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NUMERICAL SIMULATION OF RELATIVE HUMIDITY IN A MASONRY WALL APPLYING THREE DIFFERENT WATERPROOFING MEMBRANES

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Abstract

The analysis by numerical simulations can be applied to building materials subjected to different climatic conditions to envisage the influence of environmental factors in terms of drying time, water absorption and thermal performance of materials. Currently there is a wide variety of new building materials used for insulation, waterproofing and rehabilitation, each contributing in a specific way to constructions improvement during their service life. In time, every building is subjected to degradation due to the action of environmental factors. One of these is water due to its continuous acting under all forms of aggregation: vapour, liquid, solid, each having particular influence on the building's elements. The present paper highlights a numerical simulation of hygrothermal waterproofing characteristics for three different membranes applied on a brick masonry basement wall. The simulation was performed using WUFI2D 3.2 computer software. The information extracted from the analysis results made reference to the materials performance while subjected to moisture transfer processes.

Key words: capillary rising, drying masonry, rehabilitation, waterproofing membrane

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1. Introduction

Nowadays, due to population increase and lack of space for new buildings, civil engineers tend to build on vertical or below natural ground level. The increasing use of underground structures like tunnels, communication vaults, basements, elevator pits, missile silos, control rooms etc., is directly proportional to a high interest in the area of waterproofing, energy conservation, thermal envelope, thermal comfort etc. (Butt et al., 2016; Collepardi, 1990).

Considering the variety of structural degradation factors, water can cause direct or indirect damage to buildings, affecting not only the structural part, but also the health and life quality of the occupants, by mould formation, mildew, etc. Another issue of high interest nowadays and closely related to water action on constructions, is the reduction of carbon dioxide emissions. Wet building components mean low thermal resistance of the elements, higher heat loss and carbon dioxide emissions in the atmosphere. This is the result of different fuels combustion used to provide heat in cold seasons for a construction (Gabor et al., 2017; Künzel, 1995).

Based on the above considerations, the main purpose for engineers should be to prevent water from penetrating the building elements or to reduce their water content in order to minimize the damages. The literature presents two main forms of moisture in building elements: one is the liquid form, as a result of rain or rising damp, the second one is water vapour on the surface or inside the element. Fig. 1 shows a schematic distribution of moisture in an exterior wall.

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The objective of this paper is to simulate the rising damp and water penetration phenomenon using computer software WUFI 2D 3.2., developed by Fraunhofer Institute for Building Physics in Holzkirchen, Germany. It was used to analyze the hygrothermal behavior, in terms of water content and relative humidity, of a basement wall considering that on the external surface three different waterproofing membranes were applied.

WUFI 2D 3.2 software calculates the coupled heat and moisture transfer in building components. It evaluates the transient heat and mass transfer in two dimensions. The mathematical model in the software is described by differential equations for heat and moisture transfer. The finite volume method is used to discretize the differential equations and iteratively solve them. For heat transfer, the software considers the thermal conduction, short wave solar radiation, long wave radiation cooling and enthalpy flows through moisture movement with phase change. For moisture transfer, the program takes into account vapor, solution and surface diffusion, but also the capillary suction. Convective heat and moisture transport are disregarded (Ramos et al., 2010).

Waterproofing is a relatively impervious membrane, coating or sealer used in a concealed location to prevent water from entering or passing through either horizontal or vertical building elements. Waterproofing is designed to exclude water even more in the presence of hydrostatic soil pressure (Biggings, 1990; Spranceana et al., 2017).

The lower parts of walls and other ground supported structures absorb water through the pore system by capillary suction of ground moisture, rain and condensation of air humidity (Hall et al., 2007). Rising damp is by far the most important cause of moisture in masonry materials (Guimarães et al., 2012), which leads to the materials decay. Another important aspect of wetness in walls is the balance between the water absorbed by capillary forces and the loss of evaporation (D`Agostino, 2013). Fig.2 below presents the most common manifestations of moisture in building elements.

The building structures, in direct contact with the ground, can also be affected by water penetration if the water table rises and under pressure causes dampness or leaks into the structure.

