on similar aspects were done in terms of energy loss and gain. This research has been designed to study the roof constructions in terms of thermal comfort of the users. The predicted mean vote (PMV), which is a thermal comfort index proposed by FANGER and recommended by authoritarian organizations of the subject like American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) and International Standards Organization (ISO) is used to compare the thermal performance of the roof constructions [1–3].

## 2. The study done

Fourteen roof constructions, approximately 2 m × 2 m in size were selected and constructed on a 12 m × 4 m size single floor test house (Figs. 1 and 2). In order to avoid horizontal heat flow between the roof constructions all of them were separated from each other and from the building structure with thermal insulation materials. The test house is on the university campus with its longitudinal axis on the east–west direction.

The monitoring of the test house was done continuously between July 2001 and 2002.

### 2.1. Experimental facilities

Inside and outside of the test house various temperature and humidity probes, data loggers to collect and evaluate the measurements and computer programs were used. These are:

1. HOBO data logger and BoxCar Pro Version 3.5 for Windows,
2. ACR data logger and Trend Reader for Windows,
3. CR23X data logger.

HOBO data loggers and their own probes were used to measure the internal surface temperature, air temperature and the relative humidity. Both the internal air temperature and relative humidity were measured at two different points 2.5 m above the floor. For external relative humidity three HOBO data loggers with their own sensors were used 1.5 m above the ground. ACR data loggers with their sensors were used to measure air temperatures at the attic space of Roof 1 and 2.

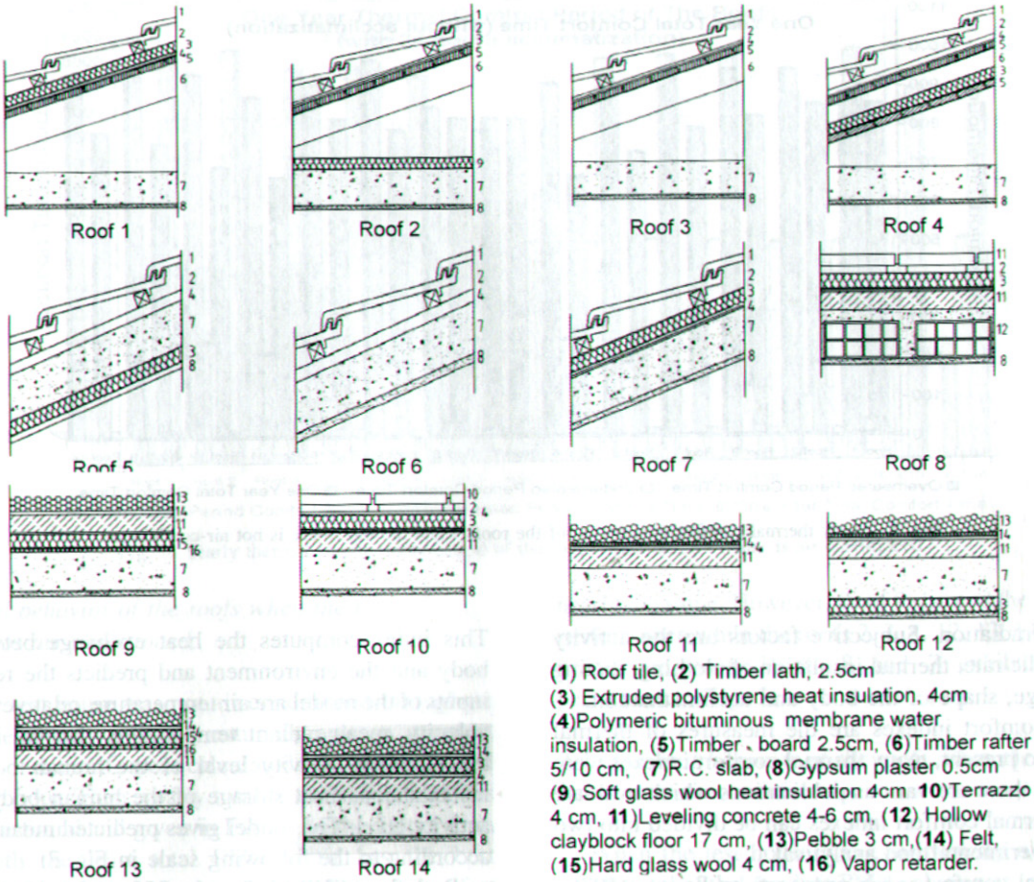
Twenty three channel Campbell Scientific CR23X micro-logger was used to measure the temperatures of the various roof layers. Cupper constantan thermocouples constructed and tested by the authors were used as temperature probes.

