Efficient energy thermal insulation façade systems for optimal savings and flexibility in architectural design

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ABSTRACT

The energy consumption matter for the building sector has come up again urgently looking for standards, measures, policies and best practices. That is because building sector have direct impact both on energy consumption and environment (cooling, heating, raw materials for construction, consumption of natural sources-water, fossil fuels and emissions of harmful substances). Buildings are responsible for the approximately 40% of the primary energy consumption in EU (164 millions buildings in EU-15, 193 millions in EU-25) and for about 50% of CO_2 emissions. Given the lifetime of buildings and the large number of existing buildings it is clear that the largest potential for improving the energy performance of buildings and creating ecologically sound and pleasant human environment in short time is in the existing building sector. Building refurbishment costs much less than demolition and reconstruction plus protects the architectural heritage. Building refurbishment with thermal insulation façade systems provide the main thermal protection of the building envelop, given the fact that this is the major thermal bridge to the environment. The building envelop has to provide the requirements of static and stability, thermal insulation, noise, moisture and fire protection, plus protection from the weather conditions. These requirements plus a vast architectural flexibility and freedom in design can be acquired by an External Thermal Insulation Composite System (ETICS), provided that this system is certified and standardized. An ETICS is composed by multiple layers: the insulation material (commonly consisting of boards of expanded polystyrene or mineral wool while the thickness varies accordingly to the average air temperature difference between inside and outside building i.e. geographical location, climatic conditions, HDD) the fixing on the substrate, the reinforcing intermediate coating (intermediate plaster and reinforcement mesh) and a variety of decorative finish coatings. A quick review of the advantages of ETICS: Energy saving up to 60% on existing buildings, reduction of emissions, important influence on the microclimate, elimination of thermal bridges, façade protection, easy, quick application, cost worthy investment, long term durability.

1. INTRODUCTION

The sustainability of European society depends heavily upon the sustainability of urban areas, which count for the 80% of the continent's population. Annual energy consumption in residential buildings averages 150-230 kWh/m^2 (COM, 2000; Balaras et al., 2000). In eastern and central Europe, heating energy consumption is 250-400 kWh/m^2, often averaging about two to three times higher than that of similar buildings in Western Europe. In northern European countries, well-insulated buildings have an annual consumption of 120-150 kWh/m^2, while the so-called low-energy buildings may even drop down to 60-80 kWh/m^2. The residential energy use per capita varies widely among European countries. Levels in most EU countries are fairly steady, fluctuating from year to year with the weather, but in some south European countries, like Hellas and Spain, residential energy use increased steadily during the last decade (Balaras et al., 2004; Papadopoulos, 1999). The fuel and amount of energy used in residential buildings varies from country to country, depending on living and comfort standards, per capita income, natural resources and available energy infrastructure (i.e. natural gas is common in most European countries and has infiltrated the household sector, but in Hellas it was only recently introduced (Papadopoulos, 1999). In European residential buildings, about 57% of the total final energy consumption is used for space heating, 25% for domestic hot water and 11% for electricity (Chwieduk, 2003).

1.1 Energy consumption and regulations

In Europe, national energy efficiency standards that mandate the use of thermal insulation in the construction of the building's envelope were introduced over the past few decades, starting from northern countries (Sweden, Norway and Germany) during the 50s. Thermal building codes exist in many variants, relying on as many different approaches as there are countries and according to the World Energy Council (WEC, 2001) can be classified in different categories including: (a) envelope component and/or entire building envelope approaches, which specify maximum thermal transmittance values for individual building components (i.e. walls, roof and windows) and/or the entire envelope with some flexibility on the individual components; (b) heating/cooling demand per unit floor area or volume, which specify maximum values while taking into account the contributions from ventilation losses/gains, passive solar gains and internal heat gains; (c) building energy performance per unit floor area or volume, which specify maximum annual primary or final energy consumption for the entire building as a system and integrate the heating/cooling demand along with the other equipment for heating and air conditioning systems, energy for ventilation, hot water production, elevators, etc., and other gains from solar energy (i.e. collectors, photovoltaics); (d) building life cycle, which in addition to the building energy performance accounts for the embodied energy in buildings and is expected to be the future trend for standard evolution. Building energy regulations have been revised in several European countries, towards more strict and complex standards, considering the energy consumption of the entire building system. More strict regulations have resulted in significant energy savings for heating, especially in northern Europe. Thermal insulation of buildings (external walls, roof and floor) and double pane windows reduce annual energy consumption for space heating, by lowering heat losses through the building's envelope, and improve thermal comfort conditions. Energy consumption in insulated buildings may be 20-40% less than in non-insulated buildings (Balaras et al., 2000), although consumer behavior may influence the level of energy demand. New high performance (passive) housing may even reach remarkably low heating demand (heating loads do not exceed $10W/m^2$ amounting to an annual heating energy consumption of about 15-20 kWh/m^2) by means of a compact form, very good insulation and windows, and heat recovery ventilation (Schnieders, 2003). Passive houses (new and renovated) consume just 1/3 of the energy necessary in conventional homes and construction costs are usually no more than 2-4% higher. Throughout Europe, new national regulations are underway in compliance to the new EU Directive on the energy performance of buildings (EC, 2002). The Directive mandates that by January 2006 all EU member states bring into force national laws, regulations and administrative provisions for setting minimum requirements on the energy performance of new and existing buildings that are subject to major renovations, and the calculation of performance–based indicators for energy certification of buildings. The cumulative energy saving achieved for new dwellings, compared to dwellings built before the 70s, average about 60% in the EU, while the additional savings that are targeted with the future revisions in the national standards will range from 20-30% (WEC, 2001). The impact of the new EU Directive on the energy performance of buildings by 2010 is estimated to be primary energy savings of 9Mtoe (COM, 2004).

