COMPOSITE MATERIALS FOR RENOVATION OF ROOFS IN EXISTING BUILDINGS

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ABSTRACT

The EPBD directive (91/2002/EU) paved the way for the European Union member states to develop and apply a holistic approach on the building's energy performance. It is documented that buildings' energy consumption represents 40% of the total energy consumption in Europe, a significant figure when compared to the industry and transportation sector. Respectively the CO2 emissions are calculated to be around 30%. A series of published data indicates that the uninsulated or poorly insulated roofs account for up to 25% of energy losses. Taking into consideration the significant downturn of new constructions monitored all over Europe after 2008, energy refurbishment of the existing building stock appears as a nodal point towards the mitigation of the energy consumption.

In particular for retrofitting insulation solutions for the roof we need to apply insulation with regard of the technical parameters of the roof. Thus, a combination of a board of extruded polystyrene with a ceramic tile would provide effective thermal protection. Moreover, a material like this can be characterized as cool material because of its light colour and the high reflectance. Application of this kind of material in existing roofs in Greek buildings indicated a reduction on the energy consumption and an amelioration of the temperature of the apartment below the roof.

In this paper, the results of the application of the composite material are presented along with its technical characteristics.

KEYWORDS

Energy performance, Roof insulation, Composite insulation materials

1. INTRODUCTION

EPBD directive defined the way to reduce energy consumption by improving the buildings envelope. Though it captures only 10% of the potential from buildings, a fully extended EPBD could reduce total emissions from buildings by 460 million tons a year, more than the EU commitment under the Kyoto Protocol [Ecofys II - 2004 and V - 2005]. With new buildings only representing 1% of the building stock and with the normal renovation cycle for buildings being 30 years, there is no time to lose in terms of bringing both new built and renovation standards up to speed.

The building sector is, together with transportation, the major energy consumer. In the OECD countries this consumption was in 2004 close to 28 trillion of Btu's and accounted nearly the 20% of the total energy consumption (IEA, 2007). In particular, the Greek building stock consists of 4.3 million dwellings (Theodoridiou et al, 2012 a), whereby only 26% were constructed after the implementation of the first Greek Insulation Law (TIR, 1979). Thus, approximately 3 million dwellings are lacking insulation in the building's envelope. Data indicates that uninsulated or poorly insulated roofs account for approximately 25% of conductivity energy losses from the envelope as such (figure1).

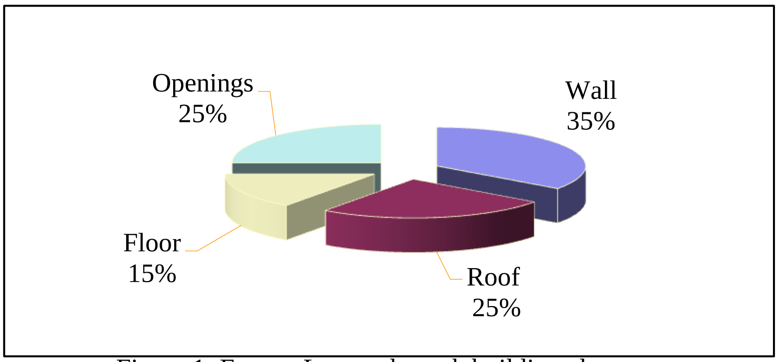

Figure 1: Energy Losses through building elements

In this direction, Greece has put in 2008 into force thelaw on energy performance of buildings, Law 3661/2008 which harmonized the European Directive on Energy Performance of Buildings (EPBD) 91/2002/EC. The Energy Regulation deriving from this legislation, foresees, adequate thermal protection of the building's envelopel, to be achieved mainly with the implementation of the increased thickness of thermal insulation, as well as the use of state of the art materials and construction solutions, as those are are the main tool towards the mitigation of the energy consumption in buildings and the reduction of environmental impacts. In early 2013 the EPBD recast (21/2010/EU) was harmonized by means of Law 4122/2013; the revised Energy Regulation is expected to become valid by the end of 2013.