When the test house was not acclimatized in summer all the windows were kept 2 cm open and ventilated. However, in winter all the windows were kept shut. For cooling two window type air conditioning devices with 4000 W capacity each, were used on the narrow side walls, 50 cm above the floor. For heating three electric radiators with 2000 W capacity each, were used. Heating and cooling devices were connected to a thermostat separately. During the acclimatization period, when the internal air temperature fall below 21 °C the heaters, and when it exceeded 25 °C the coolers started to work automatically.

### 2.2. Thermal comfort

Most of the computer programs for analyzing building energy performance neglect thermal comfort. They mainly aim in finding how much energy can be conserved. They don't handle whether the people in energy conserved buildings are thermally comfortable or not [4].

Thermal comfort is defined as the state in which the body adapts itself to the environment by spending the least amount of energy [5]. It is possible to divide the thermal comfort factors into two groups as objective and subjective. Objective factors are air temperature, relative humidity, air



(1) Roof tile, (2) Timber lath, 2.5cm
(3) Extruded polystyrene heat insulation, 4cm
(4)Polymeric bituminous membrane water insulation, (5)Timber board 2.5cm, (6)Timber rafter 5/10 cm, (7)R.C. slab, (8)Gypsum plaster 0.5cm
(9) Soft glass wool heat insulation 4cm 10)Terrazzo 4 cm, 11)Leveling concrete 4-6 cm, (12) Hollow clayblock floor 17 cm, (13)Pebble 3 cm,(14) Felt, (15)Hard glass wool 4 cm, (16) Vapor retarder.

Fig. 2. Sections of the roofs tested.

| Hot | Warm | Slightly Warm | Comfort Scale Range | | | Slightly Cool | Cool | Cold |
|---|---|---|---|---|---|---|---|---|
| + 3 | + 2 | + 1 | + 0.5 | 0 | - 0.5 | - 1 | - 2 | - 3 |

Fig. 3. ASHRAE thermal sensation scale.

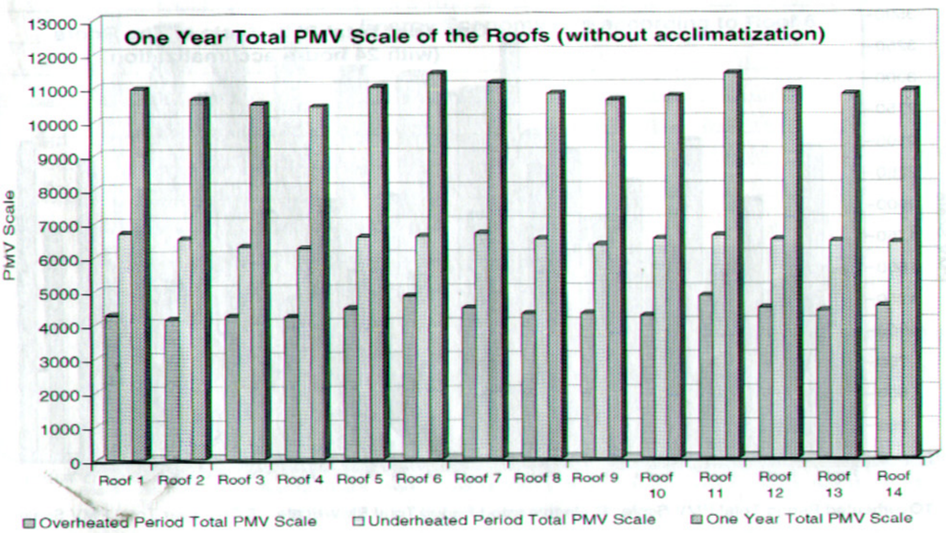


Fig. 4. Yearly absolute PMV values of the roofs when the test house is not air-conditioned.

