Modelling of rising damp in historical buildings

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ABSTRACT: The conservation of historical buildings assumes, nowadays, a considerable importance and it has had a great development in these past few years. We can say that among all the different kinds of manifestations of dampness, rising damp in historical buildings is an important one and is the cause of:

-The destruction of stone materials due to the cycles frost/defrost and to the presence of salts associated to the crystallization;

-The decay of the elements in contact with the stone halls, such as wood beams, wood ceilings and other finishings;

-The insalubrity caused by the excess of humidity associated to the development of fungus and mould.

In order to select the best treatment to apply, it becomes indispensable to assess the hygrothermal behaviour of building components through computational programs that allows a two-dimensional analysis of the simultaneous heat and moisture transfer.

In our paper we intend to show the results of same simulations of rising damp in historical buildings, as well as analysing the influence that the material properties and the interior and exterior climatic conditions have in this phenomenon.

1 INTRODUCTION

Since experimental investigations are rather expensive and time-consuming, there is an increasing interest in use calculative methods in order to assess moisture behaviour of building components. Computational programs like WUFI 2D – developed at the Fraunhofer Institute for Building Physics – allows a two-dimensional analysis of the simultaneous heat and moisture transport in building components, which is the best approximation to rising damp. Nevertheless, for a correct simulation, several material properties are needed, such as bulk density, porosity, heat capacity, thermal conductivity, vapour diffusion resistance factor, moisture storage function and liquid diffusivities.

Beside the correct material properties the indoor and outdoor climatic conditions are very important for an accurate simulation.

In our study we simulated the behaviour of the walls face up to rising damp by doing several simulations under the pattern showed in figure 1.

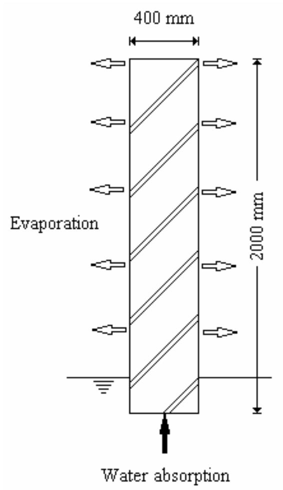


Figure 1: Schematic diagram showing the masonry stone test piece

2 SIMULATION MODEL

2.1 Introduction

The theorical study of moisture and heat transfer in porous building materials has always been of great interest. In the last decades several theories have been developed, most of them based on fluid mechanics using the laws of mass – Fick and Darcy, and heat diffusion – Fourrier [2].

V. Freitas, in 1992 [6] developed a computer program, Trhumidade, based on Luikov and De Vries model, which has been, until now, the main tool for the work developed at FEUP in the study of moisture and heat transfer in porous building materials.

There is no unanimity about potentials for the moisture transport. Most calculation models, like Trhumidade, used the moisture content. But due to the fact that the moisture content is a non-continuous function the models appear to be outdated.

One of the advantages of the chosen model –WUFI-2D- is that the relative humidity serves as driving force for vapour and liquid transport [3]. The other advantage is that the required material data are easy to measure.

The program WUFI is based on the following equations:

$$\frac{\partial w}{\partial j} \cdot \frac{\partial j}{\partial t} = \nabla .\left(D_j \nabla_j + d_p \nabla \left(j\, p_{sat} \right) \right) \tag{1}$$

$$\frac{\partial H}{\partial T} \cdot \frac{\partial T}{\partial t} = \nabla .\left(l \nabla T \right) + h_v \nabla .\left(d_p \nabla \left(j\, p_{sat} \right) \right) \tag{2}$$

where: j - relative humidity, T - temperature, w - moisture content, p_{sat} - saturation vapour pressure, l - thermal conductivity, H - total enthalpy, D_j - liquid conduction coefficient, d_p - vapour permeability, h_v - latent heat of phase change.

On the left side of both equations are the storage terms. The fluxes on the right hand side are both equations effected by heat and moisture. Due to the close coupling and strong no linearity of both equations, their descretization is done by a fully implicit volume scheme with variable gird spacing.

