HEATING AND CONDENSATIONS IN BUILDINGS WHICH CLOSINGS PRESENT SOME TYPE OF PATRIMONIAL PROTECTION

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ABSTRACT

It is obvious that comfort standards nowadays are not even similar to those during the construction of the buildings that today present some type of patrimonial protection. Therefore in most of them, there have been thermal systems installed.

Great part of these buildings present constructive and aesthetic characteristics that have made it very difficult the installation of complete acclimatization systems, this is way these systems are fundamentally heating ones, acting on the operative temperature, on its dry temperature component or in the mean radiant temperature, without acting simultaneously on other comfort variables such as relative humidity.

Additionally, we have tried to minimize the energy expense, while improving the thermal conditions, acting on some of the building enclosures. If we center our attention in properties which opaque closings present some characteristics that have made them worthy of protection: wall paintings, inlays, coffered ceilings, etc. there have been no actions on them, but, in any case, improving the carpentry and window panes.

The incorporation of heating systems to these properties usually becomes in production of condensations in the uninsulated enclosures. If we add the eventual increasing of water tightness caused by the improvement of carpentries, condensation problems, both superficial and interstitial, increase and are much more damaging the more worthy of protection and the more sensitive to moisture the closures are. For example wall paintings or wood coatings or any other type of hygroscopic material.

The present communication presents the possible measures to adopt in properties with patrimonial protection in which some of these pathologies caused by this type of condensations originate.

1. INTRODUCTION

Even though all the materials have the possible qualities in varying degrees (e.g. both metal and fiberglass are capable of conducting heat, but not with the same ease), the issue can be settled considering that a material has a determined quality only when it is used at a significant grade, that is to s ay, superior to a limit universally accepted (although this limit can be imposed, generally, in an random way). Therefore it is not common to say that metal is a thermal insulating material and, on the contrary that fiberglass is.

Bodies, in general, and construction materials in particular, have two properties that have to be analyzed to evaluate the thermal behavior when used in a building: the heat capacity and thermal inertia. Heat capacity is the potential that bodies have to store heat, while thermal inertia is the resistance to gain or lose such heat, that is to say, the velocity with which they give or absorb heat from the environment. These two properties depend on: the mass of the body, in our case the closings, the specific heat of its materials and the conductivity coefficient. The higher the thermal inertia is, the greater the gap and the absorption of the thermal wave provoked.

Traditionally, thermal insulation of a facing was entrusted, beside its thickness, to its heat capacity and its thermal inertia, which, in the time of construction was very beneficial with variable or continental weather (with great variation of external temperature), because it produced stability in the interior temperature, which was, and still is, highly desirable and the more evident the greater the thickness, and therefore a higher thermal inertia the walls would have (roofs had variable composition, being, in many occasions, of low thermal inertia, in comparison with the walls, for example, wooden frames finished in a single board and tile, etc. Nevertheless, the existence of this weaker insulation was desirable to facilitate the thermal stratification based on air quality).

Only with this attenuation effect of the thermal wave, was achieved to reach the acceptable levels of temperature for the criterion of comfort of the time, generally superior or close to 15ºC, depending on the climatic zone where the building was placed, at least in climates similar to the Castilian plateau of the central area of Spain.

Nevertheless, the need of great thickness and the high cost and therefore the elevation of the price of the floor have caused this type of construction unable to compete with the current materials that Ignacio Paricio calls “specialized”[1]. The incorporation of insulating materials has permitted that the thickness decrease of the new constructive methods does not mean that the heat generated in the interior of the buildings looses more than before, in fact it is often lost less, but it has meant a substantial change in its thermal behavior, losing some of the advantages the traditional materials gave us, among them, the weight of the thermal wave.

To this fact, we have to add the comfort standards required in the present, which differ greatly from the old ones. These comfort criteria have been modified, considerably elevating the level of demand regarding the existing criteria when the building of several antique properties that still exist was carried out, and that are usually protected.

The elevation of comfort standards has brought with itself in the XIX century, fundamentally during the XX century and so far this century, the gradual incorporation of heating and acclimatization systems to the preexisting buildings.

These methods have gone from the simply radiant ones (which act, specially, on the mean radiant temperature of closings) to convective methods (acting, fundamentally, on dry air temperature), but one way or another, they have been incorporated to buildings in which their insertion had not been considered and were projected with another conception of thermal functioning.
Combining the fact that buildings in the present are designed using specialized thin materials, with the usual installation of thermal systems in the interior of our properties (allowing to keep an artificial stable weather, controlling all the comfort variables, that is to say, not just temperature, but also relative humidity and air quality, among others), the result is that we have accustomed to design buildings in a specific way form the thermal point of view. The consequence is that when acting on existing buildings, weatherizing them, one does not take into account that these buildings were not always design with these premises.
In the present, a contradistinction of these two thermal operations is produced, resulting sometimes, counterproductive with each other, and producing the deterioration of the property.
We will discuss next one of the pathologies caused by this fact and how can it be solved when it happens on buildings with protected walls because of their special historic or artistic value, that is to say, on those a more efficient solution is not possible, the increase of the insulation.

