Comfort and Energy Saving: the External Thermal Insulation Composite System (ETICS)

Amilcare Collina
MAPEI S.p.A.
Italy
a.collina@mapei.it

Abstract: The external thermal insulation composite system (ETICS) is the only viable solution for the energetic upgrading of the existing buildings.
However, the effects of the installation of the external thermal insulation composite system are not limited to the energy saving, but include comfort, preservation of the building, and reduced emissions of greenhouse gases.
The above-mentioned advantages make the investment related to the ETICS installation attractive from the economic and financial point of view.
Keywords: Etics, Thermal insulation, Comfort.

1. INTRODUCTION

The energetic performance of a building, which has been considered not significant in the past, is becoming more and more important because of the environmental constraints and the increasing cost of the fuel.
The external thermal insulation composite system (ETICS) is the only viable solution for the energetic upgrading of the existing buildings.
However, the effects of the installation of the external thermal insulation composite system are not limited to the energy saving; a number of advantages are really obtained as indicated hereunder

2. ETICS DESCRIPTION

ETICS is a system usually including an adhesive, a leveling mortar, an insulation panel, an alkali-resistant reinforcement net, a primer and a finishing coat, as well as sealants and accessory materials for the installation. (Figure1)

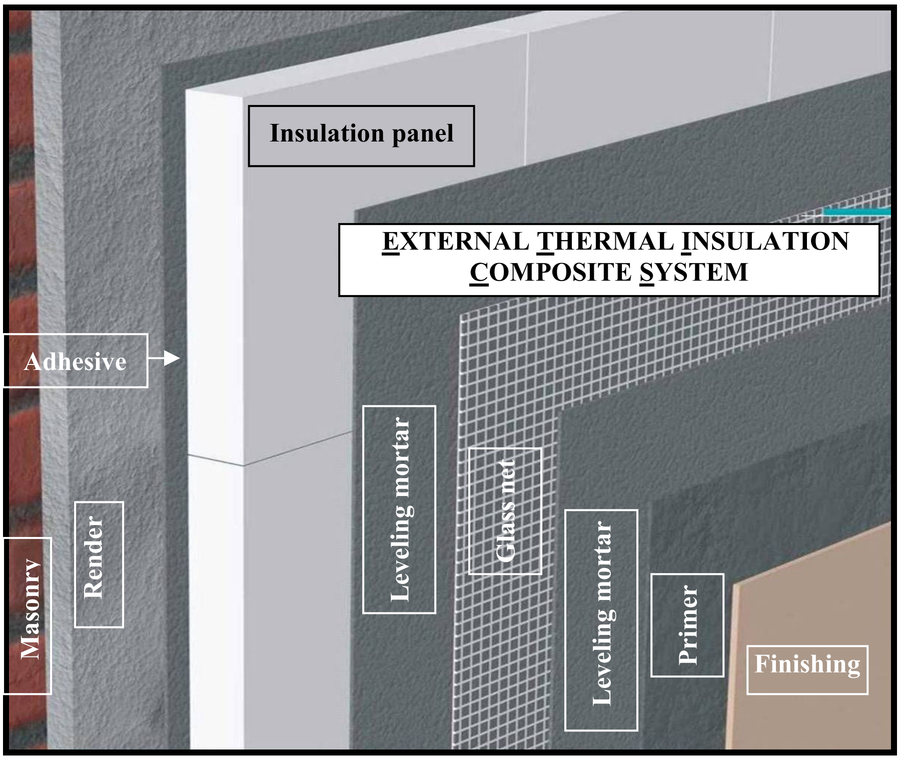

Figure 1: ETICS stratigraphy

Being ETICS a multi-component system, the compatibility among the components is a key factor in order to obtain the performances of the overall system as well as its durability

3. HEAT LOSSES

The heat losses through a wall delimiting the interior of a room maintained at 20°*C* by a heating system (with the external environment at -5°*C*) strongly depend on the insulation of the wall itself.

