The thermal performance of Lacaton & Vassal's winter gardens

Revisiting three case studies

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ABSTRACT: For the past 30 years, Lacaton & Vassal have been working with winter gardens and greenhouses, inserting a new type of space in buildings, as a mean for climate control and adaptability. Their articulation and technical specifications have been improved and systematised across the years. This research project in collaboration with the architects seeks a precise understanding of the winter gardens' behaviour to further improve and adapt them. It shows that the winter gardens are as smart passive systems that can save energy, create more enjoyable spaces that are bright, adaptable, and comfortable across the seasons and ultimately, they provide well-being and joy to their occupants. Conclusions are drawn from information provided by the architects, interviews, observations, temperature monitoring, and environmental simulations.
KEYWORDS: Lacaton & Vassal, winter gardens, environmental transformations, low energy housing

1. INTRODUCTION

Winter gardens and conservatories have been relegated from the environmental design agenda, as configurations did not seem to bring much benefit to the parent building, and they presented a higher risk in summer than a benefit in winter. Nowadays, massive amounts of insulation seem to be the only way to improve the thermal performance of a building.

However, for the past 30 years, the French practice Lacaton & Vassal have been working with winter gardens and greenhouses in a novel way, inserting a new type of space in buildings, whether residential, office or else, as a mean for climate control, free space and adaptability. They have appropriated the technology of agricultural greenhouses, engineered to work with the sun, wind and light, and of which indoor conditions are controlled with the use of geotextiles, adapted structures and nets. They have domesticated these elements to work with climate in human-occupied buildings. Their residential schemes spread across France, but new projects are being built in Switzerland and Germany.

The work of Lacaton & Vassal is particularly relevant for their strong philosophy and influence in the international architectural scene: their oeuvre is published worldwide (1,2,3), they teach in leading schools and were recently awarded the EU Mies Van Der Rohe prize 2019 (4) and the Pritzker price 2021 (5).

Their winter garden systems are a smart, passive, and adaptable design solution that can be implemented in temperate climates with warm season. This research project in collaboration with the architects seeks a precise understanding of the winter gardens' behaviour to further improve and adapt them. This paper will focus on three residential schemes in France. Conclusions are drawn from information provided by the architects, interviews, observations, temperature monitoring, and environmental simulations.

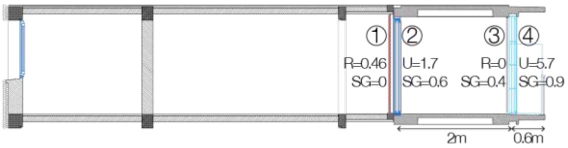
Figure 1:
Exterior and interior view of a winter garden

2. THE WINTER GARDENS

Winter gardens are used as building envelopes and "free-space": somewhere people can choose how to use, when to occupy and how to furnish (Figure 1). The architects expose their philosophy in Actitud (2017): they base their designs on doing more with less, and therefore economic savings: agricultural greenhouses offer large while inexpensive envelopes, considerably cheaper than those of traditional buildings.

"From the moment you can offer double or triple the space (for the same price), houses can function in a non-uniform way: some areas are insulated and heated whereas some others are not, and these spaces can be combined". Lacaton & Vassal explain that winter gardens can be comfortable most of the year, depending on temperature, sun and rain. Their aim is to “take advantage of outdoor conditions, domesticate them, manage them and transform them: the opposite attitude from an insulated space that defends itself from climate”. Whilst their indoor spaces are generous, winter gardens become the space of freedom, where people are liberated from pre-sets, the space where the user is given freedom of choice.

