Investigating condensation role in defects and moisture problems in historic buildings. Case study

Varamin Friday mosque in Iran

Mohammadjavad Mahdavinejad and Kavan Javanroodi
Department of Architecture, Tarbiat Modares University, Tehran, Iran, and
Leyli Hashemi Rafsanjani
Department of Energy and Architecture, Tehran University, Kish, Iran

Abstract

Purpose – The purpose of this paper is to investigate moisture problems and defects which have been caused by condensation in historic buildings. Emphasis has been put on finding condensation possibility on the external walls and inside temperature and humidity.

Design/methodology/approach – A third-part study including survey method to identify moisture problems and exhaustion, then determining indoor and outdoor temperature and relative humidity in a two-part survey within four days periods, and finally computer modeling and simulation to finding condensation possibility in the building walls by WUFI and THERM software.

Findings – Results indicated that the case study has serious defects and almost 7.5°C differences (Δt) and about 6 percent relative humidity differences (Δh) between indoor and outdoor temperature, and from analyzing computer simulations, condensation risk occurrence between wall layers is witnessed. Also this study shows that some climatic methods applied by traditional architects despite enhancing thermal comfort have caused damages and defects to the building envelope and structure. In this paper, the authors suggest a method to reduce condensation possibility by active ventilation for reducing temperature differences.

Originality/value – While there is a lock of technical researches and investigations about architectural heritages conservation, this study tries to perform a technical research and filling the gaps in this subject area.

Keywords Active ventilation, Ancient building, Condensation, Moisture problems, Simulation and modeling

Paper type Research paper

Nomenclature

C specific heat (J/kg K)
T time (s)
h_v latent heat of phase change (J/kg)
K thermal conductivity (W/(mK))
L thickness (m)
N air change number in an hour
P_w pressure component (Pa)
U heat transfer (W/K)
T temperature (K)
V velocity (m^3)
W moisture content (kg/m^3)
D_φ liquid conduction coefficient (kg/ms)
H total enthalpy (J/m^3)

World Journal of Science, Technology and Sustainable Development
Vol. 10 No. 4, 2013
pp. 308-324

2042-5945
DOI 10.1108/WJSTSD-02-2013-0017

p_{sat} saturation vapor pressure (Pa)
δp relative humidity
U_{vap} vapor penetrability (kg/s m^2 Pa)
t_d frost temperature (°C)

Greek units

P density (kg/m^3)
Ω
Λ thermal conductivity (W/m^3/K)
Φ porosity
Σ sum of quantities
∇ differential operator

Subscripts

Air air
C capillary
Con conductive
G conductive
I index
In indoor
J index
Out outdoor

1. Introduction

Several ancient and historical buildings demands major repairs and rehabilitation in Iran. Nevertheless, due to the low attentions and considering housing demand in this young country, rehabilitation has not been mentioned in a proper way. After a period of war and political chaos in Iran, the Cultural Heritage Organization has been reorganized again. This institute began to rehabilitate and repair some of the famous historical buildings and performed some researches to preserve them. But a large number of these buildings face major problems especially with moisture and condensation.

Moisture condensation is one of the main causes that produce negative effects on the behavior of building envelopes in terms of deterioration of materials, increasing of the thermal conductivity of the insulation, weakening of structures, growing of mold, and mildew. Humidity is a major source of problems in buildings worldwide. Moisture can damage the building structure, the finishing, and furnishing materials (Ransom, 1987, p. 121), and can increase the heat transfer through the envelope and thus the overall building energy consumption (Hagentoft, 1998, p. 35). The presence of moisture problems in building walls (moisture accumulation) derives from different reasons, such as using wet materials during construction, capillary rise from ground, leakage of piped water, continuous high-humidity conditions, and condensation of water vapor which crosses exterior walls (due to the difference of partial vapor pressure between indoor and outdoor).

The building surface temperature is strongly dependent on the radiate and convective heat flux exchanged between the building envelope and the surroundings. During the night, building envelope exchanges long wave radiation with the sky, ground, and the surroundings, usually this balance is negative. Consequently, the radiate exchanges depend on the radiate properties of the building surface and on the local meteorological conditions.

Moisture-related problems are generally more severe in residential buildings due to the absence of air conditioning and presence of more intensive moisture sources, but also it can destroy important historical buildings which are not residential nowadays. Rehabilitation and maintaining of historical buildings as a heritage of a culture can revive identity of art in a region. Rehabilitation needs accurate studies to seeking problems and controlling damages.

In civil and architectural engineering, there is an increasing demand for calculative methods to assess and predict the long-term heat, air, and moisture (hygrothermal) performance of building envelope systems. Assessing the particular performance of a complete building or a subsystem on, is a critical task for an architect or building researcher. In recent years, some theoretical and experimental studies have dealt with the dynamic modeling of moisture absorption and desorption by building materials.

Lourenco *et al.* (2006), assessed moisture damages in historical city centers in Portugal with survey method. The paper analyzed 30 historical building in materials, typology, and damages and categorized main moisture damages in these buildings, also suggested practical methods to prevent rising damp in historical building (pp. 223-234). Torres and Freitas (2007) studied different treatment way of rising damp in historical buildings. The research is an experimental study, and results obtained from actual scale modeling of a sample masonry wall. Paper indicates that in historical buildings ventilation is a simple technology that holds great potential, and is not an effective way to prevent rising damp. And also examines a new technology to be implanting in these buildings (pp. 424-435). Lu (2002) modeled heat and moisture transfer in building through I model program. The overall objective of this study is to develop an accurate model for predicting heat and moisture transfer and examining it with actual data. This model can identify moisture damage causing and will enable researchers to eliminate these damages (pp. 1033-1043).

