ISESCO Science and Technology Vision
Volume 5 - Number 8 - November 2009 (79-83)

Optimisation of Insulation on Mediterranean Houses

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Abstract

As the Energy efficiency demands are constantly changing and in order to meet the more stringent thermal insulation standards and directives, it is necessary to investigate the application of insulation on the building envelope in terms of construction and building fabric to accommodate these requirements in the most cost-effective and energy efficient way.

In this paper the variable of insulation in combination with other important design variables and parameters and their effect on the thermal response of the building are studied, outlined and discussed. The study examines possible designs of the components of the building envelope, in conjunction with the application of insulation. The main aspects of insulation which are examined are:

a) Insulation and Shape.
b) The insulation Thickness
c) The stage of introduction of the insulation
d) The position of insulation on the envelope.
e) The extent of insulation application

The effect of these variables and parameters on the thermal performance of the building is assessed during both heating and cooling modes in building simulations with the aid of computer programmes. The original studies were carried out with 5000 method and they were followed by detailed studies with SERIRES. The building simulations make use of the thermal calculations and conclude to comparative assessment of results and the effectiveness of the varied insulation design measures.

1. Introduction

This study is carried out for residential buildings in the Mediterranean region and deals with a specific house type in Cyprus. The type of house envisaged to form the base-case is considered as the representative house of middle to upper class average income family; such a house would present uprising tendency for central air-conditioning installations and inherently it has the greatest potential for energy savings. The framework, within which the profile of the house base-case is outlined, is defined by:

a) Respect of traditional Cypriot architecture.
b) Response to current housing trends and demands.
c) Considerations of climatic and thermal aspects for Cyprus.

The factors considered in developing the house base-case, which is to be used as the reference building for the optimization studies, are: i) Location, ii) Type, iii) Size, iv) Shape and Orientation, v) Layout, vi) Component design vii) Shading. The insulation variable was tested on the building envelope on the walls, the floors and on the roofs.

For the building simulations the dynamic computer programme SERIRES was employed. This is particularly sensitive to the solar effects of the surfaces of the above building elements. It is mostly suitable for the analysis of residential buildings and it is designed to simulate the dynamic performance of the building in great detail. The building is represented mathematically as a thermal network with non-linear temperature dependent controls. The fundamental concept of the programme is that of heat flow paths of a structure and in terms of thermal zones. Conceptually a building is represented as one or more zones with thermal flow paths between one another and the outdoor temperature and solar radiation. The components of the building (walls, floors, windows etc) are considered as the thermal flow paths. The features of the components and their major heat flow elements are specified. This is followed by detailed description of the layers that comprise the element and the properties of the materials that compose each layer. The programme offers the user great flexibility in choosing the level of detail to be used in modeling a building. For the current study the model was used to perform detailed analysis of various insulation design options and to evaluate these options.

2. The insulation variables

The variables of insulation and their main aspects which are investigated are:

a) **Insulation and Shape:** Insulation incorporated on four basic building shapes and its effect on them was examined. The shapes under study are: Square (Base-case), rectangular, L-shape and Π-shape.

b) **The insulation thickness:** The thicknesses studied are, 2.5cm, 5cm, and 7.5cm.

c) **The stage of introduction of the insulation:** These series of tests examine the addition of insulation on unimproved house, on partly improved and on optimised house designs.

d) **The position of insulation:** The insulation effect in relation to the building mass expressed in different constructional aspects of the walls is analysed in terms of its addition externally, internally on the envelope or sandwiched in the walls.

e) **The extent of insulation:** The application of insulation when added: on the roof, on the roof and walls, on the roof, walls and floors etc.

In the following pages the variable of insulation and the above parameters are examined and discussed.

3. Insulation and shape

The effect of insulation on the shape of the building is examined on four basic shape variations (***Figure 1***). Initially, simulations were carried out on the un-insulated four building shapes, which are considered as reference buildings. In the chart analysis of energy loading of these un-insulated reference building shape variations, the following are depicted:

(i) The largest energy conservation for heating is achieved in the square shape, followed by the Π-shape, the L-shape and finally the rectangular.

(ii) In terms of cooling energy savings the rectangular house is equally efficient as the square shape, followed by Π-shape along with the L-shape.

(iii) Collectively the square shape achieves the largest amounts of energy savings. This is followed by the rectangular, the Π-shape and the L-shape.