2. INTERSTITIAL AND SUPERFICIAL CONDENSATIONS

The buildings that, generally for historic or artistic reason, present some sort of patrimonial protection, are properties built with traditional materials, quite varied: ashlars (very little use during medieval times in Spain[2]) or stone, wood, brick masonry and in poorest cases, adobe or rammed earth, though very few of the last ones have reached our times.
Even though all of these materials have in common their high calorific capacity and the high thermal inertia, they do not behave the same from the thermal point of view, in fact, the better the bearing characteristics they have, the worst they thermally insulate the interior of the building from the exterior inclemency[3], being the stone, among all of them, the one that presents the best mechanic behavior and the worst from the thermal point of view.
This is due to characteristics such as its density and porosity or compactness, given than the more dense a material is, the less porous it usually is, and the insulation of materials depends greatly on the amount of still air that it can keep inside.
Thus, we call «porosidad total o porosidad absoluta a la relación entre el volumen total de huecos y el volumen total de la muestra considerada»[4], while compactness is its complementary: relation between the volume of the solid part of the material and its total volume. Porosity is, along with the capacity of water absorption, a very important characteristic in materials, because it influences decisively in the amount of water that material is able to absorb and retain, and this is aspect is highly important because water is the only material that can exists simultaneously in nature in its three states: solid, liquid and gaseous.
If pores initially filled with air –which guarantees its thermal insulating capacity- are filled with water, the material loses largely its insulating capacity, additionally appearing a great quantity of associated pathologies to this absorption of water.
It is very difficult for a material to reach its level of maximum water absorption, even being submerged, given that pores create canals and bags, and they can even encapsulate leaving air enclosed and forbidding a liquid to penetrate its interior, this

is why it is practically impossible for materials installed above the level of the ground to absorb a significant level of water, except for its capillarity.
Because of this, pathologies associated with humidity that suffer materials installed above the level of ground are dictated by the phenomenon of capillarity.
But there is another cause that can originate pathologies associated with capillarity, condensations, to analyze the probability of the material permeability, that is to say, the capacity that presents to «dejarse atravesar por un fluido cuando existe una diferencia de presión entre las dos caras de dicho material»[5].
The level of porosity of the material does not have to determine its permeability, given that, in reality, it will depend specially on its type of porosity: a pore of type canal, will have a determine permeability in function of its size, while a close pore will not let the fluid pass by, regardless its size. Nevertheless, it is important to consider that this permeability will be stable while the nature of the material is not modified.
So, exclusively considering internal factors, we find that the increase of size of the pores in a material caused by any type of physical phenomenon (dissolution of salts contained in the material, etc.) or its decrease (by total or partial silting of the pores with dirt and absorbed gases), can alter the porosity. Likewise, the increase of the thickness of the material can alter this porosity, decreasing the number of open pores to the exterior, that is to say, the material permeability.
Nevertheless, what does increase the quantity of fluid able to cross the material, are external factors: the increase in vapor pressure difference on both sides of the material and the temperature rise, in the material and the exterior.
If we focus in these external factors, it is obvious that the installation of a hygrothermal treatment system in the building -which will increase temperature and simultaneously increase the difference between the internal and external vapor pressure- will contribute significantly to alter the behavior of its closings regarding the permeability of water vapor.
Antique constructors used solar heat exploitation bioclimatic methods to heat the walls, which was in fact a method of natural radiant heating, in which in addition was produced, as we saw, a temporal displacement of the thermal wave and an attenuation of the wave, which is higher when the material inertia is elevated.
These systems were the only heating methods historic-artistic Spanish buildings had, because during the long period of time they were built, efficient heating methods were not used, except for the traditional "*Glorias*", adapted to the roman hypocaust that can only be found in determined properties from very cold regions and destined to high economic classes. The only other source of heat these buildings could have was human warmth and this rarely contributed in a determined way to elevate, even just slightly, the temperature of interior spaces. Nevertheless, these thermal variations of the closing heated by these bioclimatic methods are of little value and very slow –with twenty four hours cycles- which allows materials to have a natural and gradual reaction. Humidity also fluctuates in the interior of the closings of spaces submitted to these thermal methods, but it is practically done at a seasonal level, staying high during winter and low during summer.
On the other hand, the content of water in construction materials is generally high and fluctuates in a natural way with the exterior climatology and the level of internal occupation, so that relative humidity variations should not cause any type of additional damage in traditional construction materials, since they are all permeable to a greater or lesser extent. In fact, as far as there are not damages in the walls, a low rise of water vapor in the interior of the wall of a not heated place may be beneficial, since part of the heat from the summer that enters the wall from the

exterior will be used to evaporate this water and will not be introduced in the property, while during winter, condensation will have liberated heat that increases the temperature of the wall.

Likewise, being this closing permeable to vapor, every time there is certain gap in vapor pressure between the interior and exterior, a flow of this vapor will exist through the closing, which will allow the regulation of relative humidity in the interior. This is what is usually called «respiración de los paramentos»[6] (breathing of the walls).

In almost every Spanish building that have been qualified as historic-artistic, the main material used as binder is lime, in its two varieties –both aerial and hydraulic lime-. Also, superficial finishes in lime or plaster mortar (in occasions ancient writings do not differ between both materials) were frequent, without pigments and stucco type, and occasionally fresh paintings are done on them. The hygrothermal stability that was reached without using heating methods, made this finishes to have a long life, since its damage was not important when the humidity fluctuation internally was low.