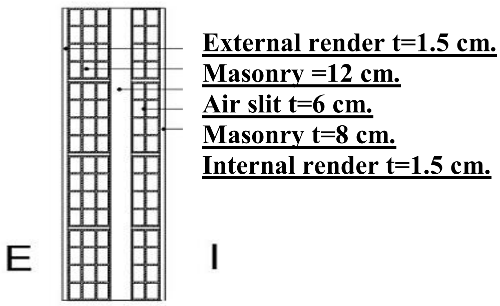

Figure 2: Wall stratigraphy

Considering a wall with the stratigraphy shown in Figure 2, which includes (from the exterior to the interior):

- An external render having a thickness of 1.5 *cm*.
- An external masonry having a thickness of 12 *cm*.
- An air slit having a thickness of 6 *cm*.
- An internal masonry having a thickness of 8 *cm*.
- An internal render having a thickness of 1, 5 *cm*.

the heat flux in the above-mentioned environmental conditions is 28 W/m^2.
The heat flux through the same wall with an ETICS applied to the external surface (with an insulation panel 8 *cm*. thick) will be reduced to 8 W/m^2.
In order to fully understand the reasons of such a great reduction, as well as the other positive effects related to the ETICS application, the mechanisms of heat transfer from the interior to the exterior will be summarized.

4. HEAT TRANSFER MECHANISMS

Every transport phenomenon observed in nature is associated to a driving force. In the case we are considering now, a heat transfer from the interior to the exterior is taking place and the driving force is the temperature difference.
We have to conceptually split the heat transfer in three steps:

- The heat flux from the internal environment to the internal surface of the wall φ_1
- The heat flux inside the wall φ_2
- The heat flux from the external surface of the wall to the external environment φ_3

In steady state condition :

$$\varphi_1 = \varphi_2 = \varphi_3 \qquad (1)$$

The heat flux φ_1 and φ_3 are determined by the mechanisms of natural convection and radiation occurring in the air nearby the wall, while the flux φ_2 is determined by the mechanism of heat conduction in the solid wall.
These mechanisms are well described in the technical literature [1] and suitable mathematical models, which correlate heat flux and temperature drop, are available.

a) NATURAL CONVECTION
SCHMIDT, BECKMANN, and POLHAUSEN have developed the model. The correlation between the contribution of natural convection to the heat flux φ^c and the temperature drop nearby the wall, for a wall having a height of 3 *m*., is reported in Figure 3.

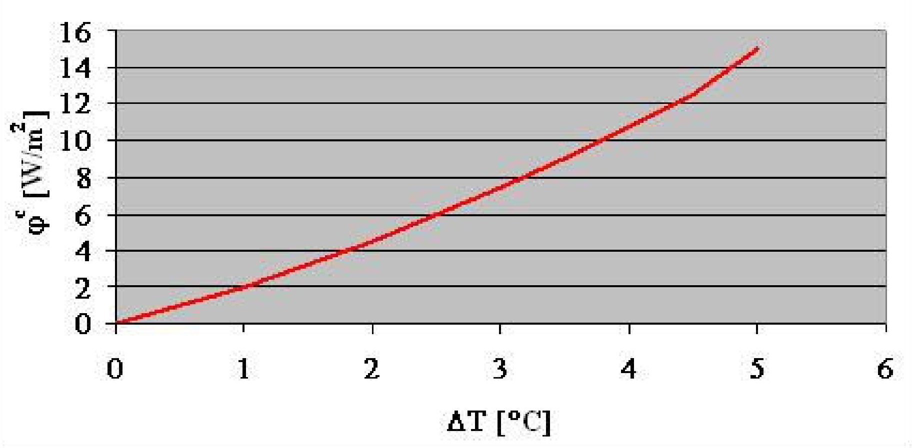

Figure 3: Heat convection flux vs. Temperature drop

b) HEAT RADIATION
STEFAN and BOLTZMANN have developed the model. The correlation between the contribution of radiation to the heat flux φ^r and the temperature drop nearby the wall is reported in Figure 4.