Chen and Chen (1998) also explore a method to calculate moisture absorption and desorption in buildings. Study indicates the materials with deferent moisture response behavior to the dynamic change of indoor humidity exist in buildings. Material moisture behavior depends on its geometrical configuration and moisture property, as well as the boundary conditions. Finally, paper used these facts to finding critical moisture points in walls (pp. 201-207). Guimarães *et al.* (2010) performs a mathematical analysis of the evaporative process of a new technological treatment of rising damp in historic buildings. Paper introduces a numerical calculation of a simple technology to reducing rising damp with technical details and examines this technology to be implanted in historical buildings (pp. 2414-2420).

With this background, this paper is an attempt to analyze condensation role in moisture damages in one of the famous historical buildings in Iran, Varamin Friday mosque. The paper, first, after defining the problem, describes the case study and after explaining methods, results, and discussion are next sections.

2. Governing transport equations in modeling

The moisture transport in porous materials is largely due to vapor diffusion, surface diffusion, and capillary conduction. The governing equations used in the model for moisture transfer and energy transfer are as follows.

Moisture transport:

$$\frac{\partial_w}{\partial_\varphi} \cdot \frac{\partial_\varphi}{\partial_t} = \nabla \cdot \left(D_\varphi \nabla_\varphi + \nabla(\varphi p_{\text{sat}}) \right) \tag{1}$$

Energy transport:

$$\frac{\partial_H}{\partial_T}\cdot\frac{\partial_T}{\partial_T}=\nabla\cdot((k\nabla T)+h_v\nabla\cdot\delta_p\nabla(\varphi p_{\text{sat}})) \tag{2}$$

Storage terms are on the left-side and fluxes on the right-side in energy and moisture equations are shown above. Fluxes are influenced with heat flux and moisture, enthalpy flux from vapor diffusion with phase changes depends on moisture fields and fluxes. The liquid flux in the moisture transport equation is only influenced by the temperature effect on the liquid viscosity and then on $D\varphi$. The necessary input data include the composition of the examined building component, its orientation, and inclination, as well as the initial conditions and the time period of interest. The material parameters and the climatic conditions can be selected from the attached database. Starting from the initial temperature and water content distributions in the component, the moisture and energy balance equations have to be solved for all time steps of the calculation period (www.wuffi.com).

Energy balance:

$$\rho_i c_h V_i\frac{dT_i}{dt}=U_{i,i+1}(T_{i+1}-T_i)-U_{i-1,i}(T_i-T_{i-1}) \tag{3}$$

And on which:

$$U_{i-1,i}=\frac{1}{\frac{L_{i-1}}{2k_{i-1}A_{i-1}}+\frac{L_1}{2k_iA_i}}\,U_{i,i+1}=\frac{1}{\frac{L_i}{2k_iA_i}+\frac{L_1}{2k_{i+1}A_{i+1}}} \tag{4}$$

Mass transfer:

$$\rho_{\text{air}}V_{\text{room}}\frac{d\omega_{\text{in}}}{dt}=N\rho_{\text{air}}V_{\text{room}}(\omega_{\text{out}}-\omega_{\text{in}})+m_b+m_{\text{gen}}+W \tag{5}$$

On which:

$$W=\sum A_{\text{wall}}U_{\text{vap}}\rho_{\text{air}}\times\frac{R}{M}(T_{\text{in}}\omega_{\text{in}}-T_{\text{out}}\omega_{\text{out}}) \tag{6}$$

And also:

$$U_{\text{vap}}=\frac{1}{\sum z} \tag{7}$$

These equations presented above are governed to the paper and modeling simulations. The moisture balance equation includes the derivative of the moisture retention curve, the liquid transport, and the vapor diffusion, which are related to gradients in relative humidity and vapor pressure. Also the model requires hourly weather data, such as temperature, relative humidity, wind speed and orientation, driving rain, and solar radiation, which are employed in the hygrothermal calculations.

3. Characterization of the historic mosque of Varamin

Varamin mosque located on Varamin city, 42 kilometers distances from southern Tehran. This mosque by the order of Abo-Sa'eid Bahador Khan, substitute of Illkhanid king Oljeitu, has been built in 1301 (Wilber, 1986, p. 170). Author of this monument is Mohammad-Bin-Mansur Al-Ghohedi, which first mentioned by Etimad-Al Saltane, Iranian history researcher in seventeenth. The mosque has been once repaired in Timurid era (seventeenth), and then in nineteenth up to now. One of the most famous features of the mosque is its brilliant ornaments that have been made by native materials like ceramic and bricks (24 × 24 × 5) (Sheibani, 1987, p. 29). The court surrounded on its four sides by a one-story arcade covered with pointed barrel vaults. It includes to the south, a 10 m per side-domed chamber with its portico overlooking the court, and the main portal portico is on the north side of the court. In addition to the main portal, two lateral entrances were formerly located on the east and west (Grabar, 1988, p. 591). The main materials of building are adobe and bricks (Figure 1). The climatic conditions are rather harsh with considerable rain (an annual average of 800 mm, mainly between October and May) and rather cold temperatures in the winter in Varamin city. Also temperature difference between winter and summer and between days and nights are considerable.

4. Material and methods

The investigation was carried out in consecutive steps and using three levels of revision. The consecutive steps were damage survey in the building envelope and structure (Section 5.1), temperature and relative humidity measurements inside and outside of building with a data logger (TMH-1 Model) (Section 5.2), and computer modeling of mosque sample wall (Section 5.3). The research method is modeling and simulations and conclusion stated through logical reasoning (Groat and Wang, 2002, p. 168), also survey method applied to investigating damages in building (Plate 1).