2.2 Material properties

For a correct solving of the equations several material properties are needed: bulk density, porosity, heat capacity of dry material and its moisture dependence, vapour diffusion resistance factor, moisture storage function respectively water retention function and liquid diffusivities.

Most of these material properties are easy to determine or can be found in literature [7]. Only for the determination of moisture storage function and the liquid diffusivities coefficients more extensive experiments are needed. The moisture storage function can be determined by sorption measurements at different relative humidities, for the hygroscope range. For relative humidities above 95% we use the pressure plate method. To achieve a correct determination of the water absorption and redistribution profiles, which are needed for the determination of the liquid transport coefficients, we must use the nuclear magnetic resonance method or the gamma ray attenuation method.

But, if they are not known, approximations based on standard material properties can be introduced, which in numerous cases describes the moisture behaviour with sufficient accuracy.

The moisture storage function can be approximated with the following equation [2]:

$$w_j = w_f \cdot \frac{(b-1).j}{b-j} \tag{3}$$

where: w - water content, w_f - capillary (free) water saturation, j - relative humidity

The parameter b can be calculated using equation (4)[2]:

$$b = 0.8.\frac{w_{80} - w_f}{w_{80} - w_f .0.80} \tag{4}$$

where: w_f - capillary (free) water saturation, w_{80} - practical moisture content at 80% relative humidity

In many cases, the increase of liquid transport coefficient, D_{ws} with increasing moisture content can be described by an exponential function. The relation between D_{ws} and the A-value (water absorption coefficient), can be described by the following equation:

$$D_{ws}(w) = 3.8\left(\frac{A}{w_f}\right)^2 .1000^{\left(\frac{w}{w_f}\right)^{-1}} \tag{5}$$

where: D_{ws} - liquid transport coefficient for suction, w moisture content , w_f - capillary (free) water saturation

For the liquid transport coefficient of the redistribution no simplification was found yet.

2.3 Climatic boundary conditions

Beside material properties, for a correct simulation, we need to know the climatic indoor and outdoor boundary conditions. As outdoor conditions we need to know the hourly mean values of temperature, relative humidity, solar radiation and precipitation. As indoor conditions we need to know the hourly mean values of temperature and relative humidity, or we can approximate them with sinus functions.

As outdoor conditions we used the climate of Lisbon, according the “reference year” (year of hourly values of appropriate meteorological parameters representative of a long term climate), which was provided by IM. In figure 2 we show some of the used data:

As indoor conditions we approximated with sinus functions, like the ones we can see in figure 3.

After compilation of all this data we are ready to start calculation from initial temperature and moisture conditions. At each time step the heat and moisture transport equations are solved consecutively with a continuous update of the transport and storage coefficients until the convergence criteria is achieved.

The output data is the calculated temperature and moisture fields, as well as the heat and moisture fluxes at the surfaces of the building component.

3 CALCULATION RESULTS

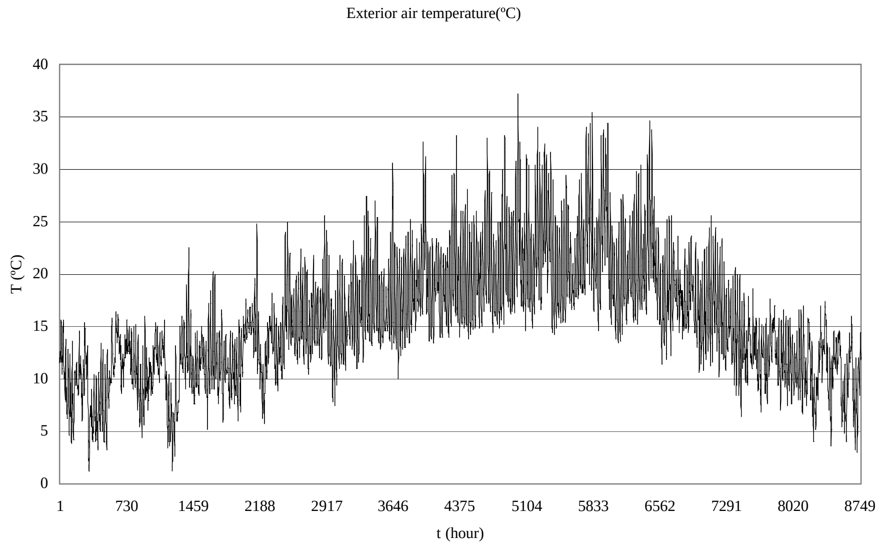
Until now, we made about seventy different calculations and we are going to present some of the most important results that we obtained.