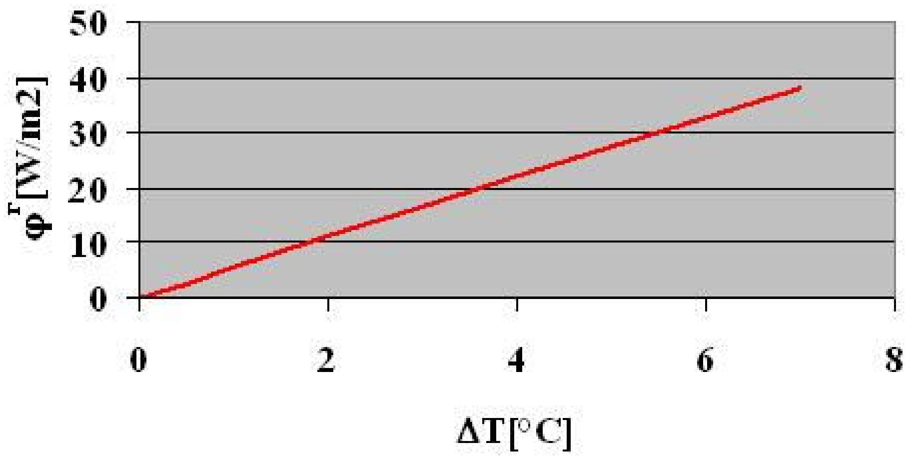

Figure 4: Heat radiation flux vs. Temperature drop

c) HEAT CONDUCTION
The heat conduction in a solid material is described by the FOURIER law, which states that the heat flux φ^h is proportional to the temperature decrease ΔT in the distance t between the surfaces of the solid:

$$\varphi^h = k_W \, \Delta T / t \qquad (2)$$

The constant of proportionality k_W is the thermal conductivity of the material.
In our specific case the wall is made up of layers of various materials (i.e. render, masonry and, as far as ETICS is concerned, leveling mortar, adhesive and insulation panel) each with its own characteristic thermal conductivity. In this case, the various resistances to heat transfer must be combined into a total resistance.

The above mentioned mathematical models of the heat transport can be applied and, by imposing the steady state condition

$$\varphi^c{}_1 + \varphi^r{}_1 = \varphi^h{}_2 = \varphi^c{}_3 + \varphi^r{}_3 \qquad (3)$$

the temperature distribution nearby and inside the wall are calculated, as well as the heat losses through the wall.
The temperature profile within and nearby a non-insulated wall (black line) is reported in Figure 5, in comparison with the profile (blue line) for a wall insulated with ETICS. The profiles have been determined considering the boundary conditions as follows:

- Internal room temperature: 20*°C*
- External temperature: -5*°C*
- Wall stratigraphy: as indicated in Figure 2
- Insulating panel thickness: 8 *cm*.

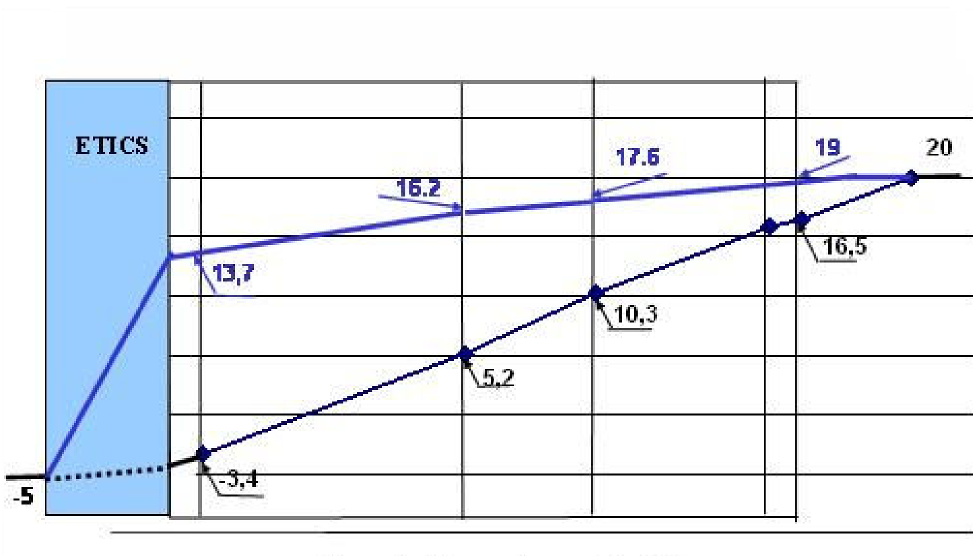

Figure 5: Temperature profiles (°C)

