Methodological Model for Evaluate the Thermal Behavior of External Walls Exposed to Moisture Phenomena

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ABSTRACT: The investigation studies the problem of the moisture in buildings. A methodological model developed allows evaluating and comparing the hygrothermal behavior in external walls under natural humidity conditions, for that two softwares are used WUFI 3.2 Pro and TRNSYS 15. With the use of this model the humidity impact in the walls of an 85m^2 house was analyzed, and placed in five cities of Chile. The analysis is centred in the integral evaluation of the following variables: inside room's temperature; thermal comfort model of PPD and PMV; humidity content in external walls throughout the time; conditions for the growth of mould and energy demand of the houses.

In the beginning, the house was evaluated with two materials in external walls typically used in Chile: brick masonry and concrete. Then, two alternatives of new constructive solutions were proposed for each type of traditional building materials, adding materials that allow decrease the humidity in the interior of the walls and also reduce the thermal transmittance, which improve the comfort conditions in the house.

Finally, even though the new solutions raised the building budget, this was amortized in time with the heating energy saving due to the incorporation of these solutions.

Keywords: moisture, thermal, energy

1. INTRODUCTION

One of the problems that influences negatively in the comfort of the users of a housing, besides to cause structural and architectonic damages, is the originating humidity as much of the outside as of the interior of this one. It is by the previous that numerous investigators of developed countries of Europe and North America, have studied the origin, causes and consequences that bring the humidity problems in the house, which has meant, in addition, that the phenomenon of transference and humidity storage in construction materials has been considered like very relevant in these studies, since the humidity is one of the first causes of the deterioration produced in the elements of the casing in general and the perimeter walls of the houses in individual. In regard to the users, the studies have been centered in the variation of the relative humidity at the interior of the enclosures and in the diminution of the thermal resistance of the casing's walls, because of the present humidity in them [1] [2] [3]

Thus, multiple laboratory experiences have been realized, in which it has been possible to observe how small amounts of humidity can have a evident impact on the thermal conductivity of the materials and therefore on the thermal transmittance of a wall [4] Also, equations and relations have been defined to explain the impact that the humidity has on the walls, in respect to the thermal problems that are originated, being based on the parameters related to the thermal conductivity of each component material of the wall and on the capacity of each material to transport and to store humidity [5].

In this investigation the hygrothermal behavior of different constructive solutions for external walls submissive to the climatic conditions and use of the houses in different cities of Chile, will be simulated computationally, leaning methodologically in a model, designed to evaluate and to compare elements of the casing exposed to humidity phenomenon's, which is sustained in two validated computational programs in different studies from the area.

2. DEPENDENCY OF THE THERMAL CONDUCTIVITY OF MATERIAL BASED ON ITS HUMIDITY CONTENT

The thermal conductivity of a dry material is a basic and indispensable parameter of him and is precise that, for cases in which the behavior of the material under natural conditions is analyzed, the dependency of this conductivity with respect to the humidity content that has the material at issue is considered. It is precise to mention that the value of the thermal conductivity also depends on other factors like for example, the temperature, but this study is centered in the repercussions that the humidity has on the construction materials. Thus, for the calculation of the thermal conductivity according to the different humidity contents, the following expression is considered:

$$\lambda(w) = \lambda o * (1 + b*w/ \rho s)$$

where:

λ (w): thermal conductivity of the wet material
λo: thermal conductivity of the dry material
b: additional thermal conductivity induced by humidity
w: humidity content
ρs: density of the dry material

The factor of additional conductivity induced by the humidity, "b", indicates which is the percentage of increase of thermal conductivity by the percentage of increase of humidity mass, in a construction material. This value depends on the kind of material, that is to say, by a side the material has greater or smaller capacity to absorb humidity and on the other hand, it shows the influence that this absorbed humidity can have on the thermal conductivity of the material. In the case of those hygroscopic materials, this factor "b", is quite independent of its density [6]

In organic insulators, in general, there isn't a linear relation between thermal conductivity and humidity content, but it is possible to be mentioned specifically for the expanded polystyrene, that the value of the drought thermal conductivity is not affected until the material absorbs about 50 kg/m3 of humidity or more. On the other hand, although the ice has a thermal conductivity four times greater than the conductivity of the water, normally the differences are minimal between the thermal conductivities of the humid materials and the congealed materials, or in the case in that these are over the temperature of freezing or under the freezing temperature respectively [1] [2].