Our main objective is to study the rising damp in the halls of historical buildings.

We began our work by considering naked halls exposed to the exterior climate of Lisbon, facing west and an interior climate approximated with a sine wave varying between 20ºC, 60%HR in winter and 22ºC, 30%HR in summer, average hourly values of the recorded climatic parameters were used. The simulation periods began on the January 1st and stopped the December 31st.

Maintaining the size of the walls, the interior and exterior boundary conditions and the duration of the simulation we made several simulations with different kinds of coverings in the interior face:

-interior plaster (gypsum plaster)
-cement plaster
-tiles
- tiles until 600mm and gypsum plaster



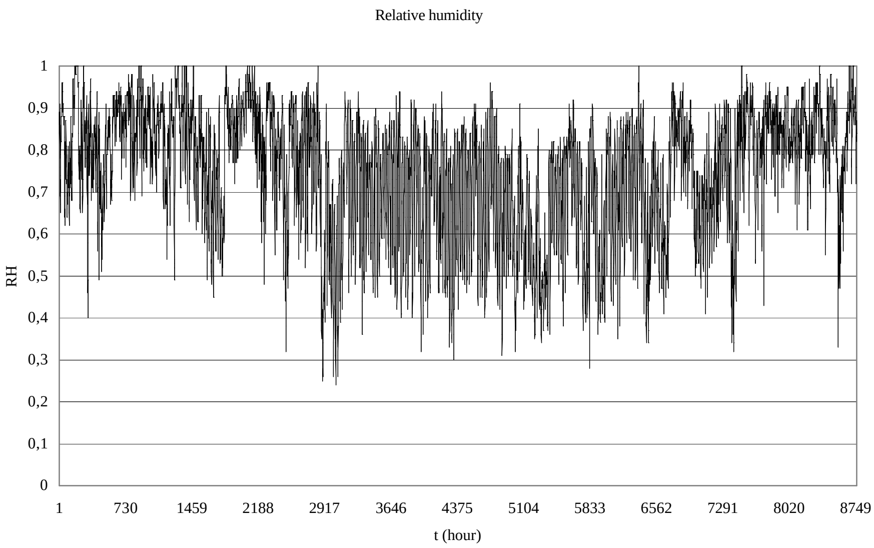


Figure 2: Same of the exterior climatic data of Lisbon

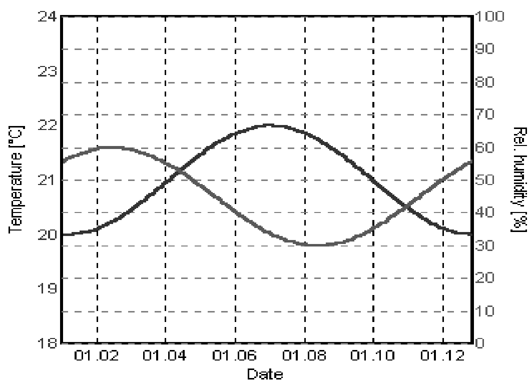


Figure 3: Interior climatic conditions approximated with sinus functions [3]

In figure 4 we can see the shape of all the samples we simulated:

