Discrepancies between indications deriving from energy and economic issues in the design of building thermal insulation

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ABSTRACT
Decisions in the first stage of the design process have to respond to often discordant requirements of quantitative reliability and operational effectiveness and have to be pursued with a systemic, environmental approach. One of the most typical cases in which the necessities of balance between distinct objectives and adoption of a systemic vision become more evident is that of the rehabilitation of building envelopes, which requires a complex kind of evaluation between costs and benefits. In the following text the criteria adopted in the design choices aimed at the recovery of a building to be converted to school in Milan will be described and some considerations will be made about the contradictions that have been identified between indications deriving from considerations regarding thermal energy and economic costs.

1. GENERAL CONSIDERATIONS ABOUT THE RECOVERY OF BUILDING ENVELOPES

The design aimed at the rehabilitation of building envelopes is a complex operation, because the factors that have an influence over it are numerous and interdependent. Those factors regard space, economy (deriving from the costs of both products and their installation), comfort levels (mainly about temperature and humidity), energy (dependent from both the influence of thermal insulation on energy consumption and the energy embodied in thermal insulation) and environmental compatibility, dependent from the availability or renewability of resources from which the objects are produced and from the ecocompatibility of productive processes.

For each existing situation is possible to define optimal solutions of thermal insulation for building envelopes in material and thickness. An essential condition to design and size the layers of thermal insulation is that integrated estimations are drawn both at the qualitative and quantitative level. This can be done when the factors in question can be analysed in one same matrix, therefore using homogeneous data, of the same or compatible kind. This cannot be done for every factor quoted above, but only for some of them, due to their qualitative heterogeneity and to their consequently scarce comparability (particularly between groups of factors profoundly different, for instance economic and environmental ones). For this motive, presently these factors have to be analysed by the means of more than one distinct matrix, more or less complex.

The importance of the economic factor is fundamental in a matrix aimed at supporting design decisions, because the effect of each of the other factors to be taken into account can be quantified in economic terms. A second factor that should reasonably be included in a decisional matrix is of the environmental kind. But about the factors of the environmental kind, even just for those quoted above (for instance, factors regarding thermal comfort and factors regarding energy consumption) the problem arises that it doesn’t exist a handy parameter suited to measure their environmental effects in one same scale of values.

One of the parameters today more widely acknowledged, understood and used, transversal to many disciplinary fields, is that of energy embodied in materials and products. The main reasons for that lies in the facts that the amount of energy used to produce a material and/or an object is approximately proportional to the amount of carbon dioxide produced in the operation, and that carbon dioxide is one of the substances whose overproduction has to be considered more deleterious for the ecosystemic equilibria of the earth, as the main cause of the greenhouse effect.

Some advantages of the use of embodied energy as an environmental parameter are due to its quantitative nature and to its computability. Thanks to these facts, embodied energy may be used with reasonable approximation as a meaningful parameter for the evaluation of the relation between environmental costs and benefits, in much the same way money is used as the main parameter for the evaluation of the relation between economic costs and benefits.

With regard to building envelope insulation, the economic costs and the environmental costs implied by the use of a certain width of a certain thermal insulation material on a certain wall of a certain building are potentially usable for the creation of multi-dimensional matrices for the evaluation of different design options, aimed at the choice of the most advantageous – advantageous in the whole, integrated meaning of the word: environmental and economic – solutions of thermal insulation to be adopted in particular design situations.

2. SPECIFICITIES OF THE CASE STUDY

In the project for the recovery of the building "ex-Convitto" in the Trotter Park[1] in Milan, criteria of choice of a solution for the recovery of the building envelope have been adopted aimed to allow that the increase of its thermal resistance would be advantageous in the whole, integrated sense of the term. With this goal, different kinds of thermal insulation, different positions of the thermal insulation layer with respect to the wall, and different wall stratifications have been taken into account; and for each design solution the following points have been considered (at a qualitative, quantitative or whole, integrated level, depending from the case): embodied energy costs, effects on energy and economic costs for heating, effects on investment costs, hygrothermal conditions that would be obtained in winter inside the rooms, hygrothermal conditions that would be obtained in summer with no active cooling strategies[2].

The evaluation of the energy consequences of each design solution has been carried out through thermal simulations made with Enerwin[3], an energy tool that has been chosen considering that: a) it was well suited to the design process in the early stages; b) it was capable of evaluating both the energy consumption of the building for heating and cooling and the hygrothermal conditions of its rooms in a situation of free floating temperatures; c) no indirect gain was planned in the design hypotheses; d) the levels of precision required from the simulation was much less an issue than the speed of simulation and the speed of creation and modification of the virtual model.

