

Energetic Rehabilitation in Buildings: Cost-Effective Solutions to Minimise Thermal Bridging

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Nowadays, the energetic rehabilitation of buildings constitutes an increasing concern of national and international bodies, as a result of a strategic policy towards energy efficiency. In Portugal, one of the most current problems in buildings is thermal bridging. This is a significant source of heat building loss. The prevention of these types of pathologies is essential, for there are an enormous number of existing buildings that reveal such problems and therefore require rehabilitation. New building regulations on thermal behaviour and energy efficiency were recently enacted by the Portuguese Government, following the European Union Directive 2002/91/CE. To cope with the prescriptions of the new regulations, a better thermal quality in the building envelope is required. The rehabilitation of buildings is becoming a great issue.

This study is part of wider research to investigate cost-effective constructive solutions of rehabilitation for the improvement of envelope thermal behaviour.

From the results of previous studies which characterized the most current and problematic envelope zones, a simulation computer program was used to test the behaviour of several different solutions in order to minimise pathologies caused by thermal bridging.

Preliminary results show that it is possible to get adequate solutions that fit harmoniously with the architecture of façades and with decoration of the internal spaces. Further studies will be needed to provide construction designers and builders with appropriate solutions to make the rehabilitation process even easier.

Keywords: energy efficiency, rehabilitation, thermal bridge, Portugal.

INTRODUCTION

The European Union Directive 2002/91/CE prescribes that all member States of the European Union have to implement a national system for energetic certification of buildings in order to inform citizens about building thermal quality. Following this directive, the Portuguese Government recently put into force (INCM, 2006-a; INCM, 2006-b) the *National System for Energetic Certification and Air Quality*. These regulations, though in a phasing out process, are applied to new buildings and building rehabilitations that represent more than 25% of the building value excluding the value of land. Furthermore, in order to deal in the property market regarding sale, leasing and renting activities, an owner/promoter needs to get a certificate of the building.

The underlying provisions of the EU Directive are in line with the energy efficiency policies and programmes that have been devised or implemented in most Western European countries. However, it seems that in some countries there is a lack of an integrated framework for energy efficient construction and rehabilitation (Scrase, 2001). With respect to the building sector, it has long been recognised (the German *Institut fur Wohnen and Umwelt*, 1990, cited in Kohler and Hassler, 2002) that the

important issue concerning both (primary) energy and air pollution (green house effect) is the refurbishment of existing buildings.

A recent Government document (INCM; 2005) pointed out that the increase in energy consumption in the building sector over the last two decades is higher than the average of the economy. Thus the thermal rehabilitation of the building envelope is certainly becoming an important issue to the building market in coping with new regulations concerning thermal efficiency.

Thermal bridges represent an additional increase of 10-15% in heat losses by building envelopes (Corvacho, 1996). Thermal bridges are envelope building zones where, due to geometry or the existence of constructive materials with high U-values, the heat of the indoor environment finds an easy path to get through to the outside environment. The most current situations are the junctions between different constructive elements.

Another consequence of thermal bridges is the cooling of the inner surfaces on those zones, resulting in higher condensations and the growth of moulds, creating poor air quality conditions. Figure 1 illustrates the heat flow lines and the isothermals on the corner between two exterior walls. We can identify in Figure 1 the increase of the number of heat flow lines and the reduction of the temperature near the junction, relative to the current zone.

