HYGROTHERMAL REHABILITATION OF PUBLIC BUILDINGS. A CASE STUDY ON "LUCEAFĂRUL" THEATRE IN JASSY

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ABSTRACT

In the selection of thermo-energetic rehabilitation solutions, there are certain restrictions determined especially by the imperative of preserving the architectural characteristics, a large proportion of these buildings falling under the categories of historic or cultural monuments of high architectural value. Under the second category comes "Luceafărul" Theatre from Jassy, a representative edifice for the area in which it is located. The requirement of conserving the current appearance of the façade areas veneered with travertine has imposed the placing of thermal insulation on the interior surface. Taking into account that interior insulation implies a higher risk of interstitial condensation, a non-steady state coupled heat and mass transfer analysis was performed, by using the WUFI program. The results of this study are plotted as annual variations of relative humidity in the structure of envelope elements, pointing out the layers that are susceptible of excessive values. By numerical simulation of heat transfer with ANSYS program, the discussion is extended with the influence that the insulation of two adjacent envelope elements has on the surface condesation risk, for the case in which at the thermal bridge obtained there a discontinuity exists in the insulation layer.

Keywords: heat and mass transfer, building envelope, condensation risk, hygrothermal improvement, cultural monument

REZUMAT

În alegerea soluțiilor de reabilitare termo-energetică, apar anumite restricții determinate în special de necesitatea menținerii aspectului arhitectural, o bună parte din aceste clădiri fiind încadrate în categoria monumentelor istorice sau de importanță arhitecturală deosebită. În această din urmă categorie se încadrează şi Teatrul "Luceafărul" din Iaşi, edificiu reprezentativ pentru zona în care este amplasat. Necesitatea conservării aspectului actual pe zonele de fațadă placate cu travertin a impus plasarea izolației termice la suprafața interioară, pe aceste porțiuni. Având în vedere faptul că izolarea prin interior implică un risc sporit de producere a condensului interstițial, a fost efectuată analiza transferului termic cuplat cu transferul de masă, în regim termic nestaționar, cu ajutorul programului WUFI. Rezultatele acestui studiu sunt reprezentate grafic prin variații anuale ale umidităților relative în structura elementelor de anvelopă, cu evidențierea straturilor susceptibile de valori excesive. Prin simulări numerice ale transferului termic cu ajutorul programului ANSYS, discuția este completată cu influența pe care izolarea a două elemente de anvelopă adiacente o are asupra riscului de condens superficial, în cazul în care în puntea termică rezultată nu se realizează continuitatea termoizolației.

Cuvinte cheie: transfer termic şi de masă, anvelopa clădirilor, risc de condens, ameliorare higrotermică, monument cultural

1. INTRODUCTION

The requirements of European Directive 2010/31/EU, regarding the enhancement of energy performance of existing buildings, with the purpose of decreasing the energy consumption from non-renewable resources, and also the greenhouse gas emissions, are achievable only if the considerable share of non-residential existing public buildings in the overall energy demand is taken into account. This part of the building stock, erected in a wide majority before 1990, is a major energy consumer, for the following reasons:

– the predominantly low thermal protection level, determined by the constructive solutions, specific to the period in which it was built-up;
– the conditioning schedule, which is generally defined by intermittent heating, in some cases with long periods of service interruption;
– the necessity of maintaining certain microclimate conditions, as determined by the building function (museums, archives etc.) or by the occupancy rate, attainable only by means of ventilation/air-conditioning appliances.

In addition, it must be stated that a great number of these buildings fall in the categories of historic or cultural monuments of high architectural value and, therefore, the necessity of preserving the appearance of façades is an essential issue for the decisions regarding the actions that the building is subjected to. Following this criterion, the solutions currently applied to rehabilitation of residential buildings are suited only for some particular situations.

In this respect, there are several constraints to be fulfilled in the process of granting hygrothermal rehabilitation solutions to public buildings, and this process must include thorough studies for each separate objective, so that a proper prediction can be made on the submitted solution effects, according to the actual situation and the service conditions.

Such issues were identified with the occasion of thermo-energetic rehabilitation study for "Luceafărul" Theatre for children and youth in Jassy.

2. BUILDING DESCRIPTION

The edifice, built-up in the 80's, is distinguished by the building's volumes (Fig. 1) and the different approaches in assessing the façades – mostly veneered with travertine, which enhance the individuality and monumentality of the building (Fig. 2) – and thus it features as a representative unit for the area in which it is located.