3. METHODOLOGICAL MODEL

Next appears the diagram that represents the flow of information that must enter the methodological model and the results that of him will be obtained for their later analysis:

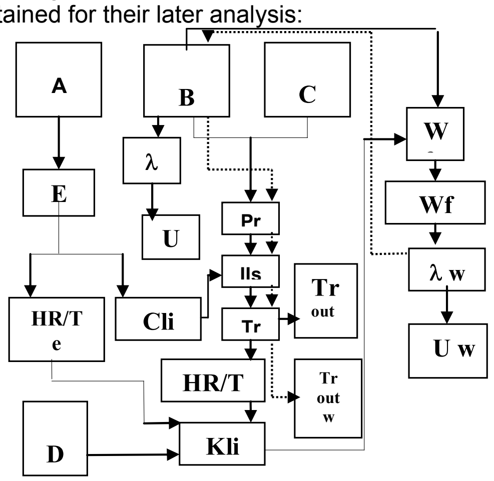

Figure 1: Diagram of methodological model

where:

A: geographic and climatic data bases of cities
B: definition of materials of the house and its properties
C: use conditions of the house
D: rain data base of cities
E: software Meteonorm, for generation of climatic data bases
HR/T e: relative humidity archives and exterior temperature
Cli: climatic archives for subprogram of TRNSYS, IIsibat
Kli: climatic archives for WUFI 3.2 Pro
λ: thermal conductivity of materials in dry state
U: thermal transmittance of casing elements in dry state
Pr: entrance of information to subprogram of TRNSYS, Prebid
IIs: entrance of information to subprogram of TRNSYS, IIsibat
Tr: entrance of information to program TRNASYS
HR/T i: file that delivers TRNSYS with relative humidity and inner temperature of the house
Tr out: results for analysis stage that gives software TRNSYS (dry and wet)
Wf: entrance to software WUFI 3.2 Pro
Wf out: results for stage of analysis and for new iteration that gives software WUFI 3.2 Pro
λw: thermal conductivity of materials in wet state
Uw: thermal transmittance of elements of casing in wet state

Basically the model allows, through the use of two software of analysis in dynamic conditions, to integrally study the impact that has the humidity content (by higrocospicity, condensation and rain) in the components of the casing of the house through the time, in relation to the results of the following variables of analyses, all which are obtained in dry and humid state:

a) Effect of the humidity in the materials of the house, through the variability of thermal conductivity
b) Effect in the capacity of thermal insulation of the elements of the casing, through the study of the variation of thermal transmittance
c) Diminution of the resistant capacity and aesthetic degradation of the component elements of the house, through the study of the humidity content in them throughout time
d) Thermal Comfort of the users of the house, through the application of the P.O. Fanger's theory, in relation to the values of PPD (prediction of percentage of unsatisfied people) and PMV (prediction of average of vote)
e) Efficient Use of the energy, through the study of losses and gains of the house in dry and humid state
f) Users Health, through the study of risk conditions for the development and growth of molds and fungi

Economic analysis, through the calculation of the cost of the energy use to maintain the house in zones of comfort in relation to the cost of the constructive solutions propose to improve the behavior in relation to humidity

4. THE STUDIED CASE

The methodological model before described was applied in the case of Chile. For this, a house and a family with his respective conditions of use of this house were defined. The analysis was centered in the behavior of the external walls, for which two materialities typically used in Chile were defined, these are, brick masonry walls and reinforced concrete walls. As well, five cities located between the center and south of the country were defined, zones that correspond to those of greater rain presence throughout the year. Once the house with the walls before mentioned was simulated in each city, two alternative constructive solutions where proposed for each traditional materiality, these were simulated in each city, which finally allowed to establish an integral comparison between the two traditional solutions in each city and each traditional solution in relation to its two propose alternatives.

It is possible to indicate, that in the case of Chile, when not counting with on hour climatic data bases, it was necessary to use the software Meteonorm (see Fig 1), which, based on climatologic data averages, develops an hour data base for the required city.