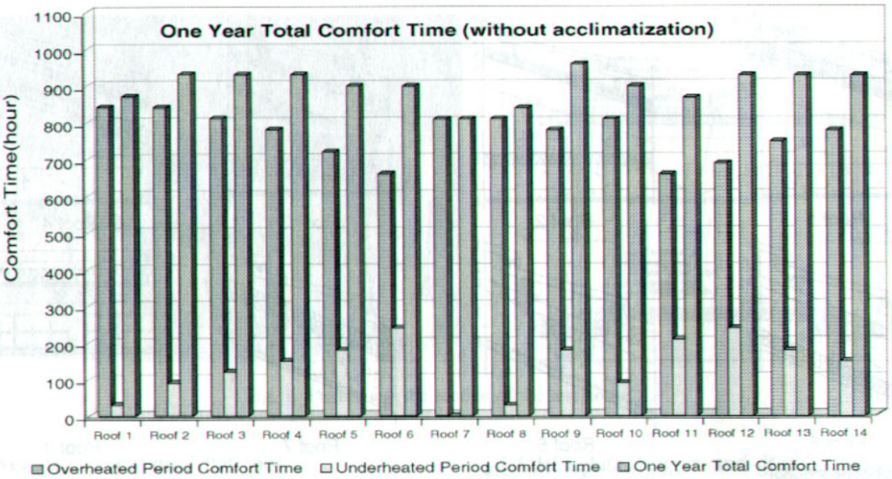


Fig. 5. Yearly thermal comfort time period of the roofs when the test house is not air-conditioned.

velocity and radiation. Subjective factors are the activity level, metabolic rate, thermal insulation of clothing, dieting habits, sex, age, shape of the body and acclimatization.

Thermal comfort indexes are the measures of thermal comfort. Up to present, many thermal comfort indexes were proposed and there are various publications which evaluate them [6]. Thermal comfort indexes can be divided into two groups as experimental and analytical.

The thermal comfort index proposed by Fanger (1970–1982) is an analytical one, and developed for the steady conditions of human environment. Later with the works of Gagge et al. [7], the index was developed in order to measure thermal comfort in varying environments.

At present the mostly used analytical thermal comfort index is the one prepared according to the Fanger model and recommended by ASHRAE (1994) and ISO (1994) [3,8]. This index computes the heat exchange between human body and the environment and predicts the response. The inputs of the model are air temperature, relative humidity, air velocity, mean radiant temperature, thermal insulation of the clothing, activity level of the human body, and the instantaneous heat storage of the human body due to the activity level. The model gives predicted mean vote (PMV) according to the following scale in Fig. 3.

Both the ASHRAE Standard 55 (1989) and ISO Standard 7730 (1994) indicate that for the +0.5 and −0.5 thermal sensation scale interval, at least 80% of human beings will feel thermally comfortable while 20% might be dissatisfied. With this model it is possible to find percentage of persons dissatisfied (PPD) for any PMV value. This model was used in testing the fourteen roof constructions in terms of thermal comfort.

