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Common Sense Architecture – Harnessing Local Wisdom for Sustainable Future

Refurbishing the Maneggio in Turin's Cavallerizza Reale

Evaluation of the passive potential to host a theatre meeting contemporary standards

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1. INTRODUCTION

In the context of the climate crisis and EU Renovation Wave, thousands of buildings are currently undergoing renovation. As energy regulations increasingly demand high environmental performance, prevailing design choices often focus on controlling the air indoors, which leads to adding insulation, increasing airtightness, and installing extensive mechanical systems. These solutions, easier to calculate, have become the de facto approach[1].

As this renovation wave approaches historic buildings, there is a risk that cultural heritage suffers irreversible damage in the name of this reductive approach to energy efficiency. While standard strategies typically focus on the envelope and mechanical conditioning, more subtle interventions are often overlooked. Modulating existing systems or window operation, adjusting occupancy, or broadening occupant thermal comfort expectations may yield greater energy savings. These subtler measures also avoid architecturally invasive interventions, their embodied and operational emissions and costs, and the progressive loss of the spatial and cultural qualities that motivated reuse in the first place. However, these solutions usually remain unexplored as they require the careful analysis of existing structures to minimise unnecessary interventions – a level of effort rarely included in project planning.

This paper presents the preliminary design studies for refurbishing the Maneggio Alfieriano, part of the Cavallerizza Reale (Fig. 1) within Turin's UNESCO World Heritage site. Originally built as a theatre for the equestrian shows of the Savoy court, the 18th-century structure has been abandoned for decades. The city sought to bring the building back into use in the early 2020s, and a first renovation project was developed that can illustrate the standard approach that often prevails. Rather than being carefully studied, existing buildings tend to be treated as deficient: lacking thermal insulation and efficient equipment when compared with modern buildings. As a result, large air-handling units and an invasive network of ducts were proposed despite their impact on the building's heritage and increasing energy and equipment dependence.

This first project was paused, and a new refurbishment project is now led by Lacaton & Vassal, together with TRA, Caractère Spécial and Atmos Lab. The team set out to assess whether the building could be brought back into use with minimal intervention while meeting today's indoor requirements. They focused on understanding the environmental qualities of the existing building first, and developing a targeted strategy second. This paper presents the building, climate and team approach in section two, the renovation projects in section three and methodology in section four. Section five shows the understanding of the building using fieldwork and simulation, section six includes the thermal model calibration used for the studies, and section seven presents the project strategy backed by environmental simulations. Sections eight and nine include the discussion and conclusions.

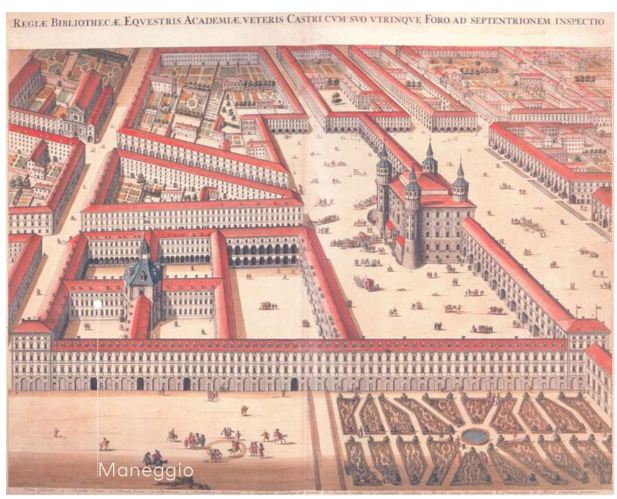


Figure 1: Original design for the Cavallerizza and academy complex in Turin, Castellamonte 1674. Source: Museotorino

2. CLIMATE, BUILDING AND DESIGN APPROACH

2.1 The climate

Turin (latitude 45°N, altitude 240 m) has a temperate climate — Cfa in the Köppen-Geiger classification — with a mean annual temperature of 15.9°C and four distinct seasons. Summers are hot and sunny, with July average highs of 28.4°C and an average diurnal range of 5.5 K; temperatures regularly exceed 30°C between June and September (Fig. 2). Winters are relatively mild and moderately sunny, with temperatures rarely falling below freezing; January is the coldest month, with an average minimum of 4.5°C. Owing to Turin's position in the Po Valley, wind speeds remain very low throughout the year, averaging 0.8 m/s. Therefore, natural ventilation is mostly driven by stack effects rather than wind.

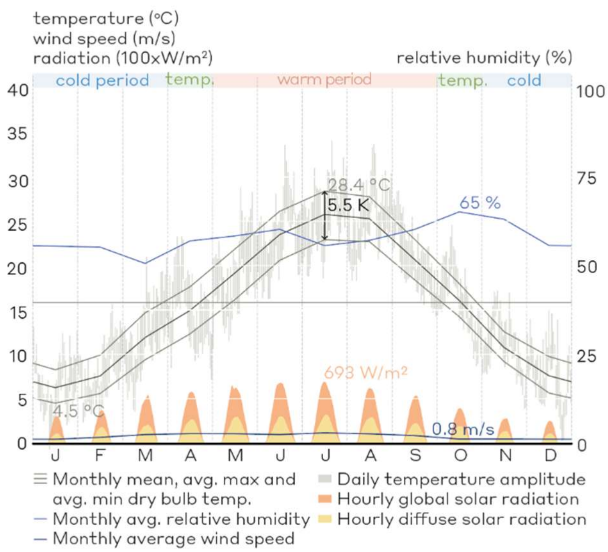


Figure 2: Weather data for Turin.

2.2 The Maneggio Alfieriano and Cavallerizza Reale

The Maneggio sits within the Cavallerizza Reale, part of the UNESCO World Heritage complex of the Residences of the Royal House of Savoy (Fig. 3 and 4). Inscribed on the list in 1997, it forms an exceptional Baroque ensemble radiating from the Palazzo Reale to express the absolute power of the Savoy dynasty through architecture. The Cavallerizza Reale was conceived in the mid-17th century by Castellamonte and realised in 1740 by Alfieri as a royal equestrian complex.

The Maneggio Alfieriano was constructed as the royal riding arena: a covered hall for the equestrian exercises and entertainments of the Savoy court. The main space is a compact volume of roughly 25m×38m plan and 15m height at the centre of the vaulted ceiling. It is structured along a central axis running southeast to northwest, with an attic area some 6 m tall located above. The main space is accessed from the south-east façade and the opposite wall houses a staircase, some storage areas and a passage to an adjacent central circulation space. The remaining two long facades, facing southwest and northeast, open to two courtyards of the Cavallerizza complex. Window to wall areas are moderate – 10% for northeast, 14% for southeast and 11% for southwest - even if the space has up to 35 openings in varied configurations, and the window to floor area is 16%. External walls are solid brickwork exceeding 1m and the brick-vaulted ceiling is some 25cm at the centre. The attic is covered by a clay-tiled roof over a wooden structure and ventilated by windows at each gable end.

The complex was substantially transformed in 1840 by Ernest Melano, bombed in 1943, and subsequently abandoned, making it one of the most historically layered buildings within the listed site.