4.1 The studied house and its users

A house with an 85 m2 surface was defined, composed by the following enclosures with its respective zones and directions:

Dormitory A: northeast
Dormitory B: north
Dormitory C: southeast
Bath: south
Kitchen/ living room/ dinning room: south/west/north

Besides of the walls, subjects of analysis, the house is composed by: carpet (dormitories) and ceramics (other enclosures) pavements over the concrete floor; plaster-cardboard inner partitions; plaster-cardboard inner ceiling and cover of fiber cement, with expanded polystyrene insulation at the attic of thickness and density according to in force thermal regulation in the country (see Table 1); finally the windows are of simple glass and aluminum marks and the doors are made of wood.

Table 1: Termal zone, insulation and U-value

Thermal zone	Thickness of insulation -attic-	U-value -attic- (W/m^2K)	U-value -walls- (W/m^2K)
3.Santiago	80mm	0,47	1,90
2.Valparaíso	60mm	0,60	3,00
4.Concepción	100mm	0,38	1,70
5.Valdivia	120mm	0,33	1,60
7.Pto. Aysén	160mm	0,25	0,60

The users of the house correspond to a familiar group made up of two adults, an adolescent and two children. The use that they give to the house with their respective activities is incorporated in the Prebid subprogram of the TRNSYS software.

There is also considerate the use with the corresponding gains of heat and humidity given by the equipment of the house, which is made up of: a washing machine, cooks, television set, skillful, refrigerator and an electrical kitchen. It is possible to indicate that although the heating equipment, depending of the type on energy that they use, they are an important water steam generating source inside a house, in this investigation has been done this simplification considering a stove that does not generate humidity, which will be sensitized in a following stage.

4.2 The cities

For this study, cities that display different climatic precipitations and conditions (temperature, relative humidity, among others) were selected. Thus, the selected cities appear next:

Table 2: Cities selected in Chile

City	Latitude	Length	Annual Precipitation (mm)	Amount max. of precip. in 24 hrs
Santiago	33º S	70º O	333	71
Valparaíso	33º S	71º O	380	83
Concepción	36º S	73º O	1.340	105
Valdivia	39º S	73º O	2.471	102
Pto. Aysén	45º S	72º O	2.973	67

In addition, is possible to observe the general climatic characteristics of each city:

Table 3: Climate of cities selected

City	Tº(ºC) minimum annual	Tº (ºC) maximum annual	Tº (ºC) average annual	(%)RH average annual
Santiago	-3.0	33.7	14.6	71
Valparaíso	4.0	26.5	12.9	81
Concepción	-3.0	32.0	12.3	79
Valdivia	-6.0	31.0	11.1	82
Pto. Aysén	-6.0	30.0	9.8	87

4.3 Traditional Walls and alternative studied

As it was mentioned previously, the study considered the house constituted by two kinds of traditionally used external walls in Chile, brick masonry and reinforced concrete, also, for each one of them, the two possibilities of improvement alternative in relation to humidity phenomena were evaluated, all which is described next:

a) Brick masonry: made with pressed brick of 140 mm thickness and mortar

a.1) Alternative 1: case a) with outside waterproofing material and inner expanded polystyrene 20mm (thickness according to new thermal regulation) plus polyethylene of 0.1 mm thickness and plaster-cardboard of 15 mm

a.2) Alternative 2: case a) with outer expanded polystyrene 20mm (thickness according to new thermal regulation) plus asphalt felt of 1mm and stucco with incorporated waterproofing material

b) Reinforced concrete: made with normal concrete and framed with reinforcement steel

b.1) Alternative 3: case b) with stucco and waterproofing material incorporated in the outside and expanded polystyrene 20mm (thickness according to new thermal regulation) plus polyethylene of 0.1 mm and inner plaster-cardboard of 15 mm

b.2) Alternative 4: case b) with outer expanded polystyrene 20mm (thickness according to new thermal regulation) plus asphalt felt of 1mm and normal stucco

5. RESULTS

As it was mentioned in point 3, the methodological model allows to make an integral analysis of the behavior of different building solutions over a house exposed to humidity phenomenon's, this way, for the case studied in Chile, some of the obtained results examples will be shown.