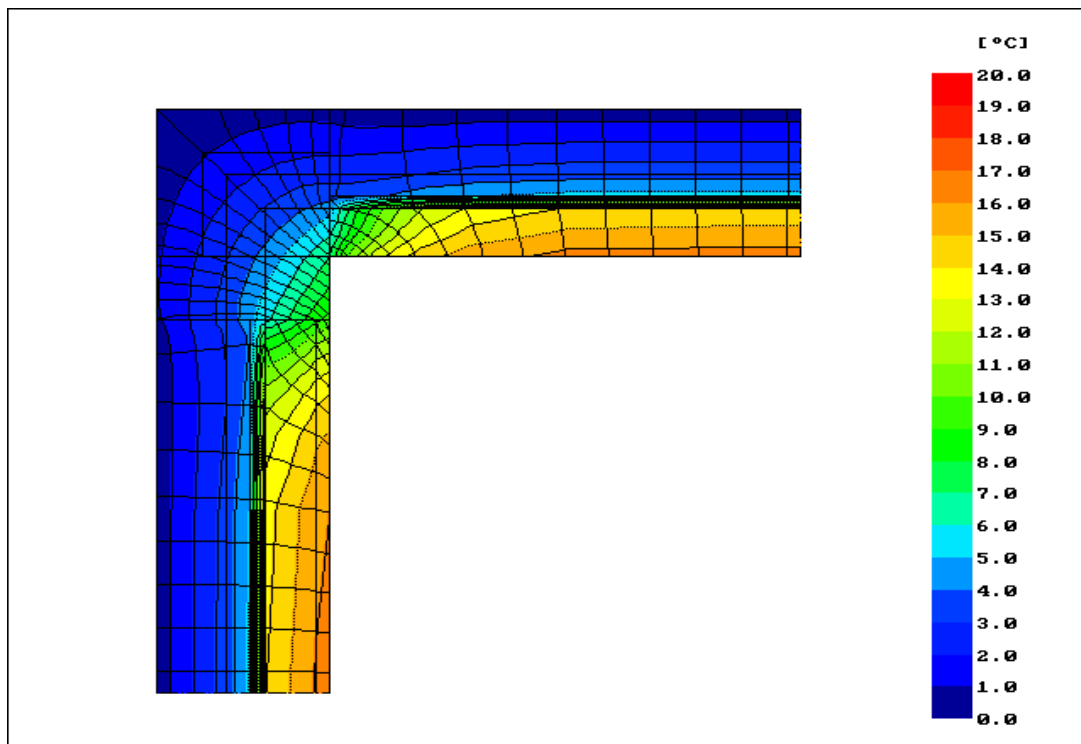


Fig. 1: Heat flow lines and isothermals in a junction between two vertical walls.

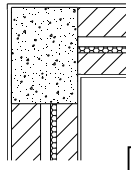
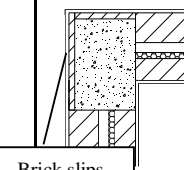
In Portugal, the most current system façade is a cavity insulated masonry wall (partial fill cavity), framed by a concrete structure. The thermal bridges arise in the tops of masonry just in the junctions to the concrete structure and around windows and door openings. But there are also problematic thermal bridges when internal insulation systems are applied. In a study dealing with the thermal behaviour of buildings in

Portugal, Corvacho (1996) pointed out the most problematic zones of the building envelope. They depend on the thermal conductivity of the construction materials, on the constructive system and on the type of thermal isolation used. In most cases, the worse situations are those that present greater heterogeneities of materials and big changes of the geometry of the elements. The junctions between two different exterior elements with large changes in geometry are the most critical zones. The contour of windows and doors (sills and reveals) is also a problematic zone.

THERMAL AND CONSTRUCTIVE PERFORMANCE OF THERMAL BRIDGES ZONES

In order to try to solve the thermal bridges problem, it became usual in Portugal to use brick coverings (brick slips) in the structural elements by the outside or the inside surface.

As an example, Table 1 presents results of a numerical simulation of a wall corner, without and with brick covering, where it can be observed that the improvement in the thermal behaviour introduced by these solutions is limited. Thus, there are no real thermal advantages in the placement of solutions by the outside of the concrete structure (Corvacho, 1996).

Construction Detail		Incremental thermal loss coefficient (W/m °C)	
Without Brick Covering	With Brick Covering	Without Brick Covering	With Brick Covering
	 Brick slips	0,499	0,453
Increment on total envelope thermal loss		0,499 x L	0,453 x L

L - Length of junction (m)

Table 1: Comparison of the increase of thermal losses in a wall corner with a column in relation to envelope current losses, without and with brick covering, for an internal temperature of 20 °C and an outside temperature of 10 °C (Corvacho, 1996).