In the present paper, we are focusing on the retrofitting insulation of roof elements, mainly with the use of composite insulation materials. Based on the results of a research performed in 500 apartments, we have studied 6 simulation scenarios with thicknesses from 100-300mm of insulation material, extruded polystyrene.

2. GREEK RESIDENTIAL BUILDINGS

There are some 4.4 million dwellings in Greece; out of those more than 3.2 millions are in urban areas [Statistical Services, 2002]. The vast majority of urban residential buildings have the shape of multi-storey apartment buildings and was constructed since the 1970's. They feature three to five floors of residential uses, rarely reaching up to seven. On the ground floor lie the main entrance, the building's utilities and either an open sided parking area where the residents park their cars (pilotis) or shops if there is commercial activity in the area [Papamanolis, 2004].

According to the classification discussed by Theodoridou [Theodoridou et al, 2011 b] most Greek residential buildings constructed after 1946 in have balconies in the form of projected overhangs. They are met in several widths usually narrower in older buildings and wider in later constructions, sometimes up to 2.5 m. The Greek urban residential building stock can be classified in three categories regarding the thermal protection of the buildings' envelopes. The first category includes the buildings constructed before 1979, which are not thermally insulated at all since they were constructed before the implementation of the national Thermal Insulation Regulation. The second category includes the buildings constructed during the period 1980 – 1990, which are considered to be partially insulated. As a rule they feature limited, if at all, insulation on the load bearing structure. Finally, the third category includes buildings constructed from 1991 until today and they can be considered to be, at least in most of the cases, fully insulated (Chadiarakou,2007).

Almost all apartment buildings have accessible flat roofs, used as terraces. They are constructed as conventional flat roofs or as upside-down ones (inverted). Until the early 1980s the conventional flat roof was the rule, as the roof was utilized for auxiliary uses making accessibility and mechanical strength properties a prerequisite. but Since then the inverted roof began to establish itself on the market, as flat roofs are rarely used for any purposes other than installing solar collectors and TV and satellite dishes. In the latter case the thermal insulation is placed above the dampness proofing and not below it. The final layer is usually gravel or pavement plates or even terrazzo. The inverted rood presents for the Greek climatic conditions a series of advantages, in terms of energy performance, water proofing performance, construction cost and maintainability. The results have been recognized early enough, but the traditional conservatism of the building sector combined with the aforementioned usage restriction of the 1960s' and 1970s' did not make the inverted roof popular until the early 2000s [Papadopoulos, 1998]. Not rarely, in colder regions in Northern Greece, apartment buildings may be found with tiled roofs resting on inclined concrete slabs. [Chadiarakou,2007]).

3. STATISTICAL DATA OF GREEK RESIDENTIAL BUILDINGS

The research started in 2005 and finished in 2007. The measurements took place in Thessaloniki, the second biggest city in Greece, situated in the North, with a Mediterranean climate. The city's climate has a heating demand of 2,184 degree days, αρε whilst the design maximum and minimum temperatures are 34,8°C and -4,2 °C respectively [Papakostas et al, 2004]. The research was carried out via a questionnaire, where the owners of the apartments provided information on its technical characteristics, the number of occupants and the energy bills for electrical and thermal consumption.

The analysis focused on the energy consumption of the constructions. The classes that was used was as described above. The annual electrical energy consumption per surface and person show stability through the three classes. Thus, the total energy (Figure 2) is present without any significant reduction and varies apporoximately around 100 kWh per surface and person through all the classes. (Chadiarakou, 2013). New thermal insulation law has applied new lower limits of thermal transmittance (table 1) which is leading to new higher thicknesses of insulation (table 2)