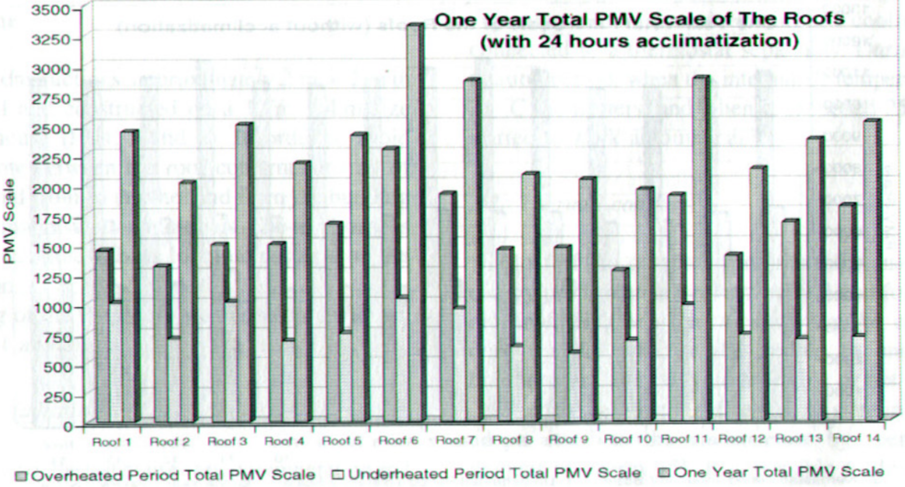


Fig. 6. Yearly absolute PMV values of the roofs when the test house is air conditioned.

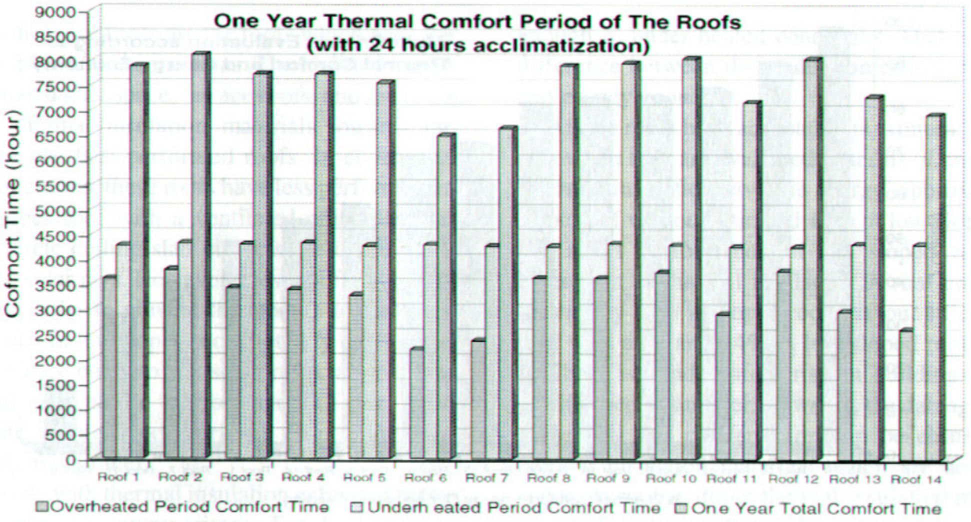


Fig. 7. Yearly thermal comfort time period of the roofs when the test house is air conditioned.

### 2.3. *Thermal behavior of the roofs when the test house was not air-conditioned*

When the test house was not air-conditioned throughout the whole year and ventilated naturally only in summer, PMV values of the roofs were calculated from the measured data for each hour. Then, yearly total of the absolute values of PMV were found and given in Fig. 4. As the first criteria the roof with the least total PMV value has the best performance. The figure also shows the thermal comfort time for the overheated and the under heated periods separately. Accordingly, roofs 9, 4, 3, and 2 are the best, and the roofs 7, 11 and 6 are the worst performed roofs (Fig. 4).

As a second criteria, the yearly total time when the thermal comfort is achieved (when PMV is between −0.5 and +0.5) is given in Fig. 5. The performance differences of the roofs according to the thermal comfort time are very nearly the same. However, Roof 9 showed the slightly better performance while the roofs 2, 3, 4, 12, 13, 14 and 7 are the next good ones. Roofs 8 and 7 exhibited the worst performance (Fig. 5).