Fig. 1. Main façade

Fig. 2. Architectural details

The building footprint is inscribed in a hexagon, with the contour line cut in by the four staircases and the stage pockets (Fig. 3). The main part is the auditorium, totaling over 400 seats.

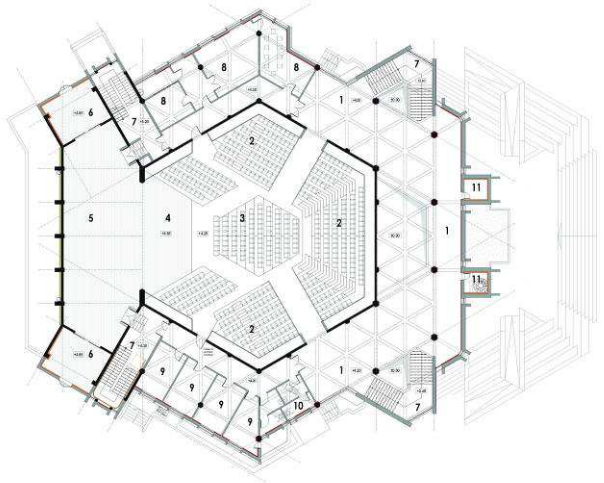

Fig. 3. Building plan: first story

The specific functionality is set out in vertical section as well, with the stage tower reaching a higher elevation, and the auditorium being covered by a pyramidal roof with hexagonal base, on truss structure (Fig. 4).

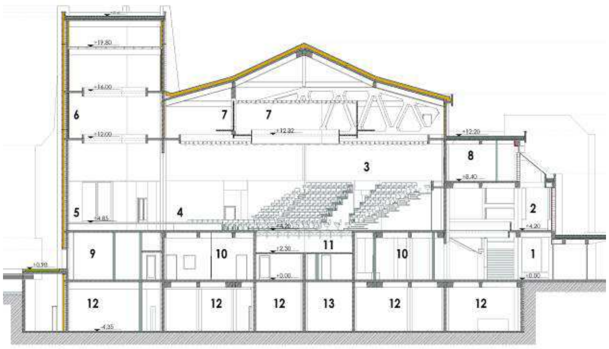

Fig. 4. Vertical section

These aspects have decisively intervened in the submission of rehabilitation solutions, these being based on thorough analyses of energy and condensation risk effects, as well as on thermal comfort provisions.

3. PROPOSALS REGARDING THE ENVELOPE ELEMENTS ASSESSMENT FOR THERMAL INSULATION IMPROVEMENT

The spatial configuration of the building, the structural elements and the façade finishing solutions determined different detailing solutions, even for the same type of enclosing elements. Consequently, the solutions for improving the level of thermal insulation of these elements were different as well, arising from the imperative of preserving the exterior finishing on certain areas – undecayed travertine veneer – but also from the exigence of ensuring the overall dimensions required for the specific activities course. A special interest was shown for the areas where the inferior slab comes in contact with the exterior air, detail for which two alternative interventions were proposed (Fig. 5).

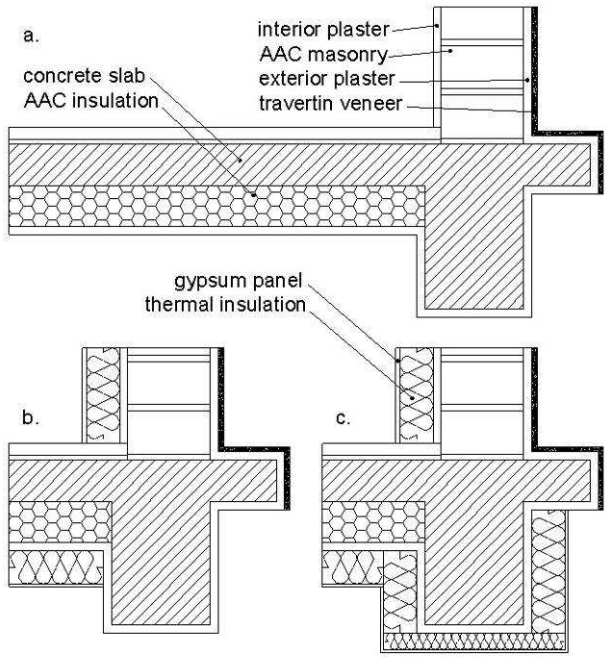

Fig. 5. Intersection of inferior overhang slab and exterior wall: a. before rehabilitation; b. additional insulation on exterior wall and slab; c. additional insulation on exterior wall, slab and girder.