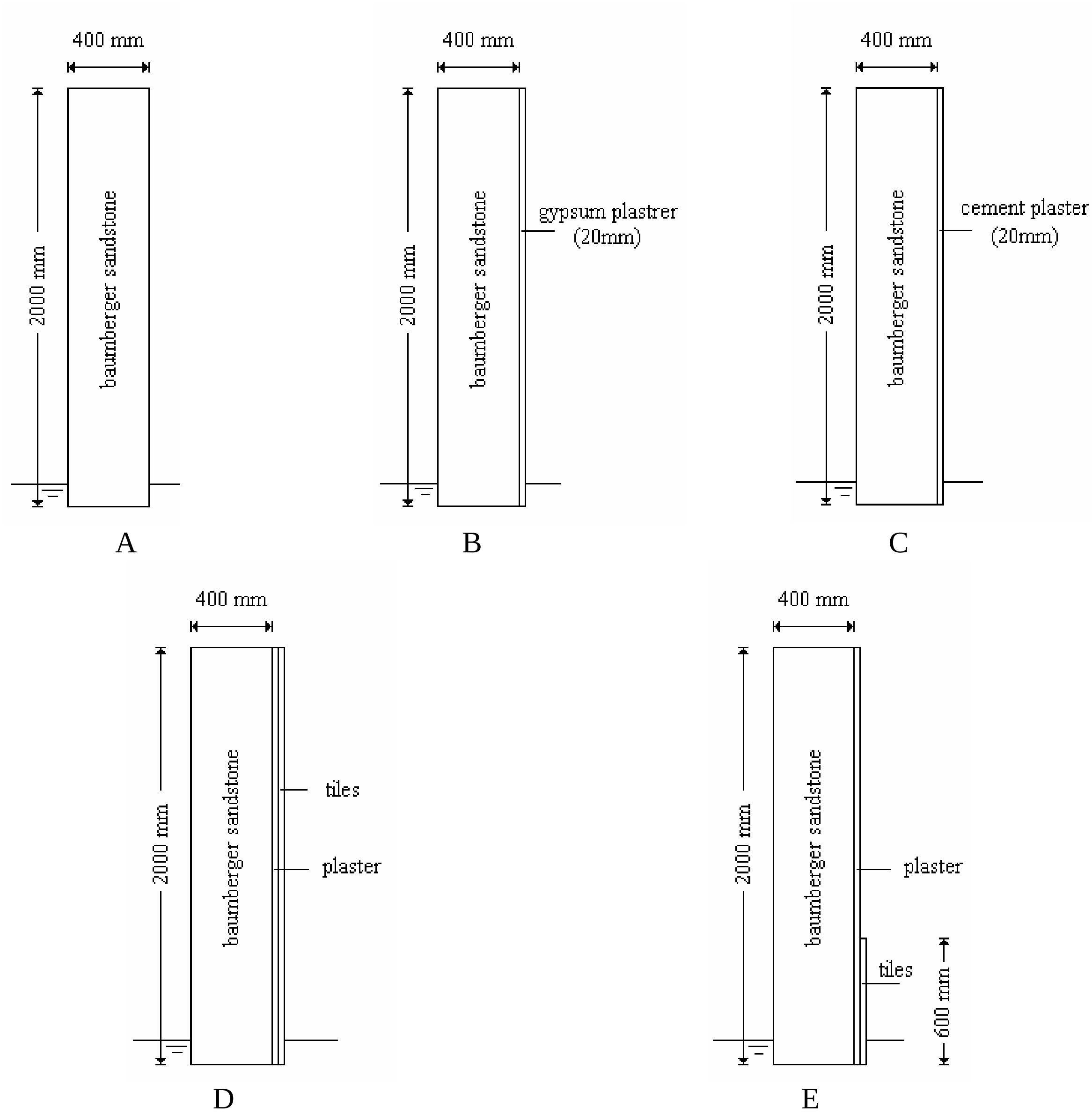


Figure 4: Different kind of coverings of the interior face

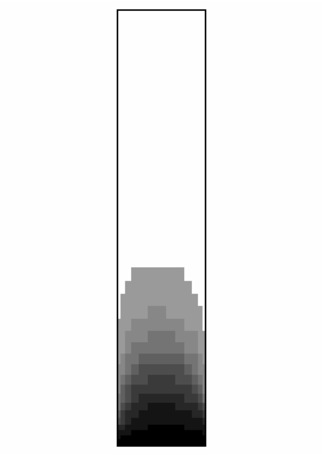
After the simulations, and in order to obtain a better analysis of the results we made some comparative graphics of the distribution of the water content along the height of the walls at the middle section. Those graphics were executed on the December 31st. We made also some comparative graphics of the evolution of the water content along the 8760 hours of the simulations. All the graphics were made for each kind of covering.