These solutions have also been responsible for the following constructive pathologies:

- Insufficient support of the outer leaf of the cavity wall (Fig 2).
- Increasing the effects of deformations of the masonries (non-structural cracking, detachments renderings, etc.).
- Instability and even collapse of the outer leaf masonry (Fig 2).



Fig 2: Deficient brick covering on the edge of a beam creating insufficient width support of the exterior leaf and the collapse of an outer leaf.

From the above, it can reasonably be assumed that the problems caused by thermal bridges need to be dealt with in a more comprehensive manner. In some cases the ensuing rehabilitation works must go forward to an intervention even more complete because those zones can show other defects. Sometimes these defects result from previous deficient solutions to solve the problem.

REHABILITATION STRATEGIES

As previously mentioned, all the rehabilitation solutions that have been analysed in the ongoing study are simulated by a bi-dimensional computer program to evaluate their thermal performances – heat flow and internal surface temperatures.

The parameter habitually utilized to evaluate the risk of surface condensations and for which a value limit will be established is the *surface temperature factor* (τ), which is a factor defined by the following formula (Corvacho, 1996):

$$\tau = \frac{t_i - t_{si}}{t_i - t_e}$$

t_i – Internal temperature (°C)

t_{si} – Inner surface temperature, where the τ (°C) will be calculated

t_e – External temperature (°C)

This characterizes a given constructive solution and allows the minimum internal surface temperature for a determined t_e e t_i to be known. The generic limit value normally adopted for good quality solutions is 0,35, but many authors point to a value between 0,25 and 0,50, considering some other factors (for example, good indoor ventilation).

These solutions are for punctual interventions in the envelope. The actions of rehabilitation were classified as thermal rehabilitation and constructive rehabilitation. By thermal rehabilitation we mean the action of finding a solution to minimise the occurrence of thermal bridging (excess of thermal losses, surface condensations and the growth of moulds) and improving the thermal behaviour of these zones. The constructive rehabilitation has the goal of solving existing constructive anomalies (instability, cracking, moisture expansion, disruption of brick slips) in those zones. In as far as constructive rehabilitation is concerned, it should be noted that the thermal bridges are located especially in the junctions between different constructive elements of the envelope that are most often points where there are localised tensions and where it is necessary to ensure mechanical performance. Therefore it

will sometimes be necessary to devise actions that offer an answer to the thermal problem and, simultaneously, to the mechanical or constructive problem.

In the case of building rehabilitation, it is important to take into account the existing constructive solution. This requires two different forms of actions: keeping the existing solution and increasing additional elements, or replacing some of the existing ones. Keeping the existing solution implies an easier rehabilitation and is usually more cost-effective than its replacement. Both options can be responsible for some important changes on the geometry of the façades, but they can also be solved with new aesthetical façade solutions. The replacement of elements implies a deeper intervention, with demolition and subsequent reconstruction.

All the solutions adopted follow one of these guiding rules: locally increasing the thermal resistance; modification of the inner surface geometry; or minimisation of the thermal insulation interruption.

The thermal solutions proposed can be carried out by the outer or the inner surface. The former implies some modification on the aspect of the façade. The internal rehabilitation can be carried out by the owner/occupier if they want to improve the thermal performance. This option can reduce the indoor space area and modify the aspect of the inner surfaces.

There are two points that are essential to define: the thickness of the thermal insulation to be applied to reinforce thermal resistance should not be in excess as this can introduce more discontinuity, but neither should it be very reduced in order to achieve effectiveness. The study recommends a thickness of around 30 - 40 mm in the majority of cases. This study also concludes that the solution carried out with thermal insulation reinforced by the outside needs a thickness higher than the interventions by the inner surface. Another important question relates to the area of rehabilitating a thermal bridge. An additional and sufficient extending area is needed beyond the thermal bridge influence zone which depends on the type of thermal bridge. An intervention that does take into account this aspect could result in the transference of the thermal bridge to the zone immediately after the end of the rehabilitation zone.

