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 CO2 emissions (Commission of the European Communities, COM 769, 2000; Balaras et al., 2000). 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 interior 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 envelope, given the fact that this is the major thermal bridge to the environment (Balaras et al., 2004). The building envelope has to provide the requirements of statics 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 composite insulation system, provided that this system is certified and standardized (Papadopoulos, 1999), applied by certified applicators according to the technical details and specifications provided by the materials' producer. An external thermal insulation composite system (ETICS) is composed by multiple layers: the insulation material (commonly consisting of boards of expanded polystyrene (Chwieduk, 2003) 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 (adhesive and/or dowels), the reinforcing intermediate coating (intermediate plaster and reinforcement mesh) and a variety of decorative finish coatings. ETICS are proven to minimize energy consumption of buildings, while reducing emissions of greenhouse gases. ETICS technology has been developed (after the 1st energy crisis) in order to achieve lower times of application, longer lifetime of the materials, greater protection of the building according to its geographical location and climatic conditions, plus protection, if such is desired, by electromagnetic radiation (electro smog), contributing to a better and healthier indoors environment. A quick review of the advantages of external wall insulation systems: 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, reduction of black-out possibility during pick demand of electricity.

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 (Commission of the European Communities, COM 769, 2000; 2]. In eastern and central Europe, heating energy consumption is 250-400 kWh/m^2, often averaging about 2 to 3 times higher than that of similar buildings in western Europe. In northern Europe, 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 EU. Levels in most EU countries are fairly steady, fluctuating from year to year with the weather, but in some south EU, like Hellas and Spain, residential energy use increased steadily during the last decade (Balaraset al., 2004; Papadopoulos, 1999). The fuel and amount of energy used varies from country to country, depending on living and comfort standards, per capita income, natural resources and available energy infrastructure (i.e. natural gas common in most European countries has infiltrated the household sector, but in Hellas it was only recently introduced (Papadopoulos, 1999). In EU 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 EU, 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 (World Energy Council, 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, 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, etc., and other gains from solar energy (i.e. 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 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, 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 ($<10W/m^2$ 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 (European Commission, on the Energy Performance of Buildings, 2002). The Directive mandates that by January 2006 all EU member states bring into force national laws, regulations and administrative provisions to set 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% (World Energy Council, 2001). The impact of the new 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 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 and the large number of existing buildings it is clear that the largest potential for improving energy performance and creating ecologically sound and pleasant human environment in short time is in the existing building sector. Building refurbishment costs much less than demolition plus protects the architectural heritage. Building refurbishment with thermal insulation façade systems (ETICS) 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 ETICS, provided that the system is certified and standardized (European Organisation for Technical Approvals).

2.2 Description of Facade Insulation Systems

ETICS is composed by multiple layers: the insulation material (Table 1, commonly consisting of boards of expanded polystyrene (Badescu, and Sicre) 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 has to be of limited combustibility.

2.2.1 Fixing & required properties of insulation

Fixing secures the stability of the system. Insulation boards should be fixed in a staggered pat-

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

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

tern (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 (substrate unevenness ≤ 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, or with great uneveness 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. Standardized expanded polystyrene boards used as insulation should remain demonstratively effective, for significant long time. The density of the insulation material is one of the key factors (Table 2). Low density results in good thermal insulation 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 thermal conductivity of the material, that indicates the quantity of heat which travels through a surface of 1m² with a thickness of 1m and a temperature difference of 1K (1°C) during a period of 1sec 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, C.E.).

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.).

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

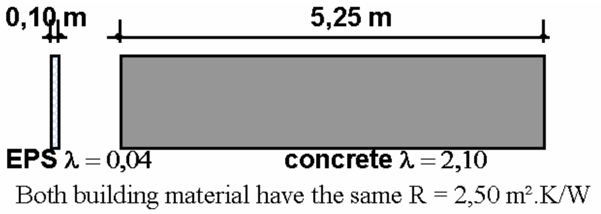

Figure 1: Example of thickness required for the same R.

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). 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).

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

Example of the thickness required for the same R-value can be understood in Fig 1. 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 becomes clear that the smaller the U-value is, 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 (see Figure 2) (Clausnitzer, K.D.). In Figure 3 it is

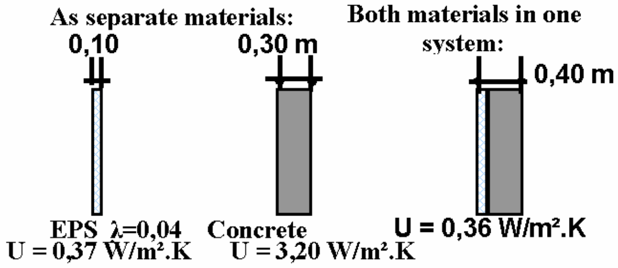

Figure 2: Total thermal transmittance U $W/m^2.K$

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

Façade insulation prevents heat from escaping from inside 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.