In normal buildings, where the internal water vapor production was low (generally it is only produced by human occupation or by several activities such as cooking or the bathroom), internal relative humidity is very low. It obviously depends on the climatic zones, but yet in areas of high pluviometry, the 15ºC mentioned before could be reached, starting from exterior temperatures of 0ºC (average case in Spain), even considering the exterior saturated air, the sensitive heat produced by the sun managed to reduce the relative humidity levels to a value around 35%, without modifying vapor pressure (fig. 1. Process of sensitive heat represented by the blue line)

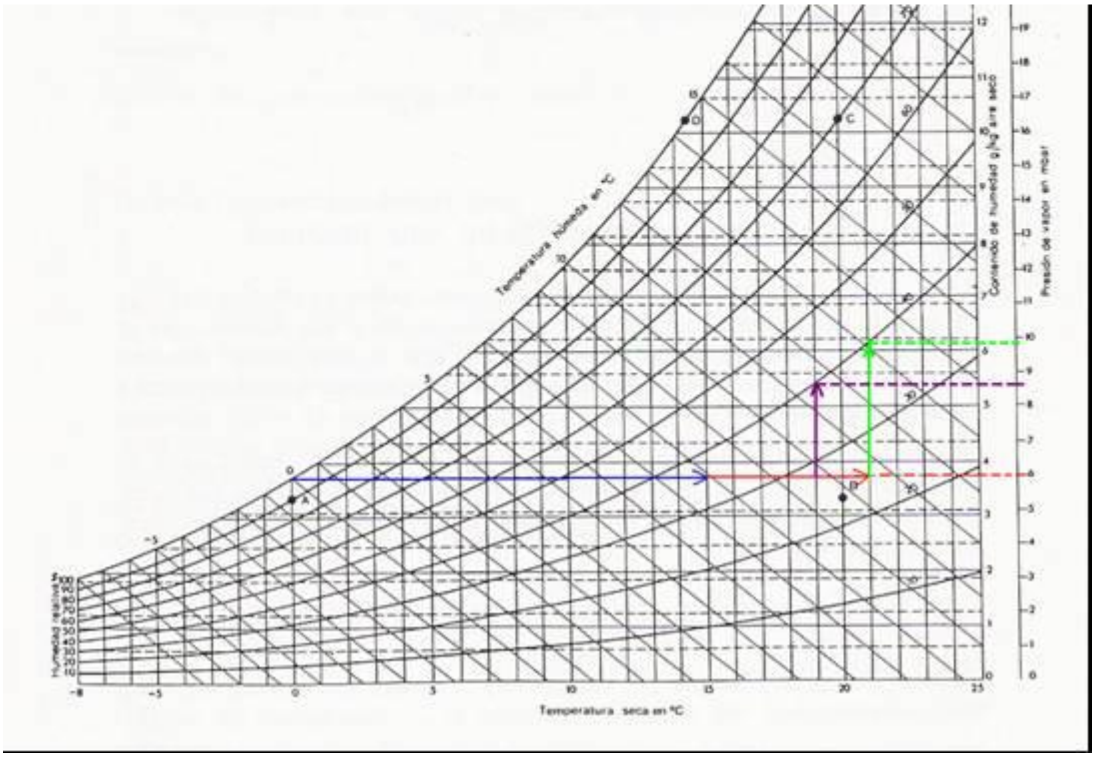

fig. 1.- “Psychometric in which sensitive heating processes were marked and moisturizations that should be carried out in a building to obtain comfort conditions.

Nevertheless, when acclimatization methods were introduced, the elevation of temperature to 21ºC involves that internal relative humidity levels are about 25% (fig. 1. Process of sensitive heat represented by the red line). Therefore, to keep the levels of relative humidity within the comfort margins established by the Spanish norms[1] –between 45 and 60% during summer and 40 and 50% during winter (even though this norm admits this value to decrease in winter to 35% during short periods of time)-, it will be essential to moisturize during winter season. Unfortunately, with this moisturization we increase internal water vapor (fig. 1. Moisturization process represented by line green).
The increase of internal water vapor pressure will get to enhance the flow of water vapor produced in all the buildings, from the highest pressure environment to the lowest, increasing the possibility to produce superficial or interstitial condensations in the interior of the closings.
With the installation of modern artificial acclimatization methods, not only hygrothermal conditions of the interior were altered, but also those construction materials that constitute the closings are subjected to much faster cycles with higher heating-cooling amplitude and to increases of the difference between vapor pressures that will favor that such water vapor penetrates the closings.
Great part of these buildings presents constructive and aesthetic characteristics that have made it very difficult to introduce complete acclimatization systems, these thermal systems often, in most of the cases of Spain, fundamentally heating: they act on the operative temperature – in its dry temperature factor or in the mean radiant temperature one - , without acting simultaneously on other comfort variables such as relative humidity.
But even without moisturizing, the rise of interior temperature caused by the heating affects the internal vapor pressure, which will increase the possibility to produce superficial or interstitial condensations. For example, we can see in figure 2 a calculation of condensations of an 80cm thick stone wall, without any type of finish. The first graphic was obtained with an external temperature of 0ºC and an internal temperature of 15ºC, which are very usual mean climatology conditions in one of the historic-artistic properties in a Spanish town. We observe that there is no condensation in the wall.

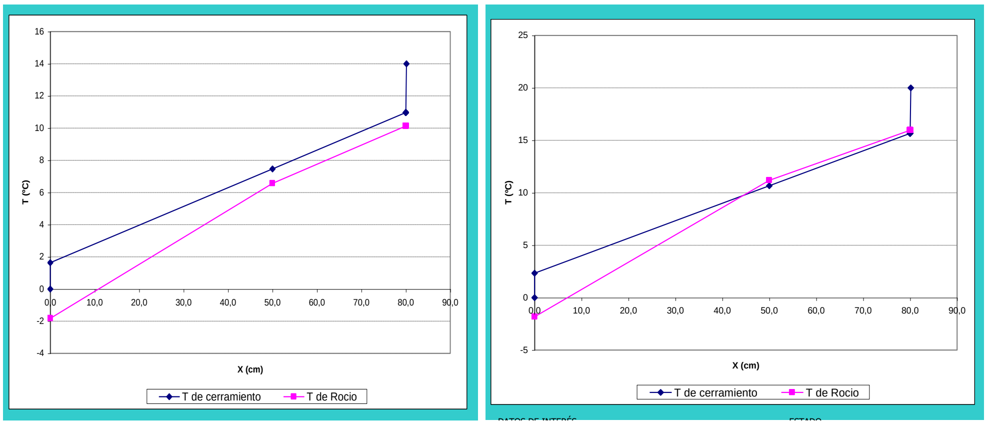

Fig.2.- Graphic of interstitial condensations in an 80 cm thick stone wall.