Preliminary results of the study show that it is possible to improve the thermal performance on those zones, guaranteeing less heat losses and condensations.

In walls with block slips by the outer surface, it may be necessary to take into account the stability of the wall. The instability of walls is becoming frequent in many building reconstructions. One solution is the introduction of an additional support at each floor level (for example, a shelf angle), fixed at the edge of slabs or beams. Another complementary solution is the introduction of wall ties between the two leaves to reinforce stability.

The same brick slips can be maintained as an architectural restriction to keep the same aspect of the façade; for example, with brick clay masonry. This solution should be accompanied by some essential operations:

- They must be fixed to the structure with the application of a high adhesion fixing system (for example, polyester and epoxy resins) or by a mechanical method with ties.
- They must be separate from the current masonry with movement joints - vertical or horizontal.

If opting for the replacement of brick slips by other types of constructive elements, these must be the object of a detailed set of actions to ensure the stability of the outer leaves.

EXAMPLES OF REHABILITATION SOLUTIONS IN ZONES OF THERMAL BRIDGES

Presented below are some simple constructive rehabilitation solutions that showed, through numerical simulation, good performance results. We see, for example, the junction between two exterior walls (Figures 3, 4, 5).

JUNCTION BETWEEN TWO EXTERIOR WALLS

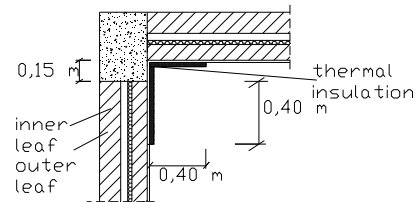
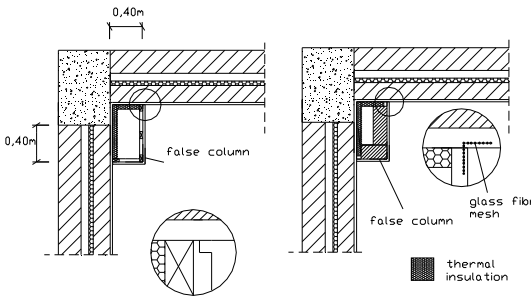
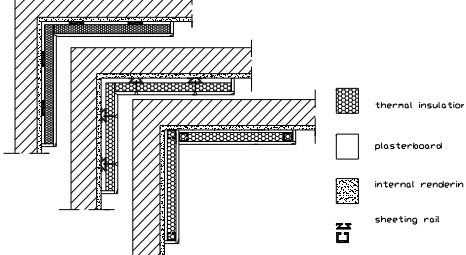

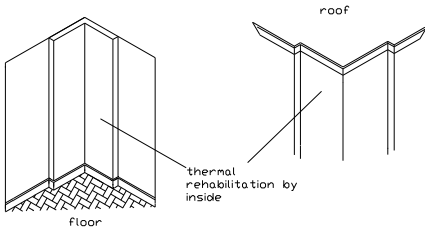
<p>REHABILITATION BY THE INNER SURFACE- Junction between two exterior walls</p> <p>Could be associated with an outer constructive rehabilitation</p>		
<p>Rehabilitation Solution:</p>	 <p>surface temperature factor $\tau = 0,30$</p>	
<p>Guidelines:</p> <ul style="list-style-type: none"> - increase locally the thermal resistance - minimize the thermal insulation interruption 		
<p>Construction Details</p>		
<p>Thermal Insulation Thickness = 0,03 -0,04 m</p> 	<p>Thermal Insulation Thickness = 0,03 / 0,04 m</p> 	<p>Detail of the punctual thermal rehabilitation with dry-lining or plasterboard panels with vapour control layer</p>
<p>Final aspect</p>	 	

Fig. 3: Thermal rehabilitation by the outer surface in the junction between two external walls.

