Challenging the suitability of French energy regulations for unconventional renovations:

A Case study of the underground spaces of La Defense in Paris

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ABSTRACT: This paper focuses on the suitability of energy efficiency regulations for the renovation of unconventional buildings. The authors present a case study in Paris, the formerly abandoned underground spaces below La Defense, which are under renovation to host cultural, artistic and sport uses. Rather than requiring a performance level, French energy regulations for renovations impose prescriptions to all buildings that must be achieved. The authors evaluated the existing condition, the regulatory scenario and alternative insulation strategies using a dynamic thermal model calibrated with temperature data recorded on site. The results show that meeting regulations has the largest carbon footprint – even larger than the existing uninsulated condition - and generates an overheating problem. Based on the findings and the upcoming wave of building renovations in the EU, the authors argue the need for performance-based options in energy regulations.
KEYWORDS: Renovation, energy efficiency, calibrated thermal model, underground spaces, carbon emissions

1. INTRODUCTION

The EU must renovate 35 million inefficient buildings by 2030[1] to meet its emissions target and achieve climate neutrality by 2050[2]. This unprecedented wave of renovations is subjected to efficiency requirements by country, which are often set as prescriptive regulations to reduce the technical burden on the industry: projects must meet certain rules rather than achieve a level of performance.

This paper challenges the suitability of these prescriptive regulations for certain building renovations and exposes the need for a performance-based alternative. The problem is illustrated by a case study in France, the renovation of the underground spaces in La Defense (LD) designed by Baukunst. The main Business district in Paris, LD is organised around a central square with some 10,000m^2 unoccupied spaces below it. The spaces will host cultural, sport and artistic uses: programmes usually characterised by a dense occupancy and high internal heat gains. An aerial view of the project can be seen on the right (Fig. 1).

The residual spaces of LD extend over an area 380m long and 100m wide and are distributed in two levels. They are the leftover space between multiple highway tunnels on each side and the ground, and form a series of broken underground volumes partially connected to each other, each of them some 15m high. The project connects these leftover spaces through a semi outdoor promenade that becomes the main circulation axis on level -1 (Fig. 2). As a result, each space has a different degree of exposure to the new semi outdoor promenade, the ground, the surrounding roads or outdoors.

The unique characteristics of the spaces below LD give them a large thermal stability: all the spaces have at least two sides in direct contact with the ground (or other underground tunnels), and are delimited by large infrastructure-sized concrete walls and slabs, 30cm thick or more. Indoor temperatures are remarkably stable and completely decoupled from outdoor variations, which makes them ideal to host intense uses such as those proposed by the project, especially during Parisian summers when temperatures easily exceed 30^{o}C. Furthermore, the underground spaces in LD are exceptional candidates for the existing local network of heatwave refuges[3].