Figure 2:
Composition of winter garden system

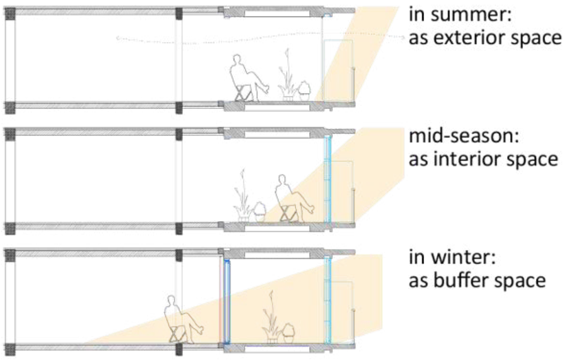


The articulation of the winter gardens has been improved and systematised across the years. They are composed of 4 adaptable layers that ensure an optimal performance throughout the year. From the inside out, the first layer is a thermal curtain (R=0.46m^2K/W) that insulates the living areas at night, protects from the sun in the hottest hours. The second layer is the limit of the heated envelope. It is a double glazing with minimum U-value, maximum light and solar transmission. The last layer is the outer glazing, which is single and often permeable to air through slits. In front of it, a permeable geotextile screen controls solar access or privacy. Its opening ratio is project specific depending on orientation and climate. 2/3 glazing panels are always operable to maximise air flow. The interior surfaces of the winter garden are exposed concrete to take advantage of its thermal mass. A small balcony helps to control the highest sun and is also used for fire prevention purposes. Figure 2 shows the different elements of the system with their U or R value and the Solar Heat Gain Coefficient. The careful design of each element guarantees that users consider the space as a buffer in winter instead of a heated area. The ease of operability ensures that occupants use every element regularly.

The environmental benefits that these systems offer are numerous, both for the parent building and for the inhabitants: they act as buffer spaces, regulating thermodynamic exchanges with outdoors and allowing users to take advantage of the climate through its adaptive features. They mitigate heat loss thank to the insulation provided by the air and by the extra layer, but unlike that of an insulation product, they allow in maximum solar gains and daylight and preserve the surrounding views and contact with nature. Regarding airflow, winter gardens reduce infiltration towards the parent building by reducing wind pressure on the façade. Also, the incoming air from the winter garden is pre-heated which is more hygienic and healthier than through mechanical systems. A small opening during the cold period enables the renewal of fresh air. Regarding acoustics, winter gardens can halve incoming noise.

The use and function of the winter gardens vary with the seasons (Figure 3). In winter, when both layers are closed, they function as buffer spaces. In summer, when the external layer is opened, the system becomes a deeper balcony shading the interior from the high sun and functions as a protected outdoor space. During the mid-season, gentle temperatures inside allow the occupants to leave the internal layer open and use the area as an extension of the indoor space.

Figure 3:
Use of the winter garden across the seasons



3. THE CASE STUDIES

This paper presents the work carried out in three of their residential schemes. Plans, sections, images and climate data of each cas and city are summarised in Table 1:

-“Cité Manifeste”, in Mulhouse (2005) featuring row houses. It was one of their first buildings. Units are organised by pairs, in two levels.

-“Logements étudiants & sociaux, Ourcq-Jaurès”, in Paris (2014). Newly built, inside the urban tissue.

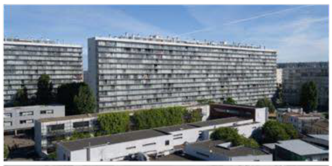
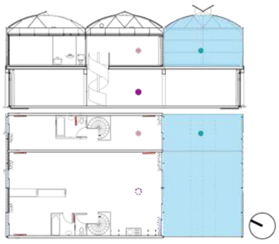
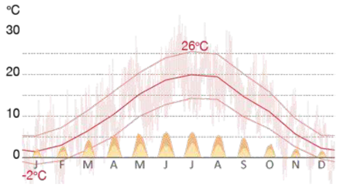
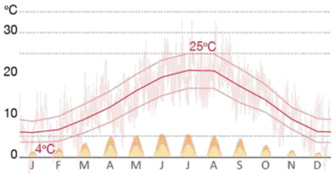
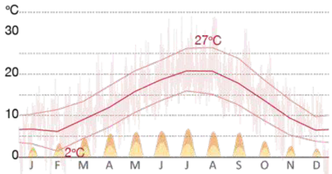
-“Transformation de 530 logements au Grand Parc” in Bordeaux (2016), a refurbishment of a typical 60-70’s building where winter gardens were added.

The 3 climates are classified as Cfb in the Koppen Geiger classification, Temperate Oceanic with all month’s average temperature below 22°C and warm summers. Mulhouse is closer to a Cold climate and has lower averages in winter. Bordeaux is lower in latitude and has the warmest summers.