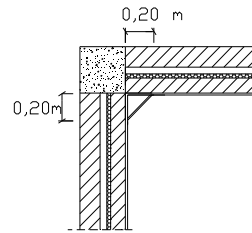
REHABILITATION BY THE INNER SURFACE - Junction between two exterior walls

Could be associated with an outer constructive rehabilitation

Rehabilitation Solution:

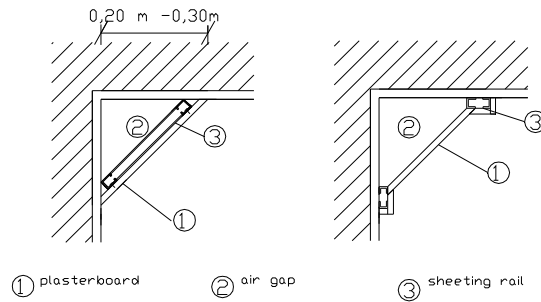
Guidelines:

- modification of the inner surface geometry



surface temperature factor $\tau = 0,29$

Construction Details



Final aspect



Fig. 4: Thermal rehabilitation by the inside surface in the zone of junction between two exterior walls.

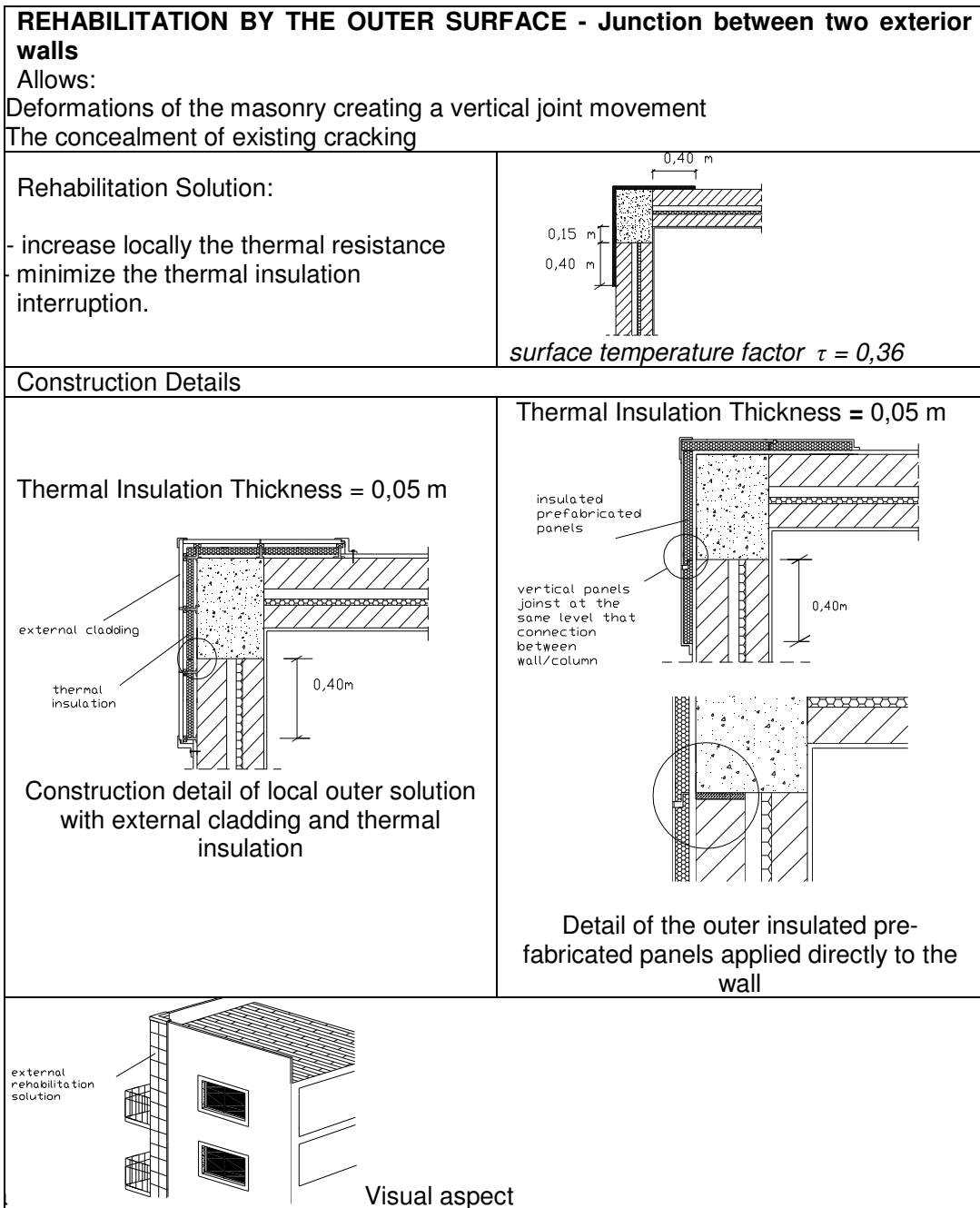


Fig 5: Thermal rehabilitation in the outer surface in the junction between two external walls.

JUNCTION BETWEEN AN EXTERIOR WALL AND A ROOF SLAB

Another example is the junction of an external wall with a roof slab, where both thermal and constructive rehabilitation are sometimes required. Figure 6 illustrates the case of the maintenance of brick covering, while Figure 7 shows the solution that proceeds to its demolition.

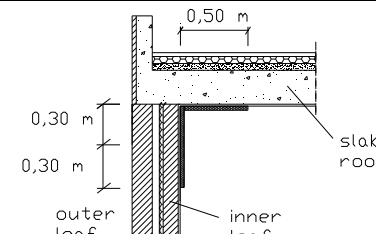