Figure 1: Aerial view of the spaces below ground. Source: Baukunst

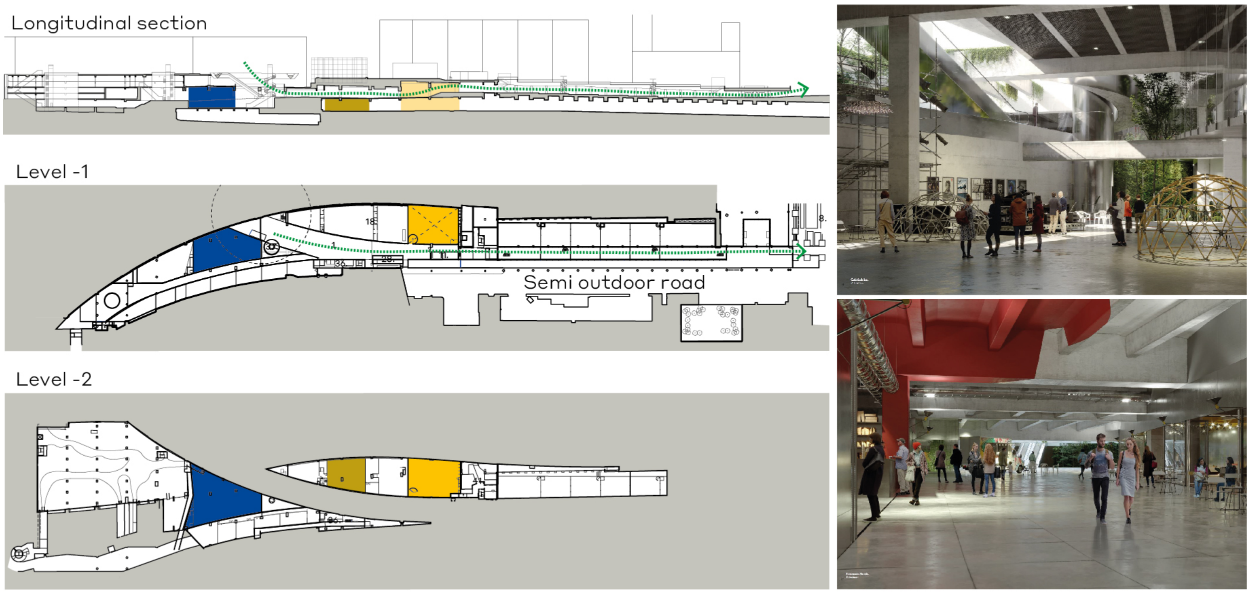


Figure 2: Longitudinal section and plans of levels below ground (Spaces: Cathedrale in blue, Atelier bas in dark yellow and Espace Moretti in lighter yellow. Promenade in dashed green). Source: Baukunst

2. COMMON PRACTICE WITH ENERGY REGULATIONS

As in many European countries, French regulations for building renovations (RT-Existant) [4] establish maximum U-values required in all areas of the project under any regulatory route. These maximum U-values, reproduced in Table 1 below, are defined as minimal thermal insulation exigences on article 43 and usually referred to as *garde-fous* by the industry.

Table 1: Maximum U-values required by French building regulations for renovations [4]

Element	U-value (W/m^2K)
Wall in contact with outdoors or ground	0.45
Wall in contact with an unheated space	0.45/b*
Floor slab in contact with outdoors/collective parking	0.36
Floor slab in contact with sanitary void/unheated space	0.40
Concrete/masonry floors and sheet metal roofs waterproofed	0.34
High floors with metal sheet roofing	0.41
Other high floors	0.28
Bare windows and patio doors to outside	2.60
Curtain walls	2.60
Roller shutter boxes	3.0

* b is the reduction coefficient for the heat loss to unheated spaces, defined on the French national calculation method TH-C-E ex [5].

As shown in table 1, walls in contact with the ground have the same thermal insulation requirements as those facing outdoors ($U = 0.45$ W/m^2K). Similarly, no specific mention is made to floor slabs in direct contact with the ground, which are subjected to outdoor requirements ($U = 0.36$ W/m^2K). For the underground spaces of LD, these U-values translate into the following insulation requirements (thermal conductivity = 0.035 W/mK): 7cm for walls and 9cm for slabs. Due to the configuration of the spaces, this thermal insulation can only be installed on the internal side of the perimeter walls and slabs of the existing building, a common problem in numerous building renovations. Some other smaller internal partitions must also be insulated, although they are considered irrelevant for the content of this paper.

As a result of regulatory requirements, all the underground spaces must be wrapped with thermal insulation, a counterintuitive strategy from an environmental point of view: the large thermal inertia of concrete walls and slabs in direct contact with the ground is now blocked by insulation installed on their inner side. The lack of thermal inertia, and its temperature stabilisation effect, is particularly impactful on spaces destined to intense indoor uses, such as those proposed by the project.

An European Standard exists that regulates heat transfer via the ground, EN ISO 13377 [5] and, in most cases, reduces or eliminates the need for thermal insulation for underground elements by considering the thermal stability of the ground. However, the regulatory text [4] or the national calculation method [6] make no reference to this standard, and traditional U-value calculations are usually performed for all elements disregarding their position.

Alternative routes for compliance [7] exist in the French context: the ELAN law [8] and the exclusion list from RT-Existant[4], both of which are discussed in some detail in section 5 of this paper.

3. METHODOLOGY

The methodology to evaluate the existing building and develop the project from an environmental point of view was based on fieldwork conducted on site, a calibrated thermal model, and the evaluation of different project scenarios both in free running conditions and active mode.