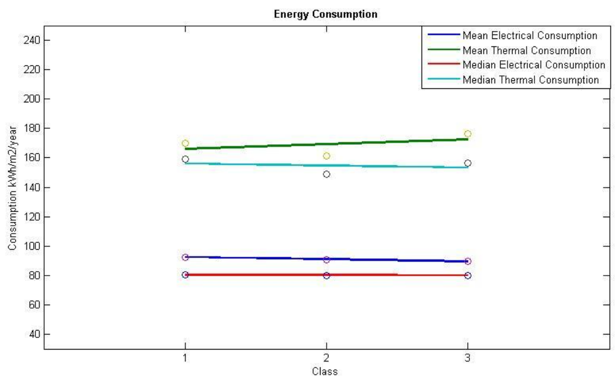

Figure 2: Total energy Consumption in Residences in Greece

Table 1: Comparison of U values in old and New Greek Regulation

Building Element\Climatic Zone	A		B		C		D
Regulation	Old	New	Old	New	Old	New	New
Vertical Element (Wall)	0,7	0,6	0,7	0,5	0,7	0,45	0,4
Horizontal Element (Roof)	0,5	0,5	0,5	0,45	0,5	0,40	0,35
Windows		3,2		3,0		2,8	2,6
Km	1,9		1,9		1,9		

Table 2: Comparison of U values in old and New Greek Regulation (old value with red color)

Climatic Zone	A	B	C	D
Minimum Thickness	cm	cm	cm	cm
Roof	6 /4	7 / 5	7 / 5	10 / 7
Wall	5 / 4	6 / 5	7 / 5	8 / 6
Concrete element	5 / 4	6 / 5	7 / 6	8/ 7

4. RETROFITTING INSULATION SOLUTIONS

Retrofitting insulation scenarios faced several difficulties concerning the type of the building, the adjacency with the neighboring buildings and its own architecture. Thus, even though walls seem to be the first choice for the retrofitting insulates solution; in reality it is not possible. Some of the reasons are very narrow balconies which do not allow external insulation with the adequate thickness, the distance with the neibhoring buildings which limits the possibility of external insulation. Therefore, the next best possible scenarios include the insulation of the roof. Flat roof are in most cases open unused spaces. A small percent might have the solar collectors on the roof. The retrofitting scenario that could be used is the one of inverted roof (figure 3). The majority of flat roofs acquire rather new water proofing, so the solution acquire only the insulation and the final layer.

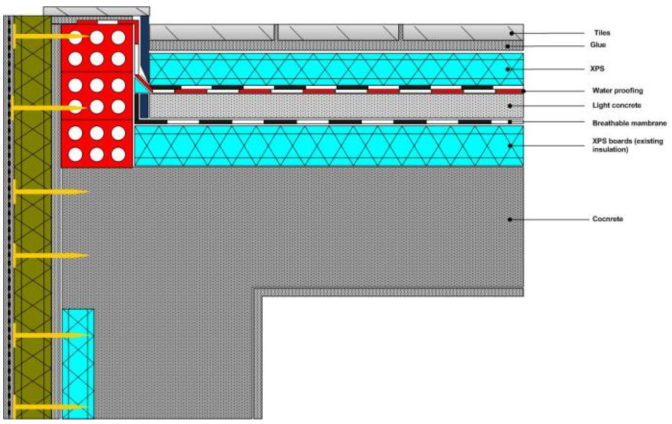

Figure 3: Retrofit insulation on Flat Roof

We need to take into consideration a few limitations for the roof thermal insulation. First of all is the weight of the total construction. The problem is focused on the fact that the majority of the buildings have been constructed before the year 2000, when the requirements according to the seismic control regulation was not as strict as they are today. Thus, the insulation solution should comply to strict limitations with respect to itse weight. The best solution is in theory the use of a composite insulation material with ceramic tile which are light enough and has a layer of thermal insulation up to 100mm. Detailed photo of the material is shown in figure 4. The composite material includes a layer of extruded polystyrene with thermal conductivity of 0.033 W/mK (up to 60mm) and 0.034 W/mK (for thicknesses 60-100mm) and a ceramic tile usually in light white of ivory color. The white ceramic tile can be characterized as cool material.