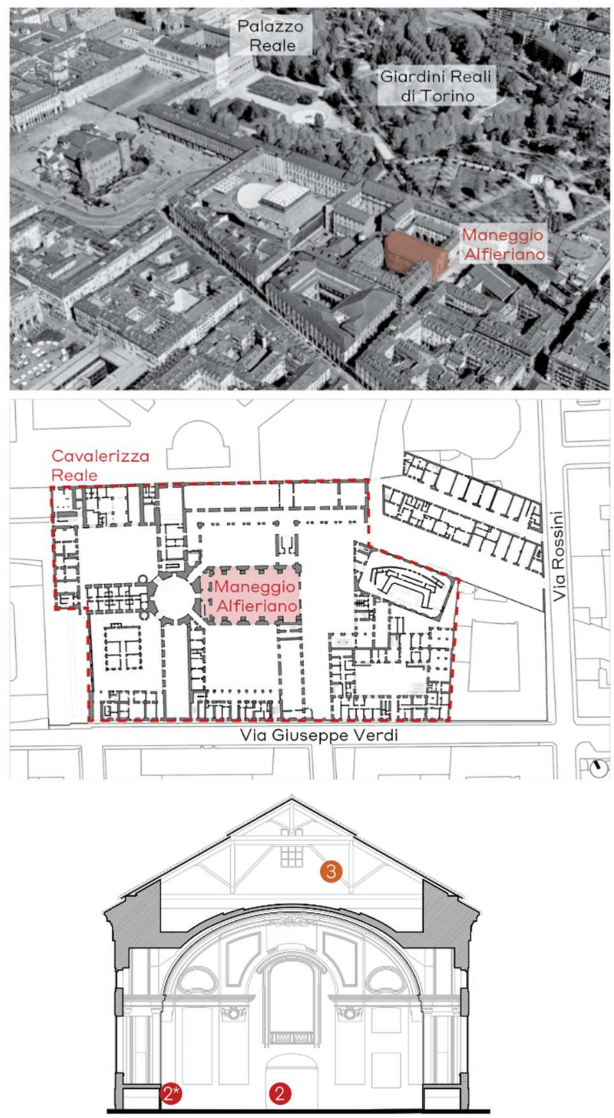


Figure 3: Aerial overview and site plan of the Cavallerizza reale showing the Maneggio Alfieriano. Section of the building below showing datalogger locations.

Figure 4: Photos of the Maneggio Alfieriano: southwest façade above and main space below.

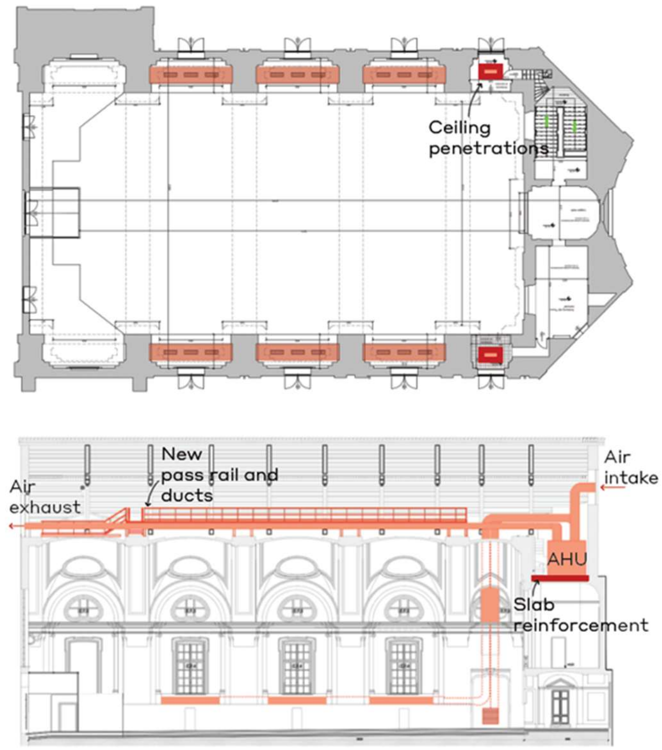


Figure 5: Preexisting project drawings for the Maneggio showing the intervention required for ventilation only.

2.3 The team's approach

Lacaton & Vassal have worked with existing buildings for decades, developing a design approach that is both sensitive to the qualities of the existing and occupant-centred [2, 3]. This is perhaps best evidenced in their project for the Palais de Tokyo in Paris, where extensive technical studies underpinned the decision to keep the existing structure as it is; and in the renovation of 530 residential units in Bordeaux, where the orientation and layout qualities of the existing apartments were amplified through the addition of winter gardens on strategic facades, radically improving occupant comfort and spatial experience.

Atmos Lab has worked alongside them over the last decade, supporting their careful approach to intervention in complex existing buildings, learning from past projects [4], and deepening a shared understanding of thermal and visual comfort and opportunities for adaptation. The collaboration usually begins before any design strategy is formulated, and focuses on understanding the environmental qualities of the existing structure in depth: its passive potential and limitation relative to the intended future use. From an initial position of minimal intervention, each proposed modification to the building fabric is carefully examined and justified or refused through calibrated simulations.

3. RENOVATING THE MANEGGIO

3.1 Preexisting design project

The previous renovation project may be seen as an example of standard refurbishment practice, as the design seems to have given limited consideration to the existing building's qualities. Despite the building's three exposed façades and numerous windows, ventilation was outsourced to an Air Handling Unit (AHU) with extensive ductwork for ventilation; a radiant floor was proposed for heating; and no cooling was planned.

The proposed ventilation solution, sized for 480 occupants, required ductwork extending through the main space and attic and penetrating significant areas of historic fabric. Structural reinforcement of the ceiling beneath the AHU, and a new service rail along the full length of the attic were also deemed necessary. The extent of the proposed intervention could have resulted in irreversible modifications to the structure, and permanent alterations of the spatial qualities of the building (Fig. 5).

3.2 The new renovation project

The renovation project led by Lacaton & Vassal sought to become a manifesto: it aimed to show that once the passive potential of the old theatre is understood, it is the programme that can adapt to the building and not the other way around. The intervention positions itself as a stage in the life of the building, not a definitive one, but a stage at a given moment in time, that is reversible. The project seeks to build on the existing building's qualities to minimise any impact to the heritage.

Theatre capacity and layout requirements were undetermined by the client, so the design team worked with reversible or movable stage elements to repurpose the Maneggio and give maximum flexibility under today's requirements. These movable elements can be configured in different layouts with audiences of 252, 336, and 420 spectators for theatrical performances, and 900 people for exceptional concerts (Fig. 6). In terms of environmental performance, the team decided to look at passive solutions before mechanical interventions were decided. For example, the potential of the existing operable windows and current indoor conditions were assessed before determining the need for ventilation, heating and cooling equipment.

4. METHODOLOGY

The environmental assessment of the Maneggio was divided in three phases: (1) understanding the qualities of the existing building through fieldwork and preliminary analysis, (2) development of thermal simulation models and validation against measured temperatures, (3) development of the intervention strategy based on scenario testing and comparison against relevant standards.

4.1 Understanding the qualities of the existing building

A detailed survey of materials and constructions in the building and its neighbours was carried out. Fieldwork included sub-hourly monitoring of indoor and outdoor air temperature and humidity, using Testo174H dataloggers [5] in locations shown in Figure 3. Monitoring was carried out during two typical periods: 8 days in December 2023 and 18 days in August 2024.

Architectural drawings of the building and its surroundings were used to build a 3D model including vegetation in Rhinoceros. The model was used to simulate incident solar radiation on glazed surfaces and daylight access using Ladybugtools [6] and Radiance [7].

4.2 Thermal simulation model and validation

Indoor air quality and thermal comfort conditions were evaluated with a multi-zone thermal model built with Ladybugtools and Energyplus [8]. The model was calibrated against measured temperatures to validate its accuracy.