3.1 Fieldwork

Temperature and humidity were recorded in five rooms and outdoors during autumn of 2019 (8^{th} to 17^{th} of October) and a summer week in 2020 (25^{th} of June to 2^{nd} of July) using Dataloggers TESTO 174-H. Temperature recordings can be seen in Figure 3, overlaid with solar radiation data from a local weather station (Wunderground ID IHOUILLE89). The graphs show the large thermal stability of the spaces in both seasons. In autumn, indoor temperature always remained within 17.5 and 21ºC in all spaces while outdoors it fluctuated between 11 and 24.5ºC. In summer, despite outdoor temperatures reaching 32 and 30ºC on the first two days of the recordings, indoor temperature remained always below 24ºC. Monitoring was also performed in winter but is not included in this paper for brevity.

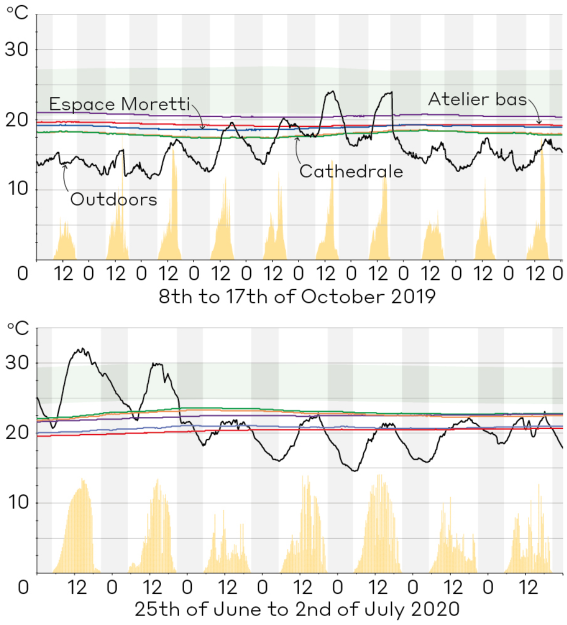


Figure 3: Recorded air temperatures during a week in autumn (above) and a summer week (below).

3.2 Calibrated thermal model

A thermal model of the underground spaces of LD and all the surrounding areas was built in Energy+ v.9.2, using Honeybee plugin [9] for grasshopper and Rhinoceros. These were built following a survey of the existing spaces and images of the thermal model can be seen in Figure 4.

Temperatures recorded on site during the summer week were used to calibrate the thermal model: properties of the ground heat transfer algorithm in Energy+ (Basement Preprocessor), soil (thermal conductivity) and air infiltration were adjusted iteratively until the resulting indoor mean air temperatures for the five thermal zones followed the recordings. Results of the calibration can be seen in Figure 5, which shows a maximum difference between simulated and measured temperatures of some 1.5ºC, while it remains within +-0.5ºC during most of the time.

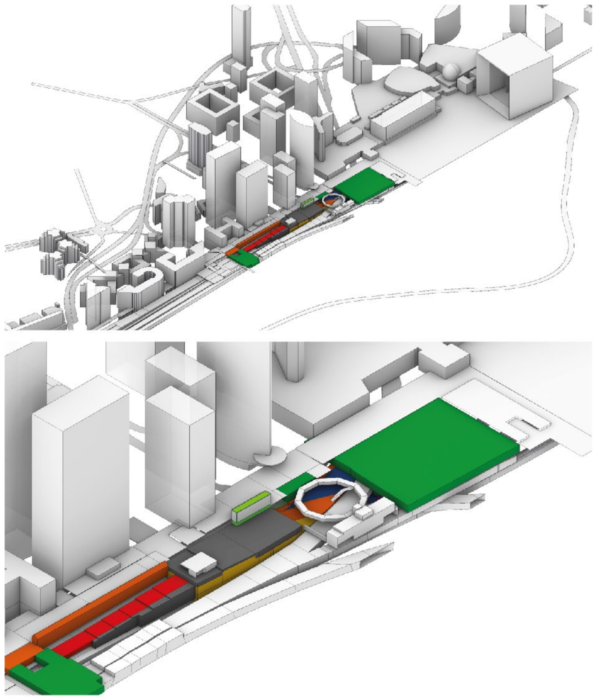


Figure 4: Image of thermal model and surrounding context to the southwest (context in grey, and thermal zones in different colours).