Synthetically, the additional thermal insulating solutions are presented in the following.

3.1. Exterior walls

Depending on the structure, two types of exterior walls were identified:

- autoclaved aerated concrete (AAC) masonry of 25 cm thickness;
- reinforced concrete wall of 20 cm thickness, insulated with 12.5 cm AAC blocks.

To increase the thermal protection level, the following solutions were proposed:

- additional thermoinsulation on the exterior surface with mineral wool of 10 cm

thickness, inserted in a ventilated façade system, with natural stone parament, on frontage areas faced with stone powder decorative plaster;
- additional thermal insulation on the interior surface, corresponding to façade areas veneered with travertine.

Three alternatives were proposed for the interior insulation:
- with Multipor mineral panels of 10 cm thickness, for the walls enclosing rooms wide enough to permit the reduction with the insulation thickness;
- with Aerogel Spaceloft composite blankets of 3 cm thickness, for the areas corresponding to narrow spaces, where a gauge reduction would result in activities obstruction; the high thermal efficiency of this material permits an increased level of thermal protection for a considerable lower thickness;
- with mineral wool of 5 cm thickness, for areas where vapours emissions and fire risk are reduced to minimum.

3.2. Roof elements

The protection against weather conditions is achieved through a terrace at 22.40 m elevation, corresponding to the stage tower, and through the inclined rooftop over the auditorium, in a pyramidal design, on a truss structure covered with roofing sheets.

The proposed insulation solutions consist of:
- 20 cm of extruded polystyrene disposed at the terrace;
- 20 cm of mineral wool disposed under the roofing sheets, for the inclined rooftop.

3.3. Overhang slabs, in contact with the exterior air

For the overhang slabs, in contact with the exterior air, which enclose heated areas, an exterior insulation with mineral wool of 10 cm thickness was proposed.

4. HYGROTHERMAL BEHAVIOUR INVESTIGATION FOR THE SUMBITTED SOLUTIONS

4.1. Interstitial condensation risk for interior insulated walls

The placement of insulation at the interior surface of envelope elements can determine the occurrence of condensation at the interface between the insulating material and the existing structure. From this point of view, the investigation of proposed solutions was carried out with WUFI Pro, a computer program with which transient heat and mass transfer phenomena through building elements can be simulated. The program takes into consideration the thermal conductivity and vapour diffusion dependency on the material humidity, the latent heat of evaporation and fusion, as well as the capillary conduction.

For obtaining conclusive results, it is necessary for the simulations to be conducted over a long period, so that the influence of the initial conditions is diminished.

The exterior climate was considered through hourly recorded data at the Mădârjac meteorological station.

For the indoor climate conditions, the methodology in the EN 15026:2007 standard was applied, which considers the interior temperature and relative humidity as functions of outdoor air temperature, with the indoor relative humidity depending also on the level of moisture load.

The numerical simulation of heat and mass transfer with WUFI revealed the yearly variation of relative humidity in the structure of elements, with highest values at the layers interfaces, thus assisting the condensation risk assessment.

Such analyses were conducted for each wall structure for which the increasing of thermal protection level involves the placement of insulating material at the interior surface. The results showed that, by placing a layer of Multipor mineral insulation on the interior surface, no interstitial condensation risk occurs (Figs. 6 and 7), while aerogel insulation might imply, in some cases, a certain risk (Figs. 8-11).

