A SIMULATION STUDY TO ASSESS THE IMPACT OF NATURAL VENTILATION ON THE HYGROTHERMAL BEHAVIOUR OF A HISTORIC LIBRARY USING ENERGYPLUS AND ITS AIRFLOW NETWORK

Nuno Baía Saraiva[1], Adélio Rodrigues Gaspar[1], José Joaquim Costa[1]
[1] University of Coimbra, ADAI, Department of Mechanical Engineering, Rua Luís Reis Santos, Pólo II, 3030-788 Coimbra, Portugal

1 Abstract

Taking a historic library of the University of Coimbra as a study case, this work is focused on assessing the impact and conservation risks of using the main door of its noblest room. From a previous monitoring campaign, it was possible to correlate important fluctuations of the indoor environment conditions with the natural ventilation induced by opening the main door. Consequently, a comprehensive study is required to assess the impact of such ventilation events on the hygrothermal conditions and to study mitigating solutions.

The present work is based on the simulation of the hygrothermal behaviour of this heritage building using EnergyPlus and its airflow network (AFN) model that accounts for the effects of natural ventilation. The thermal model of the building is validated by comparing the results with the data available from continuous monitoring campaigns. Several operating configurations with alternative entrances for visitors are simulated.

The analysis of the simulation data allows (*i*) to estimate the heat balance between adjacent spaces of the building; and (*ii*) to assess the impact of the indoor conditions relatively to the conservation requirements. This assessment is based on the short period fluctuations (SPF) of the indoor air temperature and humidity and on the concept of a performance index (PI), which represents the percentage of measured/predicted data that lie within a range defined by thresholds recommended in the most used guidelines for conservation, namely ASHRAE (2015) and UNI 10829 (1999).

The results suggest that the door should remain closed as much as possible. Finally, the need to improve the hygrothermal conditions leaves an open field for further research regarding climate control systems.

Keywords: conservation, airflow network model, natural ventilation

2 Introduction

The conservation of a collection within a historic building has a strict relation with the indoor environmental conditions. The control of this environment is important but complex, particularly when heritage building are regularly open to visitors. Taking as an example for this study a heritage library, previous monitoring studies (Pereira et al. 2017) showed that using the main door of its noblest space induced thermal stress on the indoor environment. Therefore, due to the urgent need of safeguarding this cultural heritage, it is important to determine how to manage tourism and reduce its impacts on the indoor environment. In this way, the present study targets the assessment of this impact and aims to study ways to minimize it by several alternative visiting itineraries. For instance, changing the itinerary of the visiting tours may have impacts on the indoor environment, especially when there is direct indoor-outdoor contact. In this way, simulation is useful to test in advance the efficacy of different visiting tour configurations using the airflow network (AFN) model available in EnergyPlus to evaluate the ventilation promoted by opening the main door for the tourists' exit. The software outputs allow the study of the heat balance through infiltrations (mostly from door opening and leaks from the envelope) or/and from the natural ventilation mix between thermal zones. Since this door operation is the main reason for the observed SPF, an alternative solution should be studied to keep the main door permanently closed. In this sense, an alternative circuit and different operation configurations are tested to improve the conservation conditions.

3 Material and Methods

The case study is a historic library built in the 18th century at the courtyard of the University of Coimbra. The building is located at the city hill and is slightly rotated to east (12 º E) granting no shading obstructions on its southern façade. The building envelope includes 2-meter-thick walls (limestone and half-timbered with infill); and 4 mm single glass for the glazing systems (Saraiva et al. 2019). It this divided into three floors having the so-called Noble Floor, at the courtyard ground level, with 33.6 m × 12 m × 11.5 m, a total area of 550 m^2 with 12 windows (8 facing South and 4 facing North) which was divided into three contiguous Spaces 1, 2 and 3. It houses old books, painted wooden shelves, paintings and frescoes and has no HVAC system. The library operates from 09h00 to 19h00 during Summer and from 09h00 to 17h00 during Winter, and closes only five days a year. The visits are organized by groups of a maximum of sixty people every 10 minutes, and, at the end of each tour, the main door opens for 5-minute period. Internal thermal mass and loads are also considered with the respective schedules based on the current operation.