The corresponding heat losses, as already mentioned, are:

- Wall without any insulation: φ=28 W/m^2
- Wall with ETICS: φ=8 W/m^2

The temperature profile of the wall without any insulation has the following distinctive characteristics:

- The temperature of the external masonry is rather cool ranging from -3.4 to 5.2*°C*. The average value is 0.9 *°C*.
- The temperature of the internal masonry ranges from 10.3 to 16.5*°C*, with an average value of 13.4*°C*. There is 12*°C* difference in the average values of the temperature between the external and the internal masonries.
- The temperature of the internal surface of the wall is 16.5*°C*, 3.5*°C* less than the room temperature.

On the contrary, the temperature profile of the wall insulated with ETICS is characterized by:

- Warm temperature of the external masonry (average value of 15*°C*).
- Temperatures of the external and internal masonries close each other (3*°C* difference)
- Temperature of the internal surface of the wall close to the room temperature (1*°C* difference).

The application of ETICS has therefore four main effects:

- Avoids the vapor interstitial condensation
- Strongly reduces the stress of the building structure
- Improves the comfort
- Makes it possible a significant energy saving

5.VAPOR INTERSTITIAL CONDENSATION

Water condensation occurs where the partial pressure of water tends to exceed the saturation vapor pressure.
There is a vapor flow through the wall delimiting the internal environment (at a temperature of 20*°C* and 60% of relative humidity) from the external one (at a temperature of -5*°C* and 50% of relative humidity).
The driving force of the mass transport phenomenon [1] is the water partial pressure drop across the wall, the partial pressure in the interior environment being 1399 *Pa* while the partial pressure in the exterior environment is 224 *Pa*.
Even if the flow rate of vapor diffusing through the wall is very low and does not have any significant effect on the relative humidity of the interior, the phenomenon is to be taken into consideration in order to evaluate possible local conditions of water condensation within the wall.

The water partial pressure profile inside the wall without insulation is reported in Figure 6 (black line), as well as the saturation partial pressure (red line) for the above-mentioned environmental conditions. In the external masonry, the low temperature creates the condition for interstitial water condensation. The installation of the ETICS System removes such a condition because of the increasing of the masonry temperature and consequently of the local values of the saturation partial pressure.