[1] Reglamento de Instalaciones Térmicas en los Edificios (RITE) y Código Técnico de la Edificación (CTE)

The second graphic was obtained for the same wall and under the same conditions, but elevating the interior temperature to 20ºC. One can observe that there are interstitial condensations produced.
Moreover, where an acclimatization system is installed, the incorporation of simultaneous moisturization to a heating system of the properties usually becomes a production of condensations in the uninsulated closings. If we add the eventual increase of water tightness, caused by the improvement of carpentries[2], condensation problems, both superficial and interstitial, are increased and are much more damaging the more worthy of protection and sensitive to humidity the closings of the building are (for example: wall paintings, wood coatings, or any other type of hygroscopic material).
Oscillations of temperature in a body generally cause alterations in its dimensions. The dimension increase is called dilatation. But one has to take into account that the superficial dilatation coefficient of a material is considered twice the lineal dilatation coefficient, and the volume dilatation coefficient triples lengths.
Yet, if we only analyze alterations caused in the closings by the increase – or in the case of refrigeration the decrease – of temperature, we observe that they are not too significant.
Only in case radiant technology is used with high temperatures (heaters, etc.) a problem is found: the gradient of temperature that the parts of the wall placed behind the radiant elements have. Without the contribution of such heating, the difference of temperature the exterior face of walls are submitted covers a very wide range – from temperatures below -20ºC in the coldest areas to temperatures above 85ºC in those opaque areas exposed to the summer sun-, but the variation of temperature is gradual, which makes materials adaptable to this change without any problems. Besides, the gradient found in the thickness of the wall is not excessive.
The problem is not due to the extreme temperatures a wall can acquire, because these are temperatures easy to reach in the diverse climatology of Spain, and the existing walls do not present sensible damage for this reason-, but to the thermal difference between both faces of the wall, since when installing a high temperature heating element (80-90ºC), we can find, in exceptional cases, that the external face has reached a temperature of -20ºC, by influence of the exterior temperature, and that the internal face has 85ºC by influence of the radiant element attached, so the wall has to absorb a thermal break of over 100ºC, with the dilatation differences that this break supposes.
So, in cases where high temperature radiant systems are used, especially if they are attached to the radiant elements of the wall, thermal gradients of the walls soar (if the radiant element was designed at low temperature – about 45ºC -, like would happen to a radiant floor or radiant baseboard, the effect is much lower, and therefore, will affect less the wall. In the case of radiant floor, besides being a low temperature installation, the exterior temperature of the wall will not acquire in any case such extreme values like the ones cited before, because ground temperature is always much more moderate).

[2] In many occasions the increase produced in condensations are only due to the elevation of water tightness caused by the substitution of window carpentries. (Normally, with the incorporation of a heating system, we try to reduce energy expense without stop improving thermal conditions, acting on some of the building closings. If we focus our attention in properties which opaque walls present characteristics that have made it worthy of protection: wall paintings, inlays, coffered ceiling, etc. there would not have been any actions on the, but in any case, improving the carpentries, and windowpanes.)

The increase of thermal gradients will magnify heat loses trough the wall, because in an element composed by just one layer, heat flow going through the wall only depends on the temperature difference and its thermal conductivity coefficient (this coefficient is variable with temperature and humidity content in the wall) besides its thickness, which evidently will not change.

Also, we can find that, as heat flow is always produces from hot bodies to colder ones, these flows may have different sign. Even so, the alterations of the conditions of relative humidity and vapor pressure are considerably more important, because «experimentalmente se ha comprobado que la humedad relativa influye más que la temperatura en el valor de la difusividad»[7], so there can be deterioration in the walls and at worst, damages.

Analyzing the possible damages that can be found in a building, we can distinguish physical, mechanical and chemical damages.

Physical damages are caused by physical processes and the most important is without a question, humidity – whether it is in the building site, filtration, condensation or accidental-.

Mechanical damages are actually, physical deteriorations as well, but because of their importance they are studied separately. This block of damages includes: deformations, cracks, fissures, landslides or erosions. The incorporation of an acclimatization system or just heating to the building usually causes only fissures and in more severe cases, cracks. The appearance of fissures when installing a thermal system it is often caused to dilatation movements –contraction or retraction in mortars case, this last case is intimately related with the decrease of relative humidity generated by the increase of temperature without a simultaneous wetting of the environment (regarding this matter it is important to consider that with the implementation of the radiant heating systems mentioned before, high temperature behind the heater, regardless the external temperature of the wall, will produce an increase of desiccation. This desiccation will produce differential retractions and affect the stability of the factory for the mortar disaggregation, as well as seriously deteriorate the coating of the wall, which will be extremely more dangerous in those with frescos, because of traction stresses that successive dilatations and contractions caused by temperature variations and humidity produce)[8].