Some simplifying assumptions are acknowledged such as: schedules resulted from averages (the real situation is not possible to model in detail); wind coefficients are based on EnergyPlus recommendations; the weather file is based on average values of the last 30 years, so data do not correspond exactly to the real exterior environment conditions. These limitations influence part of the validation process but do not compromise the main objective of the work.

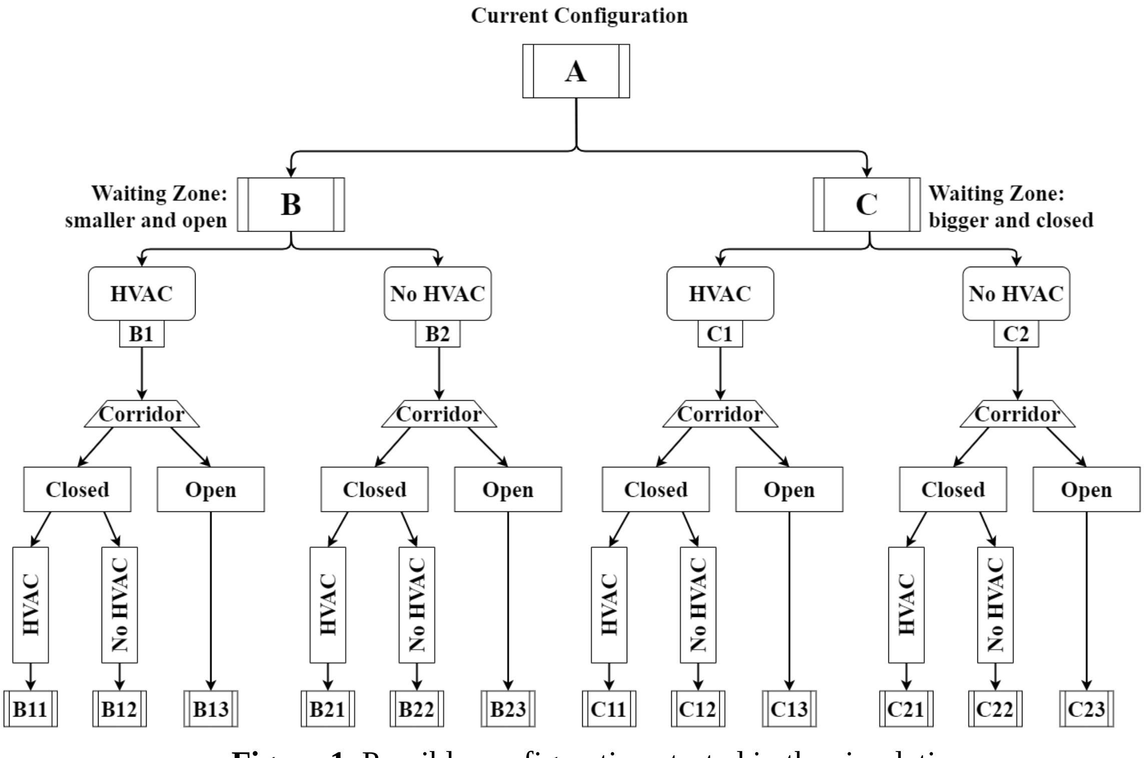

Figure 1. Possible configurations tested in the simulations.

Besides the current visiting circuit, named as A, 12 configurations were further tested (see Fig. 1). The main difference between A and others consists in keeping the main door closed by changing the circuit: visitors enter the building in a reception room and leave through the bottom floor (which in case A is the entrance). That room, named as Waiting Zone, can serve only as an access to the noblest floor without any separating walls (all configurations B) or it can be a reception room, as a virtual pre-visit space, being separated by doors from the rest of the building (all configurations C). Among the alternatives, there are additional sub-configurations: with/without HVAC in the Waiting Zone and/or the Corridor and maintain closed or opened one or both spaces) as shown in Fig. 2.