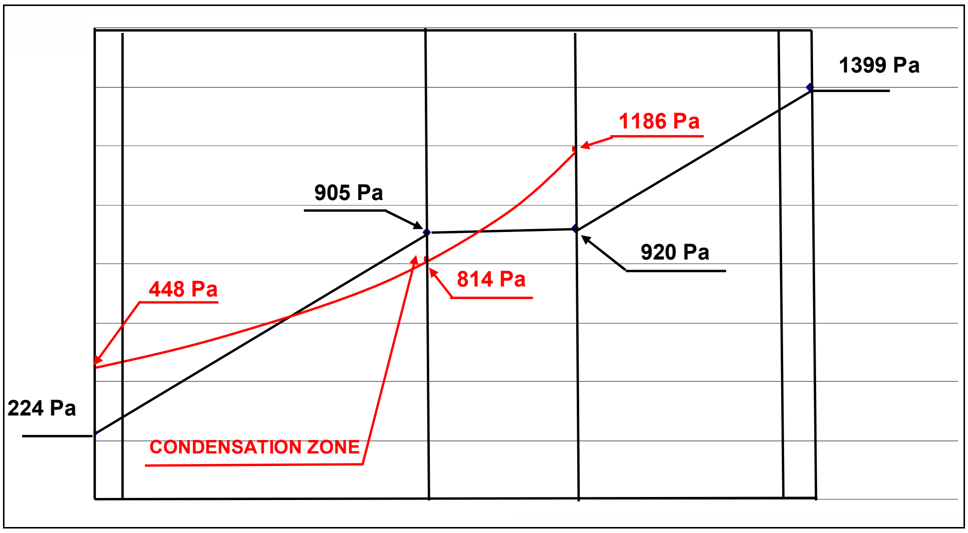

Figure 6: Water vapor pressure

6. STRESS OF THE BUILDING STRUCTURE

Any temperature difference between the external and the internal masonries causes stress in the structure[3]. The stress is due to the restrained differential shrinkage.
In other words, as, in the case of a wall without insulation, the average temperature of the external masonry is 12*°C* lower than the temperature of the internal masonry, you should observe a differential shrinkage of around 100 *μm/m*. between the two masonries.
Being the two masonries linked each other as part of the building structure, the differential shrinkage is restrained and the result is the generation of a tensile stress in the external masonry itself. The value of such a tensile stress is as high as 1.3 *MPa,* which can exceed the mortars resistance limit causing cracks in the mortar of the masonry.
The installation of the ETICS System reduces the temperature difference between the two masonries to 3*°C* and consequently the tensile stress is reduced to 0.34 *MPa,* far away from the mortars resistance limit. In this case, the stress is transferred into the ETICS System and in particular into the adhesive which links the insulation panel to the render of the external masonry. The adhesive must have suitable resistance to the shear, peel and pull-out stresses generated by the restrained differential thermal elongations/shrinkages of the insulation panel. More generally, the ETICS System must be properly designed and installed following the good practice rules recommended by the supplier.

7. COMFORT

The internal surface temperature value of a wall without insulation has been calculated in 16.5 °*C*, 3.5 °*C* lower than the room temperature.
This difference is quickly decreasing with the distance from the wall surface and within a few centimeters distance is becoming close to zero.
Is this temperature difference, even if restricted to a very limited zone nearby the wall, significant for the comfort?
The FANGER[2] model, based on the wellbeing feeling and the thermal balance of the human body gives you an answer.
According to the FANGER model, the heat loss of a human body performing sitting activities is 126*W*. The mechanisms of such a heat loss are respiration, perspiration, convection and radiation. While respiration, perspiration and convection are depending on the room temperature and are not affected by the wall temperature, the radiation is strongly dependent on the temperature difference between the room and the wall.
For a temperature difference of 3.5 °*C* like in the case of the wall without insulation, the heat loss by radiation (which is of 43*W*. for a temperature difference of 1 °*C*.) increases to 58*W*.; the thermoregulation system of the human body compensates this anomalous heat loss, but a cold feeling occurs giving you a sort of alarm.
As a conclusion, the room temperature corresponding to a wellbeing conditions is depending on the wall temperature also, as shown in Figure 7.

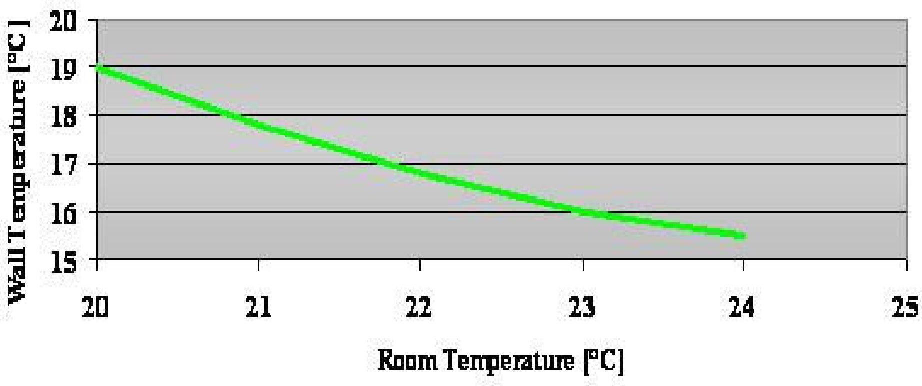

Figure 7: Wellbeing condition line

The installation of the ETICS System, increasing the wall temperature to 19°*C*, guarantees the optimal comfort conditions minimizing the energy consumption.
The FANGER model is not limited to the particular aspect of the balance between the wall temperature and the room temperature, but it takes into consideration a number of parameters:

a) ENVIRONMENTAL:
   - air temperature
   - relative humidity
   - air velocity
   - radiant average temperature.

b) PERSONAL CONDITION:
   - level of activity
   - clothes

Based on the above-mentioned parameters, the model is suitable to define wellbeing maps.