5.1 Humidity content and thermal transmittances (dry and humid) in houses with traditional walls in Valdivia

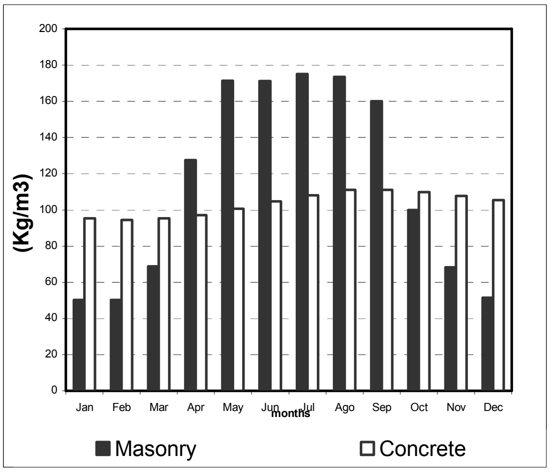

Figure 2: Humidity content in traditional walls in Valdivia (kg/m3)

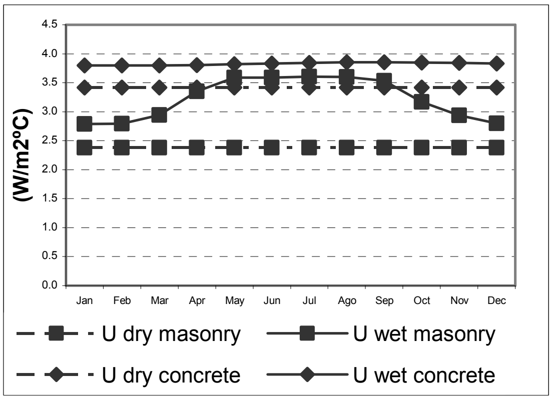

Figure 3: Thermal Transmittance in traditional walls in Valdivia (W/m2ºC)

As observed in both previous graphics, the dependency of the thermal conductivity and therefore in the thermal transmittance, in relation to the humidity content is evident, still more if it is considered that is a city with a high precipitation level in the autumn-winter period, but that nevertheless also presents rains in spring-summer. One is due to emphasize that the concrete reaches its capillary saturation zone around values much below the curve of the brick wall, and also that the curvature of the brick wall follows a slope very similar to the marked presence of the stations of the year, is to say the moisturizing and drying cycles are noticeably identifiable in the brick wall, not thus in the one of reinforced concrete.

5.2 Difference of energy demand, of the house in the five cities with dry and humid traditional walls

Table 4: Annual difference of heating demand (kWh/m2), considering the house with dry and humid walls

	Masonry	Concrete
Santiago	8	13
Valparaíso	10	16
Concepción	35	19
Valdivia	50	24
Pto. Aysén	72	30

The analysis of Table 4, compared with precipitations indicated in the Table 2, shows that the brick masonry house, is the one that sees increased its differences of heating demands in greater proportion as the climate becomes rainier and of marked stations. This is confirmed still more, when observing that the concrete has greater variations than the masonry in cities like Santiago and Valparaiso and although, also exists an increase of this difference as the climate is more unfavorable, this one becomes less noticeable for this wall. All this makes considerably increase of the requirements of heating for the masonry.

5.3 Impact of the humidity in the thermal transmittance of the traditional brick masonry walls, and its two alternatives in Santiago and Valdivia

Table 5: Percentage Increase of U by the effect of the humidity in Santiago (wet - dry)

Station	Tradicional Masonry	Masonry with interior insulation	Masonry with exterior insulation
Summer	2.1%	1.8%	1.9%
Winter	23.1%	10.5%	1.9%

Table 6: Percentage Increase of U by the effect of the humidity in Valdivia (wet - dry)

Station	Tradicional Masonry	Masonry with interior insulation	Masonry with exterior insulation
Verano	17.2%	5.3%	1.9%
Invierno	51.7%	12.3%	1.9%

The Tables 5 and 6, show the impact of the humidity in the thermal transmittance of the traditional brick masonry wall and its two alternatives, in Santiago (center of Chile) and Valdivia (far south of the country).

The solution most affected by the humidity is the traditional masonry, which in Valdivia's city and Santiago sees its thermal transmittance increased in 51,7 % and 23,1 % respectively in the winter's months. The impact of the humidity on the humid thermal transmittances, for the solutions with interior and exterior insulation, is widely lower that in the traditional solution, emphasizing that it is even lower in the case of exterior insulation, where the masonry is less exposed, reaching an increase lower than 2 % and not suffering modifications depending on the environmental conditions of each city.

Finally, it is possible to observe that while more exposed on the outside the masonry is, the wall is more affected thermically, for its humidity content effect.