Considering that all other design parameters are constant in all shape variations, there remains the extent, form and aspect of exposed surfaces as the only parameters in this tests which determine the heating and cooling load. This indicates the higher potential inherent in the compactness of the form.

It was further observed that a small decrease of the roof area of the rectangular house resulted to considerable cooling energy conservation and raised this shape from the last to the first position along with the square shape. This further reinforces the issue that compact shapes are more economical than the more complex ones. The compactness of the square shape incurred lower heat loss than the three other shapes. The roof area decrease of the rectangular shape resulted to lower heat gains.

The comparison of the extent of the energy savings in the four shape variations is made having as reference their base-drawings and the addition of insulation on these. From these studies is incurred that the introduction of insulation on the four basic shapes, selected for the study,

a) Improves their efficiency and their energy consumption for both heating and cooling, decreases.

b) The introduction of Insulation affects mostly the performance of Π-shape; it upgrades it and renders it as the best energy saving shape, pushing the rectangular last on the ranking order for savings.

These results indicate the greater potential for energy saving inherent in the more composite buildings, with bigger exposed surfaces, complex geometric configurations and projections than the compact simple shapes, when insulation is applied. This is attributed to the greater extent of insulation addition on the more composite building shapes. The higher heat losses due to the more complex Π-shape are counteracted by adding thermal insulation. This is obviously achieved at a larger additional cost.

4. Insulation thickness

This range of tests examines the impact of three varying thicknesses of insulation on the thermal performance of the reference house, base-case. The three tested thicknesses are:

(a) 25mm

(b) 50mm

(c) 75mm

From test analysis it is concluded that the energy savings incurring from increasing insulation thickness, do not increase proportionally (***Table 1***). Specifically the following are observed:

(i) Introduction of insulation on the reference design reduces the energy load of the building.

(ii) The application of 25mm insulation causes the same reduction of energy consumption both in heating and cooling; this amounts to 20%.

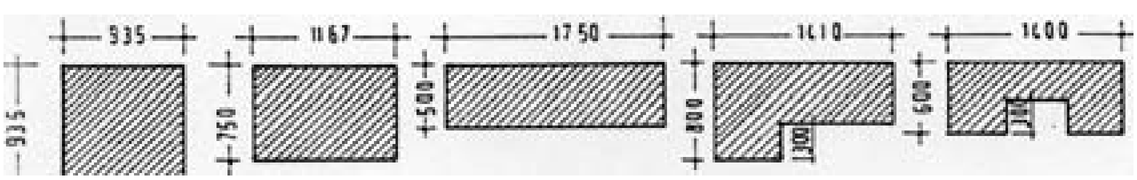

Figure 1. *Basic Shape Variations on which insulation was introduced.*

(iii) The savings achieved by doubling the insulation thickness on the design are only 6%; this increase is only 1/3 of those incurring from the initial insulation of 25mm thickness. The tripling of insulation causes only 3% energy load reduction. This low amount of savings difference, when insulation thickness increases, is attributed to the fact that there is less to save on an already insulated house.

(iv) The extra insulation cost of using 50mm thickness instead of 25mm on the reference design balances out the resulting savings and so concludes to the same pay-back period of 8 years. As in any conservation strategy the first gains are the least expensive and most cost effective. As more care is taken in the process and insulation levels increase, costs escalate rapidly.

(v) Although introduction of 25mm insulation reduces uniformly cooling and heating load, doubling or tripling the thickness increases savings unevenly for heating and cooling; the savings in cooling are half of those induced in heating. A possible explanation for this is that the reduction of cooling energy achieved by the application of insulation externally is mainly caused by the interception of radiation, irrespective of the thickness of insulation the introduction of the initial 25mm insulation intercepts most of it and does not leave much for further reduction when insulation thickness increases. Whereas heat transfer is resisted in conjunction to insulation thickness.

The related economic aspects regarding insulation thickness are summarized on ***Table 1*** below.

TABLE: Insulation Economics in relation to thickness and stage of its introduction

Design	Reference			Improved	
Insulation Thickness in (mm)	25	50	75	25	50
Savings in Total Energy Cost	20%	26%	29%	41%	52%
Savings in Heating Energy (GJ)	20%	27%	30%	40%	59%
Savings in Cooling Energy (GJ)	20%	24%	28%	37%	47%
Pay-back period in years	7.9	7.0	6.5	7.7	6.9

5. Stage of insulation introduction

The stage of insulation application is examined in three phases.