The object of the thermal simulations has been a representative, significant and repetitive part of the building in question (which was constituted by blocks distinct from the point of view of volume, quite similar from the point of view of materials, and of considerable extension).

The walls of the building in the original configuration were constituted by masonry walls about 38 cm thick, that, although able to give to the building an appreciable thermal inertia, were characterized by too a low thermal resistance to derive from them satisfactorily low winter energy consumptions and above all satisfactory summer comfort levels. The most advantageous design solution from the thermal point of view would have been to apply an additional insulating layer to their outer face; but that solution could not be adopted for all the envelope walls, only for some of them: one of the two main elevations of the building, that of the façade looking to the Park, for historical-artistic reasons wasn't indeed aesthetically modifiable.

The chosen solution has constituted a conscious compromise between the necessity of

[1] The author has participated to it as a consultant with regard to energy saving and thermal comfort.

[2] The evaluation was aimed to an early stage design, so the parameters have been chosen on the basis of meaningfulness. In an evaluation aimed at a final stage design, a higher number of parameters would have been taken into account. Among them, is the cost of plants.

[3] Produced from Prof. Larry Degelman of the Texas A&M University.

preserving the thermal inertia of the building and the necessity of increasing its thermal insulation, even at the expenses of thermal inertia: their main features are an insulating layer on the internal face of the facade to be aesthetically preserved and an insulating layer in the inner face of the other façade (solutions implying, approximately, an halving of the thermal inertia produced by the two main facades, accepted in order to increase the thermal insulation of both of them)[4].

This compromise has been estimated advantageous for mainly to reasons: a) the thermal inertia of the building would have been sufficient for the purposes of passive heating and cooling, being produced also by the bearing masonry walls orthogonal to the facades and by the floors of the second level of the building, built in reinforced concrete and hollow brick tiles; b) the destination of the building: school. Adequately for this destination, a small decrease of thermal inertia in winter would make possible to heat the building earlier in the morning, and the greater and quicker decrease of temperature that would take place during nights would not produce significant disadvantages for the users (considering, obviously, their absence from the building in those hours).

The material adopted for the thermal insulation of the walls has been cork aggregate in panels, chosen for its ecocompatibility, for its low hygroscopicity (that makes it well suited for the use in the external face of the facade walls) and for its low vapour permeability, which, in the case of application on the internal face of the façade walls, prevents the risk of condensation of water vapour inside the walls even in unfavourable winter conditions (Bynum, 2000; Oliva, 2001-02; Strother and Turner, 1990).

3. CONSIDERATIONS ABOUT THE COSTS/BENEFITS RELATION RELATIVE TO ALTERNATIVE INSULATION SOLUTIONS

In the following part of the text the suitability of alternative insulation solutions adoptable in the project will be verified, and this will be made on the basis of a combined evaluation of their economic convenience and their energy convenience (comparing the convenience of different materials and different thicknesses of the insulating layers); and this evaluation will be made with simplified criteria, consistent with the nature of the project, which was indeed an early stage project, a masterplan.

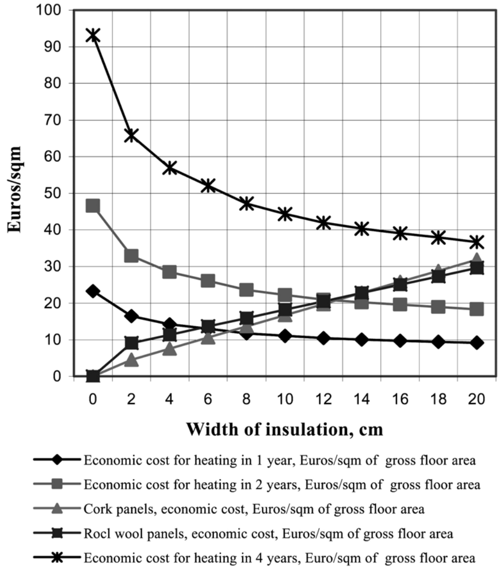

Figure 1: Economic costs for heating in 1, 2, 4 years and economic investment costs of the two insulation solutions, relative to increasing widths of the insulation layer.

As one of the insulating products alternative to cork panels, rock wools panels had been chosen, that may be characterized by a conductivity similar to that of the cork panels. For the specific aim of this study, the conductivity hypotesized for both materials has indeed been the same, 0.045 W/m^2°K, because that made possible to focus with great clarity and simplicity on the energy embodied in the panels as one of the two decisional factors to be evaluated[5].

In Figure 1 the economic costs (in Euros/m^2 of gross floor surface, inclusive of construction costs) relative to various widths of cork and rock wool are shown, together with the eco-

[4] In the simulations, the thermal conductance of the roof has been kept constant to about 0,25 W/m2°K and the thermal conductance of the basement floor has been kept constant to about 0,5 W/m2°K.