The calculations performed on monthly scale basis, taking into account internal moisture production rates and outdoor climatic conditions and modeling software tool (WUFI, 2012), assessed moisture and thermal behavior of building wall with collected climatic data by authors. The software, allows determining the condensation points through modeled walls of a building component in order to identify surface humidity, and to check if interstitial condensation occurs in a multi-layer masonry wall. First, climatic data of monument collected and an average (77 cm) value was assumed, and then by THERM software climatic factors (permeable coefficient, thermal resistance, and moisture resistance) determined. Then, main climatic data (air, temperature, and

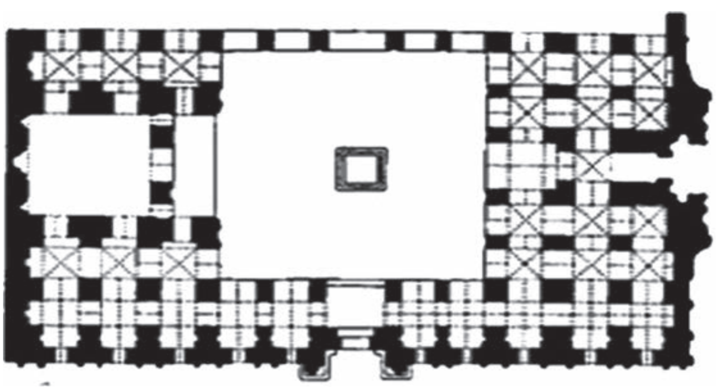
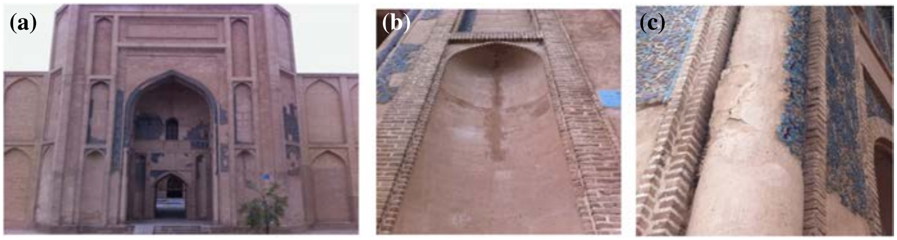


Figure 1.
Ground floor plan of Varamin mosque

Source: Wilber (1986, p.124)



Notes: (a) Main entrance of the mosque; (b) damages in the entrance of the mosque; (c) damages in the column of the entrance of the mosque, left pillar
Source: Authors

Plate 1.
Moisture damages in mosque entrance

moisture) collected from place in a two period and then, a sample wall had been modeled in WUFI-ORNL/IBP software with original material. Then, climatic data added to the evaluating software and the moisture performance analyzed in a climatic chart and results extracted in charts, diagrams, and figures.

The model is a transient, one-dimensional heat, and moisture transfer model that can be used to assess the hydrothermal behavior of a wide range of building material classes under climatic conditions in Varamin city. Research is attempting to find the relationship between temperature difference and moisture and condensation problems. Thus, for modeling the sampled wall of monument, moisture transport rate calculated. The process of research is explained in Figure 2.

5. Results and discussion

5.1 Survey in the building envelope and structure damage

The survey method to which applied, indicate serious damage in mosque main structure. As is represented in figures, serious moisture damages are obvious in mosque. Plate 1 is showing mosque entrance, with some serious moisture damages in the pillars and portico. This damages causes brick and ceramic collapse process. Plate 1a is showing main entrance of mosque with remaining ceramic pieces is eye-catching. Also in Plate 1b, moisture damage can be recognizing in muqarnas in entrance portico, which caused damp in bricks. Plate 1c is showing severe moisture damage in entrance left pillar, which causes ornament collapse and martial damping that can damage entrance structure.

Plate 2 is showing more damages in mosque envelope. Plate 2a is a close view of entrance portico. As is clear in the photo, most of ceramic and tile ornaments are collapsed, for sure finding defect origin demands more investigation. Plate 2b is illustrating a brick arch in main structure. Moisture effect detect in the top of the arch, which can cause serious defects in the structural stability. Plate 2c is a close view of pillar capital with defected plaster ornaments.

Plate 3 is showing more damages in the whole building. Plate 3a-d are illustrating damages in ornaments in different part of mosque, which indicates serious problems in envelope and structure of building that demands special concerns. Plate 3e, is close view of brick ordering in the west court wall of mosque. The mortar has spoiled caused by moisture problems. Moreover, Plate 3f, indicating damages inside of mosque in one of its plaster altar.

5.2 Temperature and relative humidity measurements inside and outside of building

Temperature and relative humidity measurements inside and outside of building was second section of survey. Because of having accurate calculations the temperature