2. Material and methods

The process of moisture transfer in porous media, particularly for building materials, is due to vapour diffusion, convection and water content (Martin et al., 2009; Ramos et al., 2010).

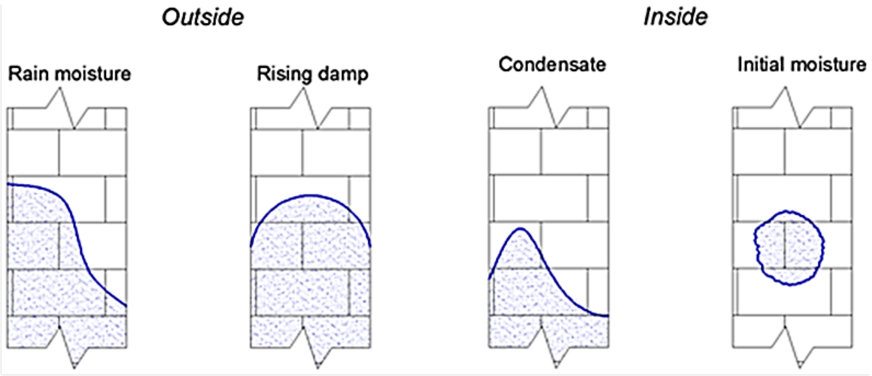

Fig. 1. Schematic distribution of moisture in an exterior wall (updated upon Künzel, 1995)

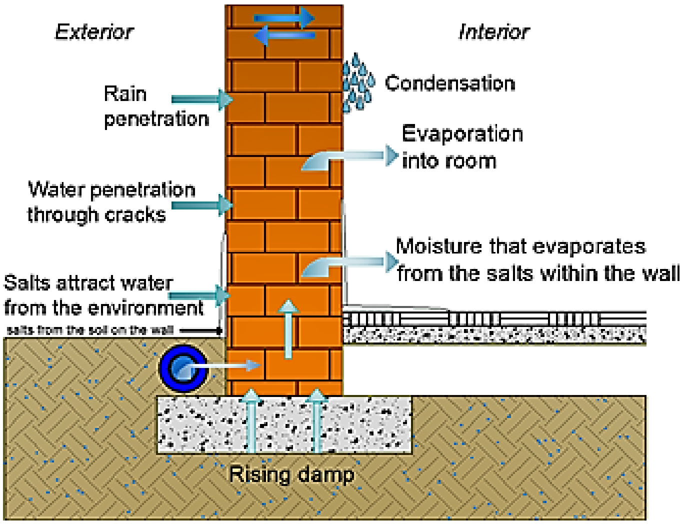

Fig. 2. Typical causes of damp on wall (updated upon Guerra, 2011)

Another feature of importance for underground building elements is the influence of ground water. The soil permeability and high hydrostatic pressure of ground water can determine a significant pressure on both underground walls and underground floor slab. Thus, it is necessary to create a continuous and impermeable membrane for all external underground walls and floors, in order to prevent infiltration.

Generally, the numerical simulation of hygrothermal performance for a building element implies, at least, defining the enclosure geometry (the building macro and micro details and enclosure assembly), material properties (bulk density, porosity, specific heat capacity, thermal conductivity, vapour permeability and diffusivity, water absorption coefficient etc.) and boundary conditions (interior and exterior environment, interaction between interior/exterior environment and enclosure, boundary conditions between elements) (Baghban et al., 2010; Plagge et al., 2007; Ramos et al., 2010)

The paper objective was to evaluate the quantity of water content accumulated in 10 years by a foundation wall. In order to do this, it was considered a 2.2 m high brick wall, half of it in direct contact with saturated soil. Four numerical simulations have been applied. First, it was considered a basic case, meaning no waterproofing materials applied on the wall. After that, three different case studies have been modelled, consisting in application of different membranes on the exterior surface of the wall and on the entire high of 40 cm of the foundation. It must be mentioned that a single damp-proof component layer was applied without considering the other waterproofing systems (thermal insulation, vapor barrier etc.).

It is very important to define correctly the boundary and transient conditions in the design of the envelope elements. The WUFI 2D 3.2 software allows the user to either select the climatic parameters from a database or to introduce them manually. The basic climatic parameters under consideration are: ambient temperature, air moisture, influence of solar radiation, rain, speed and wind direction (Martin et al., 2009; Ramos et al., 2010). The input data for the temperature and relative humidity of hygrothermal environmental loads can be seen in Fig. 3.