Finally we found chemical damages –efflorescence, oxidations and corrosions, microorganism's proliferation and erosions-. In buildings built with factory, we rarely find oxidations and corrosions, except for accessory elements no always present, such as grates. Nevertheless, the appearance of efflorescence, the proliferation of microorganisms and, somewhat, erosions, usually correspond to fluctuations of the environment humidity.

In case of a chemical attack by microorganisms and insects to structures or wood closings, it is highly important to consider that this attack is intimately related with hygrothermal conditions reached by the environment, given that both fungus and xylophages insects require minimum conditions of humidity under which many of the species can not develop. Therefore, it is observed that humidity control is vital for the conservation of closings.

Water can be associated to construction materials in many diverse ways, keeping attached rather than dissolving them. Among all of these ways, the most dangerous effects, within the attributable to the installation of thermal systems, are the ones caused by condensation humidity's, both superficial and interstitial, even though the danger is not the production of condensations, but to do so to an excessive degree. Even not producing these condensations, the rise of water vapor flow in the interior of

the walls, can also increase impact of certain damages generated by the dissolution of soluble salts towards the interior of the building, where such water evaporates when it meets with a lower vapor pressure atmosphere. With the evaporation of water, salts recrystallize resulting in efflorescence.
The solution to capillarity humidity is often easier than the applicable to condensation humidity.
For example: in San Lorenzo's church –declared National Monument in 1931- it was opted to execute edge stairs, both in the interior and exterior, with what water table was reached and therefore eliminate condensations that were damaging the walls (figure 3).

Fig. 3. - Perimeter gutter executed in San Lorenzo's Church in Segovia to solve the existing problems of humidity capillarity.

San Lorenzo's church in Segovia is a Romanic building whose first documentary reference is from 1247[3] (about the revenue contribution from the town council of Segovia), even though archeological excavations have manifested that a church existed there back in ancient times (possibly from the beginning of the resettlement) of which a Romanic apse was found under the current northern apse that today performs sacristy functions. These remains, located to a much lower level than that

[3]Dr. Alberto García Gil, architect and author of the last rehabilitation of the church, in the memory of the Project of restoration Works, from 2005, introduces the opinion that San Lorenzo was erected before the XII century (He even considers that the beginning of the construction can be advanced to the X century), and that could have been at first a one nave property, maybe with a rectangular apse, with access trough the west Mozarabic door; delaying the date of the south door to the XII century, considering it contemporary with the construction of the arcaded gallery.

of the current church but which was the probable level of the adjacent contemporary streets because there have been located possible remains, were greatly damaged during medieval centuries because of the location above them and because it was near to the cemetery named earlier. It seems clear that a primitive Romanic church existed before the current one and that it was located to a lower level, that, whatever the reasons was demolished and served as base for the current church.
This church was always found free, surrounded by its own space until the XIX century, which included a cemetery. This space was given to the neighborhood to build the square.
The construction of this new square altered the water table of the surrounding areas y capillarity humidity problems started to show in the church’s walls that were gravely damaged.

3. SOLUTIONS TO PREVENT SUPERFICIAL AND INTERSTITIAL CONDENSATIONS

The most effective performance to solve this problem is the increase of insulating capacity of the closing through the incorporation of one of the modern insulating materials. Whenever the thickness of the closing is adequate, we will avoid the production of superficial and interstitial condensations in the closing.
Nevertheless, there are determine closings that because of their characteristics have to be protected, such as closings with mural paintings that can be seen in the interior of buildings like the “Hercules Tower[4]” in Segovia (figure 4), wood coatings or any other type of hygroscopic material or external valuables coatings of “*esgrafiado*” type from Segovia (figure 5).

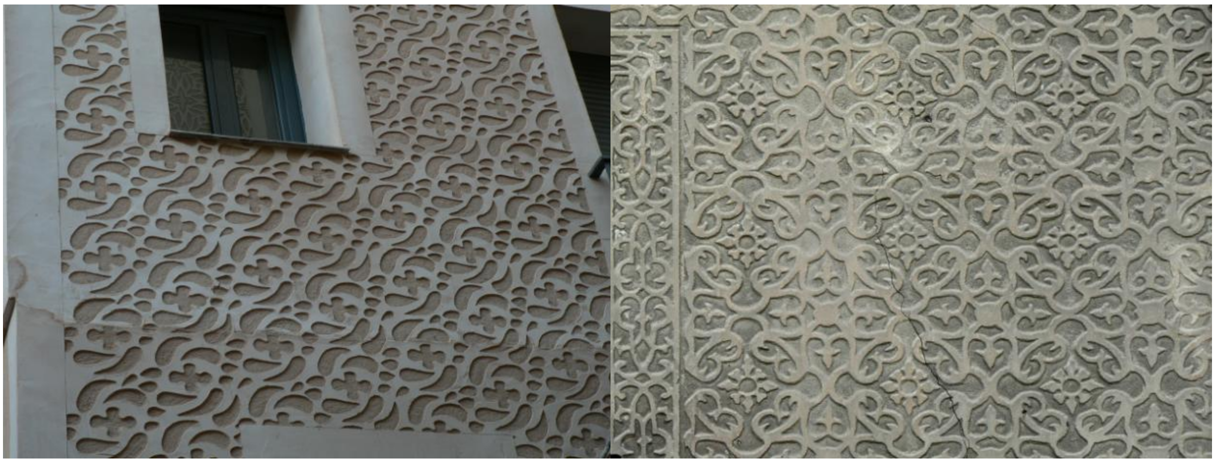

Fig. 5. - Different examples of “*esgrafiado*”.