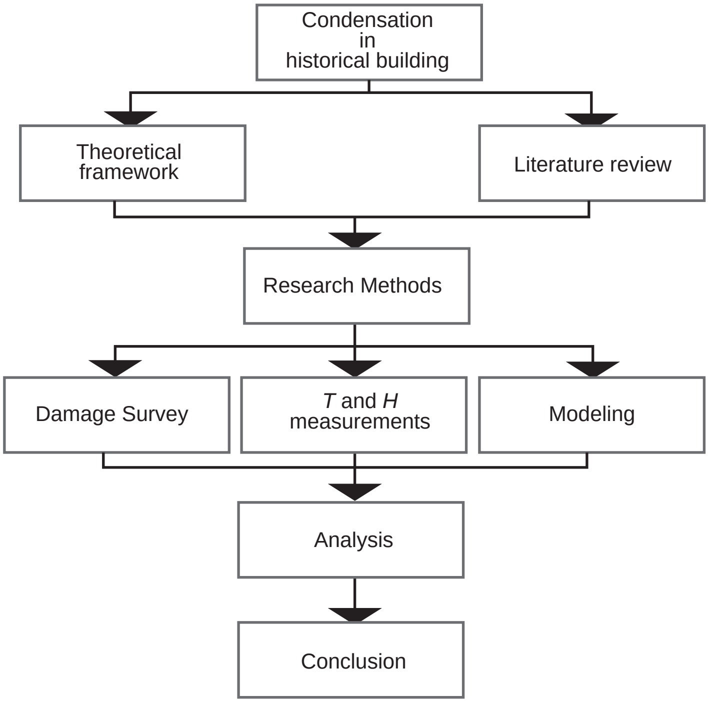


Figure 2.
Research process

Source: Authors

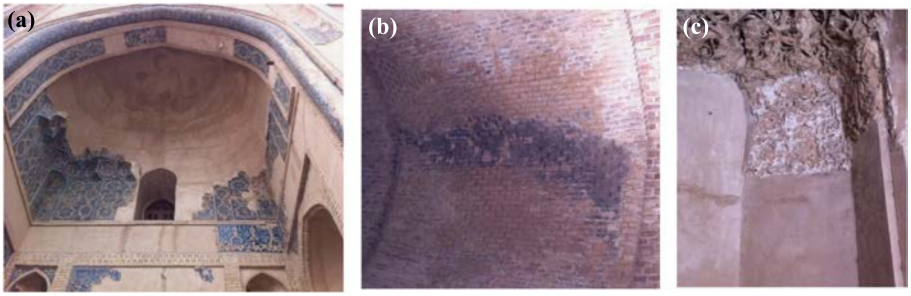
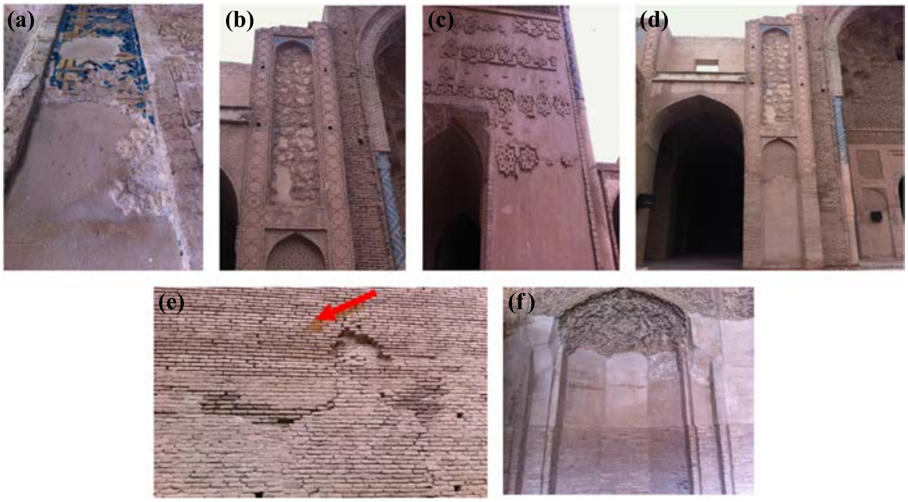


Plate 2.
Moisture damages in mosque entrance

Notes: (a) A close view of entrance portico; (b) a brick arch in main structure; (c) a close view of pillar capital with defected plaster ornaments

and relative humidity have been measured through a two-part four days period. Also, for dealing better with purpose of research, two four days have been chosen, in which 11-14 of December as coldest days in Varamin and 21-24 of June as hottest days in Varamin according to synoptic station in the region. Table I is showing data collected from site in these two main dates.

Temperature difference between outside and inside of mosque is a remarkable point in different times of the day. There is a 7.75°C temperature difference, which cause



Notes: (a) Main entrance of the mosque; (b) damages in the entrance of the mosque; (c) damages in the second entrance of the mosque; (e) damages in the outside wall; (f) damages in the exterior ornaments
Source: Authors

Plate 3. Moisture damages in outside and inside of mosque

Date	Time	Average T_{in}	Average T_{out}	Average Δt	Average Δt in period	Average RH_{in} (%)	Average RH_{out} (%)
2010.12.11	9	20	25	5	7.75	78	73
2010.12.12	12	23	34	11		83	77
2010.12.13	15	24	34	10		89	81
2010.12.14	18	22	27	5		74	76
2011.06.21	9	28	33	5	7.75	40	42
2011.06.22	12	31	41	10		37	39
2011.06.23	15	29	38	10		46	50
2011.06.24	18	28	34	6		43	49

Source: Authors

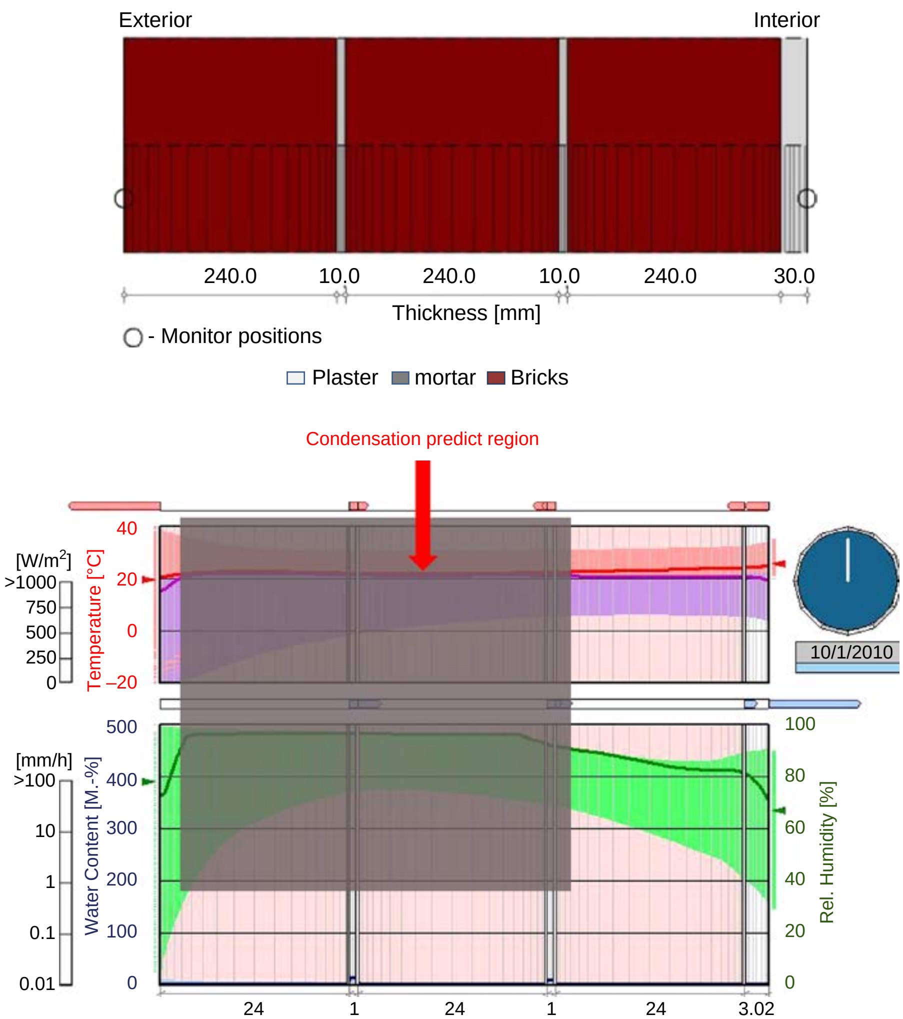
Table I. Temperature data collected in mosque in certain times