1.2 Pollution and Environmental regulations

Buildings are also a major pollution source. They account for about 50% of SO_2 emissions, 22% of NOx emissions and about 10% of particulate emissions. They also contribute to about 35% of CO_2 emissions that is closely related to climate change. According to agreed targets of the Kyoto Protocol total emissions of Green House Gases in developed countries during the first commitment period (2008-2012) must be reduced by at least 5% below 1990 levels. The EU has agreed to a total reduction of its emissions by 8%. Therefore, buildings constitute an important sector in the effort to reduce environmental emissions (Papadopoulos, 1999).

2. FAÇADE INSULATION SYSTEMS

2.1 Introduction

Given the lifetime of buildings and the large number of existing buildings it is clear that the largest potential for improving the energy performance of buildings and creating ecologically sound and pleasant human environment in short time is in the existing building sector. Building refurbishment costs much less than demolition and reconstruction plus protects the architectural heritage. Building refurbishment with thermal insulation façade systems provide the main thermal protection of the building envelop, given the fact that this is the major thermal bridge to the environment (Papadopoulos, 1999). The building envelop has to provide the requirements of static and stability, thermal insulation, noise, moisture and fire protection, plus protection from weather conditions. These requirements plus a vast architectural flexibility and freedom in design can be acquired by External Thermal Insulation Composite System (ETICS), provided that this system is certified and standardized (European Organisation for Technical Approvals).

2.2 Description of Facade Insulation Systems

An ETICS is composed by multiple layers: the insulation material (Table 1, commonly consisting of boards of expanded polystyrene (Hagentoft, 0000) or mineral wool while the thickness varies accordingly to the average air temperature difference between inside and outside building i.e. geographical location, climatic conditions) the fixing on the substrate, the reinforcing intermediate coating and reinforcement mesh and a variety of decorative finish coatings. The concept of ETICS is to cut to a minimum the heat bridges and losses and to remain reliable and durable protecting the building against environmental and climatic factors (i.e. wind, frost, IR etc). The system has to have very high crack resistance, high resistance to mechanical stress, permeability to CO_2 and to water vapor, and must meet fire regulations of the Building Code.

Table 1: Insulation materials.

Synthetic foam board according to DIN 18 164	
Polystyrene expanded (EPS)	035-040
Polystyrene extruded (XPS)	030-040
Polyurethane (PUR)	030-035
Mineral fibre board according to DIN 18 165	
Rockwool facade board	035-040
Rockwool lamella	040
Mineral foam board	045
Cork expanded board according to DIN 18 161	045
Woodwool cement board according to DIN 1101	093
Cellulaire foam board according to DIN 18 174	050
Natural insulation materials (coconut fibre, wool etc.)	045-050

2.2.1 Fixing & required properties of insulation

Fixing is of great importance for the external wall insulation systems. Fixing of the insulation boards secures the stability of the system. Insulation boards should be fixed in a staggered pattern (like brickworks) completely level and tightly butt-joined. Fixing on the substrate can be done with the suitable adhesive mortar, by whole surface adhesion or by spot-edge (for substrates with unevenness of up to 1cm). The adhesive mortar should have very good adhering properties, very good starting adhesive power and good application properties. Fixing can be also done by a combination of adhesive mortar and dowels recommended in those cases that the load-bearing ability of the substrate is uncertain and it is necessary when the weight of the complete insulation system (excluding adhesive) exceeds $0.1kN/m^2$ ($10kp/m^2$) usually only when very thick render is applied. Mechanical fixing with profiles and dowels should be done in those cases that the substrate is of great unevenness. Standardized expanded polystyrene boards used as insulation should remain demonstratively effective, without loss of efficiency, for significant long time. The density of the insulation material is one of the key factors (Table 2). Low density results in good thermal insu-