4.3 Intervention strategy

Targeted design interventions were simulated as variations to the models described above, with passive solutions tested first. Simulations were run using weather data extracted from Meteonorm for an interpolated location in central Turin and validated against local station data from ARPA Piemonte. They were used to evaluate:

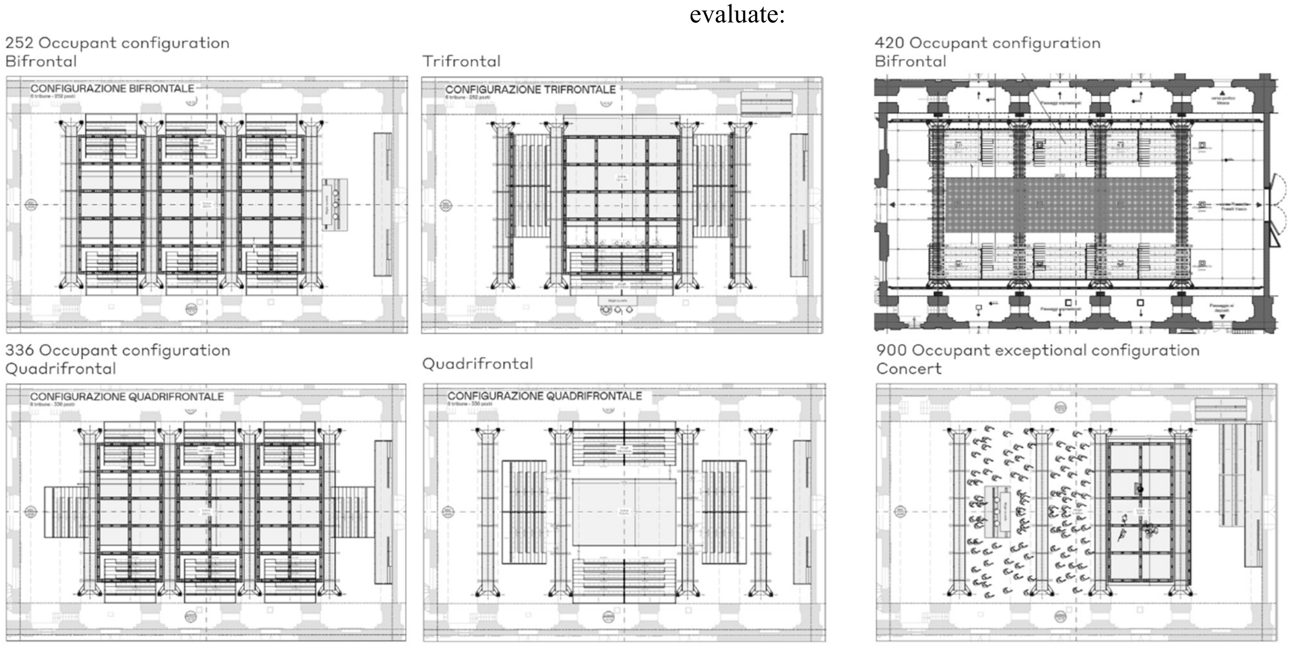


Figure 6: Theatre layout configurations for 252, 336 and 420 occupants and an exceptional 900 people concert configuration..

i) Indoor air quality based on CO_2 concentration and assessed against EN16798 [9]. Wind-driven ventilation was excluded from the assessment due to low local winds. Window ventilation rates were calculated in Optivent [10], considering stack effects only and using indoor–outdoor temperature differentials extracted from Energyplus. These ranged between 1.3 to 4.9K depending on the occupancy scenario for a typical evening show in spring, deemed the worst case scenario for shows that can rely solely on window ventilation (auxiliary fans were considered to enhance summer ventilation). CO_2 concentration indoors was simulated in Energyplus considering airflow rates calculated in Optivent, and occupant CO_2 emissions.

ii) Simulated indoor operative temperatures, assessed against EN16798 Cat.II and Cat.III. Regarding summer comfort, EN 16798-1 Cat.III for free-running buildings provides a directly applicable regulatory benchmark, though its adaptive comfort framework has limited applicability in a theatre where occupant opportunities are constrained: natural ventilation is controlled by the theatre operator, while clothing adjustment and access to drinks remain at the spectator's discretion.

iii) Physiological Equivalent Temperature (PET), adopted as a second overheating metric as it is based on a steady-state human energy balance model independent of adaptive opportunities. It is calculated in Ladybugtools, using the results from the thermal model and considers the combined effect of air temperature, humidity, radiation, and air speed.

iv) Heating energy demand and need for cooling.

5. UNDERSTANDING THE QUALITIES OF THE EXISTING BUILDING

Site surveys were combined with analytical work to understand the existing building.

5.1. Building survey

A detailed survey of the building's current condition was carried out by the architects, cataloguing the existing windows and the repairs required to restore each type to operation. It identified 35 originally openable elements that could be reinstated with varying levels of intervention to provide natural ventilation. Detailed architectural drawings of the building were also developed.

5.2. Preliminary solar and daylight analysis

Incident solar radiation during summer is low on the long southwest and northeast façades, and significant on the southeast one (214 kWh/m^2 on average) (Fig. 7). The pattern remains similar in winter, when only the southeast façade receives noticeable radiation (132 kWh/m^2 on average). Overall, total summer and winter solar gains in the space are low, amounting to approximately 10 kWh/m² and 7 kWh/m² of floor area respectively, reflecting the moderate ratio of glazed area to total floor area and nearby obstructions.

Daylight indoors was evaluated considering the inputs shown on Table 1. Results show daylight autonomy for two illuminance thresholds (Fig. 7): 100 and 300 lux. The space achieves 100 lux during the vast majority of daylit hours throughout the year, with a spatial average of 96% DA100. At 300 lux, daylight autonomy is expectedly lower and unevenly distributed. The area closest to the southeast façade is the brightest one, reaching this threshold for around 50 to 70% of daylit hours.

Table 1: Daylight model inputs

Element	Reflectance	Visual transmittance
Brick context	0.11	
Grass context	0.17	
Trees	0.17	
Surrounding pavement	0.25	
Ceiling/walls	0.74	
Floor	0.17	
Wooden frames	0.15	
Doors	0.05	
Single glazing		0.8

Low solar heat gains over the year point to the fact that indoor conditions are largely unaffected by the sun. By contrast, the high windows on the three exposed façades bring daylight deep inside, with the analysis indicating that little or no supplementary electric lighting will be required to maintain 100 lux during the day. This illuminance level meets the requirements for audience areas in theatres and public assembly spaces [11], and is sufficient for ancillary activities such as cleaning, fit-out, rehearsals, and informal gatherings. The building's fenestration and spatial proportions prove well suited to both the daylight and solar control requirements of a performance venue; a less surprising result given its original function as a space for equestrian performances.

5.3. Temperature monitoring

Temperature monitoring carried out during summer and winter showed that:

1. Temperature in the main space is exceptionally stable during both seasons, and stays within a very narrow range despite outdoor swings (Fig. 8). In winter, outdoor temperature varies within a range of 2 and 10°C, while indoors does so by only 2 K between 6 and 8°C. Mean air temperatures for the period are 4.7°C outside, 6.9°C in the main space. In summer, outdoor temperatures vary by 14 K between 20 and 34°C, while the main space remains stable within 24 and 26.5°C. Average air temperatures over the entire monitored period are 26.8°C externally, and 25.5°C in the main space, while during the initial five hot consecutive days these rise to 28.5°C, and 25.9°C.