5.4 Effect in the interior temperature of the housings enclosures, considering walls in dry and humid condition

The result of the application of the model in the different raised stages, considering the different traditional materialities of walls and its alternatives, shows that the variation of the interior temperature of the different enclosures changes according to its orientation, because of the effect of the humidity in them, from 0,1ºC up to 2,2 ºC in the most unfavorable condition. It is necessary to emphasize that, solutions with exterior insulation shows a variation between dry and humid tending to zero.

5.5 Risk conditions for the growth of moulds

Multiple investigations have demonstrated that, with minimal differences between some and others, the ideal conditions for the development and growth of molds and fungi, are given when simultaneously the temperature places between 4,5ºC and 38ºC and the relative humidity in the immediately attached space to the zone of risk, is over the 70 %

The present study demonstrates that, in general terms, all the analyzed situations that have not considered any heating system, show that the temperature conditions are inside the propitious range for the risk of growth of fungi, likewise the relative humidity places over 70 % which would mean that a potential risk exists for this to happen. Nevertheless, on having considered to be some heating system, the propitious condition of relative humidity disappears, which happens because when having raised the temperature of the enclosures, the air contained in them is capable of sustaining major quantity of water steam, minimizing with this the risk of the development of microorganisms in the inside.

5.6 Economic analysis, in regard to the energy consumption and the cost of implementing constructive solutions that improve the behavior before phenomena of dampness

Table 7: Period of amortization of the extra cost of construction, in regard of the traditional solution of masonry, considering the saving of energy in Valdivia. (Currency: Chilean pesos)

	Masonry with interior insulation	Masonry with exterior insulation
Heating saving of in 1 year	$ 277.961	$ 312.221
Extra Cost of construction with regard to traditional housing	$ 507.847	$ 484.700
Amortization (Approximate)	22 months	19 months

Table 8: Period of amortization of the extra cost of construction in regard of the traditional solution of concrete considering the saving of energy in Valdivia. (Currency: Chilean pesos)

	Concrete with interior insulation	Concrete with exterior insulation
Heating Saving in 1 year	$ 363.278	$ 370.787
Extra Cost of construction in regard to traditional housing	$ 968.559	$ 484.631
Amortization (approximate)	32 months	16 months

Tables 7 and 8 show that the extra cost of construction for incorporating improvements in the solutions of perimeter walls of a housing, amortizes as maximum in three years because of the savings that take place in relation to the decrease of the fuels consumption to generate the necessary energy to support the housing in the comfort zone In the case of the house with external walls of brick masonry, a decrease take place in the energy demand in the two alternatives solutions in regard to the traditional wall, of a 42% and 47% respectively in the city of Valdivia (city with heavy conditions of rainfall), and the increment of the construction cost in the two alternatives is amortized in 17 and 15 months respectively considering the energy savings in both cases. On the other hand, in the case of concrete wall, the two alternatives of traditional wall present decrease in the energy consumption of a 48% and 50% and the increment of construction cost is amortized in 44 and 23 months respectively.

6. CONCLUSIONS

In short, it is possible to observe, at the examples of the presented results, that the methodological designed model can, from the utilization of programs that possess the similar characteristics to TRNSYS and WUFI 3.2 Pro, deliver information for the analysis of the proposed variables, in such way that the user of this methodology, from his own interests, could rely on objective facts to take a decision in relation to a certain typology of components of the casing.

In the specific case analyzed in Chile, it is possible to observe and demonstrate that the cost of implementing improvements in the walls typology of a housing, can really be amortize in a prudent time in view of the savings of energy that take place, even without considering the economic appraisement of obtaining more healthy environments for the users and of an awaited less deterioration of the different components of the housing.

Finally, its been possible to verified the impact that has the humidity on the materials and therefore on the elements of the casing of a housing, which does significantly to incorporate this kind of analysis at the moment of defining a certain construction typology for a housing, in a climate with specific characteristics of temperature, relative humidity, rainfalls, solar radiation and wind direction and speed, among other relevant parameters.

ACKNOWLEDGEMENT

This document would not have been possible to realize without the work and support of the Civil Constructors, Maria Macarena Celis C. and Maria Alejandra Aranda C. and of the School of Civil Construction, Pontifical Catholic University of Chile, Santiago, Chile

Likewise, it is grateful the guide and support of the teacher André de Herde, of the team of Architecture and Climate of Lovaina's Catholic University in Belgium.

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