(i) On the reference house "Base-case"

(ii) On a thermally improved structure.

(iii) On thermally optimized structure.

The reference house used, in these series of tests, is the profile of a representative house type for Cyprus, as developed for the study and as explained in the introduction. Improved building in this context is the building on which such design energy conservation measures were adopted so that the energy load is reduced by 70% to 75%. The term optimized is the stage of design improvement which minimizes energy load nearing zero consumption. From the tests the following are observed, tabulated on ***Table 1*** and illustrated in ***Figures 2*** and ***3*** below:

(i) Addition of insulation on improved building design doubles the amount of savings incurring when insulation is applied on reference design and the results are compared with those of improved design. It seems that the combination of other design measures increases the effectiveness of insulation.

(ii) The pay-back period of insulation application on reference and improved design remains the same in both cases; the actual savings in money are minimal due to the low cost of energy in Cyprus, as fuel for heating is subsidized.

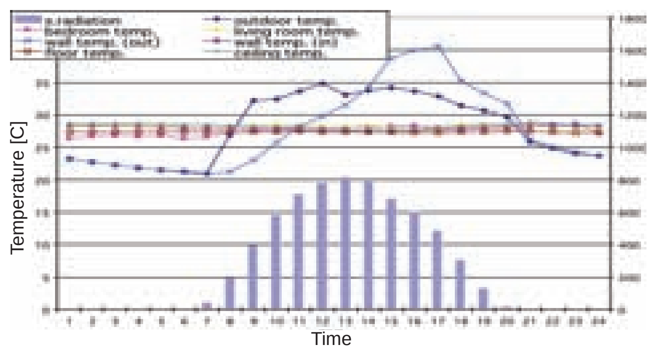

Figure 2. *Externally insulated house of improved design: Average temperature measurement results for August 1997*

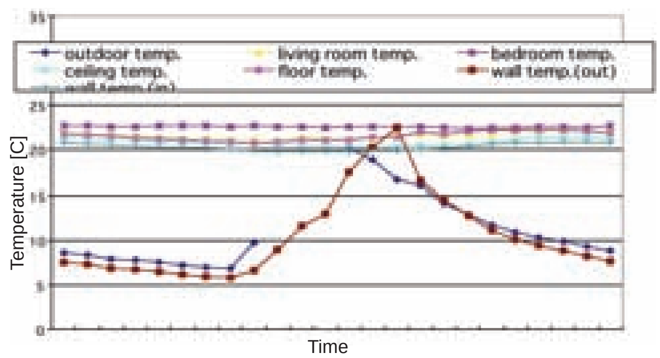

Figure 3. *Externally insulated house of improved design: Average temperature measurement results for January 1998*

6. Position of insulation on the envelope

Concerning the position on the envelope the insulation is examined as follows:

a) Internally

b) Sandwiched

c) Externally

From the tests it is observed, that savings from energy conservation, increase as insulation moves from the internal