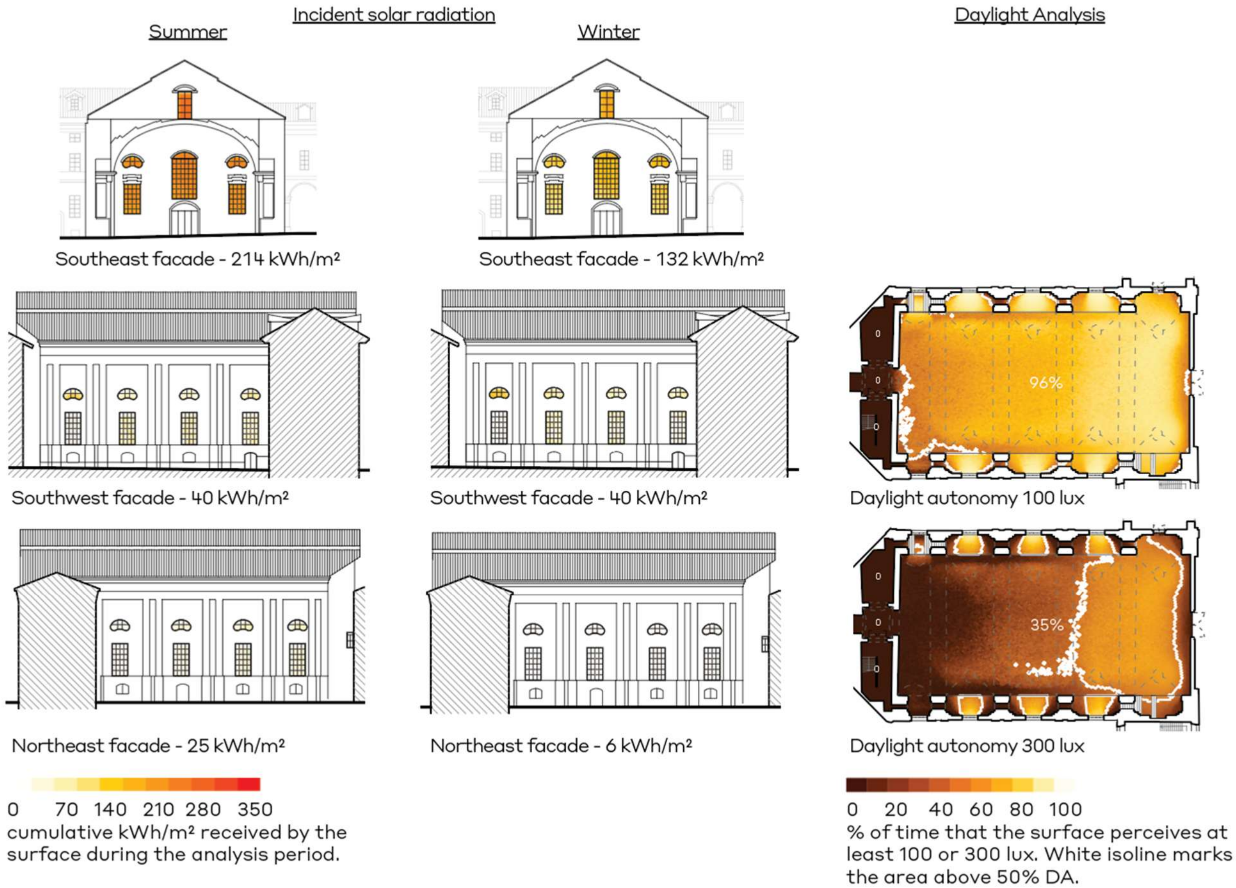


Figure 7: Solar irradiation on glazed surfaces during winter and summer (left). Daylight autonomy for 100 and 300 lux (right).

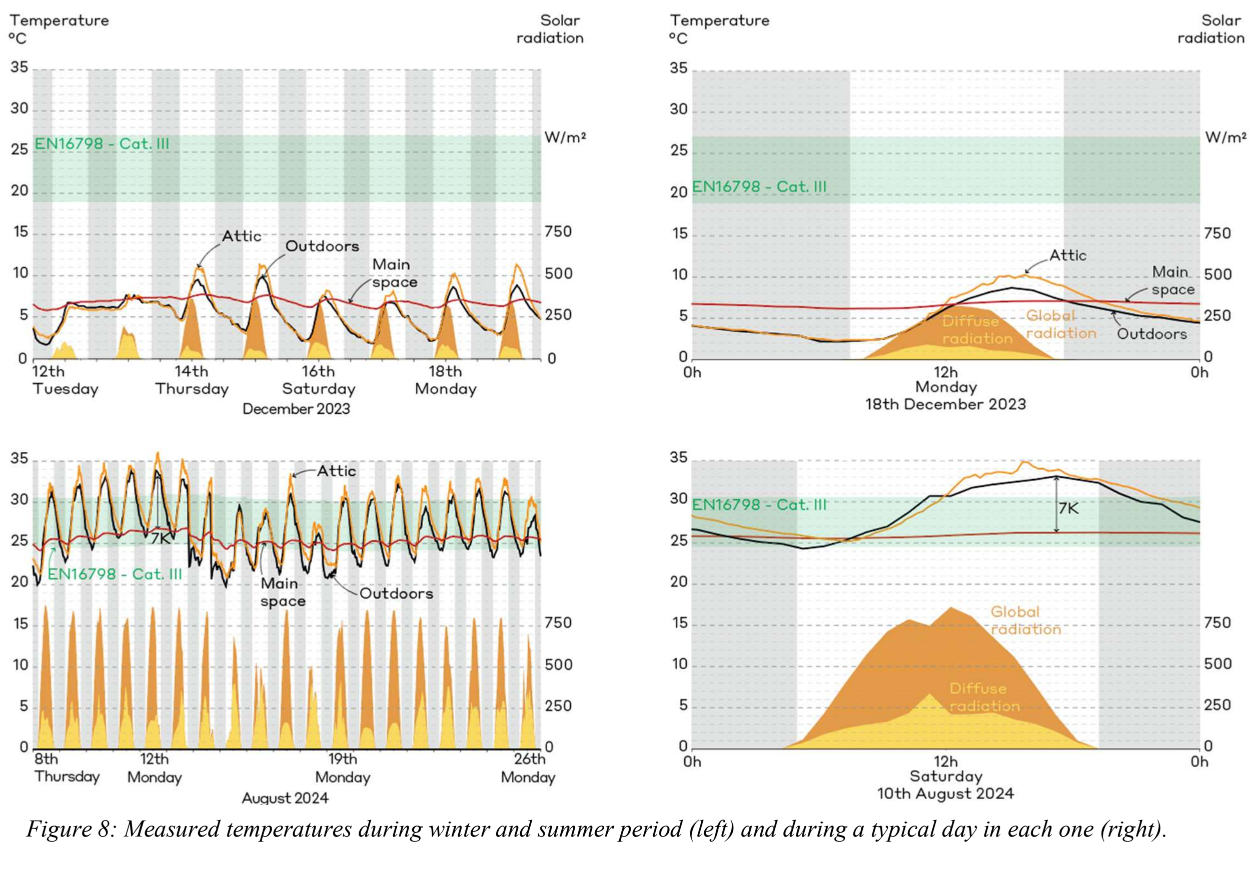


Figure 8: Measured temperatures during winter and summer period (left) and during a typical day in each one (right).

The main space was 2.6 K below the external mean on average. The temperature stability is caused by the large thermal inertia of the walls, the moderate window to wall ratios and contact with the ground.

2. Temperature in the attic tracks outdoor temperature in summer and winter, with moderate increases of 1 to 2 K during sunny days (Fig. 8). Mean air temperatures for winter are 4.7ºC outside and 5.7ºC in the Attic, while for summer they are 26.8°C and 27.6°C respectively. The open windows and leaky roof let outdoor air into the attic which evacuate any heat from indoors. On sunny days, solar heat gains conducted by the roof slightly increase indoor temperature.

3. Sky conditions and solar radiation barely affect temperature in the main space in winter and summer. Indoor temperature remains stable across sunny or cloudy days, with gradual and slow variations following multi-day trends. This can be seen on the 2 K increase over the first five days of the summer monitoring (Fig. 8). The finding is further evidenced during the sunny winter day shown. Space decoupling from solar conditions is caused by the moderate window to wall ratios (10-15%), large thermal inertia of the space, the ventilated attic and surrounding trees on the southwest façade.

4. Summer temperatures in the main space stay at the low end of the comfort band, some 7 K below outdoor peaks, without any active cooling (Fig. 8). Despite large diurnal swings and outdoor peaks of 34°C, internal temperatures remain at the lower end of the Category III adaptive comfort band, around 25 to 27°C. These exceptional temperatures are influenced by the thick brick walls and ground slab capacity to store heat during hot days; and the moderate window to wall ratios and ventilated roof that prevent solar gains.