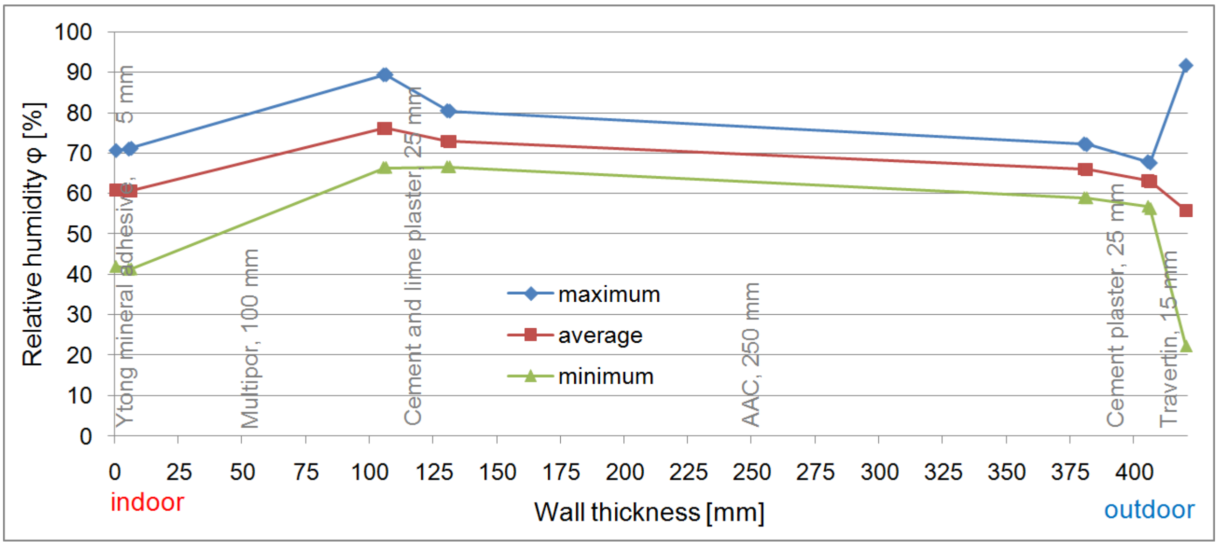

Fig. 6. Annual specific values of RH – AAC wall with Multipor insulation

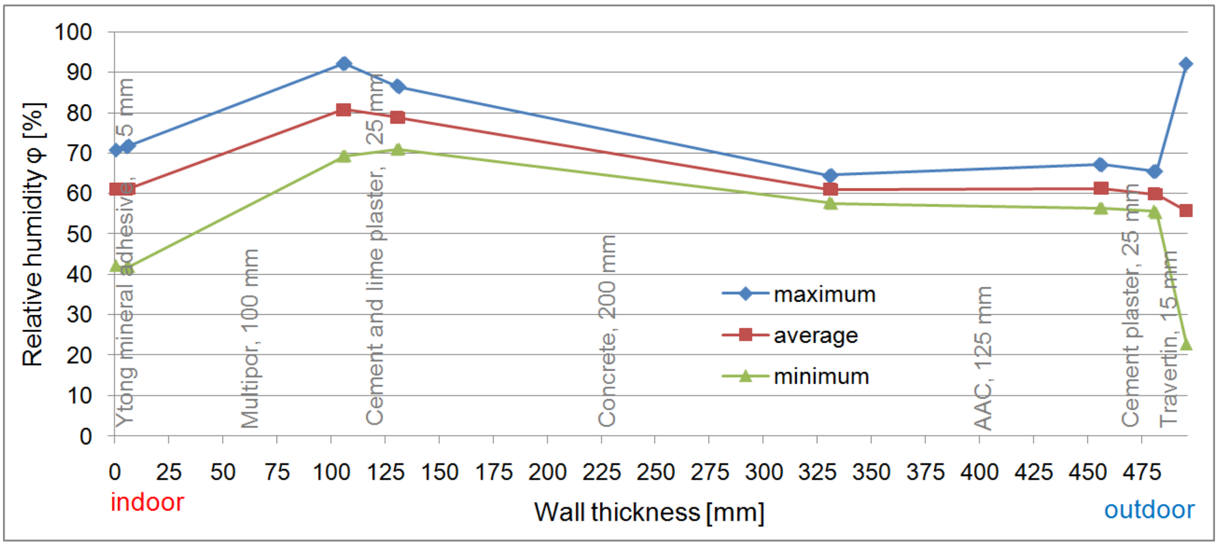

Fig. 7. Annual specific values of RH – concrete and AAC wall with Multipor insulation