4. METHODOLOGY

Fieldwork was carried out in the three buildings. It consisted of interviews to occupants of 10 units to learn from their impression of the space and

Table 1:
Case studies and corresponding climate

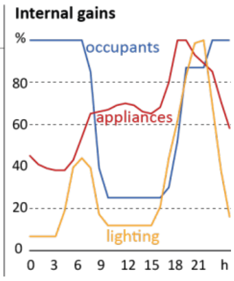
Case study	CITÉ MANIFESTE - Mulhouse	OURCQ-JAURES - Paris	GRAND PARC - Bordeaux
Exterior view			
Interior view			
Plan and section wintergarden			
Local climate avg temp. daily range avg min and max. temp total radiation diffuse radiation			

elements; and leaving temperature dataloggers to study the thermal behaviour. The case studies were assessed using environmental design principles and analysis tools.

Weather data were obtained from Meteonorm 7.0. Thermal models were simulated in Energy Plus and calibrated with measurements and interviews. Building inputs were provided by the architects. When available, internal gains and setpoints were set according to the French regulation RT 2012. Schedules and other inputs (unavailable in the regulations) were set according to EN 15251. Table 2 shows a summary of inputs.

Table 2:
Input summary

Material specifications	MH/OU/BO	Internal gains	
U_{walls}	0.3/-/0.2	Total occupants	3
U_{floor}	1.2/-/-	Appliances W/m²	
U_{roof}	0.2/-/-	Livingroom	3.5
U_{window}	4.4/1.1/1.7	Kitchen	10
$SHGC_{window}$	0.4/0.6/0.5	Rest	0
VLT_{window}	0.4/0.6/0.8	Lights W/m²	
U_{wg}	5.7	Living/Kitchen	5.0
$SHGC_{wg}$	0.9/0.7/0.9	Bedrooms	2.5
VLT_{wg}	0.9/0.9/0.9	Rest	0
		Fresh air m³/person·h	30



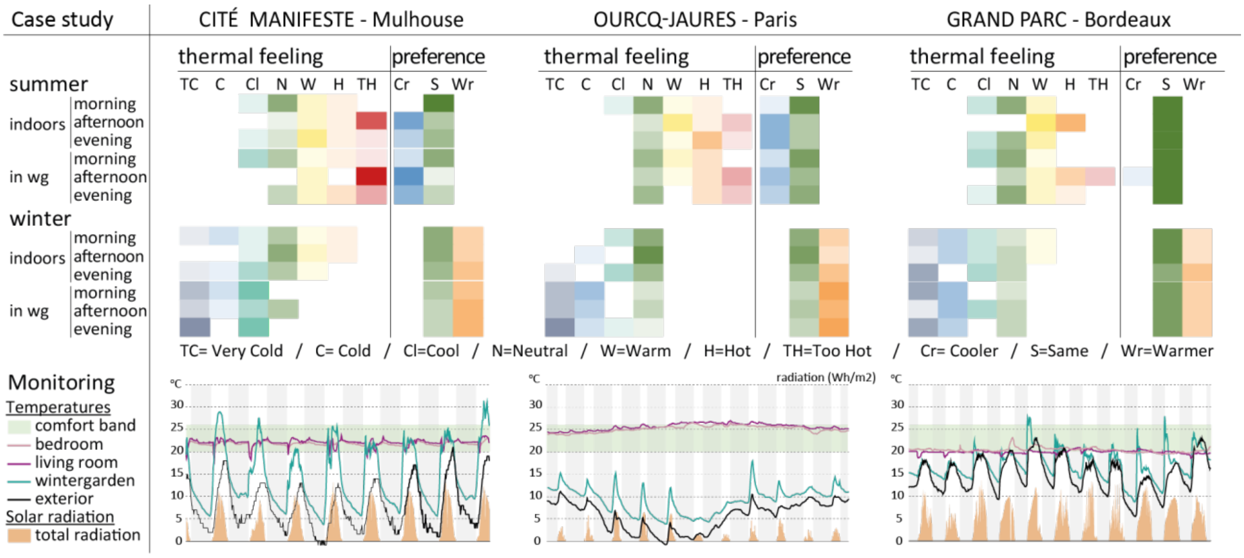
For the calibration, exterior temperature was introduced from the measurements. Solar radiation, wind speed and direction were extracted from nearby weather stations. Simulated free-running zone operative temperatures were evaluated against the adaptive comfort zone based on EN 15251 (cat. II).