These findings demonstrate that indoor conditions in the main space are largely decoupled from short-term weather variations: the building maintains a microclimate of its own in each season. In summer, this microclimate falls within the adaptive thermal comfort band without any active cooling. The results suggest that mechanical conditioning systems may be far less necessary than conventional assumptions would imply — and that the building's passive performance constitutes a significant asset for its proposed new use.

6. BUILDING A CALIBRATED THERMAL MODEL

6.1 Multi-zone thermal model

A multi-zone thermal model was built in Ladybugtools and Energyplus, based on architectural drawings of the building and its surroundings. The detailed model inputs can be seen in Table 2 and the geometry and three analysis zones in Figure 9.

Table 2: Thermal model inputs

Envelope		
	Composition	U-value [W/m²K]
Floor slab	20cm concrete + 5cm screed + 30cm gravel	1.40
Side external walls	1.2m brick + mortar	0.56
Front wall	0.45m brick (+ vegetation in some areas)	1.30 (1.15)
Internal ceiling	0.25m brick + mortar	1.99
Roof	Wood board + clay tiles	2.83
Windows	Single glazing	5.7
Infiltration	3.6 m^3/m^2h	

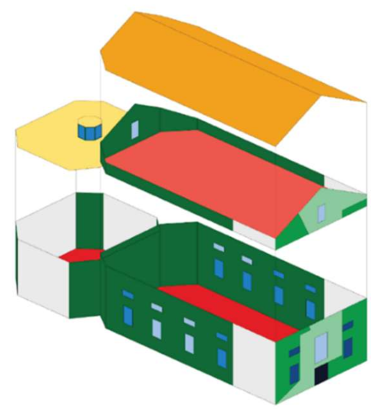


Figure 9: Thermal model built in Ladybugtools showing the three thermal zones. Walls in grey were set as adiabatic, as they are facing adjacent spaces.

6.2 Thermal model calibration

The multi-zone model was calibrated using recorded data: material properties assumed from literature, infiltration and ground heat transfer properties were adjusted until simulated and measured temperatures matched to an accuracy of R2=0.99, calculated as the combined fit across both monitoring campaigns. Figure 10 presents simulated temperatures alongside measured ones, demonstrating the general agreement between the simulation model and monitored data across both monitored periods. In the main space, simulated temperatures differ by up to 1ºC; most likely caused by the microclimatic variations induced by the courtyards on both sides of the space, which cannot be replicated in the model.

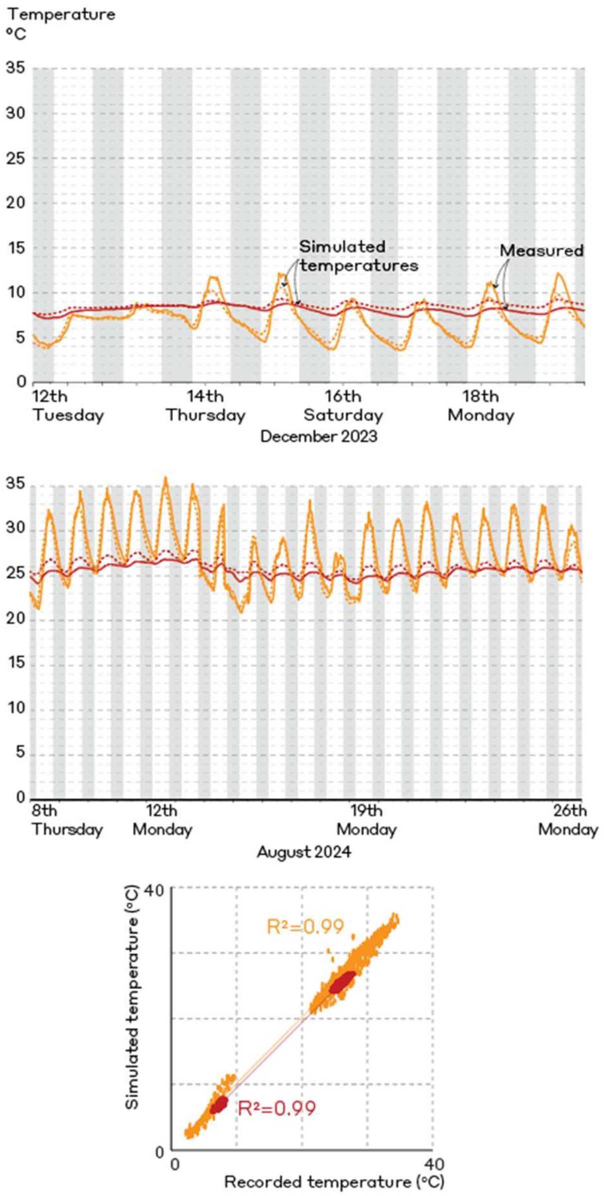


Figure 10: Temperature graphs (above) showing model calibration with simulated temperatures in dash and measured ones in solid. Model validation plot showing the correlation between simulated and measured temperatures (below).

7. EVALUATING INTERVENTIONS THROUGH ENVIRONMENTAL SIMULATIONS

Targeted design interventions were developed based on the characteristics of the existing building. The following sections show the performance of the current state, and the strategies proposed to mitigate any shortcomings.

7.1 Ventilation and fresh air provision

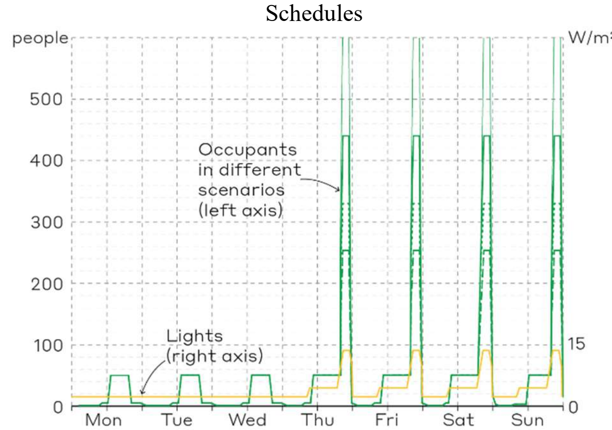
Fresh air provision for occupants is one of the main challenges in heavily occupied spaces such as a theatre. For the Maneggio, air quality simulations were used to evaluate the need to repair existing windows and make them openable. As the Maneggio sits in a dense part of central Turin, the acoustic impact of open windows on the neighbourhood was a concern during shows. Several window opening scenarios were simulated to mitigate acoustic impact.

7.1.1. Indoor air quality simulations

The calibrated thermal model was simulated with four occupancy scenarios, representing different theatre layout scenarios. Occupancy inputs are shown in Table 3.

Table 3: Thermal model inputs for occupied scenarios

Internal loads	
People	156 W/person
CO_2 emissions	$6 \cdot 10^{-6}$ $m^3/s \cdot$person
Equipment + Lights	14 W/m^2
Schedules	



The simulation approach enables the large volume of the space to be considered as a fresh air reservoir [12], maintaining acceptable indoor air quality for a defined period at the start of occupancy without ventilation. Once exhausted, operable windows can become the primary means of replenishment — though if the reservoir alone proves sufficient for the intended occupancy, reinstating the heritage windows may not be required. Traditional ventilation rate calculations cannot capture this effect, assuming instead that ventilation is required immediately upon occupancy.

7.1.2. Assessing the need to repair existing windows

The basecase and three window refurbishment scenarios were evaluated to balance cost implications with achieved airflow for each theatre layout scenario. Figure 11 shows the basecase (BC) with no openable windows; scenario 1, with openable low windows only; scenario 2, with openable low and high windows; and scenario 3 with openable low, high and bean windows.