We will show some of the results that we obtained for one kind of natural stone: baumberger sandstone

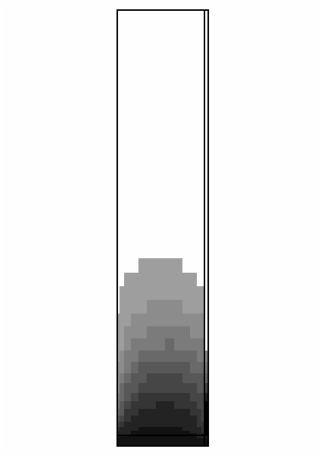
In figures 5, 6 and 7 we can see, respectively, the distribution of the water content (kg/m^3) over the cross section, along the height of the walls, after one year, the distribution of the water content along all the height of the sample at the middle section and some graphics showing the evolution of the water content of the stone along the whole year.

From those first simulations we can already draw same conclusions:

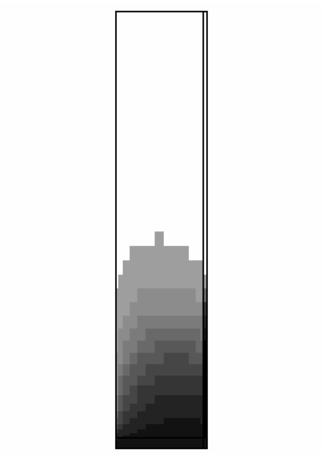
For all the kinds of stone, the naked wall is the better solution. We confirmed that the naked walls were those with lower rise heights and lower water content, followed, by increasing order, the walls with interior plaster, the walls with cement plaster, walls with tiles until 600mm and the walls with tiles. In a certain way those were the expected results: as far as we difficult the evaporation with a covering the rise height grows until a new equilibrium between the water that comes in by capillarity and the water that goes out by evaporation is reached. In fact we verify that as far as we put coverings with higher diffusion resistance, the absorbed water rises.



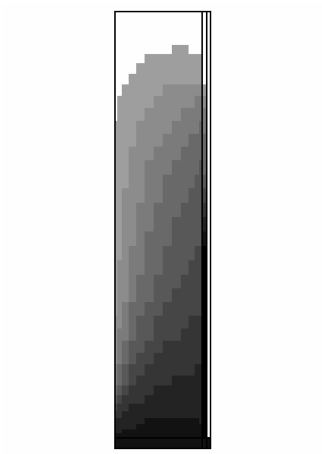
A) naked



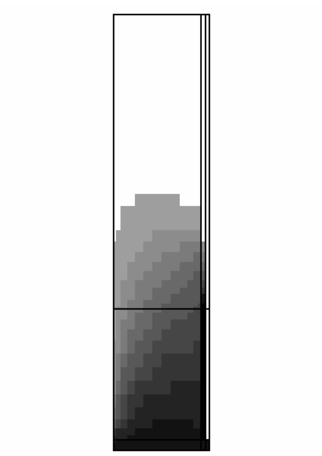
B) interior plaster



C) cement plaster



D) tiles



E) tiles until 600mm

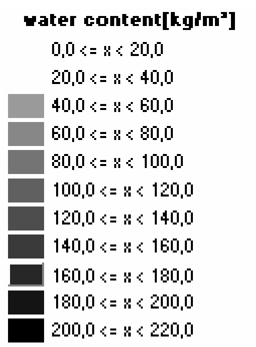


Figure 5: Distribution of the water content in the wall of baumberger sandstone after 1 year

