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Advanced Hygrothermal Performance of Building Component at Reconstruction of S. Radonezhskiy Temple in Volgograd

Sergey Korniyenko[1, a]

[1]*Volgograd State University of Architecture and Civil Engineering, Akademicheskaya st., 400074, Volgograd, Russia*
[a]*svkorn2009@yandex.ru*

Abstract. The paper presents new thermal design of external wall S. Radonezhskiy temple in Volgograd is developed according to author's concept. The three-layer brick wall, including a thermal insulation layer from concrete with polystyrene aggregates, is considered. Calculation of interstitial condensation in building component is carried out according to simplified calculation method developed by the author and harmonized to ISO 13788. Analysis of calculation results shows that condensation occurs at one interface during some months but there is no accumulation over the year as all the condensate is predicted to evaporate again. Thus, there is no systematic moisture accumulation at the building component within a year. The risk of run-off from non-absorbent materials will be very low. Analysis of the evaporation rates at the interface shows that duration of drying wetted layer in external wall during initial stage does not exceed admissible values.

1 Introduction

The priority direction of modern architecture and construction is energy efficiency and energy saving. Increase of hygrothermal performance of building components and optimum indoor thermal comfort are necessary during all life cycle of the building, i.e. at design, construction, operation and reconstruction of buildings. For objects of cultural heritage the issue as important as ever. Saving of the historical and cultural monuments which are national property is important both for present and future generation.

Now there are no evidence-based technical solutions on a hygrothermal performance of building envelope for new and reconstructed cultural buildings. It should be noted that the designer is faced by restrictions at the choice of thermal insulation of cultural buildings.

External insulation is an optimum thermal technology and therefore often used in mass construction.

As discussed by Murgul [1] in historical and cultural monuments case often is impossible to use as external walls have design and decorative features.

Indoor insulation is dangerous from the point of view of moisture conditions and often it is also impossible as liturgical rooms have specific internal finishing. Thermal insulation layer in external wall has numerous thermal bridges as connectors. Multidimensional temperature and moist fields are formed in heterogeneous building elements that considerably complicate carrying out thermotechnical calculation. It complicates design process, construction and reconstruction of cultural buildings and demands an individual approach to design with involvement of highly qualified specialists. Relevance of this scientific issue is defined by it.

In articles [2–11] the issue of thermal performance and indoor thermal comfort for cultural buildings is considered. Need of thermal reconstruction of some cultural buildings is shown in articles [4, 5, 9]. Heat and moisture conditions of some cultural buildings are in detail investigated in articles [3, 6]. In articles [3, 7, 8] modern issues of improvement of thermal comfort in temples by means of heating and ventilation systems are considered.

As discussed elsewhere [8, 9] issues of improvement of ventilation systems with heat recovery in the historical buildings are important for achieving comfortable microclimate. Increase of buildings thermal performance due to improvement of building components with thermal bridges is considered in articles [9–13, 21].

Most accurate assessment of moisture conditions for building components can be executed by final differences or final elements methods. In this case it is possible to receive very exact analysis of processes heat and moisture transfer in building envelope [14–19]. Simplified calculation methods, such as method ISO 13788 and others, have smaller accuracy in comparison with mathematical modeling [20, 22]. At the same time the engineering methods do not demand application of specialized computer programs and are available to designers.

The review of scientific literature showed lock of study of hygrothermal performance for building components at reconstruction of the cultural buildings. Based on the review of scientific literature the purpose and objectives of research are formulated.

2 Materials and Methods

The object of research is reconstruction of Sergey Radonezhskiy temple in Volgograd [9]. Temple was built in 1999. Reconstruction of the temple started in 2011. Reconstruction purpose is increase total structural volume of the temple. Reconstruction objective is construction of the heated addition to western facade of temple for liturgical rooms. Now reconstruction of the temple is almost completed (see Figure 1).

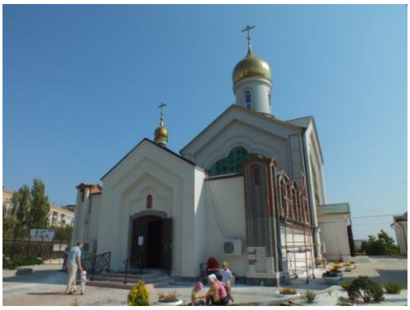

Figure 1. General view of temple (September, 2015)

Figure 2. Construction of the heated addition to temple (July, 2013)

The original project and construction of the heated addition to temple has essential defects as shown in an article [9]. The detail analysis of these defects is not the purpose of this article. New thermal design of external wall is developed according to author's concept. In this case the three-layer brick wall, including thermal insulation layer from concrete with polystyrene aggregates, is considered (see Figure 2).