8. ENERGY SAVING

The installation of the ETICS System strongly reduces the heat losses through the peripheral walls of the building. The heat flux of 28 W/m^2 is cut to 8 W/m^2 as already mentioned.
The dramatic reduction of the heat losses trough the peripheral walls of the building has the positive effect of a significant energy saving, both for the heating in the winter season and air conditioning in the summer season.
A reduction of the energy consumption of 25-35% has been proved in a very large number of cases. Part of the energy saving is due to the opportunity of switching-off the heating/cooling system during the night; the low heat loss granted by the ETICS System offers this opportunity maintaining the comfort conditions as shown in Figure 8.

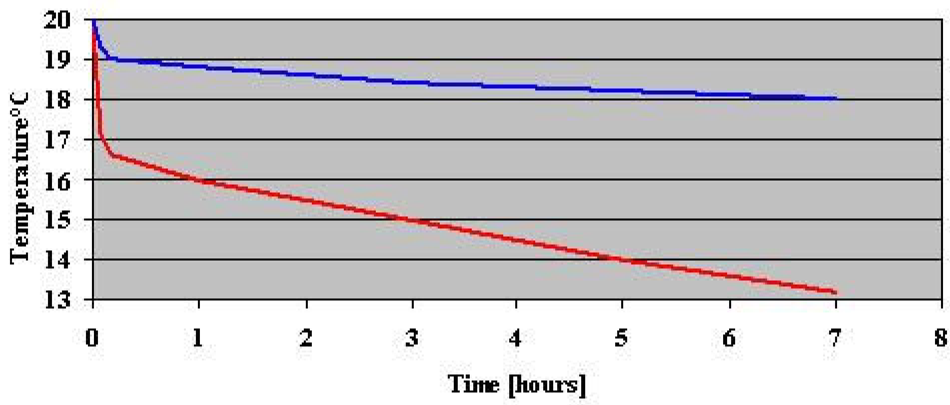

Figure 8: Transient behavior

The red line shows the decrease of the room temperature with time after the heating system switching-off in the case of wall without insulation. The blue line shows the room temperature decrease in the case of the presence of ETICS. The comfort conditions are maintained for the nighttimes in the second case only,

9. CONCLUSIONS

a) The analysis of the temperature profiles inside the wall points out that the building structure, in the case of absence of insulation, is subject to stress and to interstitial vapor condensation conditions; both of these phenomena are very dangerous and can cause important damages to the structure itself. The installation of the ETICS System removes such a dangerous conditions.

b) The application of the FANGER model, based on the thermal balance of a human organism, shows how the wellbeing conditions are correlated to the temperature profiles nearby the wall. The presence of the ETICS System grants the optimal balance between the room temperature and the wall temperature minimizing the energy consumption.

c) The dramatic reduction of the heat losses of the building through the peripheral walls obtained by the installation of the ETICS System allows significant energy savings during both winter and summer seasons. The analysis of the transient behavior of the room temperature after the heating system switching-off shows that only the presence of the ETICS System can grant comfortable conditions for a sufficiently long period.

The results of the analysis, carried out in this paper, clearly show the added value of the ETICS System:

- Comfort due to the optimal room and wall temperature conditions and their persistence after the heating system switching off.
- Preservation of the building structure due to the strong reduction of the stress conditions and to the elimination of the interstitial vapor condensation phenomena.
- Energy consumption reduction, both for heating during winter and air conditioning during summer. The saving is evaluated in the order of 30%.
- Reduced emissions of green-house gases, in agreement with the new European environmental standards

The above-mentioned advantages, not limited to the energy saving, make the investment related to the ETICS System installation attractive from the economic and financial point of view.

10. REFERENCES

[1] Bird R.B., Stewart W.E., Lightfoot E.N. (1962) Transport Phenomena. New York-London: John Wiley &Sons Inc.
[2] Fanger PO. (1982) Thermal comfort, analysis and applications in environmental engineering. Florida: Robert E. Kreiger Publishing Co.
[3] Gambarotta L, Nunziante L, Tralli A. (2003) Scienza delle costruzioni. Milano: McGraw-Hill Co.