[4] Medieval military tower that belonged to the Arias Dávila family and that is now part of Santo Domingo del Real Convent. Its plinths are decorated with geometric figures and its name comes from the scene represented in a bas-relief placed on the wall of the stairway and that has been traditionally considered like the representation of Hercules.
It was declared Historic-Artistic Monument on June 3rd 1931. Under the protection of the generic declaration of the April 22nd 1949 Decree, and the law 16/1985 about Spanish Patrimonial Protection.

Fig. 4. - Medieval wall paintings in the interior of the Hercules Tower (Segovia). These are basically geometric plinths interspersed with knight images, but in some points there are older pictures under them.

Yet, not being especially valuable, these exterior finishes can be characteristics of the property, so its manipulation would modify its external aspect. This is what happens in the mentioned Hercules Tower, built with stone masonry with angled chain ashlars, except for the last floor, which was executed with wood framework (figures 6 and 7).

Fig. 6. - Exterior of the Hercules Tower (Segovia). It does not present sgraffito, but it does have a characteristic aspect with seen stone masonry finishes provided with angled chain composed by granite ashlars.

Fig. 7. - Another view of the exterior of the Hercules Tower (Segovia), from the internal patio of the building.

The traditional way of solving superficial condensations – in cases where, for any reason, insulation could not be increased – is waterproofing, even though it also presents external risks when it is external because it inhibits the rapid evacuation for water evaporation contained in the walls, suppressing the hygrometric interchanges and in occasions producing the collapse of the factory if there is ice in its interior.

Historically, closings have been waterproofed in the interior, if there was low condensation with the whitewash («Esta avidez de la cal viva por el agua se aprovecha desde hace años por los vecinos para limpiar o desinfectar y evitar la entrada de agua en sus viviendas, pues técnicamente es uno de los mejores impermeabilizantes»[9]), with the tilled or the plastered.

Usually, an external element such as sgraffito is thought to support high levels of humidity (it can obviously get wet by rain), so if it is not naturally waterproofed, it will support condensation humidity quite well in most of the cases. If it is waterproofed –for example, composed by fat lime or plastered- it can act as vapor barrier in the cold face, inhibiting water vapor absorbed by the closing to exit and increasing the damages, in this case there should not be any condensations in the interior of the closing at all.

Interior protected elements occasionally have certain impermeability, given that sometimes under the thin final finishes based on aerial lime mortar – either if the finishes have a single layer or several ones- there is a coating based on hydraulic natural lime (extracted from more argillaceous limestone and silica-rich). As this layer is the most impermeable, lacking of pores that make aerial cal breathable, it could cause, in certain places, superficial condensations, especially in the case there are convectic heating systems used that rise dry temperature without influencing on the wall temperature. Fortunately, the use of hydraulic lime mortars was very sporadic.

Since simultaneous existence of interior and exterior elements that require protection (if it were not simultaneous, one could act in its not protected face), forbids us to use either the method of increasing the insulation or the waterproofing of the wall, we have to use artificial methods.

The first of the methods is to slightly and homogeneously heat the interior face of the closing so condensation produces in the thickness of the wall, in a sufficiently deep area to avoid the alteration of the mural painting.

The best solution for this case if the implementation of a low temperature radiant installation trough radiant plinth (figure 8). In this type of installation radiant elements are continuous and of low temperature, which, on the one hand, will make its implementation easier along decorated walls, and on the other hand, will prevent excessive differences of temperature in the walls.

Its functioning and installation are similar to those of a conventional heaters installation, causing –constructively speaking- a minimum impact in the interior of the room, because the tracing of pipelines can be done without embedding, holding them to the base of the wall, without affecting all the elements of the property, as far as the precaution of using a lime mortar is taken for the holding of the anchors of the pipeline and the radiant elements (in specific cases, the utilization of a cement mortar can cause damages to the closings because of its different behavior to dilatations and retractions caused by variations of temperature, but the probability of this event is, generally, low due to the low entity of such fillings); pipes can also be camouflaged by trims that –in the manner of skirting- would cover those pipes hiding their existence. Industry offers this type of skirting to cover pipes with different finishes, so it is relatively simple to find an adequate one to the finishes of the treating building. Normally, these pipes are not insulated, considering –under our point of view, correctly- that the lost heat due to this lack of insulation its dissipated in the own room to be heated, improving the radiant distribution of the installation.

Fig. 8.- Section and view of a radiant plinth from Climaboard, with a total height of 14cm. (http://www.tecnicsolar.com/ique-es-la-calefaccion-por-zocalo.html).

It can also be reinforced along the perimeter a heating solution through radiant floor, even though this will affect the building considerably, especially if it has a flooring worthy to preserve, because it would have to be lifted and put back into place, with the danger of damage this action supposes (figure 9); nevertheless, since this floor is usually stony, once the installation is performed, the radiant behavior of the floor is very good, even though like any other radiant system, will increase even more the thermal inertia –these are systems that take too long to heat and remain long heat- it is not adequate for sporadic use buildings, regardless the convenient of its installation.

Fig.9.- Instalación de suelo radiante de la catedral de Getafe (Madrid)

Even the installation of a conventional radiant floor could be impossible due to the height needed for it, which would force to modify the access stairs to the locals. This problem can obviously be eliminated using a low inertia radiant floor and very low height such as the presented by UPONOR (figure 10) that can practically be installed in every case.