As shown in article [9], comparing to initial design data, the offered thermal design of external wall is more effective. Framework metal columns are located from the heated rooms, as shown in Figure 2, practically excludes the risks of moisture condensation on internal surface. Application of brick connectors in external wall (see Figure 3) reduces influence of thermal bridges. Increase in external surface of corners demanded for architectural reasons increases additional heat losses. At the same time the increase in thermal resistance of a corner reduces additional heat losses. Offered external wall joints correspond to the principles of designing without thermal bridges. Application of monolithic concrete with polystyrene aggregates as a thermal insulation increases thermal inertia of external wall approximately for 33.4 %. Cross and internal air filtration in a thermal insulation layer is practically excluded. Offered thermal design of external wall increases thermal comfort and energy efficiency during the heating and cooling periods.

Calculation of interstitial condensation in building component is carried out according to simplified calculation method developed by the author [20]. Purpose of the method is one-dimensional moisture transfer on the mechanism of water vapor diffusion under stationary boundary conditions. Generally the procedure of research assumes that there is more than one condensation interface. We call such building components with *multizone moisture condensation* [20].

Calculations are carried out according to the following input data:

- Location and building type
- External environmental conditions such as monthly mean temperature, t_{ext}, °C, and relative humidity, φ_{ext}, of external air
- Internal environmental conditions such as monthly mean temperature, t_{int}, °C, and relative humidity, φ_{int}, of internal air
- Material and product properties used for analysis such as density, ρ_0, kg/m^3, thermal conductivity, λ, W/(m·K), and water vapour permeability, μ, mg/(m·h·Pa)
- Boundary conditions as surface resistances at heat and water vapour transfer in building components

Calculation of interstitial condensation in building component is carried out on the following steps:

a) Condensation interfaces in structure for the coldest month are defined. Condensation interface is the section of building component in a condensation zone where maximum difference between water vapour pressure and value at saturation. To define the condensation interfaces the analytical calculation of water vapour pressure profile and saturated water vapour pressure profile in building component is used only [20].

b) For every month there is an amount of the moisture accumulated in the interface of condensation on the basis of moisture balance for the section.

c) Moisture accumulation rate in building component is defined, starting any month.

d) Assessment of moisture conditions in building component on annual balance of moisture is carried out.

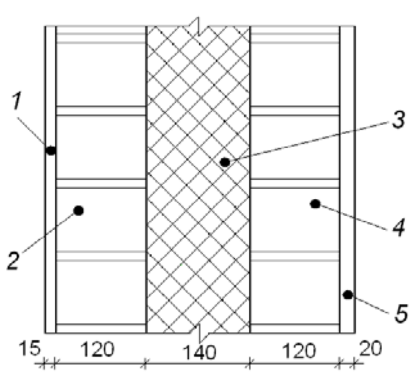

Figure 3. Scheme of external wall: *1* – plaster; *2* – inner brick layer; *3* – thermal insulation; *4* – outer brick layer; *5* – plaster

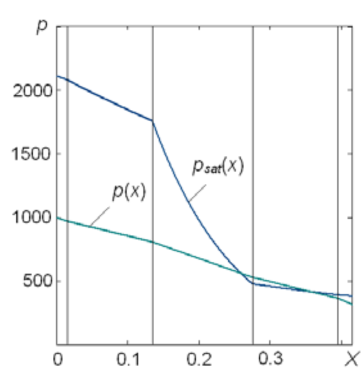

Figure 4. Schedules of $p(x)$ and $p_{sat}(x)$ in the cross section of external wall (key: x – coordinate; p – water vapour pressure; p_{sat} – saturated water vapour pressure)

The detailed calculation algorithm is given in article [20]. The method is harmonized with ISO 13788 and included in standards of the organizations in Russia. This method allows estimating moisture conditions of building components with multizone condensation. The calculation method is convenient in constructional development.

Calculation of drying of building component procedure assumes that there is an excess moisture content concentrated at the centre of a specified layer. And then moisture moves to the condensation interface and gradually evaporates from here. The monthly mean internal and external conditions are used to calculate the amount of evaporation in each of the 12 months of a year. This year is repeated until the excess moisture content of the specified layer reaches zero. During this time building component will dry out completely. Detailed calculation algorithm is given in ISO 13788.