Because of the negative impact of plastics and rubbers on the environment after their life cycle three waterproofing membranes were chosen for analysis; they are characterized below. It is estimated that the worldwide plastics production increased to 260 million tons in 2007 and thus the need for the recycling of these materials has also increased (Navarro et al., 2010). The main reason for the selection of these materials for analysis is that they can be obtained from recycled resources.

2.1. Polyethylene membrane

High polymer polyethylene waterproofing membrane is composed of extruded PE membrane with polypropylene fibbers covering both the sides of the core membrane as a reinforced layer in order to create larger friction and increase the adhesion with the concrete (Liang, 2005).

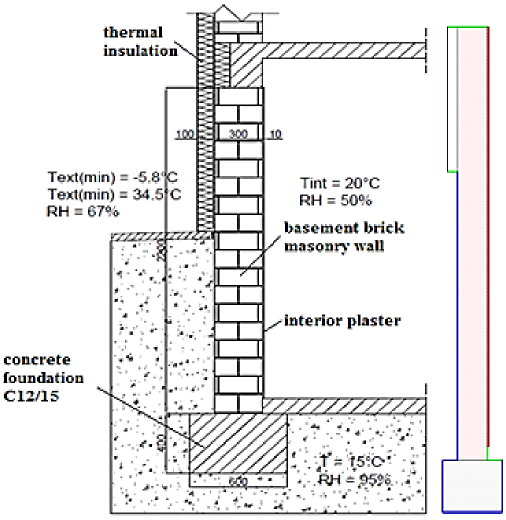

Fig. 3. Wall structure and computation scheme

2.2. Atactic polypropylene plastomeric membrane

Atactic polypropylene plastomeric (APP) membrane uses, as main component, polyester reinforcement or fiber glass and covers the insulation materials as polyethylene, sands, or gravels. This membrane is composed of a specially formulated bituminous compound of distilled asphalt modified with selected high grade viscous-elastic polymers. It is covered on both sides with protective heat sensitive polythene; this type of membrane has an excellent resistance to chemical attacks and atmospheric agents (Gubbie, 2012).

2.3. Rubberized asphalt membrane

Rubberized asphalts are composed of polymeric rubber, asphalt and solvent. A rubberized asphalt membrane is made up of asphalts, oils, fillers, natural or synthetic rubbers, thermoplastic resins and antioxidants. The asphalt content contributes to the thermoplastic, hydrophobic and adhesive properties of the system. The rubberized asphalt membrane includes the following characteristics: speed of application, flexibility at very low temperatures, no storage problems, immediately functional, few weather restrictions for the application, self-sealing and relatively good elasticity and adhesion (Biggins, 1990).

3. Results and discussion

The case study of the present paper considered the exterior basement wall, constructed of brick masonry, which is in direct contact with earth and water with hydrostatic pressure. It has been considered for analysis a wall thickness of 300 mm, complemented by a normal lime cement plaster on the interior surface, of 10 mm thickness, and polystyrene expanded on the exterior, with thickness of 100 mm (Ciornei, 2000). The waterproofing membrane, considered in the analysis, has been applied on the external side of the underground foundation wall and on the concrete foundation in a continuous layer.

The water vapor resistance factor, commonly called μ-factor, is a dimensionless number describing a material or product resistance to water vapour passage as compared with an equivalent thickness of air. Thus, high μ-factor means higher resistance to water vapour transmission. Water storage in the structure depends on relative humidity (RH), which influences also the thermal conductivity, water suction and redistribution (Zarate et al., 2013).

In Fig. 3, near the wall structure image, the computation scheme can be observed highlighting in coloured line the boundary conditions. The interior climate was modelled by a sine wave with a 20°C temperature and 50% relative humidity. These values correspond to a normal moisture transfer (Holm et al., 2000). The correspondent color of indoor climate is red. Analogously, it was defined the external climate, with a value of 5.8 °C for the winter period and 34.5°C for the summer, with 67 % RH. It is highlighted with brown color. The soil was considered at 15°C temperature, RH equal to 95% and the corresponded color blue.