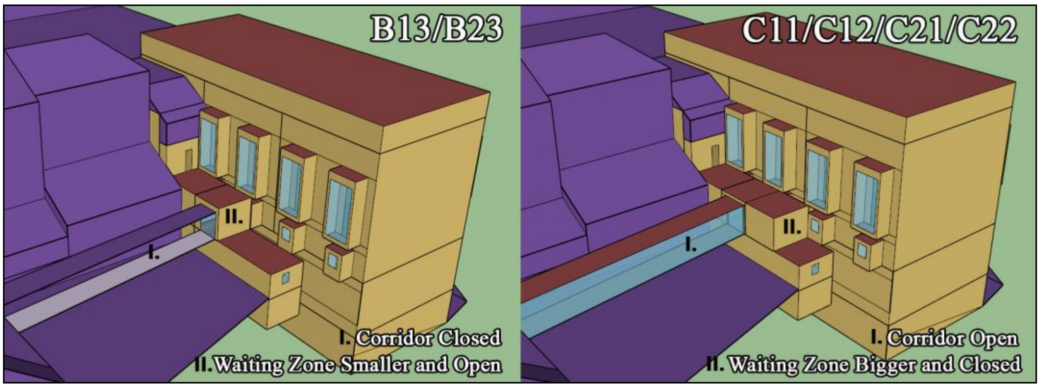

Figure 2. Northern façade with: (a) a smaller Waiting Zone and openly connected to the Noble Floor & the Corridor is exterior; or (b) a bigger and closed Waiting Zone & the Corridor is closed.

The assessment is based on the short period fluctuations (SPF) of temperature and humidity and on the concept of a performance index (PI). The SPF is calculated for each 10-min time step by the difference of the maximum and minimum values within a centred 24h running period. PI represents the percentage of measured/predicted data that lie within a range defined by thresholds recommended in the most used guidelines for conservation, namely ASHRAE (2019) and UNI 10829 (1999).

4 Results

The results for the current configuration A show a good approximation between the predicted and measured values of temperature and relative humidity, with annual relative errors of 9 % and 17 %, respectively. Heat gains and losses between zones are calculated using the air flow rates along with the specific heat (for a certain temperature and humidity) and temperature differences. As presented in Fig. 3 (a), each point represents a heat gain (positive) or loss (negative). It is evidenced that configuration A has higher heat losses (black points), particularly when the main door is open; but also, bigger heat gains from adjacent thermal zones of Space 1 (normal grey points) than in B13. In other words, the ventilation promoted by opening the main door intensifies the usual chimney effect with warmer air from lower floors rising and heating Space 1 at the Noble Floor. These heat exchanges induce fluctuations in the hygrothermal conditions affecting SPF and PIs according to the conservation recommendations. Note that for configuration B13, all the heat exchanges are minimized (dark and light grey).

Regarding the conservation conditions, it is not possible to assert that all alternative tours improve the indoor environment. From Fig. 3 (b), it is possible to note that there are no significant improvements on the hygrothermal environment. Configuration B13 is the one that leads to better PIs even if the difference in terms of PI is small (less than 10 %). However, not every configuration led to improvements; *e.g.*, configurations without air conditioning in the corridor (B22 and C22) have lower performances than the base one (A). In fact, the small connection to the Noble Floor is small (1.4 m^2) compared to the big volume of the library (Spaces 1, 2 and 3) and is not enough to bring a significant controlled airflow from the pre-visit rooms to have a positive impact on conservation. These results suggest that the Noble Floor should require the installation of an appropriate climate control system since passive solutions are not enough to maintain the recommended conditions. From another perspective, it is evident that closing the main door is beneficial on reducing the annual maximum SPF of the hygrothermal conditions as shown in Fig. 3 (c) and (d). Any improvement from changing the visiting tour circuit is more related to keeping the main door closed than with controlling the indoor conditions of the pre-visit rooms.

5 Conclusion

Briefly, further research may focus on coupling hygrometric models with the thermal model to have a more detailed tool to test other solutions. Regarding the main results, it is shown that opening the main door promotes the interaction between indoor and outdoor environments with negative impact in terms of conservation, expressed in the increase of annual maximum SPF values. Therefore, any tested configuration would reduce SPFs by keeping the door of the main floor closed and having an alternative itinerary. Configuration B13 is the one with best performance even though its improvements are small. Regardless of the configuration, the simulation results point out values of temperature and humidity outside of the recommended thresholds, reflected in PIs lower than 40 %. In this way, the design of an appropriate HVAC system to control the indoor environment should be considered for further research.