5. DESIGN FEATURES

Most of the dwellings designed by Lacaton & Vassal are exposed in at least two orientations to allow for cross-ventilation. Living areas are systematically oriented to the south or south-east, depending on the plot, to take advantage of the warming sun. Winter gardens always follow living areas and therefore receive the sun during the morning and eventually early afternoon all year round. Bedrooms are located towards the north or northwest quadrants. In between the spaces there are none or minimal divisions to allow the air to flow, doors are often sliding to foster it. Access to the units is always from the core, so that winter gardens remain private spaces of the occupants, far from the look of strangers.

All the winter gardens are composed of the elements previously mentioned. The case of Cité Manifeste is particular, as the greenhouse's roof is exposed. It has a horizontal shading and an automated roof opening (it opens when wg_{temp}>21°C). Ourcq-Jaures and Grand Parc are typical floors of larger buildings.

Table 3:
Fieldwork results



6. FIELDWORK RESULTS

Feedback from 30 interviews is summarised below:

-100% of the interviewees reported using windows and curtains to adjust their thermal comfort

-None of the interviewees reported having an extra heating device in the winter garden

-80% use interior curtains to protect from the sun or too much cold

-83% use exterior curtains to prevent from heat, light or for privacy issues

-Ourcq-Jaures was the case where occupants use the least the adaptive elements

-most of the interviewees reported opening the intermediate window "as soon as it is nice"

Also, dataloggers were left in all three cases during a week in the living room, one bedroom, winter garden and the immediate exterior (see Table 2 for locations). Table 3 shows results from thermal sensation feedback inside the unit and in the winter garden together with temperature monitoring.

In all cases, people reported being very satisfied with their thermal environment, especially in winter as there are barely any complaints. However, some points are to be noted: In Mulhouse, most of the interviewees consider that the house, but specially the winter garden are too hot during summer afternoons. This is due to the excessive exposure of the greenhouse roof. Notably, the architects did not plan any vertical shading in the winter garden, but all occupants placed a form of shading in the exposed glazing. In Ourcq-Jaures, occupants considered that bedrooms are too hot during summer evenings. The north-west orientation of the bedrooms without any exterior shading device penalises the performance. In Grand Parc, the satisfaction is remarkable as nobody reported preference for cooler temperatures in summer in any of the spaces, even the climate is the hotter. This is due to the high amount of thermal inertia in the structure and walls of the building controlling peaks.

Measurements were taken during winter (except for Grand Parc, where it was already spring), and heating was used in the three cases.

In Mulhouse, thermostats are individual, and easy to monitor by the users. The occupant had it set at 22º. She opens all the windows during the morning to ventilate, which is reflected by a drop in the temperature of 2-3◦C. Otherwise, interior temperature remains relatively stable around the target.

In Ourcq-Jaures, heating is centralised. Users can regulate each radiator, but without a clear view on the temperature. This results in a setpoint that is too high, around 25◦C. Furthermore, when outdoor temperature drops below 0◦C, the building manager increases temperature to 26.5◦C. The centralised system did not help for the occupants to regulate their own temperature, as they do not seem to be aware of that possibility. This also explains the poorer use of the adaptive features.

In Grand Parc, the thermostat is individually regulated. In the studied unit, it was set at 20◦C. Winter garden doors were left open during the day. Indoor temperatures are very stable around the target. If the winter garden had been closed, the buffer effect would have been enough to maintain the same temperatures passively.

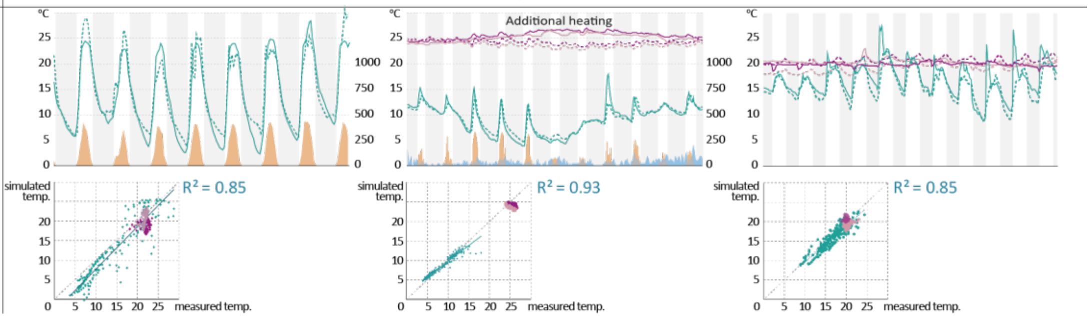
In general, the winter garden proves to be effective as a buffer space:

-In Mulhouse, its temperature is always above outdoors by 2-4º at night and 7-13º during daytime (all days were sunny). The shading was always on.