Table 2: Typical values of density ρ [kg/m³]

Concrete	2400
Concrete (leight)	800 - 1800
Brickwork (heavy)	1200-2000
Brickwork (leight)	700-1000
Lime-cement plaster	1800
Timber	600 – 800
EPS board	15 – 30
Mineral wool board	90 - 150

lation properties while high density usually attributes good heat accumulation, good noise protection and good load rating. The most important key factor for the insulation material is the thermal conductivity of the material, that indicates the quantity of heat which travels through a surface of 1 m² with a thickness of 1 m and a temperature difference of 1 K (1 °C) during a period of 1 sec meaning that the lower the thermal conductivity, better the insulation qualities. Values of the thermal conductivity λ_R of building materials are defined in DIN 4108, part 4, Table 1 or have to be proven by a test certificate from an accepted laboratory (Table 3) (Hagentoft, 0000).

2.2.2 Calculation of the U-value (W/m^2.K)

The structure of a wall is usually composed by several layers (internal/external plaster, brickworks, concrete, and/or thermal insulation, wall finish etc.).

Each one of the layers of the materials has a thickness d (m) and its own thermal conduction coefficient λ (W/m.K). The thermal resistance (d/λ) of each layer of material is added to the internal and external surface resistances (1/α). The sum is the total thermal resistance R, for the total wall structure. The inverted value of this figure is known as the total thermal transmittance: *U- value*. The factor thermal resistance R (m^2.K/W) is defined by equation 1 (Hauser, 2001).

Table 3: Typical values of thermal conductivity λ_R W/m.K

Concrete	2,10
Brickwork (heavy)	0,50 - 0,96
Brickwork (light)	0,30 - 0,45
Lime-cement plaster	0,87
Synthetic resin plaster	0,70
Timber	0,13
EPS board	0,040 - 0,035
Mineral wool board	0,040 - 0,035
Stationary dry air	0,023

$$R=\frac{thickness(d)}{thermalconductivity(\lambda)} \qquad (1)$$

where:
- R: Thermal resistance (m^2.K/W)
- d: Thickness (m)
- λ: Thermal conductivity (W/m.K)

Example of the thickness required for the same R-value can be understood in Figure 1. The calculation for the total thermal resistance R (m^2.K/W), is given by the equation 2, while the typical values of internal and external surface resistance are 0,13 m^2.K/W and 0,04 m^2.K/W.

$$R=\frac{1}{\alpha_i}+\frac{d_1}{\lambda_1}+\frac{d_2}{\lambda_2}+\frac{d_3}{\lambda_3}+\frac{1}{\alpha_e} \qquad (2)$$

where:
- d: Thickness (m)
- λ: Thermal conductivity (W/m.K)
- $1/\alpha_i$: Internal surface resistance (m^2.K/W)
- $1/\alpha_e$: External surface resistance (m^2.K/W)

The total thermal transmittance U is calculated by the following equation (3)

$$U=\frac{1}{R} \qquad (3)$$

where:
- R: total thermal resistance (m^2.K/W)

From this equation it becomes clear that the smaller the U-value, the better performance the structure has. The combination of materials (i.e. expanded polystyrene board and concrete wall) could lead to a real low U-value (Fig. 2) (Clausnitzer, 0000). In Figure 3 it is shown how the thickness (d) of the expanded polystyrene used as insulation material could provide the construction that has no insulation with the better U-value needed.

2.3 Energy and environmental savings

ETICS prevents heat from escaping from inside

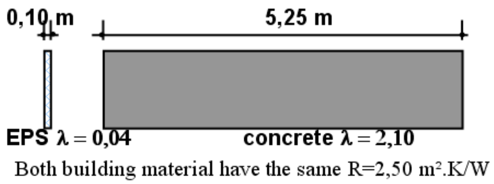

Figure 1: Example of thickness required for the same R.