inside air regulation and performs an outside to inside wind. Also by investigating on relative humidity, we can find out that this temperature difference causes humidity and moisture increasing. This cool wind can reduce air temperature and brings thermal comfort inside the mosque. This advantage can cause energy consumption reduce even. But it can be a risk to increase condensation danger in walls as stated in research literature, of course this is a theory that needs practical examination by modeling, which performed in Section 3.

5.3 Computer modeling of mosque sample wall

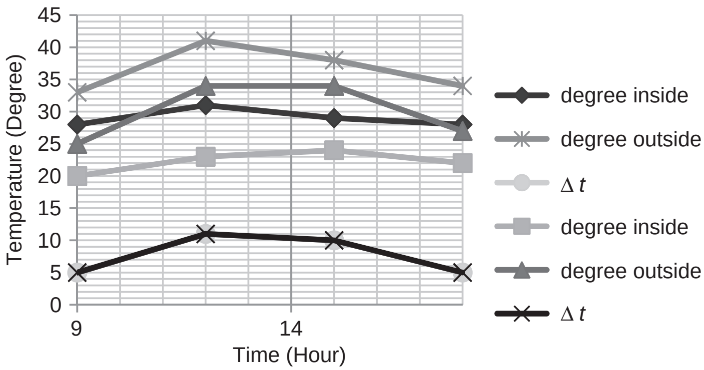
5.3.1 THERM measurements and modeling. Thermal performance analysis demands complicated computation which can be performing in validated software. In this section, thermal and damp performance analysis of building walls, is modeling through WUFI and THERM software. First, the sample wall modeled and analyzed in THERM software for calculating thermal transfer coefficient (Figure 3). The sample wall consists of brick as main materials, plaster as overlay and mortar. Figure 4 is presenting analysis results from THERM software.

Table II, is showing numerical analysis from THERM software. This analysis determines thermal and humidity resistance in a 77 cm sample wall of the mosque. This data shows that total thermal resistance in the wall is about 1.58 and total humidity resistance is about 0.022. This shows low humidity resistance and high thermal resistance which cause from traditional materials like brick and adobe.



Source: Authors

Figure 3.
Simulation and calculation of temperature, relative humidity and moisture of wall layers in the sample wall section with 90 centimeter thickness – modelling (up) in THERM and simulation (down) an WUFI



Source: Authors

Figure 4. Temperature data collected in mosque in certain times

Finally these data are needed to another modeling for determining moisture effects on mosque wall in WUFI software in the next sub-section.

5.3.2 WUFI software modeling. This program is a one-dimensional model for heat and moisture transport analysis of building envelope components, based on the finite volume method (Kuenzel and Kiessl, 1997). The mosque sample wall has been modeled and simulated in WUFI. This modeling was a two-year period modeling in hourly calculation. Also inside temperature, which determined in paper survey applied to the software and relative humidity assumed between 40 and 60 percentages. These data are variable, in the two-year period, which based on paper survey. Climatic data of region consist of raining data, solar radiation, air flow, outside temperature, and relative humidity entered in to software accurately.

Thus, graph has been extracted from the modeling. Due to the fact that the red lines on the graphs, each point represents the temperature of the walls and purple lines indicate the saturation temperature at the same point in the range specified, and in this point condensation possibility is high.

If the moisture content increases over several years, the cause for this should be investigated more thoroughly. Maybe the construction was started with unrealistically low initial water content and is just trying to reach its normal and harmless water content. On the other hand, the construction may have a design flaw allowing it to accumulate intolerable water contents. By using higher initial moisture content and/or a longer calculation period you should try to determine at which moisture level the dynamic steady state will be reached. If this long-term moisture level is so high that rot, mold, corrosion, frost damage, increased heat losses, or other unacceptable conditions may arise, the construction must be considered a failure under the applied climatic conditions.

If the long-term behavior of the total water content is satisfactory, the water contents of each layer should be examined in the next step. Here, too, no permanent moisture accumulation in single layers should take place. Please note that even if the total water content has reached dynamic equilibrium, this may not yet be the case for individual layers which may still be redistributing moisture among them.

Please make sure that not only the entire construction but also all individual layers have reached dynamic equilibrium. In addition to the general trend of the water content, you should now also consider the absolute quantity of water within each material. For example, in wood-based materials the water content should not exceed

20-mass percent for a longer period of time, as this might lead to rot or mold growth. Insulation materials should not exhibit increased water contents which would reduce their insulation efficiency. Materials on the exterior surface might become susceptible to frost damage if their water content is too high. The manufacturers of the materials may be able to provide further information on possible limits that should not be exceeded.

