Comportamiento Térmico de Muros Expuestos a Fenómenos de Humedad: Método de Análisis

Thermal Behavior of Walls Exposed to Moisture Phenomena: Method of Analysis

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Abstract

The research studies the moisture problem in buildings. A methodological model which evaluates and compares the hygrothermal behavior in external walls under natural humidity conditions has been developed. Therefore, two softwares are used, WUFI 3.2 Pro and TRNSYS 15. With this model a house of 85 m^2 placed in five different cities of Chile is analyzed. The analysis is centred in the integral evaluation of the following variables: interior room temperature; thermal comfort model of PPD and PMV (Fanger's Theory); humidity content in external walls throughout the time; conditions for the growth of mould and energy demand of the house.

At the beginning, the evaluation was made in concrete and masonry exterior walled houses, which were typically used in Chile. Then, two alternatives of new constructive solutions were proposed for each type of traditional building materials, adding materials able to decrease the humidity inside the walls and also reduce the thermal transmittance, which improve the comfort conditions in the house.

Key words: moisture, thermal, energy.

Resumen

La investigación estudia el problema de humedad en construcción. Se ha desarrollado un modelo metodológico que permite evaluar y comparar el comportamiento higrotérmico de muros externos bajo condiciones naturales de humedad, para esto se utilizan dos programas computacionales, WUFI 3.2 Pro y TRANSYS 15. Con el uso de este modelo se analiza una vivienda de 85 m^2, ubicada en cinco ciudades de Chile. El análisis, esta centrado en la evaluación integral de las siguientes variables: temperatura interior de los recintos; modelo de confort térmico de PPD y PMV (Teoría de Fanger); contenido de humedad en los muros externos a través del tiempo; condiciones para el crecimiento de mohos y demanda de energía de la vivienda.

Al inicio, la vivienda es evaluada con dos materiales utilizados típicamente en la construcción de muros en Chile: albañilería de ladrillos y hormigón. Luego, se proponen dos alternativas de nuevas soluciones constructivas para cada tipo de construcción tradicional, incorporando materiales que permiten disminuir la humedad en el interior de los muros y también reducir la transmitancia térmica, lo cual mejora las condiciones de confort de la vivienda.

Palabras clave: *humedad, térmico, energía.*

1. Introduction

One of the problems that influences negatively in the comfort of the users of housings, is the humidity which rises from the outside as much as from the interior of the house, besides the damage that can cause. Therefore many investigators of industrialized countries of Europe and North America, have studied the origin, causes and consequences that generate the humidity problem in the houses, which has meant, in addition, that the phenomenon of transference and humidity storage in building materials has been considered as 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 of houses placed in different cities of Chile, exposed to the climatic conditions, 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 computational programs validated in different studies of 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 essential parameter and it's necessary that in cases where the behavior of the material under natural conditions is analyzed, the dependency of this conductivity in regard to the humidity content that has the material is considered. It is necessary to mention that the value of the thermal conductivity also depends on other factors, for example, the temperature, but this study is centered on the repercussions that the humidity has on the building materials. Thus, in order to calculate 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

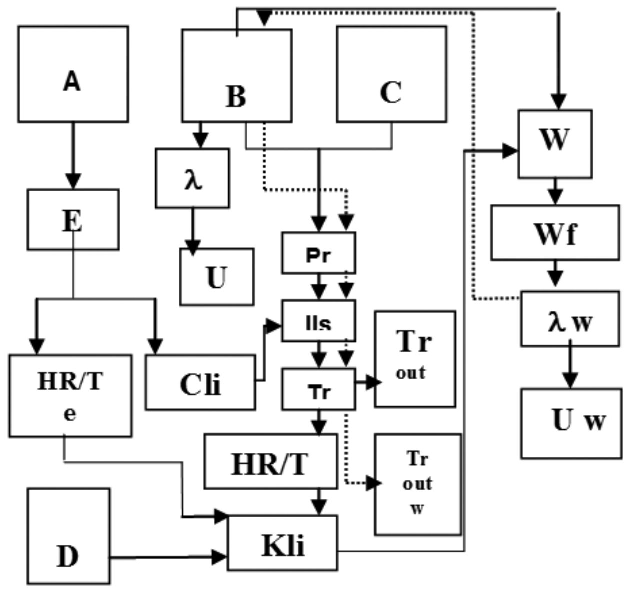
w : humidity content

ρs : density of the dry material

The factor of additional conductivity induced by the humidity "b", indicates the percentage of increase of thermal conductivity by the percentage of increase of humidity mass, in a building material. This value depends on the kind of material, that is to say, in one hand 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.