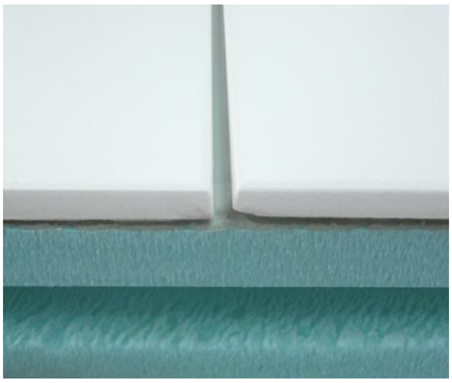

Figure 4: Detailed photo of composite material

Figure 5: Retrofit insulation on Flat Roof

5. SIMULATION SCENARIOS

The simulation scenarios were performed on a typical building for Greece. The simulation scenarios enclose insulation scenarios from 50-300mm thickness in all elements (table 3). The simulation program that we have used was Energy Plus version 3.1.0.027 through design program Design Builder. Energy Plus included a number of innovative simulation features such as variable time steps, user-configurable modular systems that were integrated with a heat and mass balance-based zone simulation and input and output data structures tailored to facilitate third party module and interface development.

Table 3: Insulation thickness of simulation scenarios

Scenarios	Thickness of Insulation			
	Wall	Concrete element	**Roof**	Floor
Basic	50mm	30mm	**60mm**	50mm
Scenario 1	60mm	60mm	**100mm**	50mm
Scenario 2	100mm	100mm	**100mm**	100mm
Scenario 3	150mm	150mm	**150mm**	150mm
Scenario 4	200mm	200mm	**200mm**	200mm
Scenario 5	250mm	250mm	**250mm**	250mm
Scenario 6	300mm	300mm	**300mm**	300mm

Other planned simulation capabilities are multy zone airflow, and electric power and solar thermal and photovoltaic simulation. Loads calculated (by a heat balance engine) at a user-specified time step (15-min) are passed to the building systems simulation module at the same time step. The building systems simulation module, with a variable time step (down to seconds), calculates heating and cooling system and plant and electrical system response (Drury B, 2001).

Integrated simulation also allows evaluating a number of processes:

- Realistic system controls
- Moisture adsorption and desorption in building elements
- Radiant heating and cooling systems
- inter zone air flow

In particular, we have explored through simulation the amelioration of the energy losses from building envelope. Furthermore, we have monitored the thermal comfort through the different scenarios. It must be stressed that the simulation model is structured based on the new thermal insulation law (KENAK).

Moreover, we need to emphasize on the fact that we have applied scenarios only on different insulation levels, keeping heating and cooling system steady. In the same context, the glazing system remains steady on the basis that it fulfills the requirements of KENAK (U value of 2,8 W/m^{2}K). The typical building consists of 7 floors and 6 apartments. The building is free of all sides.

In order to start the simulation we need to define the parameters, therefore to create a schedule under the guidelines of KENAK. Moreover, schedules for occupancy profile, appliances, lighting and domestic hot water (DHW).

To be more specific, occupancy profile specifies that habitants are in the apartment from 00:00 until 9:00 and then from 14:00 until 24:00. Totally, 18 hours per day. It is important to note that the time period between 9:00 in the morning until 14:00 at noon is the typical one, when all the members of the family are either at school or at work. As for appliances profile, this is set from 18:00 to 21:00, a total time of 4 hours per day. Lighting profile is the same as the occupancy one and DHW is set for 2 hours per day.

As a result the U value (table 4) of the elements is mitigating to the limits of the nearly zero buildings requirements.

Table 4: U value for the simulation scenarios

U value	Basic	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Walls Bricks	0,646	0,316	0,237	0,181	0,146	0,123	0,106
Walls Concrete	0,801	0,349	0,255	0,191	0,153	0,127	0,109
Walls Last Floor	0,569	0,297	0,226	0,174	0,142	0,119	0,103
Floors (ext)	0,546	0,307	0,222	0,172	0,14	0,118	0,102
Flat Roof	**0,336**	**0,237**	**0,237**	**0,181**	**0,122**	**0,105**	**0,093**

The maximum reduction of the thermal losses has been calculated to 72%. Especially, for scenario 3 the mitigation is 57%, while actual amount of the kWh saved from scenario 3 to scenario 6 is just 3 kWh/m2 (Figure 6)

Figure 7 presents the distribution of thermal losses for the flat roof is 14,18 kWh/m2. The fluctuation of values in scenario 1 and 2 is justified because we have used the same thickness of insulation. Generally, the reduction has a maximum value of 58%, while for scenario 3 are 28%.