First, the water storage capacity of the wall is generally analyzed and as you can see according to the Figure 5 over the course of the stored water volume increase reflects increased risk in the wall, and then we look at each layer. Figures 6 and 7 indicates that most of the water condensation danger is in the mortar between the bricks layer.

Green lines shows relative humidity, red lines shows temperature, and purple line used as saturation temperature in chart. Also where purple and red lines are aligned, water condensation possibility will increase.

Isopleth graph, predicts no potential for mold growth on the interior face of the dry wall. This enables to assess weather conditions of high temperature and high humidity occur at the same time which may create problems for some materials. LIMBI and LIMBII refers to limiting isopleth for building material specific fungi and substrate classes. If the conditioned lie above the limiting isopleths, mold growth may be possible, but additional criteria evaluation is required for a firm assessment. Dots crossing LIMBI and LIMBII line are at risk (Figure 8).

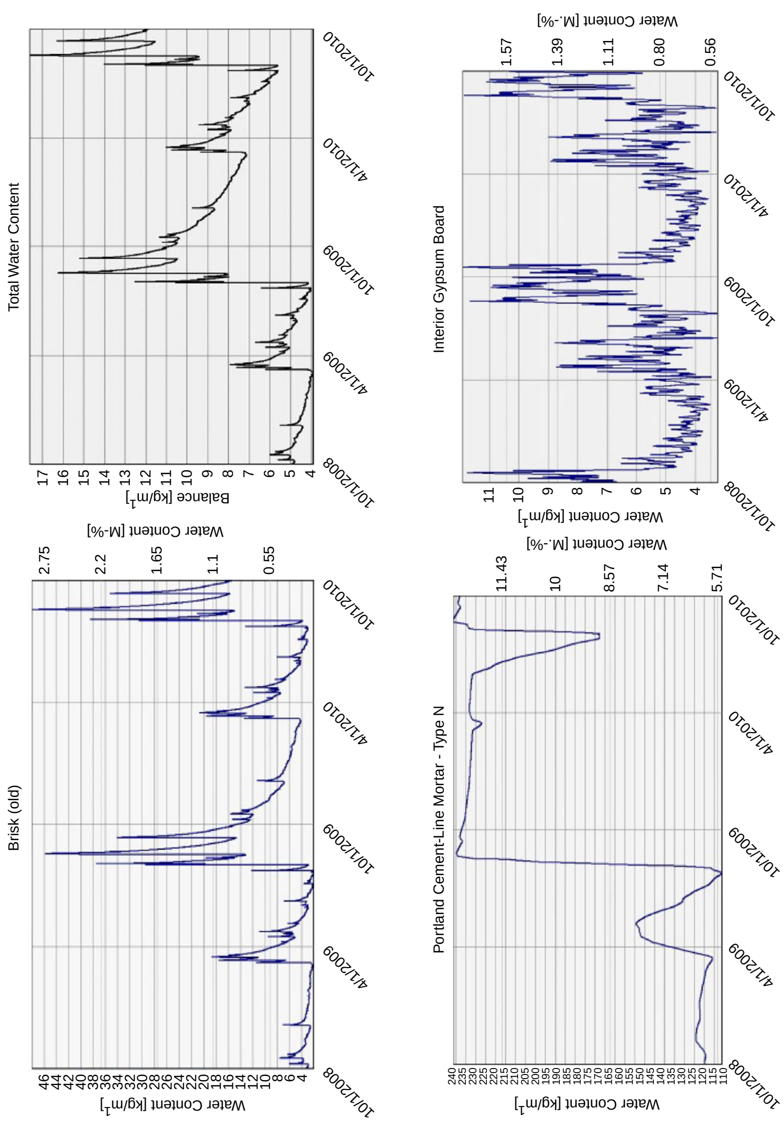
As displayed in graph, red lines shows differences curve in beginning of the period, and blue lines shows the end of analyzed period. Comparison of these two graphs indicates difference rate in the two-year period. According to these graphs in the boundary of brick layers, water accumulation risk, and condensation are possible.

Thus, these graphs and tables indicate that condensation problems are high in this building. And in the most of the walls, especially in brick and mortar layer, there is a large amount of condensation possibility. These analyses prove that Varamin Friday mosque has major condensation problems. Survey methods applied for study indicates that there is a big amount of temperature difference between indoor and outdoor temperature. Therefore, according to these temperature differences, condensation problems, and damages distinguish in building different parts, Varamin Friday mosque needs practical methods. Lourenco *et al.* (2006), states that condensation problems is related with no insulation inside and also using gas equipment and also extra solar gaining in building. But in this paper because of non-residential performance of building, cannot be main defect reason in the mosque. In Torres and de Freitas (2007) research, they results that in historical buildings, the traditional techniques of treating rising damp are not effective, and wall ventilation is a simple technology that can help damp in