[5] Panels in mineral wools characterised by a lower thermal conductivity do obviously exist, but the choice that has been taken made possible to stress with great evidence the relative incidence of width and embodied energy on the convenience of each solutions.

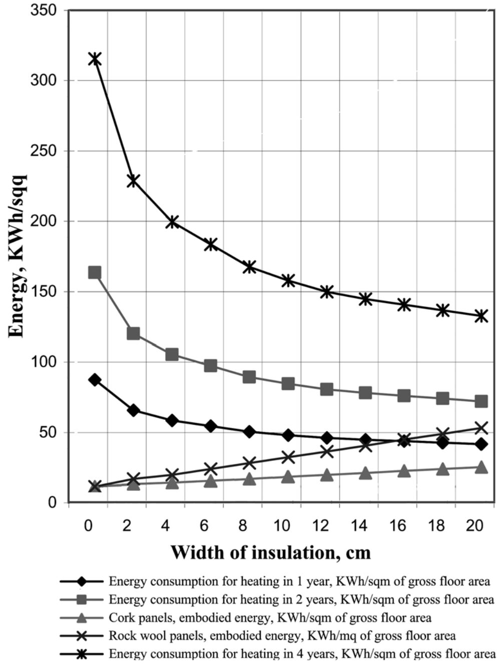

Figure 2: Energy costs for heating in 1, 2, 4 years and energy investment costs of the two insulation solutions, relative to increasing widths of the insulation layer.

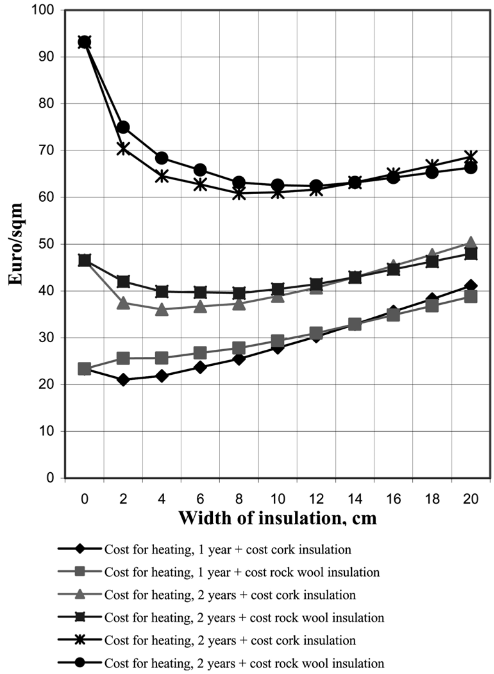

Figure 3: Combined economic costs for heating in 1, 2, 4 years added to the economic investment costs of the two insulation solutions, relative to increasing widths of the insulation layer.

nomic costs for building heating (always in Euros/m^2 of gross floor area) calculated with regard to 1, 2 and 4 years of use relative to increasing widths of insulation.

As widely known, and may be clearly seen in Figure 1, the economic cost of an ordinary thermal insulation layer increases proportionally to its width[6], while the economic expense for heating decreases more and more slowly when the width of the insulation increases, as suggested by the law of decreasing return[7].

In Figure 2 both the levels of energy embodied in different widths of cork and mineral wool (in KWh/m^{2}y of gross floor area) and the levels of energy consumption (again, in KWh/m^{2}y of gross floor area) in 1, 2 e 4 years of use are shown, relative to the same widths of insulation. Similarly to what happened in Figure 1, the level of embodied energy in the insulation layer increases proportionally to the width of the layer, while the energy saving decrease is slower and slower when the width of the layer increases.

Figure 3 shows the economic investment costs of thermal insulation added to the economic costs for heating relative to 1, 2 e 4 years of building use. With regard to a time length of 4 years, the "whole" economic convenience of the intervention (taking into account the combined costs of insulation and fuel) reaches a peak – corresponding to the minimum of the curve – for a width of 8 cm of cork and 12 cm of mineral wool; with regard to a time length of 2 years, it reaches a maximum for a width of 4 cm of cork and 4-8 cm of mineral wool; with regard to a time length of one year, the total costs of the considered insulation solutions keeps growing with width, due to the fact that this time length is too short to reach an economic gain.

Figure 4 shows the energy investment costs

[6] There are in truth small discrepancies from this proportionality, due to market factors.

[7] That, being an economic law, can also be applied to a great deal of cases concerning technical choices in the building field, showing to be valid even in situations that have no economic implications.