### 2.4. *Thermal behavior of the roofs when the test house was air-conditioned*

When the test house was continuously air-conditioned, yearly total of the absolute PMV values were given in Fig. 6. Accordingly, Roofs 10 and 2, 9, 8, 12 are the best ones in achieving thermal comfort. Then comes the Roofs 4 and 13. Roofs 11, 7 and Roof 6 showed the worst performance.

As the second criteria, the total time of thermal comfort is given in Fig. 7. Roofs 2, 4, 5, 12 and 10 showed the best performance. They were followed by the roofs 9, 8, 1 and 10. The worst roofs are 7 and 6.

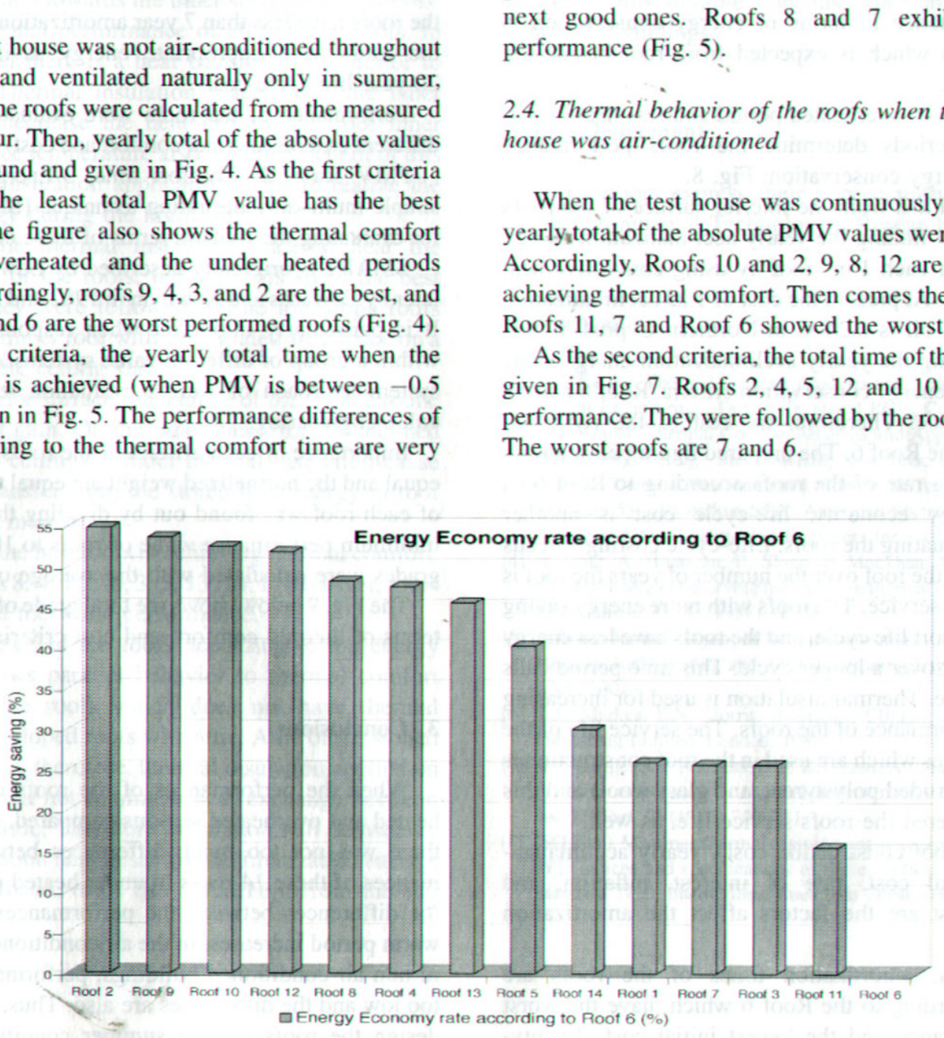


Fig. 8. Evaluation of the roofs according to energy conservation.