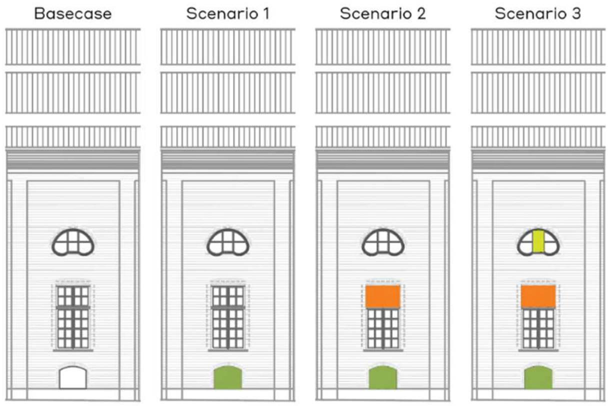


Figure 11: Design scenarios showing openable windows for one façade module.

Table 4: Effective ventilation areas per design scenario.

Design scenario	Effective ventilation window area per module (m^2) Low windows (z=0.75m)	Middle windows (z=4.25m)	High windows (z=6.2m)	Bean windows (z=9.6m)
BC	-	-	-	-
1	0.63	-	-	-
2	0.63	-	2.10	-
3	0.63	-	2.10	2.03
2*	1.05	-	2.10	-

Table 4 shows the effective areas and window heights for each scenario and includes a variation of scenario 2. Areas include discharge coefficients (Cd) from Optivent. A Cd of 0.8 is considered for side hung windows that open over 90º for middle, high and bean ones; Cd of 0.3 for low windows due to planned ventilation grills; and Cd of 0.5 for a less obstructed grill in low windows in scenario 2*. Results are presented in Table 5, and show that:

1. The existing air volume (BC) is sufficient to sustain a 2h 20m performance with 252 occupants while meeting air quality Category II. This duration reduces to 1h 10m for 420 occupants.
2. Repairing the low windows (1) only yields a marginal improvement, extending show duration from 1h 10m to 1h 20m for 420 occupants.
3. Repairing the bean windows (3) provides a marginal ventilation increase and was discarded. The ventilation benefit is not balanced by the complexity of making the bean windows operable.
4. Repairing the high and low windows with a permeable grill on the latter (2*) shows the highest ventilation, and a show can exceed 3 hours across all regular configurations within Cat.II. An exceptional 900-person concert meets EN 16798-1 Category III for the first hour. This was the adopted scenario.

Table 5: Simulation results for the window repair scenarios, showing the adopted scenario in bold.

Design scenario	Airflow per façade module from Optivent	Max. show duration (Cat.II CO_2 <1200ppm)	Max. show duration (Cat.III CO_2 <1750ppm)
Layout 252 occupants			
BC	0.0 m^3/s	2h 20m	+3h
1	0.04 m^3/s	3h 0m	+3h
2	0.24 m^3/s	+3h	+3h
3	0.26 m^3/s	+3h	+3h
2*	**0.37 m^3/s**	**+3h**	**+3h**
Layout 336 occupants			
BC	0.0 m^3/s	1h 30m	+3h
1	0.04 m^3/s	1h 40m	+3h
2	0.27 m^3/s	+3h	+3h
3	0.29 m^3/s	+3h	+3h
2*	**0.42 m^3/s**	**+3h**	**+3h**
Layout 420 occupants			
BC	0.0 m^3/s	1h 10m	2h 50m
1	0.04 m^3/s	1h 20m	+3h
2	0.29 m^3/s	+3h	+3h
3	0.31 m^3/s	+3h	+3h
2*	**0.44 m^3/s**	**+3h**	**+3h**
Layout 900 occupants (exceptional concert)			
BC	0.0 m^3/s	10m	0h 30m
1	0.04 m^3/s	10m	0h 30m
2	0.46 m^3/s	15m	45m
3	0.50 m^3/s	15m	50m
2*	**0.71 m^3/s**	**20m**	**1h 0m**

7.1.3. Window management to mitigate acoustic impact

Concerns were raised about the acoustic impact of open windows during shows, and a set of mitigation scenarios were simulated. These bring back the concept of flushing the venue during the interval, already built in venues towards the end of the 18th century [13]. Four scenarios were tested: windows always closed during shows(A); opened for 20 minutes during the show interval (B); opened for 20 minutes with the room vacated during the interval (C); and opened all show(D). Table 6 shows the results:

1. All theatre configurations can host a 3-hour performance meeting Cat.III air quality with windows closed.
2. A 252-occupant configuration can host a 2h 50m performance within Cat.II by opening windows during the interval.
3. A 336-occupant configuration can also host a 2h 50m performance by opening windows and vacating the room during the interval.
4. A 420-occupant configuration can host a 1h 10m performance by opening windows and vacating the room during the interval. Longer performances require windows open all time or accepting Cat.III air quality.
5. A 900-person concert does not meet Cat. II air quality for a meaningful duration in any scenario. Cat. III is maintained for 1 hour with windows open all time.

Table 6: Simulation results for window management scenarios for each layout configuration.

Window Management Scenario	Max. show duration EN Cat.II (<1200ppm)	Max. show duration EN Cat. III (<1750ppm)
Layout 252 occupants		
A	2h 20m	+3h
B	2h 50m	+3h
C	+3h	+3h
D	+3h	+3h
Layout 336 occupants		
A	1h 30m	+3h
B	2h 15m	+3h
C	2h 50m	+3h
D	+3h	+3h
Layout 420 occupants		
A	1h 10m	+3h
B	1h 10m	+3h
C	1h 10m	+3h
D	+3h	+3h
Layout 900 occupants (exceptional concert)		
A	10m	40m
B	10m	40m
C	10m	40m
D	20m	1h 0m

The summary presented in Table 6 is drawn from a detailed time-resolved analysis of indoor air quality across all theatre configurations and window management scenarios (Fig. 12).

The impact of window opening limitations on indoor overheating during showtime is evaluated in the following section.

Analysis shown in this section highlights that repairing two windows per module is sufficient to provide fresh air for most of the theatre design scenarios, even if windows must remain closed to mitigate acoustic impact during shows. The fresh air reservoir is able to cover the entire show with Cat.III air quality for all typical configurations.

7.2 Thermal comfort in free running mode

The calibrated model was simulated under the theatre occupancy scenarios and considering windows repaired as described in the previous section. Indoor operative temperature analysis considers unrestricted window opening during showtime. Keeping windows closed for noise mitigation during performances impacts indoor overheating, assessed against EN 16798-1 Cat III and PET criteria.