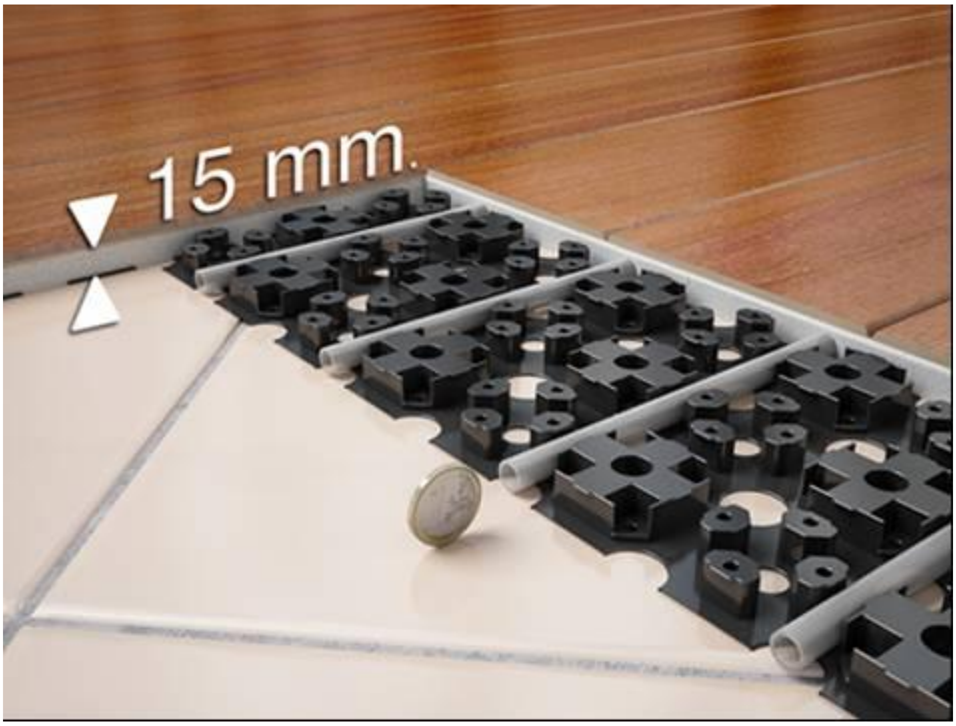

Fig.10.- Installation of a radiant floor type “MINI” of UPONOR (the image is from http://www.interempresas.net/Climatizacion/Articulos/28353-Uponor-presenta-sus-novedades-en-la-feria-Climatizacion-2009.html)

If interstitial condensation in deep layers of the closing is not acceptable either, there should actions over interior relative humidity to decrease the difference between internal and external vapor pressures.
However, It is not always possible to lower the levels of general relative humidity of a room under the comfort margins, because, even when human beings can bear relative humidity between 20 and 70% quite well, they perceive it like temperature alterations: a very low relative humidity will accelerate the evaporation of sweat, cooling the skin, which will be perceived as a decrease of temperature, while a high relative humidity will make evaporation difficult, generating higher warmth. Therefore, that low level of humidity should be compensated with the elevation of the operative temperature.
If this is not enough, the closest air to the wall affected by the condensation will have to be dried. This, could easily be done by establishing a dry air flow tangent to the surface of the wall (for example, pumping from a conduct attached to the wall on the ceiling, or preferably, on the floor, and directing it towards a wall through small nozzles uniformly distributed, generating a curtain of homogeneous air. The level of humidity should be controlled through enthalpy probes –humidity and temperature- internal and external which control the respective vapor pressures; because it is

necessary to guarantee that the wall does not dry excessively, since this could cause retraction fissures.
His air will dry superficial humidity that could have been produced in the wall and simultaneously will decrease the value of vapor pressure of the closest air layer to the wall, avoiding the possibility to produce interstitial condensations in its interior.
The great inconvenient of this type of methods is the space required, given that, by providing air with less specific heat than water, higher flows are required to transport the same thermal power and, therefore air conducts are much more voluminous than water pipes.
Generally, unless the distribution of air through the inferior floor can be done or buried in case it is a ground floor, drilling the forged in the points where the drive racks are disposed, the only way this wall sweep can be easily done with an air curtain, is doing it from the top and this usually turns into extremely visible installations, which in many occasions may not be the best option.
Nevertheless, acting on fry air temperature is much faster than acting on radiant temperature, given that the air thermal inertia is much lower than that of any other traditional construction material, so these last installations allow us to have a faster and more adjusted control than water radiant installations.

4. CONCLUSIONS

The solution to superficial condensations in protected walls, on which actions through thermal insulation cannot be done, forces us to incorporate artificial methods of relative humidity and internal vapor pressure control.
However, they are less efficient to control and eventual production of interstitial condensations, given that they limit themselves to rise the wall superficial temperature over dew point, without guaranteeing that the thermal gradient produced in very thick walls –which can be important- locates the dew point in the interior of the wall thickness.
The most efficient ones act on the affected wall radiant temperature and consist on perimeter radiation installations by means of heated water: radiant plinths or perimeter radiating bands on the floor.
The usage of dry air curtains that modify vapor pressure in the closest air layer to the affected walls is usually more complex to incorporate and much more visible.
However, the control that can be obtained with them over the air relative humidity is simpler and faster and can be regulated more precisely, which allows to control more effectively the presence of superficial condensations.
Likewise, with the modification of internal air vapor pressure (at least on the closest air layer to the wall), can reduce the condensation enough to completely avoid both superficial and interstitial condensations.
The needed control would be limited to external and internal enthalpy probes and the correspondent regulation central.