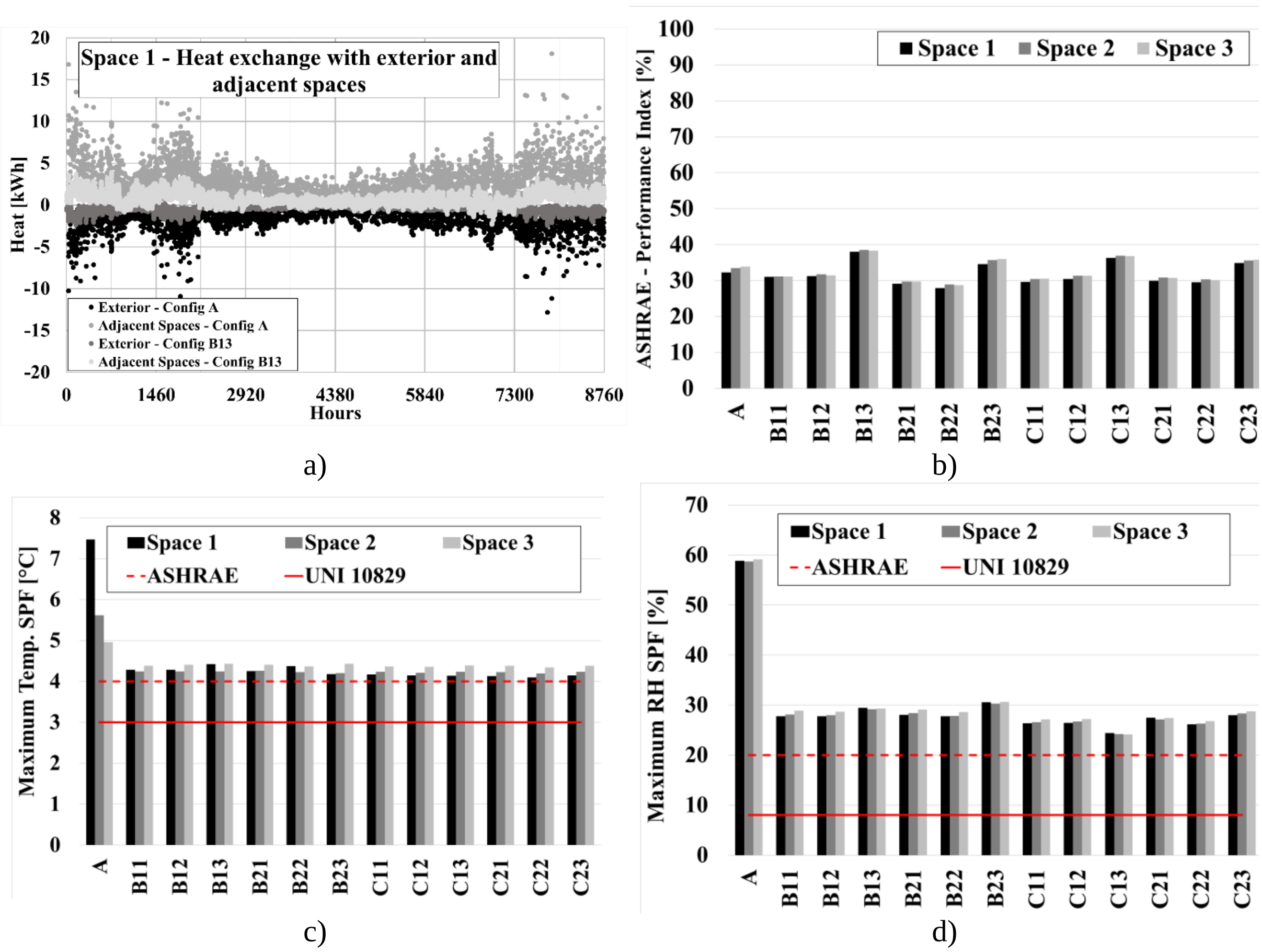

Figure 3. (a) Heat exchanges of Space 1 with exterior and adjacent spaces (config. A: black and normal grey; config. B13: dark and light grey); (b) PI according to ASHRAE; (c) annual maximum values for temperature SPF (d) annual maximum values for relative humidity SPF.

6 References

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