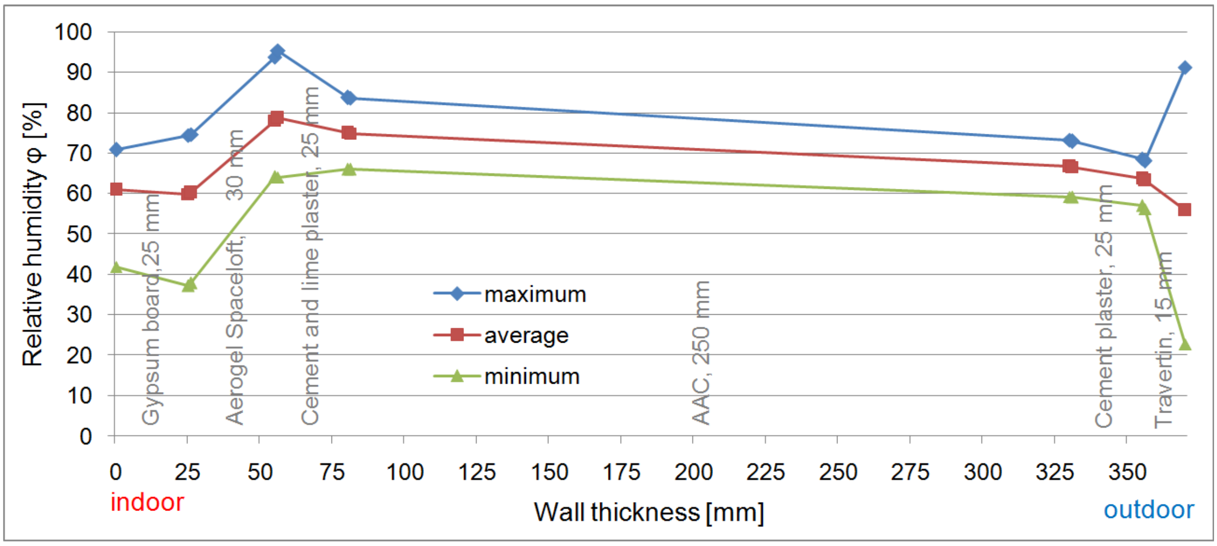

Fig. 8. Annual specific values of RH – AAC wall with Aerogel Spaceloft insulation

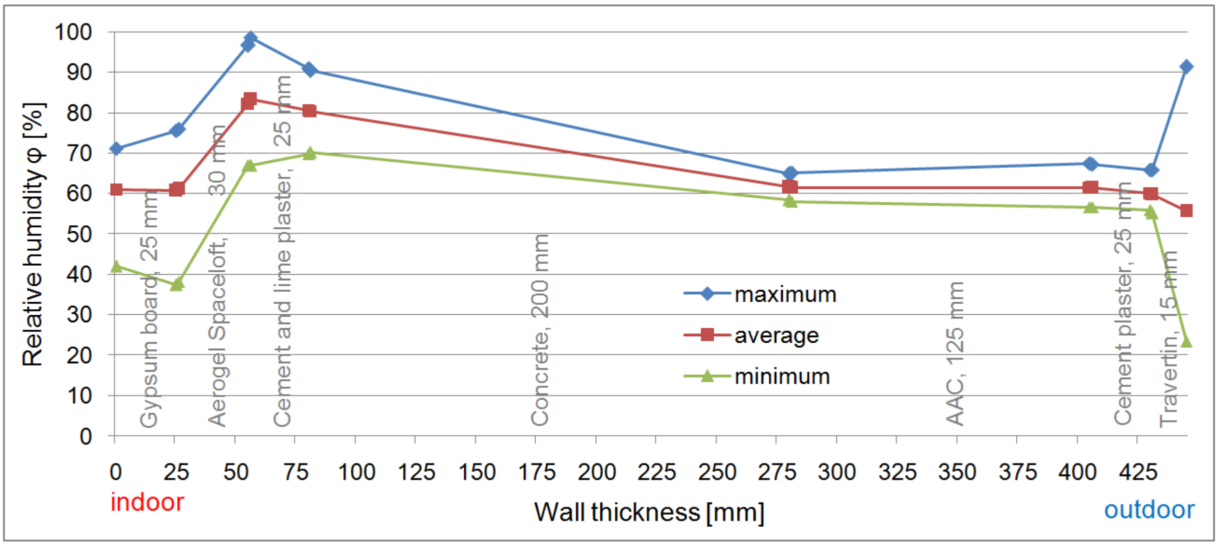

Fig. 9. Annual specific values of RH – concrete and AAC wall with Aerogel Spaceloft insulation