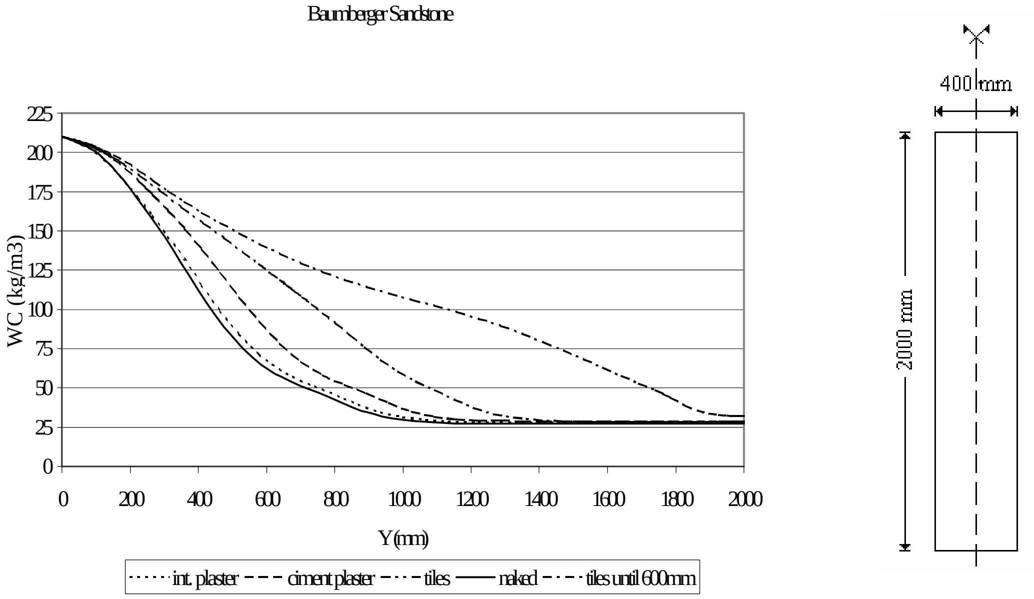


Figure 6: Comparative results of the distribution of the water content along the height of the walls, at the middle section, for baumberger sandstone

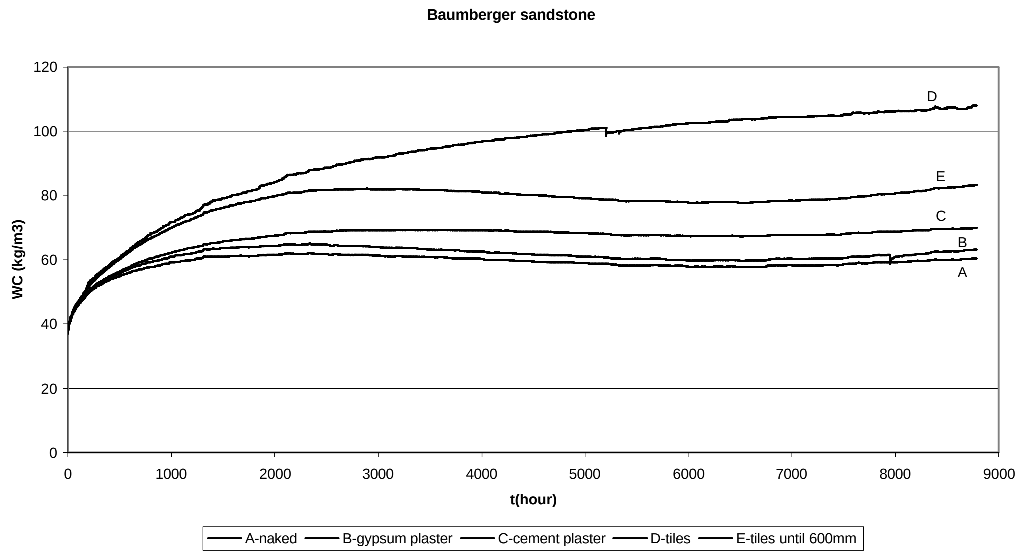


Figure 7: Comparative graphics of the distribution of the water content along the 8760 hours

After analysing the configuration of the building elements we are going to analyse the influence of the boundary conditions on rising damp.

We made some simulations with the exterior climate of IBP/Munchen, whose results are showed in figure 8.