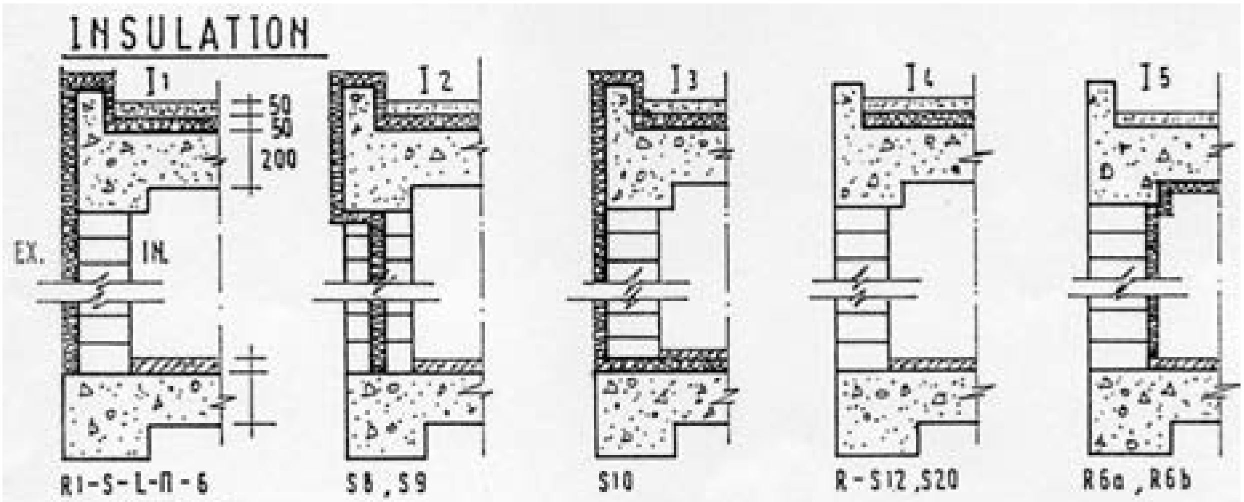

Figure 4. Details of insulation application on the roof, walls and floors, externally, sandwiched and internally

side to the external surface of the envelope, for both cooling and heating. The interception of the sun at the very external side of the buildings' skin in the summer results to the efficiency of external insulation for cooling energy conservation. In the winter with the positioning of the insulation on the external side, the mass of the opaque elements of the structure is utilized by storing the trapped solar energy contributing to the efficient bioclimatic operation of the building. The insulation on the exterior of envelope prevents heat stored in the thermal mass to be conducted rapidly to the outside.

7. Extent of application of insulation

As far as the extent of the insulation is concerned this is examined as follows:

a) On the roof only

b) On the roof and walls

c) On the roof, walls and floor.

From this range of tests the following are concluded:

(i) The application of insulation whether exclusively on the roof or/and additionally on the walls, incurs greater energy conservation for cooling than for heating.

(ii) The introduction of insulation on the roof presents a high percentage of energy savings:

- 19% for heating
- 45% for cooling

(iii) Extending insulation on the walls increases savings only by 5% for heating and 5% for cooling.

(iv) The additional cost for extending insulation on walls rises the pay-back period needed for roof insulation only, from 7.5 years to 45 years.

(v) The application of insulation on the floor show adverse effects on the efficiency of the house thermal performance; from simulation analysis is indicated that floor insulation prevents the natural thermal processes, for the climatic conditions of Cyprus, which inherently are more effective without insulation.

The related economic aspects regarding the extent of insulation application are summarized in ***Table 2*** below.

TABLE: Insulation economics in relation to extent of its application on the Building envelope

	Extent of insulation		
	Roof	**R + Walls**	**R +W + Foor**
Savings in Total Energy Cost	37%	56%	-18%
Savings in Heating Energy (GJ)	19%	72%	0
Savings in Cooling Energy (GJ)	46%	60%	-23%
Pay-back period in years	7.5	45	--

Conclusions

The comparison of insulation with other passive design measures entailing no additional or little cost gives an indication of the cost effectiveness of the insulation. The final conclusions on insulation in conjunction with other parameters are summarized as follows:

Shape: The insulation studies showed that the addition of insulation acts as the regulator of energy conservation on a geometrically complex building shape. This is at an additional cost and therefore the economic assessment of insulation should be viewed in conjunction with each building configuration.

Thickness: Energy consumption savings do not increase proportionally to the thickness increase. On the contrary there appears reduction of savings. The 50mm insulation thickness seems appropriate insulation level to be adopted in the process of minimizing energy load in the Cyprus house. The pay back period for the insulation of 50mm is the same as that of 25mm but has longer life span due to its bigger thickness. However further sensitivity studies are needed to define pattern of the effectiveness of the insulation thickness although the tests on thickness imply diminishing returns as the thickness of insulation is doubled or as it further increases.

Stage of introduction: Comparison of insulation on reference and improved design suggests that introduction of insulation on improved design is most effective. It seems that the combination of other design measures increases the effectiveness of insulation.

Position of Insulation: External insulation is derived as the most effective for the Mediterranean climate. Yet, the insulation positioning depends also on the type of building and air conditioning used.

Extent of insulation Application: The roof is thermally the most vulnerable building component of the Cypriot house; this renders the application of insulation on the roof the most cost effective energy design measure. Extending insulation on the walls reduces the energy load, but at an additional cost. Whereas extending it on the floor the energy load increases.

It is further observed from these comparative insulation parametric studies and in combination with studies of other variables (fenestration, mass etc) and the analysis of the results in establishing optimized simulation house profile, that one could locate a region of optimum design. This optimum region offers various combinations of effective parameters resulting to optimized design.

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