Table II. THERM software analysis output data

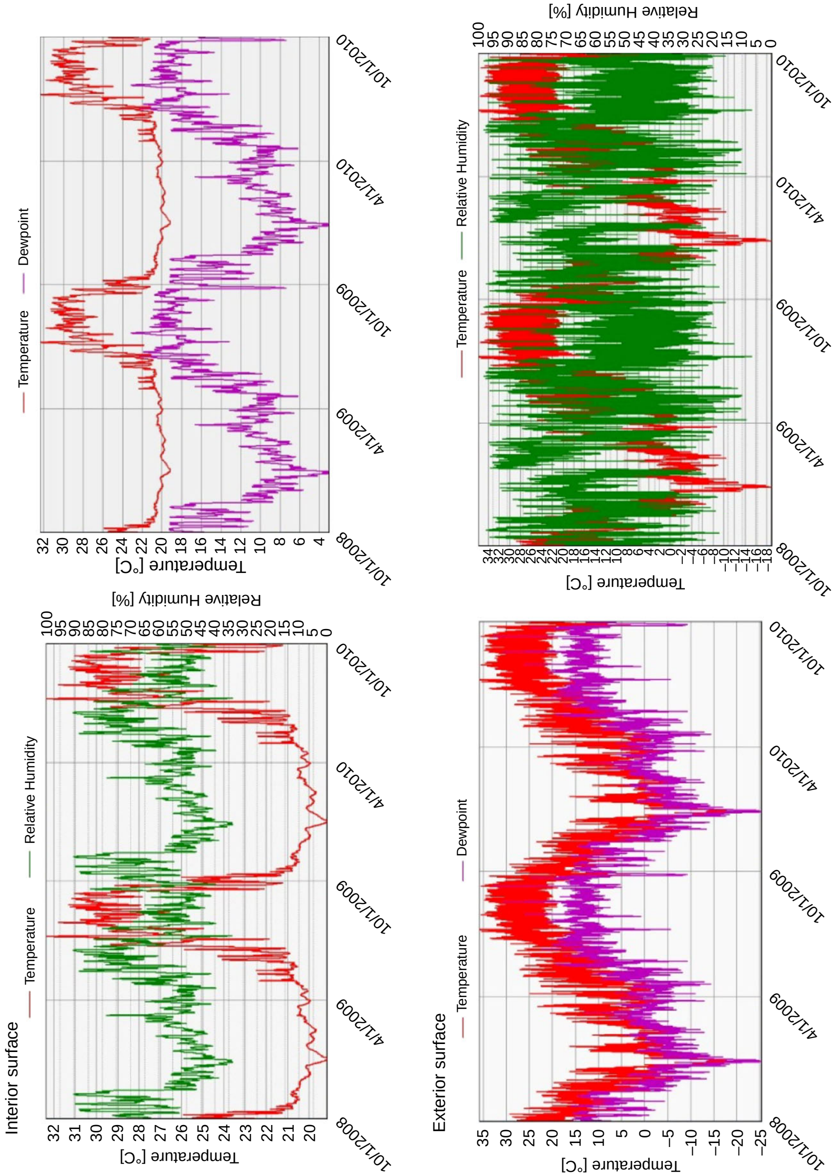
Humidity resistance (R_d)	Thermal resistance (R_t)	Coefficient (π) penetrability	Thickness (d)	Layers
–	0.11	–	–	Interior temperature
0.001	0.05	37.5	0.03	Plaster
0.021	1.36	40	0.84	Brick
–	0.06	–	–	Exterior temperature
0.022	1.58	–	–	Total

Source: Authors



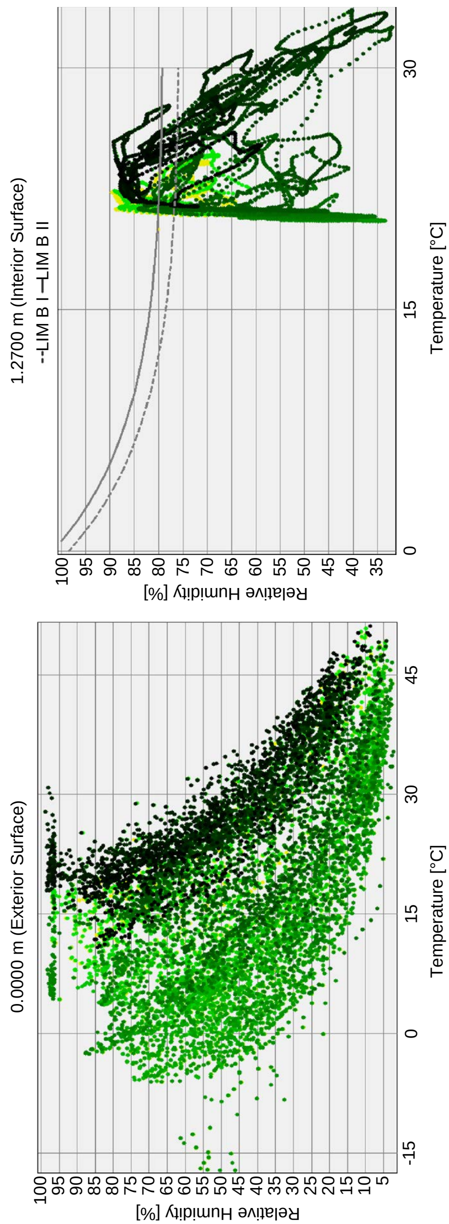
Notes: (a) Moisture differences in bricks layers; (b) moisture differences in wall layers; (c) moisture differences in motar layers; (d) moisture differences in plaster layers
Source: Authors

Figure 5.
Moisture differences in saturation temperature



Source: Authors

Figure 6.
(a) Exterial wall;
(b) Interial wall



Source: Authors

Figure 7.
Distribution of temperature and relative humidity

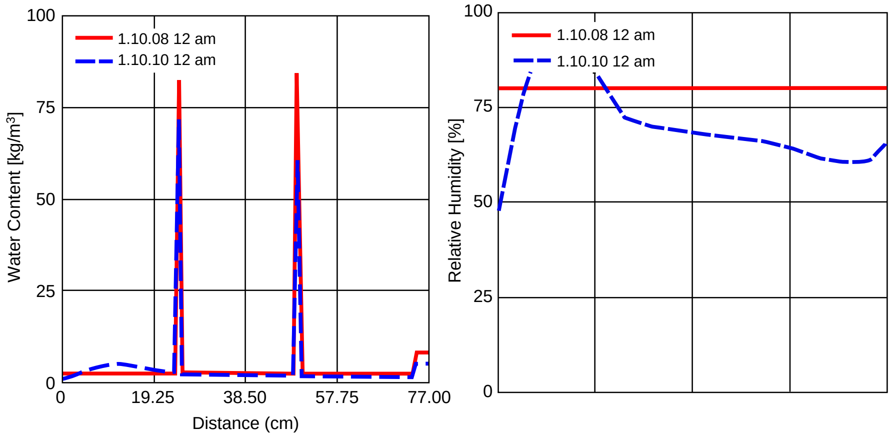


Figure 8.
Temperature and relative humidity in boundary line of brick layers

Source: Authors

building. In other way, this study also suggests active ventilation for reducing damp and temperature difference in building. Diasty *et al.* (1993) evaluate different material and their moisture capacity and condensation possibility in contemporary buildings. This subject area has an important role in moisture problems, but in this paper did not mention in analysis, specifically. The study results indicate that building material moisture buffering effects can be as important as external ventilation. Water-related problems can be confirmed as the single most important defect, which are combined with inadequate sun exposure, ventilation and heating, and excessive moisture indoor production.