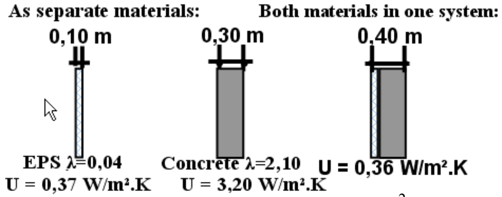

Figure 2: Total thermal transmittance U W/m^2.K

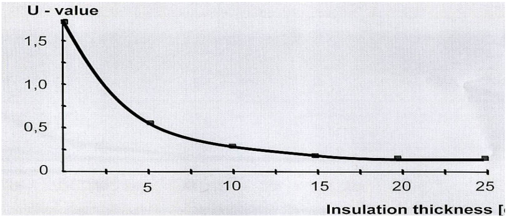

Figure 3: U-value with and without insulation.

buildings or protects buildings from heat caused by solar gain and reduces heating or cooling costs. The energy and environmental savings in kWh pro m^2 of exterior wall during one heating period, accordingly to the average air temperature difference between inside and outside building i.e. geographical location, climatic conditions, HDD, the type of heating space (i.e. fuel oil fired heating, natural gas fired heating) and the U-value of the construction can be calculated from equation (4).

$$U=\frac{(U\_valueold-U\_valuenew)}{1000}\cdot HDD\cdot 24 \quad (4)$$

where:

HDD: Heating Degree Days x average temperature difference out-/inside.

The result in kWh can be transformed into litres of fuel oil or m^3 of natural gas, depending on the type of heating method and further more can be translated into pollutant emissions savings. The energy savings can be also translated into financial savings for the tenants.

2.4 Intermediate and top coatings

The intermediate reinforcing coat should have high expansion capability, therefore reduced susceptibility to cracking, high reliability against impact stresses, and high resistance against driving rain and be highly weather resistant. Should also perform good adhesion and to be easy and fast to apply with economical consumption. The reinforcing mesh should be overlapped embedded in the upper area of the intermediate reinforcing plaster and should be alkali resistant, non-shifting and with high tensile strength absorption. The top coating could be any of the decorative ready to use and tintable finish render (synthetic resin, silicone, mineral bonding render) or can be any kind of facade coverings: brick slides, tiles etc. The intermediate and top coating should attribute very good water vapour diffusion and water permeability.

3. FLEXIBLE ARCHITECTURAL DESIGN

ETICS opens up the full scope of potential for façade design, providing the basis for seamless, attractive facades on old and new buildings. It is essentially neutral in character and can be adapted to any architectural style. Different textures and finishes can be used to fulfill the desire to change monotonous appearance of buildings. For reconstructions ETICS can provide a new optical attractive façade. The flexibility and the low weight of the insulation material permit to shape forms while insulating.

4. REFERENCE PROJECT

The renovation of a hotel in the center of Athens was made by using ETICS. The building was made of concrete beams and piles with quit large areas of glass windows. Today the large area of windows was reduced and replaced by cement boards. All façade has been coated with façade insulation gaining in heating and cooling. The façade system applied (insulation boards of ρ=15kg/m^3, λ= 0,004 W/m.K) resulted in a 50% reduction of the U-value (Table 4). The annual energy and environmental savings that come up after the improvement of the U-value are shown in Tables 5, 6. Figures 6a, b present how in short time the appearance changed to a luxury, imposing façade of the highest quality.

Table 4: Total thermal transmittance U W/m^2.K.

Before façade insulation	4,67
After façade insulation	2,35

Table 5: Annual energy savings.

	kWh/m^2	lt/m^2	€/m^2
Heating period	81.80	12.26	9.38
Cooling period	40.07	-	2.56
Total	121.87	12.26	11.95

Saving costs have been calculated with the current cost of heating fuel oil and of electricity in Hellas.

Table 6: Annual environmental saving kg of emissions/m^2

	CO_2	SO_2	CO	NO_x	HC	particles
Heating	19.268	0.037	0.004	0.015	0.0012	0.002
Cooling	21.286	0.388	0.005	0.030	0.0013	0.020
Total	40.553	0.425	0.008	0.045	0.0020	0.022

Figure 6: a. The hotel before, b. The hotel after ETICS.

5. CONCLUSIONS

As a quick review of the advantages of ETICS: Energy saving up to 60% on existing buildings (WEC, 2001; EC, 2002), reduction of emissions through energy savings, important influence on the microclimate, elimination of thermal bridges (ceilings, geometrical thermal bridges etc)- heat profits (Hauser, 2001; Kalivas, 2004), reduction of temperature tensions (high crack resistance, sufficient elasticity), better using of heat accumulation capacity, new optical attractive façade and protection, easy, quick application, comfortable internal environment, cost worthy investment with quick return, long term durability and recycling after service life of EPS.

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