From the WUFI 2D 3.2 software database the material properties of the three waterproofing membranes used mostly in waterproofing system have been extracted. Below some general properties of the considered membranes are presented and the material parameters are tabulated in Table 1. The values of hygrothermal for building materials are tabulated in Table 2. The moisture behavior in the wall has been considered and evaluated for a 10 year time period. Fig.4 shows fields of water content and relative humidity for a basic case, which demonstrates the structure potential to absorb water. It can be noticed that after the impregnation of the entire part of the wall in contact with ground the water level increased above the ground level.

If the water content is increasing then also the relative humidity, the velocity of suction and redistribution and the thermal conductivity are increasing. This means that wet structures can have large thermal leakages. So, it is important to know the distribution of the temperature inside the wall.

The basic case evaluates the moisture quantity that can be absorbed by a normal structure over a 10 year period, without using any damp-proof systems. Fig. 4 presents the moisture level rising up to 1.85 m (indicated in figure by an arrow) on basement masonry wall. Fig. 5 graphs highlight the continuous growth of water content in the analyzed time period, reaching a total water content of approximately 80 [kg/m^3].

The following step in the analysis was to consider three different waterproofing membranes in order to establish the case in which the water content is more reduced than the basic case.

3.1. Case 1: basement wall with polyethylene membrane

For this particular case, the investigations implied the application of polyethylene membrane, on the external side of the basement wall and extended to the foundation. The ambient conditions are the same as for the basic case. The results can be seen in Fig. 6. The water height in this case was 1.72 m on the entire basement wall. Since in the base case, the water level was 1.85 m, this means that by applying this damp-proof component layer the water level content has been reduced by 13 cm.

Fig. 7 presents the increase of total water content over 62.6 [kg/m^3] unlike the basic case where the water content surpassed 70.1 [kg/m^3].

3.2. Case 2: basement wall with atactic polypropylene plastomeric membrane

The water height in this case is 1.65 m on the entire basement wall. As compared with the basic case, where the water level was 1.85 m, resulted that, by applying the damp proof component layer, the water level has been reduced by 20 cm. As compared to the other analysis performed, this method seems to be the optimal solution. The results can be seen in Fig. 8. Fig. 9 presents an increase in total water content over 53 [kg/m^3] as compared with the basic case, where the water content was over 70.1 [kg/m^3] and polyethylene, where the water content was over 62.6 [kg/m^3]. The distribution of the relative humidity is graphically represented in Fig. 9 during the entire considered period.

Table 1. Hygrothermal parameters of materials used for study (Găzdaru and Manea, 1999)

Material	*Polyethylene membrane*	*APP membrane*	*Asphalt membrane*
Density [kg/m^3]	130.0	65.0	824.0
Porosity [-]	0.001	0.001	0.001
Specific heat capacity [J/kgK]	1500.0	2300.0	1500.0
Thermal conductivity, dry λ dry [W/mk]	3.0	2.9	10.0
Water vapor diffusion resistance factor μ dry [-]	25.0	4380.0	405.3
Water absorption coefficient A-value [kg/m^{2}s$^{1/2}$]	-	-	0.0011

Table 2. Hygrotermal parameters of materials used for basic case

Material	***Concrete C12/15***	***Solid brick masonry***	***Interior plaster***	***Polystyrene expanded***
Density [kg/m^3]	2200.0	1900.0	1219.0	20.0
Porosity [-]	0.18	0.24	0.3	0.98
Specific heat capacity [J/kgK]	850.0	850.0	850.0	1500.0
Thermal conductivity, dry λ dry [W/mk]	1.6	0.6	0.25	0.04
Water vapor diffusion resistance factor μ dry [-]	92.0	10.0	10.8	21.7
Reference water content [kg/m^3]	8.0	18.0	16.0	-
Free water saturation [kg/m^3]	175.0	190.0	160.0	-
Water absorption coefficient A-value [kg/m^{2}s$^{1/2}$]	0.016	0.11	0.05	-
Typical built in moisture [kg/m^3]	175.0	100.0	160.0	-