Scheme of external wall of the heated addition to temple is shown in Figure 3. In this case it is predicted that the condensation interface located between thermal insulation and outer brick layer as shown in Figure 4.

Table 1 shows external and internal environmental conditions. Internal environmental conditions are derived from the external conditions using data ISO 13788, assuming high occupancy. Material properties for each material layer are shown in Table 2. Surface resistances for assessment of interstitial condensation are shown in Table 3.

Table 1. External and internal environmental conditions used for analysis

Month	t_{ext} [°C]	φ_{ext}	t_{int} [°C]	φ_{int}
January	–6.9	0.85	20	0.43
February	–6.5	0.85	20	0.44
March	–0.3	0.84	20	0.5
April	10.0	0.65	20	0.6
May	16.8	0.56	23.4	0.67
June	21.4	0.49	25	0.7
July	23.9	0.47	25	0.7
August	22.7	0.51	25	0.7
September	16.3	0.57	23.1	0.66
October	8.3	0.71	20	0.58
November	1.1	0.82	20	0.51
December	–4.4	0.86	20	0.46

Table 2. Material properties for external wall

Layer	Layer material	ρ_0 [kg/m^3]	λ [W/(m·K)]	μ [mg/(m·h·Pa)]
1	Lime mortar	1600	0.7	0.12
2	Hollow ceramic brick laying	1400	0.52	0.16
3	Concrete with polystyrene aggregates	250	0.085	0.11
4	Hollow ceramic brick laying	1400	0.52	0.16
5	Cement mortar	1800	0.76	0.09

Table 3. Surface resistances

Thermal resistance [m^2·K/W]		Water vapour resistance [m^2·h·Pa/mg]	
External	Internal	External	Internal
0.04	0.13	$3.7 \cdot 10^{-3}$	$11.1 \cdot 10^{-3}$

It is assumed that there is excess moisture content of 15 kg/m^2 as expected value at the moisture condensation interface.

If the building component is analyzed by using the environmental data for high occupancy internal climate without the wetted thermal insulation condensation is predicted at the interface between the thermal insulation and external laying in the coldest month of a year (see Figure 4).

3 Results and Discussion

Results of calculation of moisture conditions of external wall are shown in Table 4.

Table 4. Monthly condensation rate, g_c, and moisture accumulation, M_a, at condensation interface

Month	g_c [kg/m^2]	M_a [kg/m^2]
October	–0.276	0
November	–0.0433	0
December	0.043	0.043
January	0.0572	0.1
February	0.0551	0.155
March	–0.0119	0.143
April	–0.369	0
May	–0.739	0
June	–1.13	0
July	–1.46	0
August	–1.25	0
September	–0.684	0

Moisture accumulation in every month of a year is shown in Figure 5. Drying of wetted layer in external wall is shown in Figure 6.

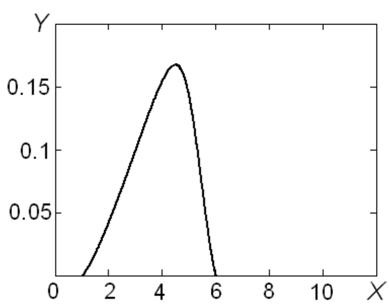

Figure 5. Moisture accumulation in external wall (key: x – month; y – condensate, expressed in kg/m^2; starting in October)

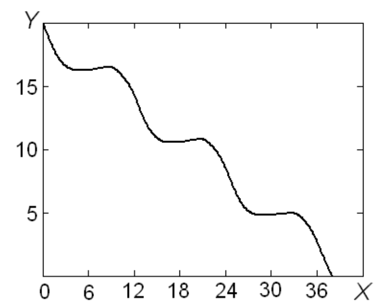

Figure 6. Drying of wetted layer in external wall (key: x – month; y – evaporated moisture, expressed in kg/m^2; starting in July)

As shown in Figure 5, the moisture accumulation at condensation interface rises to a highest point in February. From March onwards, the rate of condensation becomes negative (see Table 4), i.e. evaporation is occurring, and the accumulated moisture falls until it is close to zero in April.