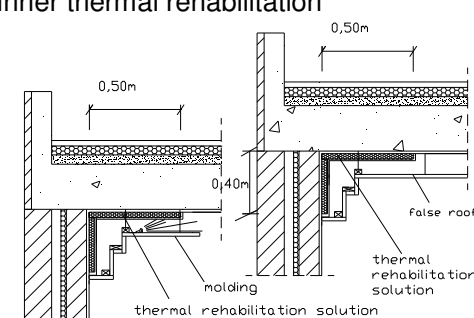
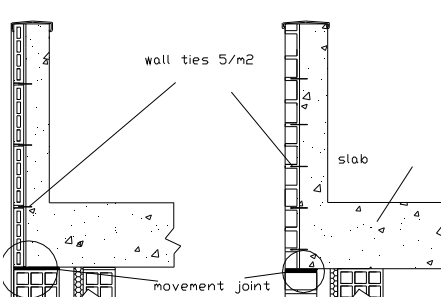
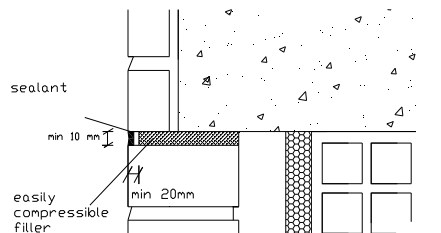
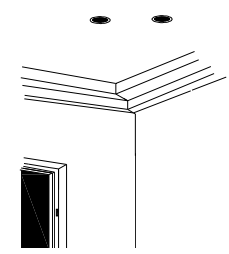
REHABILITATION BY THE INNER SURFACE AND CONSTRUCTIVE MAINTENANCE OF THE BRICK COVERING - Junction between an exterior wall and a roof slab	
<p>Rehabilitation Solution:</p> <ul style="list-style-type: none"> - increase locally the thermal resistance - minimize the thermal insulation interruption 	 <p>surface temperature factor $\tau = 0,30$</p>
Construction Details	
<p>Inner thermal rehabilitation</p>  <p>Constructive details of a solution with insulated panels by the inner surface</p> <p>Thermal Insulation Thickness = 0,03-0,04 m</p>	<p>Constructive rehabilitation of the brick covering and junction</p>  <p>Constructive detail with the introduction of wall ties</p>  <p>Constructive detail of a horizontal movement joint</p>
 <p>Visual aspect</p>	<p>Maintains the initial aspect</p>

Fig 6: Constructive and thermal rehabilitation with maintenance of the brick covering.