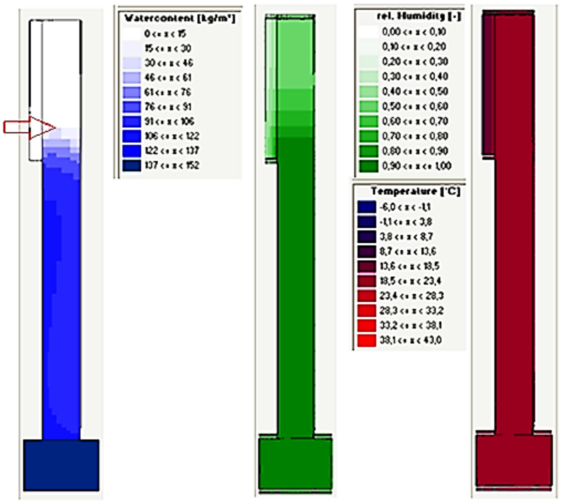

Fig. 4. Fields of water content (left image), relative humidity (central image) and temperature (right image) for a basic case (Găină, 2013)

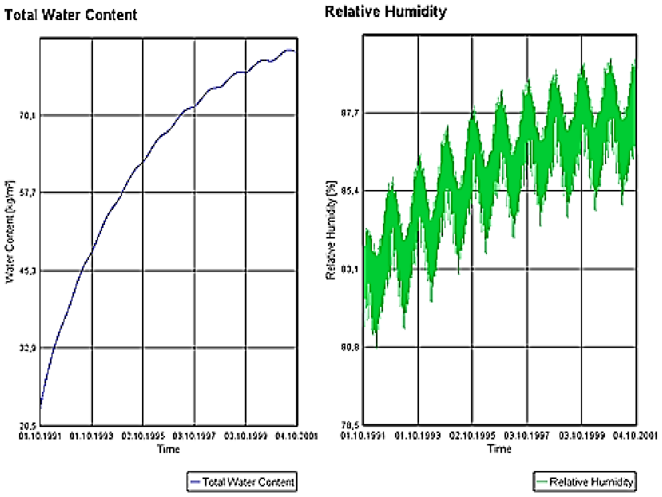

Fig. 5. Graphs with total water content (left image) and relative humidity (right image) for a basic case (Găină, 2013)

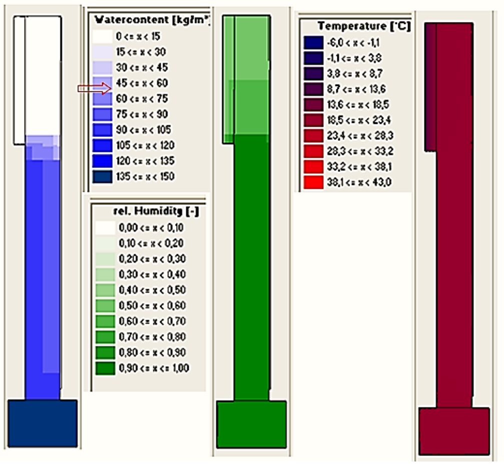

Fig. 6. The fields of water content (left image) relative humidity (central image) and temperature (right image) for a polyethylene case (Găină, 2013)

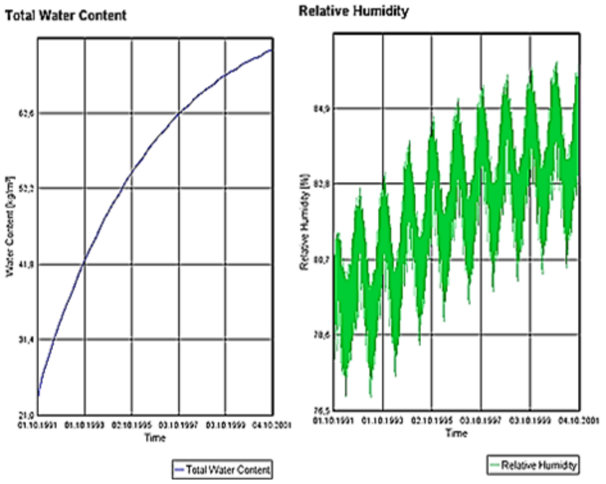

Fig. 7. The graphs with total water content (left image) and relative humidity (right image) for a polyethylene case (Găină, 2013)

3.3. Case 3: basement wall with rubberized asphalt membrane

The water height is 1.60 m for the entire basement wall. Since for the base case, the water level was 1.85 m, this means that by applying this damp proof layer, the water level has been reduced to 25 cm.