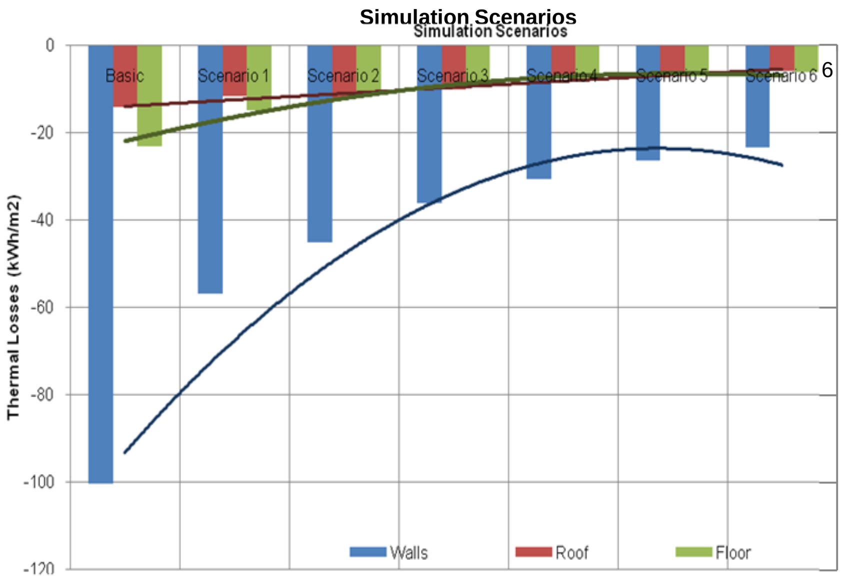

Figure 6: Thermal Losses of the building elements through simulation scenarios

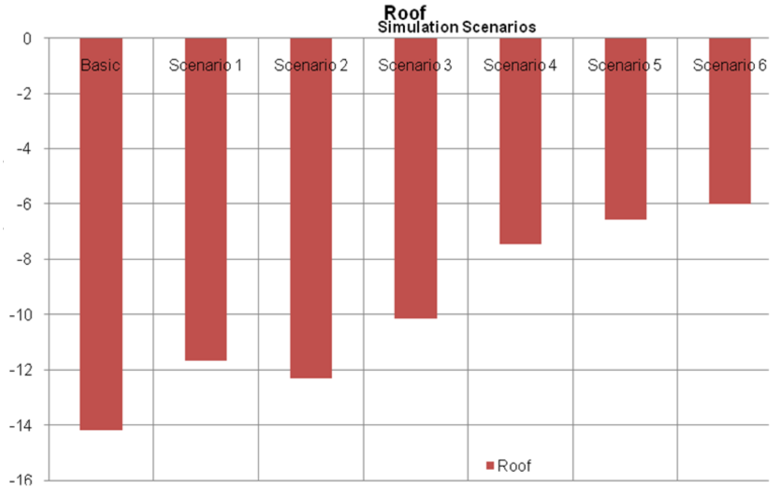

Figure 7: Thermal Losses of the building elements through simulation scenarios

6. CONCLUSIONS

The building stock of Greece requires innovating solutions for retrofitting insulation solutions for the building shell. Roof accounts approximately 25% of the energy losses and are most of the times open spaces which can be very easily insulated. Taking into consideration, the limitation regarding the weight of the applied insulation solution, a composite material of ceramic tile with extruded polystyrene could be the perfect solution. Simulation scenarios with insulation up to 300 mm provide max thermal losses reduction of 14,18 kWh/m2 in total while in comparison to un- insulated roofs the use of 150 mm provides a reduction of 28%.

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