REHABILITATION SIMULTANEOUSLY BY THE INSIDE AND THE BY OUTSIDE WITH SUBSTITUTION OF THE BRICK COVERING - Junction between an exterior wall and a roof slab

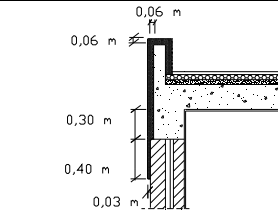
Allows:

Deformations of roof slab on the junction

- The concealment of existing cracking
- The existence of a movement joint and its protection

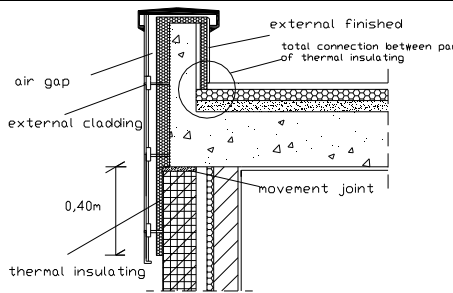
Rehabilitation Solution:

- increase locally the thermal resistance
- minimize the thermal insulation interruption.

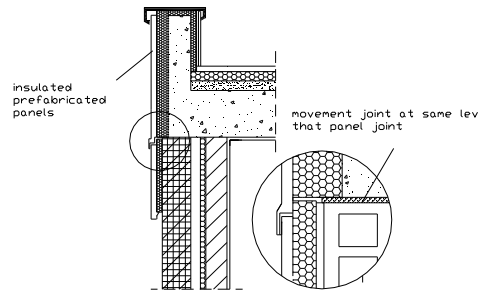


superficial temperature factor $\tau = 0,29$

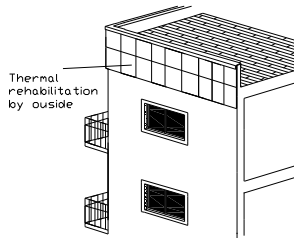
Construction Details



Thermal Insulation Thickness = 0,06/0,03 m



Thermal Insulation Thickness = 0,06/0,03 m



Visual aspect

Fig 7: Constructive and thermal rehabilitation with substitution of the brick covering.

CONCLUSIONS AND RECOMENDATIONS

New building regulations concerning energy efficiency have made new demands of the building industry, and these make the thermal behaviour of buildings a research object. In Portugal, a significant amount of the existing buildings have poor thermal performance, without any concern for energy conservation on the part of their owners/occupiers. Different forms of thermal rehabilitation will become essential. There are bright prospects for the energetic rehabilitation sub-segment due to the new regulations affecting property market activities. For instance, an energetic certification will be needed to sell a house.

Thermal bridging represents an important share of total heat losses in buildings and occurs in fragile points of their envelopes. Some solutions, like the brick coverings (brick slips) that have been used in Portugal since the beginning of the last decade, do not bring any real thermal advantages and can cause complex constructive problems. The problems caused by thermal bridging demand a careful reflection about construction details.

This study concludes that it is possible to minimise this problem with low-cost localised solutions that increase thermal resistance. The rehabilitation solution by the inner surface has greater thermal efficiency with less thickness of insulation than those by external solutions. The latter may represent a more complex intervention, requiring for example the use of scaffolding, let alone the modification of the façade. Many other constructive details need to be carefully designed in the future, adapted to the needs of new materials and constructive envelope systems.

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