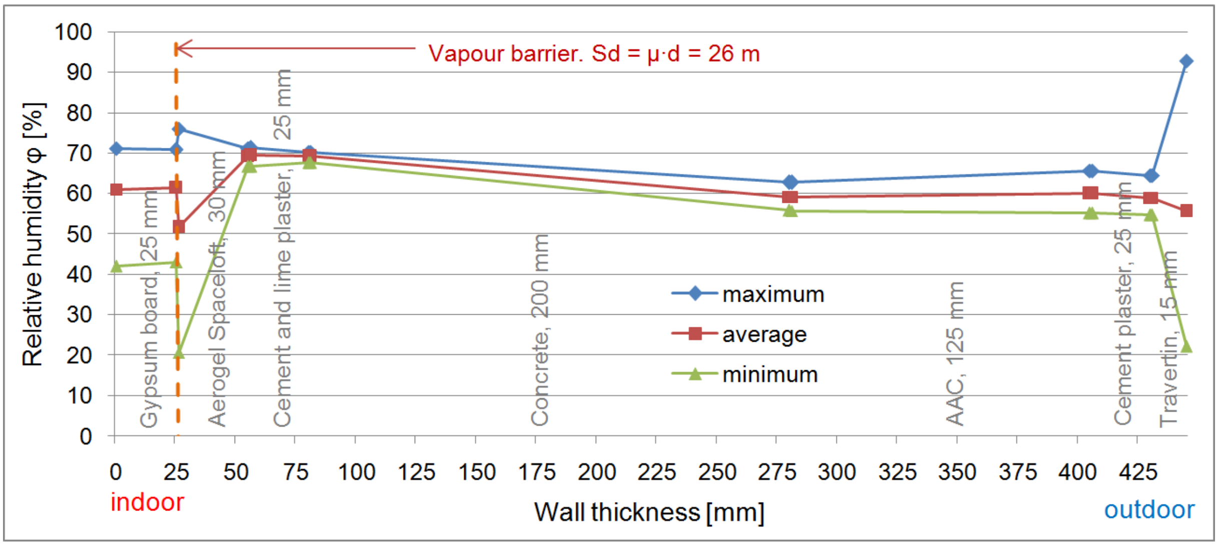

Fig. 10. Annual specific values of RH – concrete and AAC wall with aerogel insulation and vapour barrier

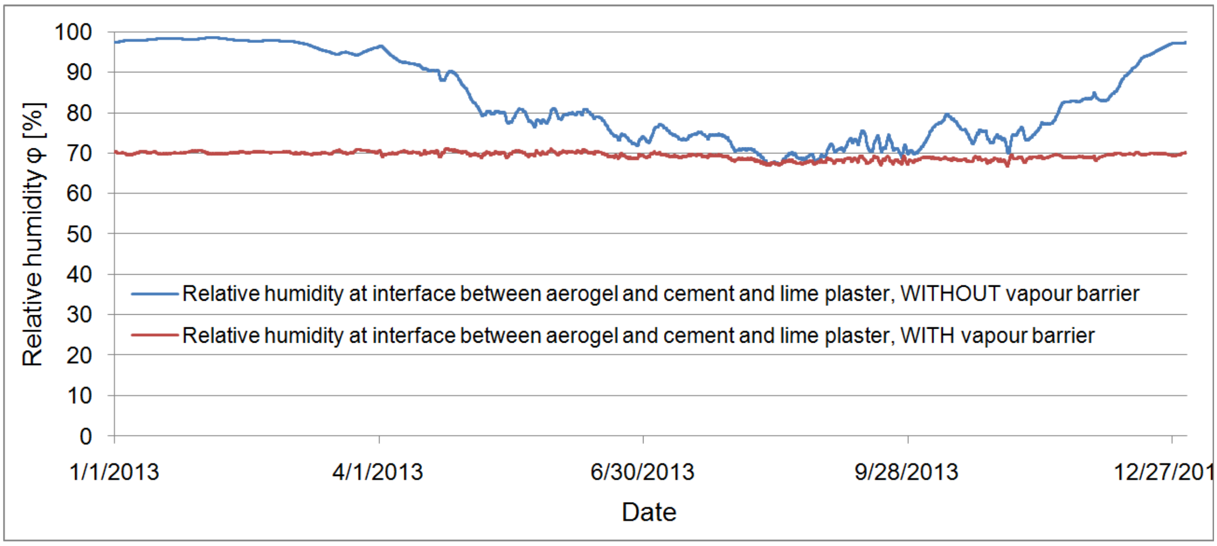

Fig. 11. Annual variation of RH – concrete and AAC wall with aerogel insulation, with and without vapour barrier