Analysis of calculation results shows that condensation occurs at one interface during some months but there is no accumulation over the year as all the condensate is predicted to evaporate again. Thus, there is no systematic moisture accumulation at the building component within a year. As the maximum accumulation of condensate does not exceed 200 g/m^2 according to ISO 13788 the risk of run-off from non-absorbent materials will be very low.

Analysis of the evaporation rates at the interface, with the procedure specified in ISO 13788, starting in July, shows that mainly moisture evaporation from interface, until the amount of excess moisture reaches zero after 38 month (see Figure 6). Thus, duration of drying of wetted layer in external wall during initial stage does not exceed admissible values.

If necessary the received results can be specified by means of modeling of non-stationary moisture and heat transfer process in building components.

4 Conclusion

1. The object of research is reconstruction of Sergey Radonezhskiy temple in Volgograd. The reconstruction objective is construction of the heated addition to western facade of temple for liturgical rooms. Now reconstruction of the temple is almost complete.

2. New thermal design of external wall is developed according to author's concept. In this case the three-layer brick wall, including a thermal insulation layer from concrete with polystyrene aggregates, is considered. Offered thermal design of external wall is more effective, comparing to initial design data.

3. Calculation of interstitial condensation in building component is carried out according to simplified calculation method developed by the author and harmonized to ISO 13788. Analysis of calculation results shows that condensation occurs at one interface during some months but there is no accumulation over the year as all the condensate is predicted to evaporate again. Thus, there is no systematic moisture accumulation at the building component within a year. The risk of run-off from non-absorbent materials will be very low. Analysis of the evaporation rates at the interface shows that duration of drying of wetted layer in external wall during initial stage does not exceed admissible values.

5 Conflict of interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

1. V. Murgul, Journal of Applied Engineering Science, **12 (1)**, 1–10 (2014)
2. G. Woroniak, J. Piotrowska-Woroniak, Energy and Buildings, **72**, 51–61 (2014)
3. M.J. Varas-Muriel, M.I. Martínez-Garrido, R. Fort, Energy and Buildings, In Press, Accepted Manuscript (2014)
4. A. Turk, M. Elif Celebi, Building and Environment, **41 (12)**, 1867–1871 (2006)
5. A.W.M. Van Schijndel, H.L. Schellen, M.H. De Wit, Building and Environment, **44 (1)**, 156–168 (2009)
6. D. D'Agostino, Building and Environment, **63**, 122–133 (2013)
7. S. Pitsch, S. Holmberg, J. Angster, Building and Environment, **45 (12)**, 2629–2643 (2010)
8. A.G. Kochev, O.V. Pasyakina, Privolzhsky Scientific Journal, **3**, 75–81 (2007)
9. S.V. Korniyenko, Construction of Unique Buildings and Structures, **5 (20)**, 39–53 (2014)
10. G.P. Vasilyev, V.A. Lichman, N.V. Peskov, M.M. Brodach, Y.A. Tabunshchikov, M.V. Kolesova, Energy and Buildings, **86**, 803–807 (2015)
11. B. Berggren, M. Wall, Energy and Buildings, **65**, 331–339 (2013)
12. K. Martin, A. Erkoreka, I. Flores, M. Odriozola, J.M. Sala, Energy and Buildings, **43 (2–3)**, 529–535 (2011)
13. G. Mao, G. Johannesson, Energy and Buildings, **26 (3)**, 233–240 (1997)
14. N.I. Vatin, D.V. Nemova, P.P. Rymkevich, A.S. Gorshkov, Magazine of Civil Engineering, **8 (34)**, 4–14 (2012)
15. S.V. Korniyenko, Applied Mechanics and Materials, **618**, 509–513 (2014)
16. S. Korniyenko, AER-Advances in Engineering Research, **22**, 529–532 (2015)
17. S. Korniyenko, Applied Mechanics and Materials, **725–726**, 1375–1380 (2015)
18. S.V. Korniyenko, Magazine of Civil Engineering, **8**, 25–37 (2014)
19. A.S. Gorshkov, P.P. Rymkevich, N.I. Vatin, Magazine of Civil Engineering, **8**, 38–48 (2014)
20. S.V. Kornienko, Energy-Safety and Energy-Economy, **4 (64)**, 12–17 (2015)
21. S.V. Korniyenko, Procedia Engineering, **117**, 191–196 (2015)
22. S.V. Korniyenko, N.I. Vatin, M.R. Petritchenko, A.S. Gorshkov, Construction of Unique Buildings and Structures, **6 (33)**, 19–33 (2015)