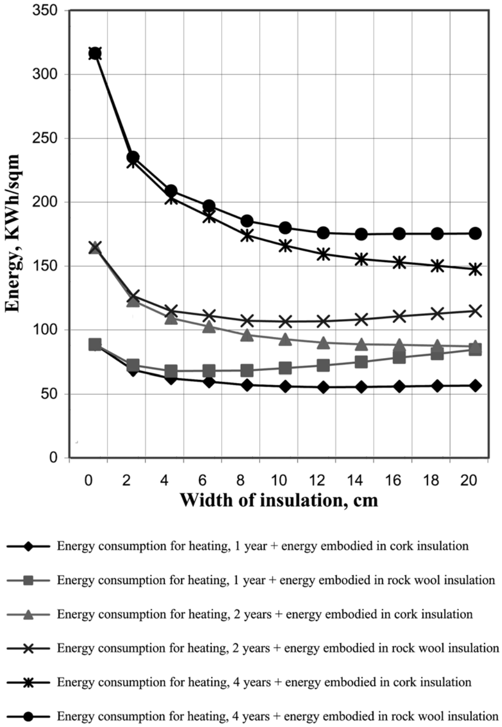

Figure 4: Combined energy costs for heating in 1, 2, 4 years added to the energy investment costs of the two insulation solutions, relative to increasing widths of the insulation layer.

of thermal insulation added to the energy costs for heating in 1, 2 e 4 years of building use. With regard to the time length of 1 year, energy convenience, considering the combined costs of insulation and fuel, reaches a maximum for a width of about 12 cm of cork (with small differences for widths between 10 and 16 cm) and about 4 cm of mineral wool. With regard to the time length of 2 years, the "whole" energy cost produced by the cork insulation layer keeps decreasing with its width (that is, its convenience keeps growing): which means that with regards to it, 2 years constitute a time length more than sufficient to obtain an energy convenience; while the whole energy cost produced by the mineral wool insulation reaches a minimum around 12 cm. With regard to a period of 4 years, the whole energy cost relative to cork obviously keeps decreasing with width, while that relative to mineral wool reaches a stable level around 12-14 cm.

Combining the information given by the data shown above, it may be noted that in one of the two technical hypotheses taken into consideration – that of the panel of mineral wool – a similar optimal thickness do is found with respect to the two considered viewpoints, the economic one and the energy one: relative to an expected time length of return of 2 years, a width of 4-6 cm would be optimal both from an energy and an economic point of view; and relative to an expected time length of return of 4 years, a width of about 12 cm would be optimal from both viewpoints. In the case of cork, on the contrary, it is not possible to define a single optimal value common to the two criteria of analysis: a discrepancy is indeed found between the indication of optimal width generated by the energy considerations and those generated by economic considerations; and this is true both for a return period of 2 years and 4 years. With regard to a return period of 2 years, from an economic point of view, the optimal insulation width would be 4 cm, while the energy convenience of this solution would keep increasing with width; and with regard to a return period of 4 years, the optimal insulation width would be 8 years, and the energy convenience would always keep increasing with width.

In the case of cork, for the building in question, a clear point of coexistence of the advantages relative to energy considerations and to economic considerations cannot be found. This situation is true for a great deal of building situations and with regard to a great deal of types of insulation. Very seemingly, all situations in which it is necessary that solutions of compromise are adopted balancing environmental considerations and economic considerations.

But what the criteria of this compromise should be is not easily defined.

The considered time length of return on investment is fundamental for the calculation of the whole convenience of an intervention of building envelope thermal insulation. But this parameter varies dependently from considerations that are not always of a technical kind, and sometimes aren't even of an economic kind. In the case of building renovations made by public administrations, for instance, an ambiguity of objectives can often be found, due to a contradiction between the electoral necessity of quickly obtaining appreciable results, and the possibility of planning operations on the building stock on time length longer than those generally characterising the expectations of private actors.

4. CONCLUSIONS

As said, situations in which energy considerations and economic considerations give diverging indications in the design of insulation solutions are rather common. For the architectural designer, those discrepancies produce the necessity of counting on simplified and efficient criteria for an integrated treatment of the information regarding energy matters and economic matters (Brunetti, 2005). What can be the most advantageous strategies to deal in a homogeneous manner with data of the economic and the energy kind in a decisional process for the early stages design? What criteria can be used in order to make one type of information reasonably convertible in the other, so to reach the possibility of gaining an integrated acknowledgement of the consequences produces by different design hypotheses? Converting the energy costs in economic costs, taking into account the energy expenditures in the production phase of each product? Converting the economic costs in environmental costs, proportionally to the increase of entropy that can be estimated being meanly implied by a rise of the economic investment put in the economic circuit? Both hypotheses have the vantage of simplicity, but none of the two appears to be wholly satisfying.

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