It can be concluded that the best damp proof solution was to apply asphalt membrane. The results can be seen in Fig. 10. Fig. 11 shows that the total water content had a value over 49.1 [kg/m^3] as compared with the base case, where the water content was over 70.1 [kg/m^3], the polyethylene, with 62.6 [kg/m^3] and APP membrane, with water over 53 [kg/m^3]. The values for the distribution of relative humidity and water content were summed up in a graphic representation in Fig. 12. It is clearly obvious that, compared to the basic case, the asphalt membranes present the best waterproofing characteristics from the analysed three. A similar analysis with WUFI 2D computer software was done on paper (Holm et al., 2000) comparing two types of wall structure rehabilitated with boreholes injections.

4. Conclusions

The main objective of the present case study was to analyse the use of waterproofing materials. The evaluation performed, has shown that the waterproofing materials are used to: prevent leakage or passage of water and vapour water, provide protection against penetration of groundwater and rainwater through the external enclosure of buildings and prevent water from penetrating a building via capillary action and hydrostatic pressure. The current paper intended to present a pre-sizing of waterproofing system efficiency excluding this way expensive laboratory and in situ experiments.

For the current case study an underground wall has been considered. The analysis focused on the construction materials capacity to absorb water. In order to perform the evaluations three damp-proof methods have been considered with similar environmental conditions and a service life of 10 years. The investigations results established that rubberized asphalt membrane is the best solution for the rehabilitation of the basement wall.

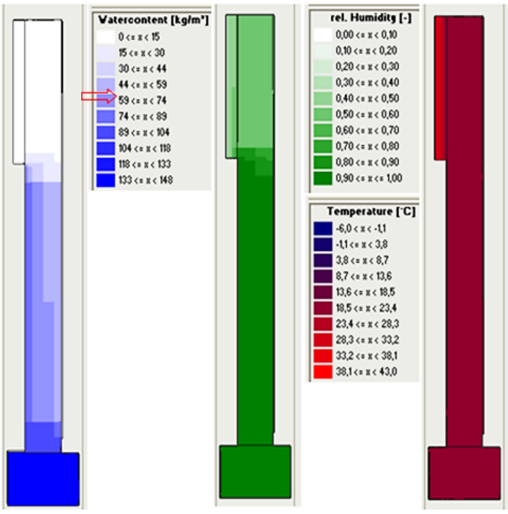

Fig. 8. The fields of water content (left image) relative humidity (central image) and temperature (right image) for an atactic polypropylene plastomeric membrane (Găină, 2013)

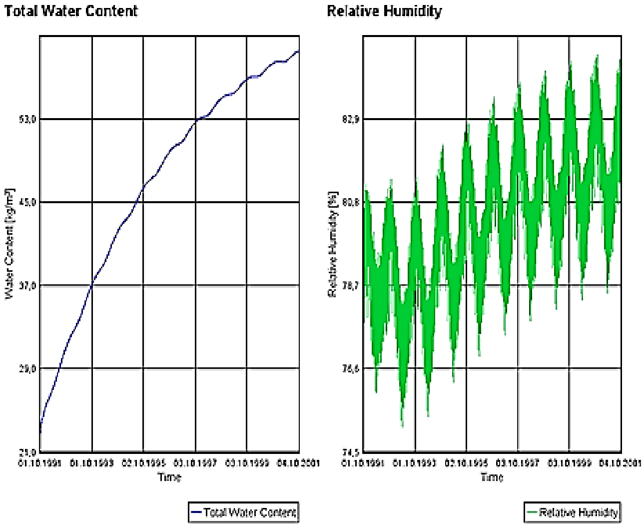

Fig. 9. Graphs with total water content (left image) and relative humidity (right image) for an AAP membrane (Găină, 2013)