In organic insulators, in general, there is not a linear relation between thermal conductivity and humidity content, but it can be mentioned specifically for the expanded polystyrene, that the value of the thermal conductivity is not affected until the material absorbs about 50 kg/m^3 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].

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/Te : 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
Ils : entrance of information to subprogram of TRNSYS, IIsibat
Tr : entrance of information to program TRNASYS
HR/Ti : 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

3. Methodological model

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

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 hygrocospicity, 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, which are all 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

4. The studied case

The methodological model described before was applied in the case of Chile. There for, a house and a family with its 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 necessary to indicate, that in the case of Chile, when it was not possible to count on hour climatic data bases, it was necessary to use the software METEONORM (see Figure 1), which develops an hour data base for the required city based on climatologic data averages.

4.1 The studied house and its users

A house with an 85 m^2 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/livingroom/dinning room : south/west/north

Table 1 *Thermal zone, insulation and U–value*

Thermal zone	Thickness of insulation –attic–	U–value –attic– (W/m^{2}K)	U–value –walls– (W/m^{2}K)
Santiago	80 mm	0,47	1,90
Valparaíso	60 mm	0,60	3,00
Concepción	100 mm	0,38	1,70
Valdivia	120 mm	0,33	1,60
Puerto Aysén	160 mm	0,25	0,60

Besides the walls subjects of analysis, the house is composed by: carpet (dormitories) and ceramics (other enclosures) pavements over the concrete floor; drywall inner partitions; drywall 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 frames and the doors are made of wood.

The users of the house correspond to a family group composed by 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 on the type of energy that they use, 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 at Table 2.

In addition, is possible to observe the general climatic characteristics of each city (Table 3).

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, which is all described next:

Table 2 *Cities selected in Chile*

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

Table 3 *Climate of cities selected*

City	T° (°C) minimum annual	T° (°C) maximum annual	T° (°C) 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
Puerto Aysén	-6,0	30,0	9,8	87

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, therefore, for the cases 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

As it's observed in both graphics (Figures 2 and 3), the dependency of the thermal conductivity and therefore in the thermal transmittance, in relation to the humidity content is evident, even more if it is considered that is a city with a high precipitation level in the autumn–winter period, but that nevertheless it 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.

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

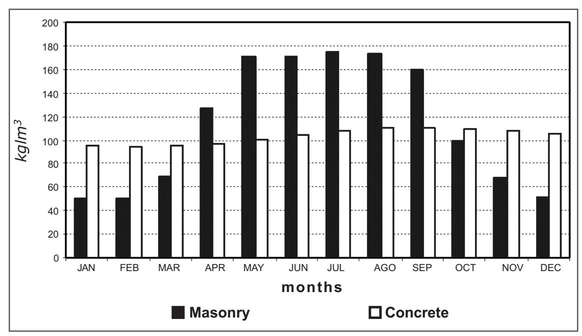
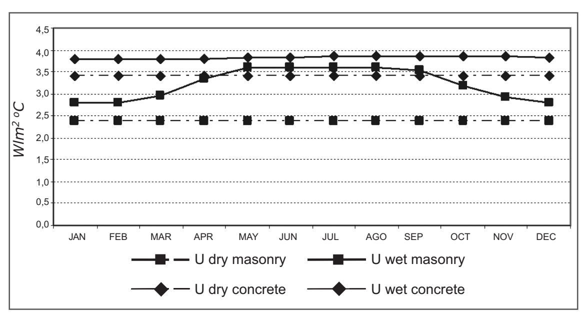


Figure 3 *Thermal Transmittance in traditional walls in Valdivia (W/m²°C)*



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

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 furthermore, 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 increase considerably the requirements of heating for the masonry.

Table 4 *Annual difference of heating demand (kWh/m^2), considering the house with dry and humid walls*

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

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

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 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, because of 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 0,1°C up to 2,2 °C 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 4,5°C and 38°C and the

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

Station	Traditional 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	Traditional Masonry	Masonry with interior insulation	Masonry with exterior insulation
Summer	17,2%	5,3%	1,9%
Winter	51,7%	12,3%	1,9%

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, when a heating system is to be considered, the propitious condition of relative humidity disappears, this happens because when the temperature of the enclosures is raised, the air contained in them is able to sustain a major quantity of water steam, minimizing with this the risk of the development of microorganisms in the inside.

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 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.

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.

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