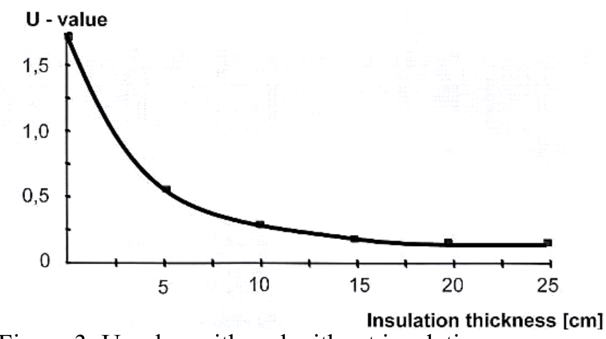

Figure 3: U-value with and without insulation.

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.

2.5 Anti Electro smog with ETICS

“Electro-smog”: high-voltage power lines, radar, radio beacons, satellite, radio and television transmitters as well as mobiles. All of them produce electrical and magnetic fields or emit high frequency electromagnetic waves. Scientists and leading experts across the world cannot agree on the exact nature of the dangers posed by electromagnetic fields (EMF), but they agree that EMF exist and are on the increase. Since Faraday first discovered that cage acting as a conductor could provide shielding against electrostatic fields, variations on this theme have been used to provide shielding to building structures when incorporated into the external fabric of the facade. This solution provides a simple, safe and economical way to limit the exposure of occupants of the buildings to 'stray' electromagnetic fields. The use results in highly efficient protection from electromagnetic high frequency irradiation. The mesh can be incorporated into the ETICS. This gives an important additional benefit without additional complexity, particularly within educational or health establishments. Using woven metal threads and a special conductive coating, the mesh is slip-resistant, dimensionally stable with a high tensile strength. It ensures more than 99% damping of the high frequency radiation especially in the pulsed signals frequency domain (eg. mobile radio stations). Also reduces low frequency electronic alternating fields (eg. high-voltage power lines) by over 99%. The application is identical to the conventional mesh. Connection of the copper cable should always be done by a qualified electrician to ensure correct earthing (Pauli, 1999.).

3. FLEXIBLE ARCHITECTURAL DESIGN

Façade insulation 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. Architecture committed to achieving low energy consumption is wrapped in an insulated envelope. An envelope which insulates is a dimensionally stable and has both tensile and compressive strength. Different textures and finishes can be used to fulfill the desire to change monotonous appearance of buildings. For reconstructions facade insulation systems can provide a new optical attractive façade. The flexibility and the low weight of the insulation material permit to shape forms while insulating.

4. THE SITUATION IN GREECE

Although the Directive should have come in force long ago, in it is now being discussed while waiting for the legal issues to be solved and for the necessarily law arrangements. In private sector things move faster. Building owners realized that they should somehow react against the constantly uprising energy costs (especially oil prices) and have become more sensitive in environmental issues. It has come the right moment for the greek construction mentality to switch from "conventional adding up heavy loads renders" to "modern", light, technologically advanced systems, that combine both insulation and façade architecture, without the severe problems from which the Greek constructions suffers of (limitations to architecture, great amount of time and money consumed for application/reparation, repainting or reconstruction). There plenty of cases in Greece, both in private and public sector, that have proven in practice that buildings with ETICS have diminished energy costs, have better indoor climate, and present no façade problems (no color fading, no cracks, no chalking, no need for conservation), not to mention that the time spent for construction was half of the time for "conventional works". The Greek construction market has still a long way to go to get mature enough to face ETICS on a façade as a quality advanced conventional application method, but it seems that private initiative has started already moving to this direction, trusting ETICS and practices that have already been applied world wide for decades.

5. REFERENCE PROJECTS

The renovation of a hotel (A) in the center of Athens and the renovation of a complex of block of flats in the Northern suburbs of Athens (B) were made by using façade insulation system. The hotel 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. The complex – constructed in 1970s was facing severe moisture and insulation problems. Both façades have 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%-60% respectively reduction of the U-value (Table 4). The annual energy and environmental savings after the improvement of the U-value are shown in Tables 5, 6. In Figure 4a, b, c, d can be seen how the appearance changed to a luxury, imposing façade of the highest quality.

6. CONCLUSIONS

As a quick review of the advantages of ETICS: Energy saving up to 60% on existing buildings (World Energy Council, 2001; European Commission, on the Energy Performance of Buildings, 2002), reduction of emissions, important influence on the microclimate, elimination of thermal bridges - heat profits (Hauser, 2001; Kalivas, 2004), reduction of temperature tensions (high crack resistance, sufficient elasticity), better using of heat accumulation capacity, façade protection, new optical attractive façade, easy, quick application, comfortable indoor environment, cost-worthy investment, quick return of investment, long term durability.

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

Before façade insulation (A)	4,67
After façade insulation (A)	2,35
Before façade insulation (B)	4,80
After façade insulation (B)	2,25

Table 5: Annual energy savings -heating / cooling period

	kWh/m^2	lt/m^2	$€/m^2$
Total (A)	121.87	12.26	11.95
Total (B)	132.57	14.32	12.87

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
Total A	40.553	0.425	0.008	0.045	0.0020	0.022
Total B	41.879	0.513	0.009	0.052	0.0021	0.024

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Figure 4a, b, c, d: Project A& B before/after renovation.