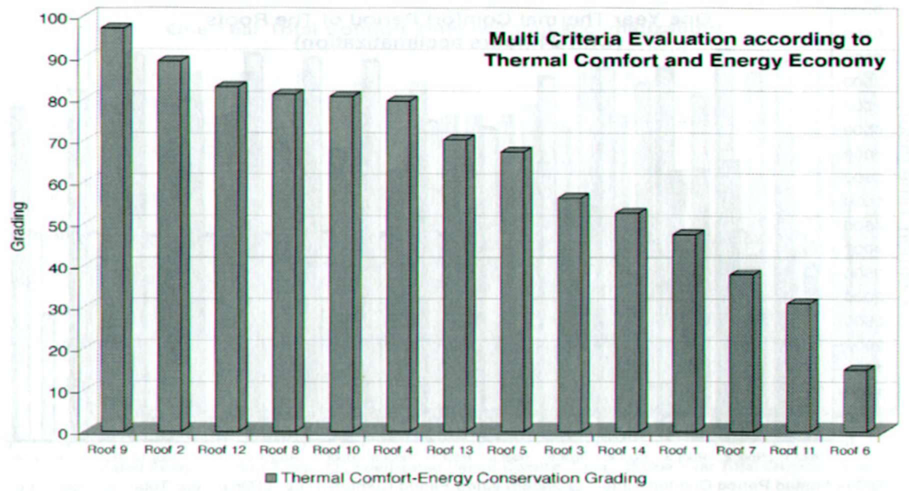


Fig. 9. Total grade of roofs according to thermal comfort and energy conservation.

### 2.5. *Cost*

High performance in terms of energy conservation is another criterion which is expected from roof beside the thermal comfort.

Less heat gain in overheated period and less heat loss in under heated periods determine the roofs performance according to energy conservation. Fig. 8.

Heat gain and lost from the interior surface of the roofs are calculated for finding the yearly acclimatization energy load and cost for each $1\ m^2$ roof by using convective heat transfer equation. At present the cost of 1 kJ acclimatization energy with fuel oil is 0.24 € in Northern Cyprus. It was used in calculating the yearly acclimatization energy cost.

According to energy conservation criteria, Roof 6 has the worst performance. Therefore, the rest of the roofs are compared with the Roof 6. The prepared figure below shows the energy saving rate of the roofs according to Roof 6.

Beside energy economy, life-cycle cost is another criterion for evaluating the roofs. Life-cycle costing spreads the initial cost of the roof over the number of years the roof is expected to be in service. The roofs with more energy saving pays back on a short life cycle, and the roofs have less energy saving pays back over a longer cycle. This time period calls amortization time. Thermal insulation is used for increasing the thermal performance of the roofs. The service life of the thermal insulations which are used in the roof construction is 15–20 years (extruded polystyrene and glass wool) and this time was considered the roofs service life, as well.

Initial cost (roof construction cost), yearly acclimatization energy load cost, rate of interest, inflation, and maintenance cost are the factors affect the amortization time.

In this study, amortization times of the roofs are determined according to the Roof 6 which, have the worst thermal performance and the lowest initial cost. Twenty-year life cycle costs are calculated with the 3.5% interest rate, 1% inflation, and initial costs of the roofs. The maintenance cost was neglected. The results indicate that, all the roofs have less than 7 year amortization time. Therefore, the roofs have appropriate energy saving according to 20-year life-cycle cost.

Performance of the roofs were evaluated in terms of 3 different criteria (thermal comfort and cost) and 3 sub-criteria (1-PMV scale, 2- Comfort time, 3-Energy conservation). simple multi–attribute rating technique (SMART) was used for evaluating the roofs in terms of these criteria.

SMART is originally described by Edwards in 1977 and later by Edwards and Newman in 1982 and Edwards in 1988. It is particularly important when responsibility is shared within a group of different value systems. SMART is a soft system approach of weight evaluation technique used in value engineering.