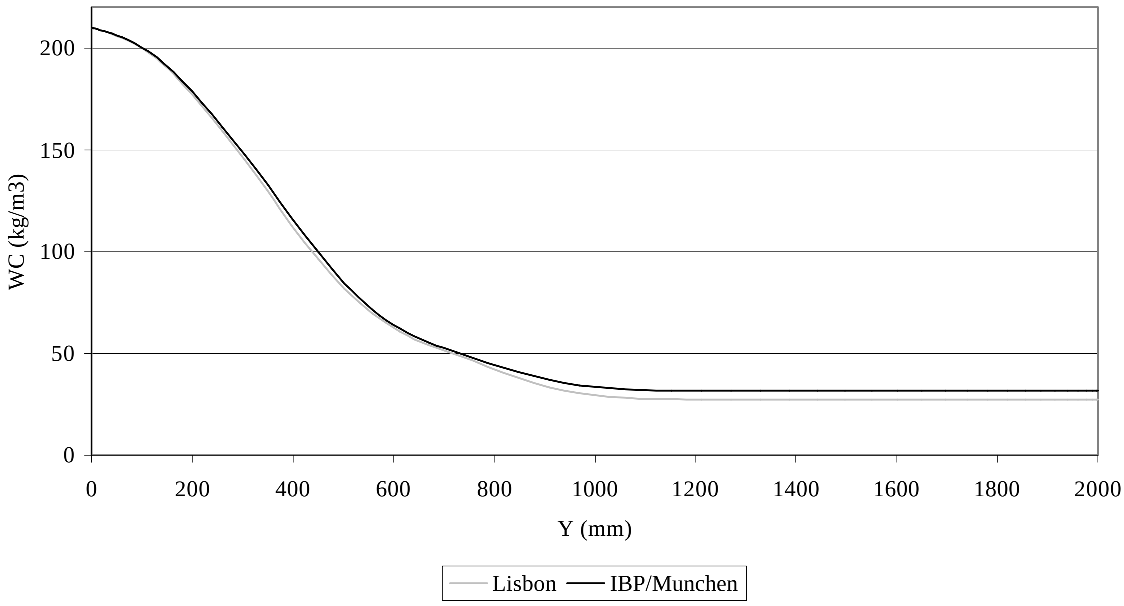


Figure 8:Comparative results of the distribution of the water content along the height of the wall, at the middle section

Finally, to analyse the influence of the interior climatic conditions we made same simulations with both faces of the samples exposed to three different interior climatic conditions. All interior climates were approximated with a sine wave, the first one (X) varying between 20ºC, 60%HR in winter and 22ºC, 30%HR in summer, the second one (Y) varying between 13ºC, 95%HR in winter and 17ºC, 75%HR in summer and the third one (Z) varying between 27ºC, 40%HR in winter and 23ºC, 20%HR in summer.

As we can see in figures 9 and 10 when we increase the relative humidity and decrease the temperature (climate Y) the rise height increases, whereas when we increase the temperature and decrease the relative humidity (climate Z) the rise heights decreases.