As a general observation for the first four cases (Figs. 6-9), the maximum annual values of relative humidity are recorded at the interface between the additional insulating material and the pre-existing interior plaster. The values range from 89.3% for AAC masonry with Multipor insulation, to 98.6% for concrete and AAC wall with aerogel insulation. For the last case, inserting a vapour barrier between the finishing gypsum board and the aerogel insulation brings in a shift of the maximum vapour accumulation layer to the inner limit of the aerogel blanket, with a maximum value of 75.9% (Fig. 10). The main effect of interposing the vapour barrier is depicted in Fig. 11, by comparing the annual relative humidity at the interface between aerogel and cement and lime plaster, with and without the vapour barrier. Although the condensation risk is present for short periods, the moisture protection measure appeared as recommendable for maintaining a lower and more stable relative humidity.

The results for interstitial condensation risk analysis are presented synthetically in Table 1.

Table 1. *Interstitial condensation risk*

No.	Structure	Materials (from interior to exterior)	Maximum relative humidity [%]	Vulnerable layer
1	AAC masonry, insulated with Multipor mineral insulation	Ytong mineral adhesive Multipor mineral insulation Cement and lime plaster AAC Cement plaster Travertine	89.3	Interface between Multipor and pre-existent interior plaster
2	Reinforced concrete wall, insulated with Multipor mineral insulation	Ytong mineral adhesive Multipor mineral insulation Cement and lime plaster Reinforced concrete AAC Cement plaster Travertine	92.1	Interface between Multipor and pre-existent interior plaster
3	AAC masonry, insulated with aerogel blanket	Gypsum board Aerogel Spaceloft Cement and lime plaster AAC Cement plaster Travertine	95.3	Interface between aerogel and pre-existent interior plaster
4	Reinforced concrete wall, insulated with aerogel blanket	Gypsum board Aerogel Spaceloft Cement and lime plaster Reinforced concrete AAC Cement plaster Travertine	98.6	Interface between aerogel and pre-existent interior plaster
5	Reinforced concrete wall, insulated with aerogel blanket and protected with vapour barrier	Gypsum board Vapour barrier Aerogel Spaceloft Cement and lime plaster Reinforced concrete AAC Cement plaster Travertine	75.9	Interface between gypsum board and aerogel

4.2. Thermal field analysis for the overhang slab and girder

In order to select the optimal thermal insulation solution, a thermal bridge was analysed at the intersection between the inferior overhang slab and the exterior wall, for the three details presented in Fig. 5, with the thermal fields presented in Figs. 12-14.