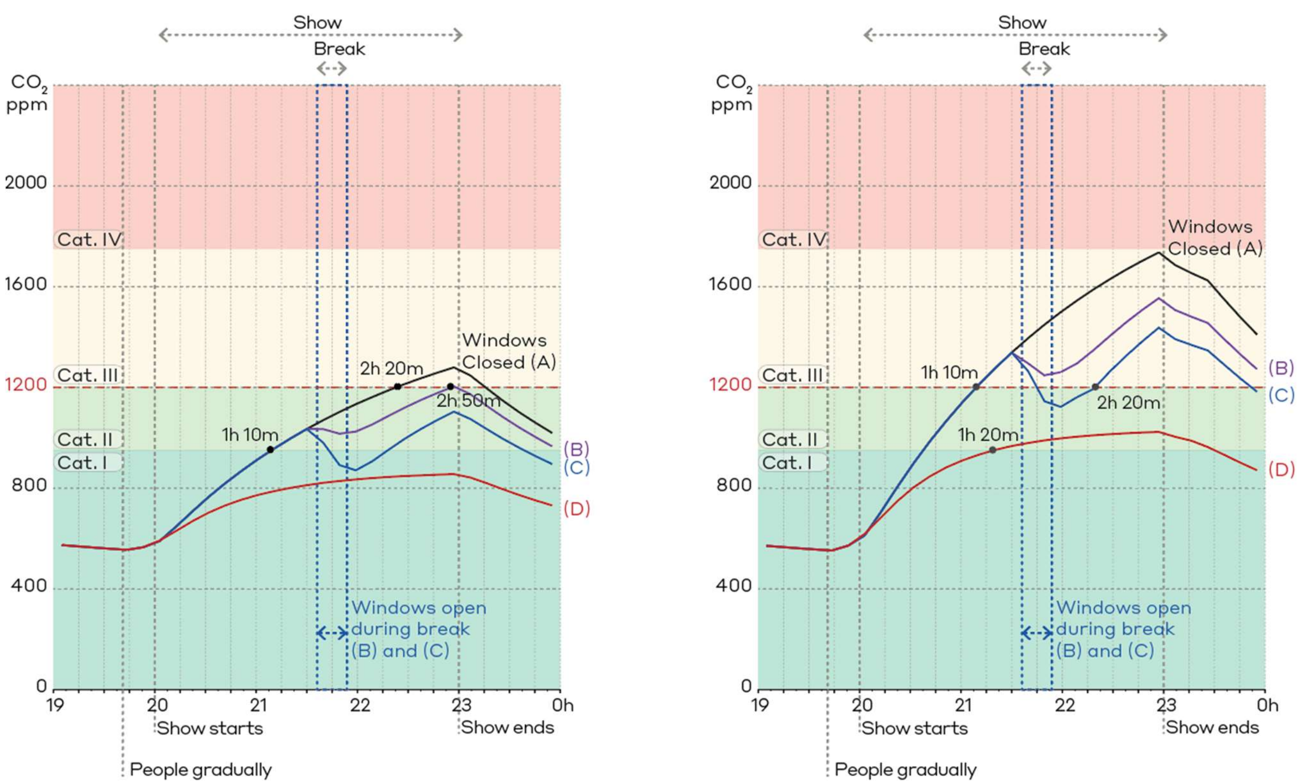


Figure 12: Indoor CO_2 concentration during a show with 252 spectators (left) and 420 spectators (right) with different window management strategies: windows closed (A), windows open during show interval (B), windows open during show interval and the room is vacated (C), windows open all show (D). Coloured bands represent EN 16798 Air quality categories.

7.2.1 Indoor operative temperature analysis

Simulated operative temperatures in free-running mode (Fig.13) for all occupancy scenarios show that:

1. Indoor temperatures evolve gradually over the year for all occupancy scenarios. Outdoor air temperature ranges from sub-zero conditions to summer peaks of 34°C, while the unoccupied scenario shows a minimum of 7°C rising to a maximum of 26°C. The 420-spectator scenario shows a minimum of 8°C rising to 29°C, the highest simulated temperature across all scenarios.
2. Occupancy has a modest but consistent influence on indoor operative temperatures: the presence of an audience and associated background internal gains from four weekly performances raises temperatures by 1 to 1.5 K relative to the unoccupied case.
3. Occupied summer operative temperatures remain mostly between 25 and 27°C, consistently within the EN 16798-1 Category II adaptive comfort band.
4. The occupied space is approximately 3 K below outdoor temperature during a performance on a hot day (18 August).
5. Spring indoor temperatures fall 1 to 2 K below the Cat. III comfort threshold during the day, with occupancy sufficient to bring conditions within the band during showtime.

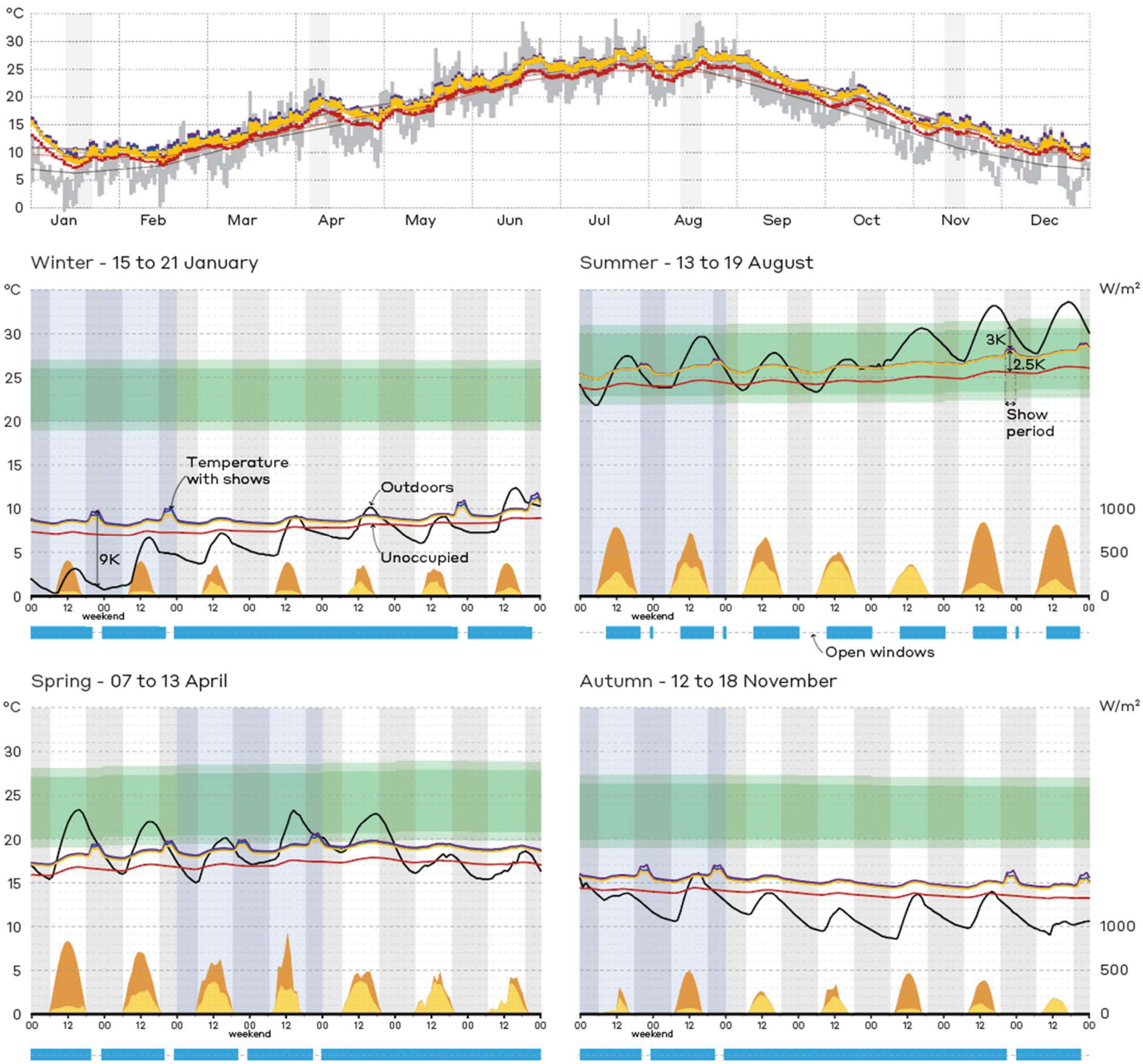


Figure 13: Indoor operative temperatures in free running mode for several occupation scenarios: empty in red, 252 spectators in yellow, 336 spectators in blue, and 420 spectators in purple. Window opening is shown as gaps on the blue band below. EN 16798 comfort bands are shown in green: light green for Cat.III and darker green for Cat.II. Outdoor temperature is shown in black, and global and diffuse radiation in orange and yellow respectively.

As previously discussed, the building's design is able to create a microclimate of its own, unaffected by solar gains or short-term weather fluctuations. The analysis discussed in this section has shown that occupancy has a fairly limited impact on modifying the buildings own microclimate. The fact that the space is used is more important than the size of shows it accommodates.