5.- BIBLIOGRAPHY

- Arredondo y Verdu. F. (1990). *Generalidades sobre materiales de construcción*, 1ª edición. Ed. Revista Obras Públicas. ETS Ingenieros de Caminos, Madrid.
- Barahona Rodríguez, C. "*Revestimientos Continuos en la Arquitectura Tradicional Española*". Madrid. Ministerio de Obras Públicas y Transportes. Dirección General para la Vivienda y Arquitectura. 1992.

- Coscollano Rodríguez. J. (2000). *Tratamiento de las humedades en los edificios*, 1ª edición. Ed. Paraninfo, Madrid.
- Del Río Merino, M. y otros. "*Ejecución de Revestimiento con Yeso*".
- Domínguez Alonso, M. *Propiedades Térmicas de los adobes*. Ponencia del libro "Arquitectura de Tierra: Encuentros Internacionales del Centro de Investigación Navapalos".
- Quirós Castillo, J.A. "La Sillería en la Arquitectura Altomedieval". Actas del V Congreso de Arqueología Medieval Española. Tomo I.
- Paricio, I. "*La Construcción de la Arquitectura*". .
- VVAA. (2001). Actas del V Congreso de Arqueología Medieval 1999. Valladolid. Junta de Castilla y León. Consejería de Educación y Cultura.
- VVAA. "*Arquitectura de Tierra: Encuentros Internacionales Centro de Investigación Navapalos*". Centro Experimental y de Investigación para la Construcción con Materiales y Técnicas Autóctonas". Madrid. Ministerio de Fomento. 1998.
- VVAA. (1995). *Curso de Patología, conservación y Restauración de edificios*, Tomo 4, 1ª edición. Ed. Servicio de publicaciones del COAM, Madrid.
- VVAA–Departamento de Construcción de la Universidad Politécnica de Madrid (DCTE–UPM) (1999). *Tratado de Rehabilitación*, Tomo 4: *Patología y Técnicas de Intervención. Fachadas y cubiertas*. Ed. Munilla–Leria, Madrid.

REFERENCES

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[1] thermal insulating materials are highly effective. For example, Ignacio Paricio tells in his book *La Construcción de la Arquitectura*, volume 2: *Los Elementos* (pag 30): «El proceso de especialización de los materiales se ha consumado. Los materiales tradicionales, y en general los materiales pesados, no pueden competir con los modernos especializados en aislamiento térmico. Los materiales ligeros, que albergan gran cantidad de aire en sus celdillas, entre sus fibras, etc., pueden multiplicar por cien la eficacia de aquellos. Recuérdese que 5 cm de poliuretano de baja densidad limitan el flujo calorífico igual que 17 cm de madera, 35 cm de cerámica hueca, 50 cm de hormigón celular, 56 cm de cerámica maciza, 100 cm de vidrio o 245 cm de hormigón.».

[2] Juan Antonio Quirós Castillo. "La Sillería en la Arquitectura Altomedieval". Actas del V Congreso de Arqueología Medieval Española. Tomo I. Pag. 281: «Aunque no contamos con buenas síntesis regionales sobre la evolución de las técnicas constructivas en la Alta Edad Media, se puede sostener que a partir del siglo IV en gran parte en Hispania se abandonaron las técnicas constructivas en sillares y se construyó casi de forma exclusiva con materiales perecederos, mampostería irregular y con técnicas basadas en la reutilización de material altoimperial».

[3] Manuel Domínguez Alonso. *Propiedades Térmicas de los adobes*. Ponencia del libro "Arquitectura de Tierra: Encuentros Internacionales del Centro de Investigación Navapalos". Pag. 67: "De forma genérica, los materiales muy resistentes, es decir, con muy buenas propiedades mecánicas, presentan un mal comportamiento como aislantes térmicos y suelen transmitir también las vibraciones acústicas".

[4] Arredondo y Verdu. F. (1990). *Generalidades sobre materiales de construcción*, first edition, página 33. Ed. Revista Obras Públicas. ETS Ingenieros de Caminos, Madrid. The translation of the quote would be: «total porosity or absolute porosity to the relation between the total holes volume and the total volume of the considered sample»

[5] Arredondo y Verdu. F. (1990). *Generalidades sobre materiales de construcción*, first edition, página 34. Ed. Revista Obras Públicas. ETS Ingenieros de Caminos, Madrid. The translation of the quote would be: «let a fluid go through when there is a difference of pressure between both faces of such material»

[6] VVAA– Construction Department of the "Universidad Politécnica de Madrid" (DCTE–UPM) (1999). *Tratado de Rehabilitación*, Tomo 4: *Patología y Técnicas de Intervención. Fachadas y cubiertas*, 1ª edición, página 17. Ed. Munilla–Leria, Madrid.

[7] VVAA. (1995). *Curso de Patología, conservación y Restauración de edificios*, Tomo 4, first edition, página 51. Ed. Servicio de publicaciones del COAM, Madrid. The translation of the quote would be: «experimentally there have been proved that relative humidity influences more than temperature in the value of diffusivity»

[8] del Río Merino, M. y otros. *Ejecución de revestimientos con yeso*. Pag. 49: "Los esfuerzos de tracción son causas mecánicas que sufren los revestimientos de yeso y para que produzcan lesiones deben ser superiores a lo que estos pueden resistir, dando lugar a fisuras y grietas".

[9] Coscollano Rodríguez. J. (2000). *Tratamiento de las humedades en los edificios*, first edition, página 116. Ed. Paraninfo, Madrid. The translation of the quote would be: «this avidity of quicklime by water has been exploited for years by neighbors to clean or disinfect and avoid the entrance of water in their houses, because technically this is one of the bests waterproofing»