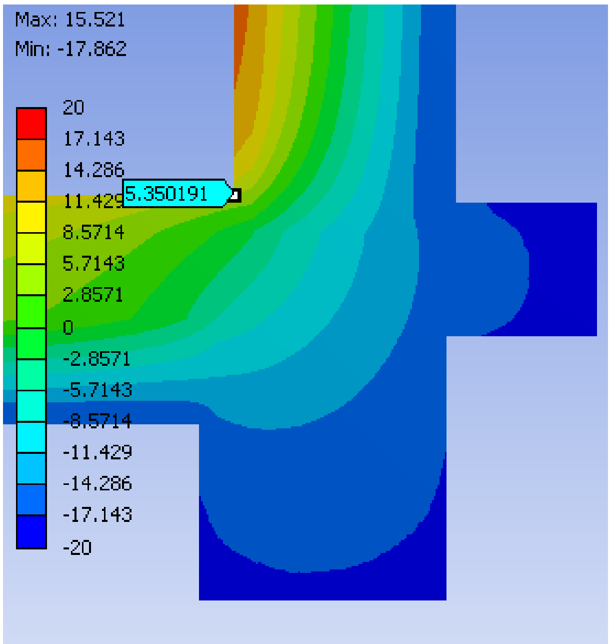

Fig. 12. Before rehabilitation

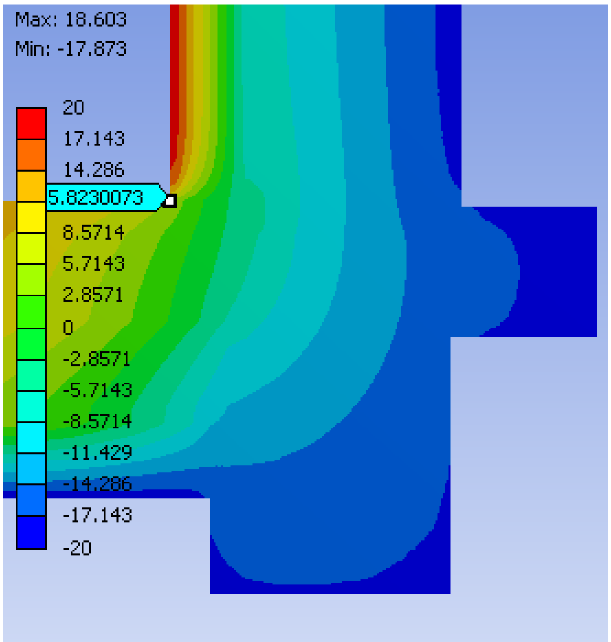

Fig. 13. Additional insulation on exterior wall and slab

Although the steady-state heat transfer analysis might be considered outdated by confronting its applications with models closer to real phenomena, it is still a practical way of revealing specific energy efficiency of details.

With values for surface temperature above 14ºC afar from the thermal bridge, in the initial situation (Fig. 12), the condition for preventing the condensation risk was not achieved due to the discontinuity of the AAC layers from the wall and the slab structures. Enhancing the thermal protection level of the adjacent envelope elements (Figs. 13-14) resulted in an increase of the superficial temperature, yet the most vulnerable areas remained at critical values.

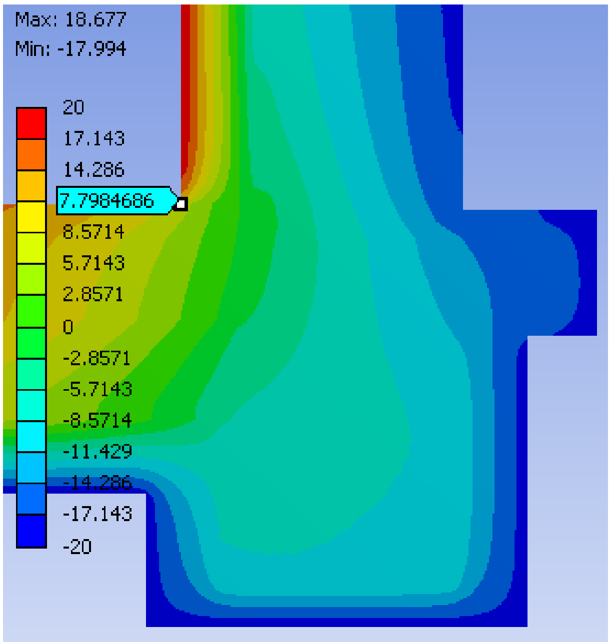

Fig. 14. Additional insulation on exterior wall, slab and girder

5. CONCLUSIONS

Most cases of hygrothermal rehabilitation of public buildings are conditioned by the necessity of preserving the façade appearance. Therefore, the improvement of thermal protection of exterior walls can be obtained only by placing the additional insulation on the interior surface.

This issue was identified at the "Luceafărul" Theatre in Jassy, in which façades are predominantly veneered with well-conditioned travertine. For those areas, two alternative solutions were proposed, by placing Multipor mineral insulation or Aerogel Spaceloft blankets on the interior surface, depending on the constraints defined by the gauge requirement. Those constructive solutions determine an interstitial condensation risk.

The investigation carried out by means of numerical simulations revealed the following aspects:

– Multipor application as interior insulation does not generate any interstitial condensation risk for the considered climate, the maximum relative humidity ranging at about 90%, for the AAC masonry, as well as for the reinforced concrete wall with pre-existent AAC insulation on the exterior surface;
– for the aerogel blanket solution, the condensation occurrence is presumable if no vapour barrier is interposed between the finishing gypsum board and the insulation; considering this intervention, the relative humidity is reduced to a lower and more stable level.

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