6. Conclusion

The mechanisms of moisture transfer are complex, particularly regarding with rising damp in historic buildings. The present paper adopts a historical building in the central plateau of Iran, as case study. Through an extensive survey work, defects, and moisture problems distinguished in building and after computer modeling and simulations condensation possibility determined. First, condensation possibility proved and then according to the simulations and actual situation of mosque, the reason behind had been analyzed.

The survey method applied to the paper, indicated that there is about 7.5°C differences between indoor and outdoor of mosque. These climatic methods applied to the mosque by traditional architect used for increasing thermal comfort in building indoor. But, this climatic method can cause moisture problems by accumulate water between wall layers and finally condensation problem, which cause serious defects and destruction. According to region climate, eliminating natural ventilation was a proper method to increasing indoor thermal comfort.

Due to the fact that temperature differences between indoor and outdoor temperature regarding to masonry materials cause moisture problems, paper suggest a method that can reduce condensation risk in building: by applying an active ventilation system, and reducing indoor and outdoor temperature difference, condensation problems can be eliminating. The design process of this system, air velocity and pressure of it demands further investigation.

References

Chen, Y. and Chen, Z. (1998), "Transfer function method to calculate moisture absorption and desorption in buildings", *Building and Environment*, Vol. 33 No. 4, pp. 200-207.

Diasty, R.E.L., Fazio, P. and Budaiwi, I. (1993), "Dynamic modeling of moisture absorption and desorption in building", *Building and Environment*, Vol. 28 No. 1, pp. 21-32.

Grabar, O. (1988), *The History of Iran*, (Trans by Hassan Anooshe) Amir-Kabir Publications, Tehran.

Groat, L. and Wang, D. (2002), *Architectural Research Methods*, John Wily & Sons Publication, London.

Guimarães, A.S., Delgado, J.M.P.Q. and Freitas, V.P. (2010), "Mathematical analysis of the evaporative process of a new technological treatment of rising damp in historic buildings", *Building and Environment*, Vol. 45 No. 11, pp. 2414-2420.

Hagentoft, C.E. (1998), "The impact of heat, air and moisture transport on energy demand and durability", *Paris: International Energy Agency*, Vol. 5 No. 2, p. 98.

Kuenzel, H.M. and Kiessl, K. (1997), "Calculation of heat and moisture transfer in exposed building components", *International Journal of Heat and Mass Transfer*, Vol. 40 No. 1, pp. 159-167.

Lourenco, P.B., Luso, E. and Almeida, M.G. (2006), "Defects and moisture problems in buildings from historical, city centres: a case study in Portugal", *Building and Environment*, Vol. 41 No. 1, pp. 223-234.

Lu, X. (2002), "Modelling of heat and moisture transfer in buildings I. Model program", *Energy and Building*, Vol. 34, pp. 1033-1043.

Ransom, W.H. (1987), *Building Failures: Diagnosis and Avoidance*, E&FN Spon, London.

Sheibani, Z.T. (1987), "The repair process of Varamin mosque", *Asar*, Vols 12-14 No. 2, pp. 110-115.

Torres, M.I. and Freitas, V.P. (2007), "Treatment of rising damp in historical building: wall base ventilation", *Building and Environment*, Vol. 42 No. 1, pp. 424-435.

Wilber, D.N. (1986), *The Architecture of Islamic Iran: The Ilkhanid Period*, (Trans by Abdollah Faryar) Elmi & Farhangi Pub, Tehran.

WUFI (2012), "PC-Program for calculating the coupled heat and moisture transfer in building components", available at: www.wufi.de/index_e.html

Further reading

Hudson, G. and Underwood, C.P. (2004), *Pre-design Analysis of Energy Conservation Options for a Multi-Story Demonstration Office Building*, National Bureau of Standards, Washington, DC.

Mendes, N. and Gerson, H.d.S. (2001), "Dynamic analysis of building hygrothermal behavior", *Proceeding of the IBPSA Building Simulation, 7th Conference, Rio de janiro, August 13-15*.

About the authors

Dr Mohammadjavad Mahdavinejad, PhD graduated from SAMPAD – National Organization for Development of Exceptional Talents of Iran – by 1996 and then enrolled at University of Tehran, School of Fine Arts in 1996. He graduated as gold medalist of the school in 2001 and continued his PhD candidacy at University of Tehran until graduation as top student in 2007. He won some outstanding national and international prizes in academic as well as architectural design competitions. He was recognized as the most cited scholar in field of architecture and planning in 2009, 2010, 2012 by MSRT – Ministry of Science, Research and Technology. Right now, he is an

Academic Staff of Faculty of Art and Architecture, Tarbiat Modares University, Tehran, Iran. He printed more than 100 scientific papers and 20 books as Author, Translator, and Editor or Editor in Chief; and focussed his researches in contemporary high-tech architecture and contemporization of valuable districts and monuments. Dr Mohammadjavad Mahdavinejad is the corresponding author and can be contacted at: mahdavinejad@modares.ac.ir

Kavan Javanroodi, MA Student and TMU, Technical Architecture, Research Area: Energy and Architecture, has published several papers on energy subject in international journals.

Leyli Hashemi Rafsanjani is studying for an MSc in Low Energy Architecture at University of Tehran. Leyli is now focussed on sustainability in traditional architect of Iran, especially courtyard element.