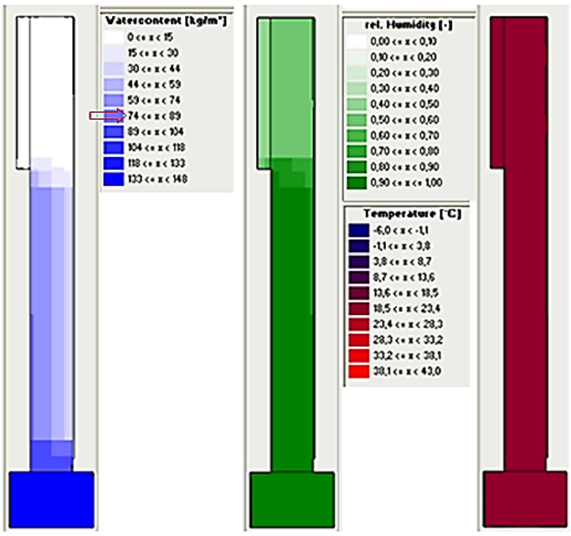

Fig. 10. Fields of water content (left image) relative humidity (central image) and temperature (right image) for asphalt membrane (Găină, 2013)

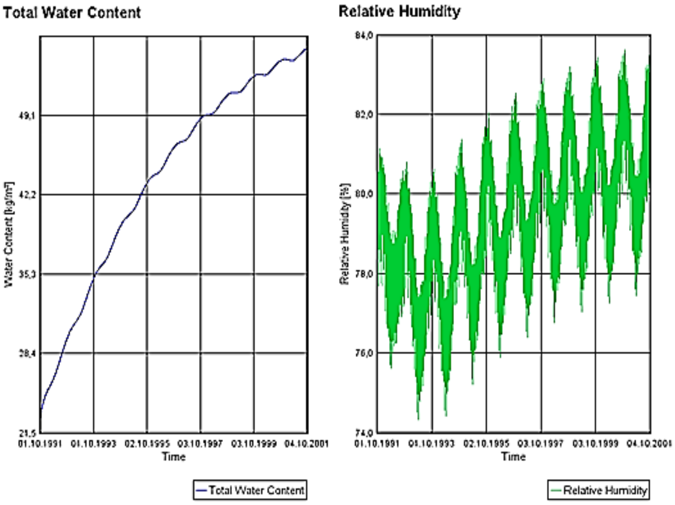

Fig. 11. Graphs with total water content (left image) and relative humidity (right image) for an asphalt membrane case (Găină, 2013)

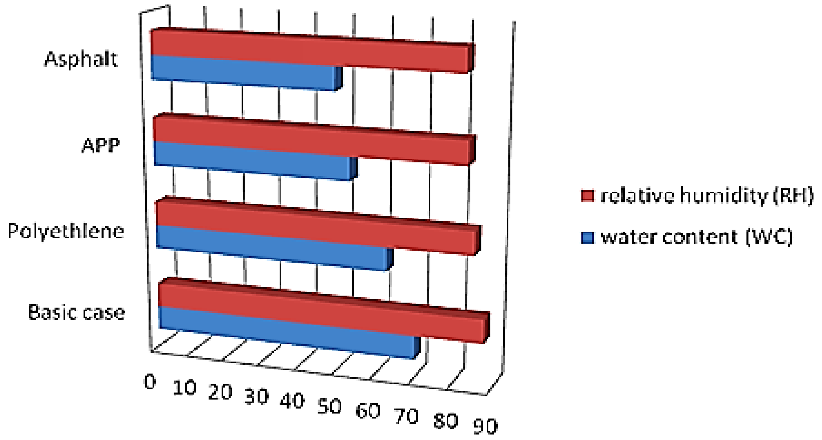

Fig. 12. Comparison between WC and RH in the whole structure

WUFI 2D software results predicted the moisture behaviour, which helped to avoid problems that can occur in the basement brick masonry wall after a period of time. Furthermore, the software provides the opportunity to compare different damp-proof methods by calculations in order to choose the optimal solution.

The analysis provides the design of a proper waterproofing system, especially for new buildings, highlighting the main advantages (save energy, life time improvement of the building, less waste of construction materials and less construction costs).

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