7.2.2 Impact of window strategies for acoustic mitigation on indoor overheating

The impact of closing windows to mitigate outdoor noise on overheating is evaluated in Table 7. Please refer to section 7.1.3 for the description of each scenario. PET results show that installing fans can mitigate most of the overheating induced by closing windows. To illustrate this point: A 252-people performance meets Cat.II air quality by opening windows during the interval only (scenario B), although such strategy increases PET overheating from 5 shows (D) to 13 (B). Using fans reduces it back to 5 shows.

EN Cat.III results tell a different story, and no overheating is predicted for any scenario. It must be noted that not all adaptive opportunities are available in a theatre venue.

The difference between PET and EN Cat.III results increases with occupant number, which may also indicate an outsized impact of indoor humidity on estimated PET comfort conditions. EN does not consider humidity, which is in accordance with latest thermal comfort research [14], but further research is required to establish adaptive comfort conditions in public venues with moderate opportunities for adaptation.

Table 7: Simulation results for window management scenarios. A total of 208 shows per year was considered in the annual simulation.

Window Management Scenario	Shows when room is too hot: PET>29°C	Shows when room is too hot with fans (0.5 m/s): PET>29°C	Shows when room is too hot: EN16798> Cat.III
Layout 252 occupants			
A	17	9	0
B	13	5	0
C	11	1	0
D	5	1	0
Layout 336 occupants			
A	24	11	0
B	22	10	0
C	16	6	0
D	10	1	0
Layout 420 occupants			
A	31	17	0
B	28	17	0
C	23	11	0
D	12	3	0
Layout 900 occupants (exceptional concert)			
A	49	36	0
B	49	33	0
C	45	31	0
D	28	15	0

7.3 Heating demand

A preliminary conditioning strategy was defined in view of the passive performance: heat up moderately with a radiant floor, ventilation is provided via windows and supplemented by movable fans in summer, and cooling is achieved by natural ventilation and, punctually, fans. Table 8 shows the annual heating demand required to condition the space during performances, the remaining time and in total. The annual total heating demand is high, and ranges from 93 to 156 kWh/m^2 for the 420 spectator and empty scenario when heated continuously. However, heating demand to condition the space up to 20°C during performances is moderate and barely affected by the number of spectators, as values range from 30 to 26 kWh/m^2 for 252 and 420 spectators respectively. On the other hand, heating up the space outside performance times demands almost double the amount of energy (67 to 69 kWh/m^2), despite a lower 16°C setpoint. Consequently, heating up the space was reserved for performance times, with some warm-up period before the show to reach thermal comfort conditions by the start of the show.

Table 8: Heating demand during shows and unoccupied hours for different theatre configurations

Layout configuration	Heating demand to meet 20°C during shows kWh/m^2	Heating demand during to meet 16°C during unoccupied hours kWh/m^2	Annual total heating demand kWh/m^2
Empty	-	156	156
252 spectators	30	69	99
336 spectators	28	69	97
420 spectators	26	67	93

8. DISCUSSION

After decades of abandonment, the city of Turin seeks to bring back into use the Maneggio Alfieriano, a structure conceived some three hundred years ago for the equestrian performances of the Savoy court. The studies presented in this paper reveal how well the building's design was calibrated to this climate and to its original programme, and demonstrate that it can be adapted for contemporary theatre use with minimal intervention to the historic fabric. Its passive environmental qualities - such as its large thermal stability, potential for natural ventilation, and generous daylight – are revealed through a careful combination of in-situ measurement and calibrated simulation. These prove to be largely aligned with the demands of the proposed new use.

Solar gains are low in both winter and summer, a consequence of the moderate window-to-wall ratio and the shading provided by the surrounding urban context. For a performance space, this is a desirable quality: controlling solar radiation was essential to avoid uneven illumination and glare for performers and audience alike, a constraint that appears to have been understood in the original design. Despite this, daylight levels are high, with the entire space meeting contemporary illuminance requirements for performance venues during almost all daylit hours. A brighter zone near the entrance has higher illuminance should it be needed in some cases.

The building exhibits remarkable thermal stability, caused by the combination of thick brick walls, ground contact, and a ventilated attic that prevents solar heat by conduction through the roof. Even large audiences have a modest influence on indoor operative temperature, raising it by no more than 1.5 K. As a result, indoor temperatures remain approximately 7 K below outdoor peaks on Turin's hottest days. In winter, the thermal inertia maintains internal temperatures above 8°C even when outdoor conditions fall below freezing. Entering the Maneggio to watch an equestrian show must have provided a pleasant relief from Turin’s climate during harsh winter and summer days.

The large number of windows does not undermine this temperature stability; they offer instead outstanding opportunities for natural ventilation. Before windows are even needed, the space volume functions as a fresh air reservoir, able to host 3h performances with moderate air quality (Cat.III) for up to 420 people without even opening them. Improved air quality (Cat.II), equivalent to modern buildings, can be achieved for shows of 252 or 336 occupants by opening the windows during the interval, a strategy commonly used in old theatres. 420 people events are restricted to 1h10min if Cat.II needs to be achieved.

Heating the Maneggio continuously to contemporary indoor comfort expectations would demand a substantial amount of energy, but that was never the building's intent nor the project’s one. Conditioning the space for four performances per week requires only a moderate heating demand.

Shows are possible during most of the summer without air conditioning for 252 spectators if windows are open, while warm thermal sensation (PET> 29ºC) is predicted during some 2-3 weeks a year for larger shows excluding concerts. By contrast, EN Cat.III adaptive comfort conditions are not exceeded for any regular occupancy scenario, and further research is required to define an adaptive comfort band suited to public spaces with moderate adaptive opportunities. Even if locals tend to change the city for the surrounding mountains or beach during this period, adaptation strategies are foreseen in heat wave events such as ventilation fans or delaying the start of the event by 1h so that outdoor temperatures cool down.

The studies included in this paper have demonstrated the environmental qualities embedded in the structure, which laid out the basis to develop a sustainable renovation project respecting the historical value of the Maneggio.

9. CONCLUSION

Architectural and operational adaptation strategies can return heritage buildings to active use without compromising their cultural and historical integrity, even for a demanding contemporary programme such as a theatre. This is achieved by building on the qualities of the existing structure and recognising the design intelligence of an 18th-century building that, through careful spatial and material decisions, delivers exceptional passive performance: low solar incidence indoors (approximately 10 kWh/m² in summer and 7 kWh/m² in winter), high daylight availability (96% average DA100), and marked thermal stability (around 2 K of indoor variation in winter and 2.5 K in summer despite far larger outdoor variations). Natural ventilation is equally favourable: the volume of the space acts as a fresh-air reservoir and maintains Cat. III air quality for shows on all typical configurations; while repairing two windows per module improves air quality to Cat.II without inducing acoustic concerns for neighbours.

These qualities, however, only become actionable through significant analytical effort invested before key design decisions are made. Understanding an existing building with this precision requires the careful combination of in-situ measurement and calibrated simulation across multiple metrics — an upfront cost rarely budgeted in conventional project planning, but one repaid in intervention avoided.

The approach demonstrated in this paper offers an alternative to the default of large, invasive mechanical systems in heritage refurbishment. Applied as a go-to solution even where it is poorly suited, such mechanical overreach risks erasing the climatic intelligence embedded in historical buildings and causing irreversible damage to their fabric.

The performance documented here is specific to its type and climate, and should be read as a single proof of concept rather than a general result. But it illustrates a principle that further cases could substantiate: that the architectural qualities of historical buildings are themselves a low-carbon resource, and that recovering them may matter as much as, if not more than, the equipment we add. Realising this at scale will require systematic architectural and environmental documentation across a wider range of building types, uses and climates, to build the evidence base and precedent that designers presently lack.

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