-In Ourcq-Jaures, its temperature is 2-8◦C higher than outdoors. In sunny days, temperature rises fast and reaches differences of 6-8◦C, which is particularly effective for very cold sunny days. The

Table 4:
Thermal model calibration

Case study	CITÉ MANIFESTE - Mulhouse	OURCQ-JAURES - Paris	GRAND PARC - Bordeaux
Calibration Temperatures — measured ---- simulated ach			



effect of the inertia is clear: after 3 sunny days, and during a cloudy one, the temperature difference is still at 4°C. In the second cloudy day, it drops to 2°C. This means that during cloudy days, the winter garden still acts an effective buffer space.

-In Grand Parc, as the windows were open during the day, the buffer effect is less clear. During night-time, the difference with outdoor temperature is 3-4ºC.

Fieldwork results proved that occupants indeed use the elements to control their environment. Winter gardens are effective as buffer spaces during winter, and enjoyable during the mid-season and summer. Only Mulhouse overheats due to the roof exposure.

7. CALIBRATION OF THE THERMAL MODELS

Fieldwork results were used to calibrate the thermal models, notably the winter gardens, as all other spaces were using heating. Key parameters to calibrate were amount of thermal inertia and infiltration air changes, to follow reality as close as possible. Table 4 shows the results of the calibration of the three cases.

Indoor simulated temperatures follow closely the measured ones, with an average difference of 1ºC and a maximum difference of 3ºC. Winter garden temperatures match more closely than internal spaces, as their temperature depends more on envelope and material properties than indoors - where cooking or number of people at any given time influence temperature. Regression analysis of the scatter plots showing measured against simulated temperature reveal a correspondence of 0.85-0.93 which is fairly accurate.

8. ANALYTIC WORK AND RESULTS

For the winter garden operation, fieldwork results were interpreted as follows:

-Interior doors open “as soon as it is nice”. The input is translated as: if t_{wg}>20.5°C and t_{int}>20°C, or if t_{int}>24°C

-Exterior doors open entirely during summer and if t_{wg}>26°C and t_{ext}< t_{wg}

-Thermal curtains are activated at night-time during the mid-season and winter

-Solar curtains are activated when incident radiation > 100W and during night-time in summer for privacy.

Thermal simulations in passive mode were used to understand the behaviour across the year. Results match the objectives of the architects:

-During summer days, temperature inside the winter garden follows outdoors and can even fall below during peak time for the two cases of the buildings where the roof is concrete. The space is therefore better than a comfortable outdoor space. In Mulhouse, temperature follows outdoors, but with with some 7°C more.

-During the mid-season, the temperature of the winter garden reaches the comfort band most of the days, especially when it is sunny. The space can therefore be used as an extra indoor space.

-During winter, the temperature difference with outdoors validates its functioning as buffer spaces: For the cases of Ourcq-Jaures and Grand Parc, temperature differences reach 3-8°C both during day and night-time, depending on the sun and thermal inertia. For Mulhouse, temperature difference at night is lower due to the large exposure of the winter garden envelope and lack of thermal inertia. During daytime, difference can be 5-15°C, depending on the sun.