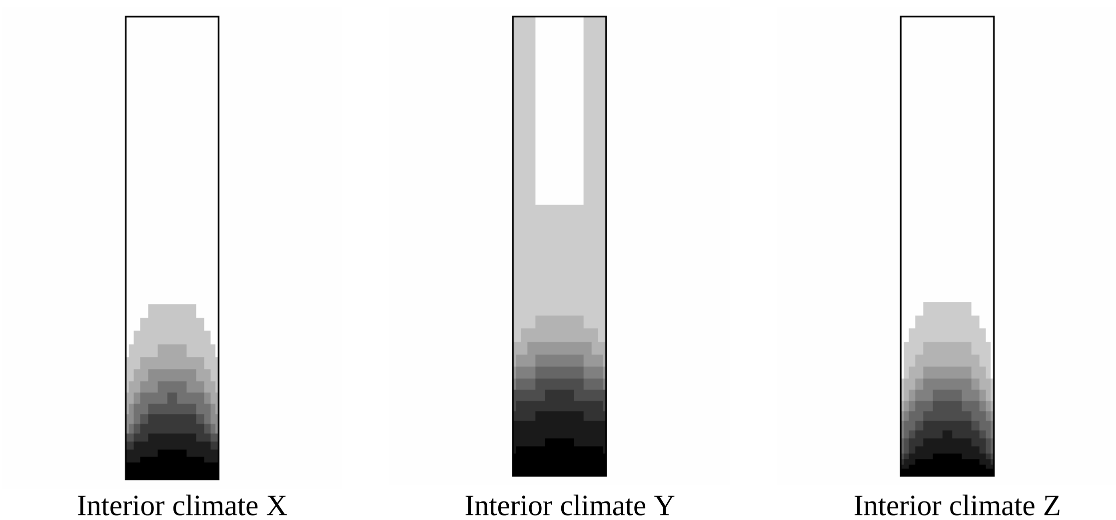


Figure 9: The influence of the interior climatic conditions, after 1 year

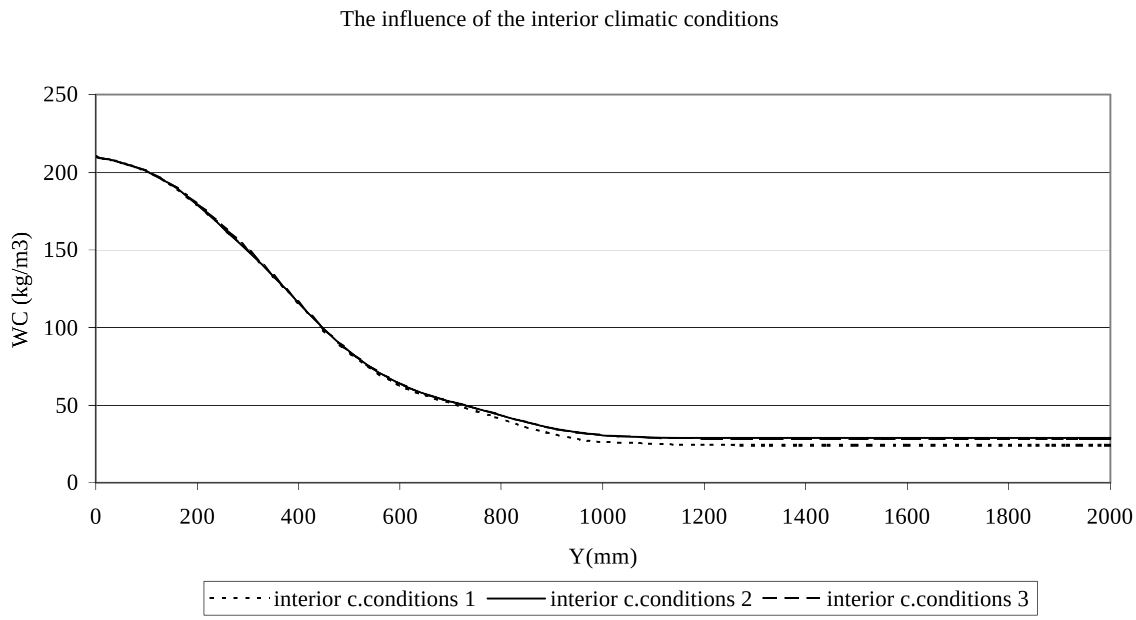


Figure 10: The influence of the interior climatic conditions in the values oh the water content

4 CONCLUSIONS

This study is part of a more wide investigation. The main goal of this work is to evaluate the influence of the material properties and the climatic conditions in rising damp in historical buildings.

The simulations made until now shows:

-the placement of impermeable materials leads to the rise of the height achieved by rising damp;

-the interior relative humidity is one of the responsible elements for the drying of walls, that's why for high relative humidities we have high rise dampness.

In the investigation made until now we have only analysed homogeneous materials, without joints. In the future in are going to introduce in our samples same horizontal and vertical joints.

To proceed our investigation we intend to measure the interior climatic data of some Portuguese historical buildings, the exterior climatic data of some other cities then Lisbon, namely Porto and Coimbra and to research the properties of materials used in Portuguese buildings.

We expect to analyse the behaviour of the different kinds of treatment techniques of rising damp.

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