Importance of each criteria of the roofs were selected as equal and the normalized weight are equal to 100. The grade of each roof was found out by dividing the maximum and minimum performance value of roofs to 100. And the total grades were calculated with the average of these values.

The Fig. 9 below shows the total grade of selected roofs in terms of thermal comfort, and cost criteria.

## 3. Conclusions

When the performances of the roofs during the under heated and overheated seasons compared, it was found that there was not too much differences between the performances of these 14 roofs in under heated period. However, the differences between the performances of the roofs in warm period increases, in the air conditioned buildings. But in non air-conditioned buildings, performances of roof are too low and the differences are also. Thus, it is advisable to design the roofs for the summer conditions in Northern Cyprus.

The high performance roofs are the roofs which have the least heat gain in overheated conditions. The inclined timber roof with a ventilated attic space, terrace roofs, and the roofs by placing the thermal insulation materials towards the inner surface, are the best performed roofs. In contrast to this, in winter conditions, these roofs have less performance. The inclined timber roof with a ventilated attic space on a reinforced concrete ceiling slab protects the ceiling as a shield against the solar rays. However, these roofs should be well ventilated in order to prevent the storage of humidity and heat at the attic. In low sloped roofs not only the thermal resistance of the roof but also the solar reflectance of the roofing material affects the performance of the roof. Bright and white colored roof surfaces reduce the heat gain considerably in summer.

All types of roofs with thermal insulation exhibited better performance in respect to many criteria. For this reason at warm climates like the climate of TRNC thermal insulation materials should be used definitely. Location of the thermal insulation materials in a roof section affects the performance. By placing it towards the inner surfaces of the roofs, increases the thermal performance of all types of roofs. In overheated period there is a heat transfer from interior to exterior space. Thermal insulation placed near the inner surface of roof decrease the heat flux on the roof inner surface and surface temperature also. Another benefit of this kind of thermal insulation application helps to realize the stored heat energy during the night time.

By placing the thermal insulation material near the exterior surfaces of the roofs, terrace roofs show the best performance. They were followed by the low-slope roofs and the inclined timber roof with a ventilated attic space on a reinforced concrete ceiling slab.

The high exterior surface reflectance of the terrace roofs, decrease the heat gain. On the other hand, for the inclined timber roofs, the ceilings without thermal insulation cause excessive heat transfer from the stored heat energy in roof attic towards the interior.

Roof 9, 2, are the best roofs in achieving thermal comfort. Then comes roofs 8, 4, 12, 10, 3, 5, 13, 14, 1. However, roofs 8 and 7 exhibited the worst performance.

The performance of the roofs according to the energy conservation, shows parallel behavior to thermal comfort criteria, except the roofs which does not have thermal insulation and the sloped roofs with attic. Attic of the sloped roofs are ventilated, therefore, thermal insulation applied on the sloped part, can not minimize heat exchange between ceiling and roof attic. Therefore, insulation will be useless.

Thermal insulation help in saving acclimatization energy, but on the other hand, roofs can not benefit from the sun enough in under heated conditions. That is why there is a difference between the evaluation criteria thermal comfort and energy economy.

All the roofs have acceptable maximum 7-year life-cycle cost when they are evaluated in terms of amortization time. Thermal insulation save the energy, approximately 24% in slope roof without attic and 15% in low-slope roofs. It does not affect performance of the sloped roofs with attic. Placement of thermal insulation in roof construction, save the energy 14% in sloped roof without attic, 28% in sloped roof with attic and 14% in low sloped roof approximately.

There is condensation risk in buildings which are air-conditioned in summer. However, the damages that might be caused by this condensation can be eliminated by using thermal insulation materials which are not affected from water. At roofs without thermal insulation materials there is no condensation risk for the air-conditioned buildings in summer. This is due to fact that water proofing layers also stop the water vapor which could enter from outside. In Northern Cyprus there is also condensation risk in winter. However, this dryable condensation can be tolerated in ventilated buildings.

## Acknowledgement

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