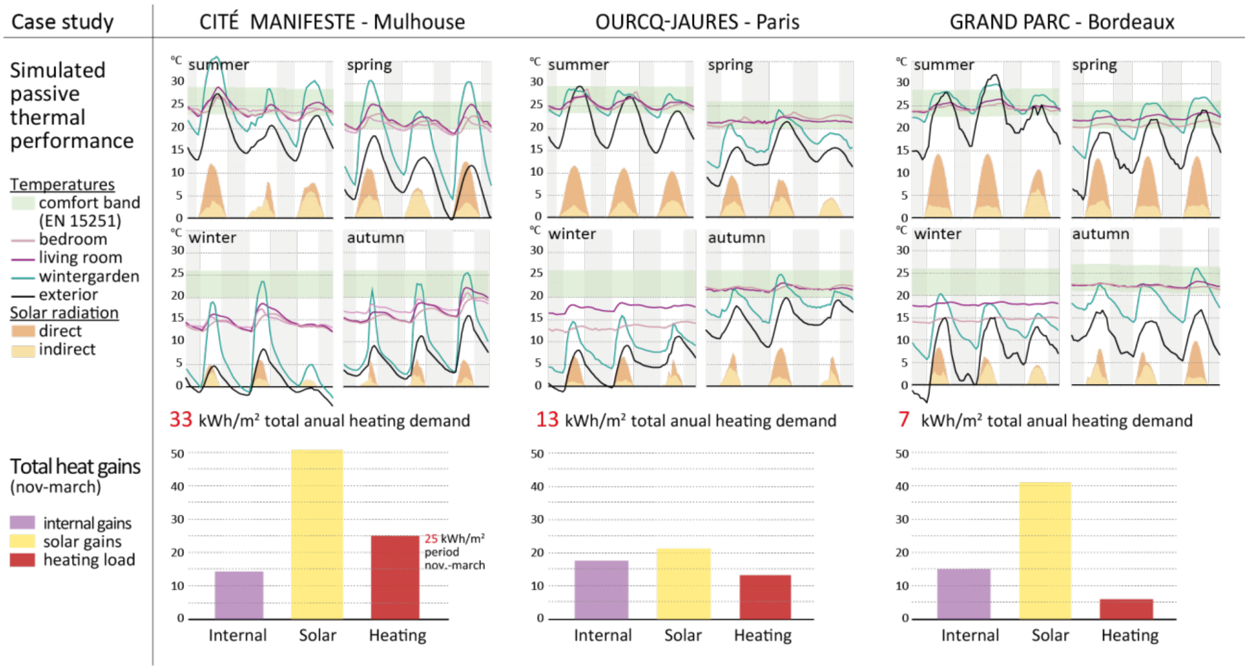
Indoors, temperatures remain stable and inside the comfort band most of the year. During the coldest months, all the units require heating.

With regards to energy demand, Grand Parc and Ourcq-Jaures require very little heating (> 15 kWh/m²). However, Mulhouse’s demand is higher (33 kWh/m²). It is relevant to remind that this climate is also the coldest one.

During peak days, the winter garden is particularly efficient. First, because the thermal inertia keeps temperatures higher and second, because those days are sunny: the sun heats the space and the buffer effect is enhanced. This helps to reduce the peak load.

Looking at the internal gains of the entire house during the heating period, it is clear that the largest contribution to rise the temperature inside is the sun, which is a more reliable and sustainable source than relying on internal gains or heating.

Table 5:
Results of analytic work



9. DISCUSSION

Lacaton & Vassal's buildings are designed consistently following bioclimatic principles. The adaptive features are maximised as many layers can be activated according to environmental conditions and user's will. The units are bright due to the large windows, and winter gardens do not prevent the units from being properly daylit.

From the two studied typologies, the winter garden with the opaque roof works consistently better as the balance of exposed surface and thermal inertia is better calibrated. With the exposed roof, interior spaces overheat considerably in summer.

Simulations demonstrated that the winter garden can be an asset throughout the year: In winter, temperature differences with outdoor validates its functioning as a buffer space, and heating demand is low even with a fully glazed envelope. Although the sun is not intense, it still represents a net heat gain. In summer, the different shadings, thermal inertia, and cross ventilation work effectively as temperatures remain and below outdoors during peak times. During the mid-season, gentle temperatures inside allow the occupants to use the area as an extension of indoors.

An adequate operability of the elements is key to regulate interior temperature properly, and most of the users seem to be doing it intuitively:

- In winter, both glazing layers should be kept closed and solar curtains open. Thermal curtains should be closed at night.

- During summer, all the layers should be open to evacuate heat and allow proper ventilation. Both curtains can be deployed to control the sun and privacy.

- During the mid-season, the operability of the elements depends on the sun and temperature. In general, especially during sunny days, doors towards the winter garden can be left open as the temperature should be comfortable as indoors. Thermal curtains closed at night help to maintain temperatures.

Individual regulation of the heating system is a key condition for the system to work properly and save energy: if the users are not aware, they use less the adaptive features, setpoints are higher, and the overall energy consumption is higher.

10. CONCLUSIONS

All in all, Lacaton & Vassal´s winter gardens act as smart passive systems that can save energy, create more enjoyable spaces that are bright, adaptable, and comfortable across the seasons and ultimately, they provide well-being and joy to their occupants. This type of configuration proves that the concept of the winter garden still has a lot to offer.

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