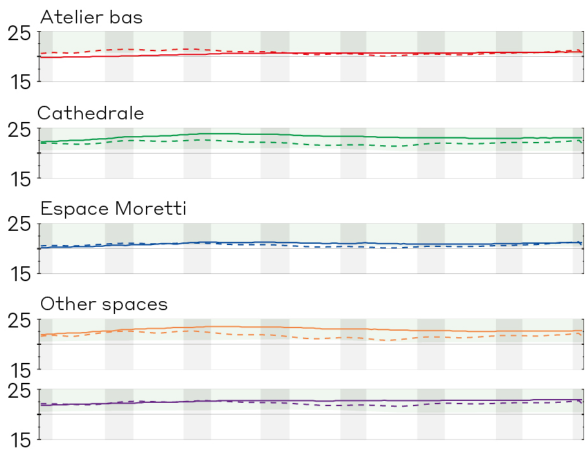


Figure 5: Graphs show simulated temperature from the calibrated model (dashed) and recordings (constant) for five selected spaces.

3.3 Simulated project scenarios

Thermal simulations were performed using the calibrated model and the weather file for Paris Montsouris, extracted from Meteonorm 7.0. Detailed inputs used for the simulations can be seen in Table 2. Five project scenarios were developed in collaboration with the project architects, of which only the following two are included in this paper in addition to the uninsulated existing building: a fully insulated scenario following regulatory requirements, and the retained solution for the project insulating only the external roof. These can be seen in Figure 6.

Table 2: Thermal simulation inputs

Element	Value	Unit
Envelope (internal insulation)		
Walls - ground and exterior	0.25	W/m²K
Walls - interior	0.25	W/m²K
Slabs - exterior	0.25	W/m²K
Slabs - ground	0.33	W/m²K
Beam thermal bridge	1	W/mK
Windows	1.5	W/m²K
	0.6	SHGC
	0.77	VLT
Internal heat gains		
Occupancy	5	m²/person
Lights	10	W/ m²
Equipment	30	W/ m²
Adjacent parking areas	8	W/m²
Infiltration via exposed envelope	1.7	m³/m²h
Ventilation	36	m³/hperson
Natural ventilation		
Operable windows	35	%
Opening temperature	24	ºC
Heating and cooling		
Heating setpoint	19	ºC
Cooling setpoint	26	ºC
Heat recovery	80	%
COP heating/cooling	2.6/3.25	
Carbon intensity heating*	0.132	$kgCO_2/kWh$
Carbon intensity cooling*	0.143	$kgCO_2/kWh$
Embodied carbon factors		
Semi rigid mineral wool	25.6	$kgCO_2/m^2$
Cellular glass insulation	43.65	$kgCO_2/m^2$
(*) District heating/cooling from Enertherm		

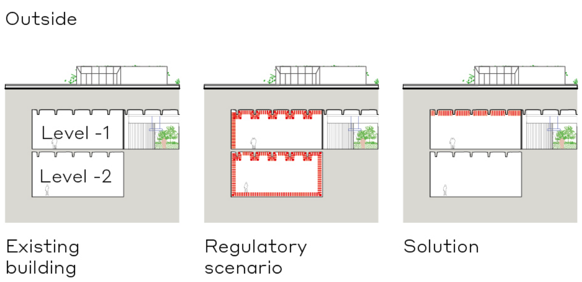


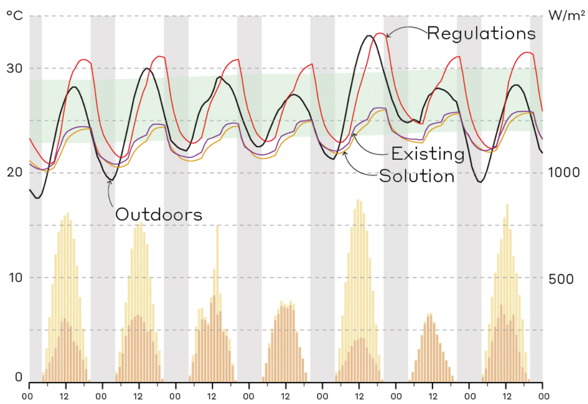
Figure 6: Section with new thermal insulation (dashed red)

The authors evaluated the performance of the selected scenarios under free running conditions through their indoor operative temperatures during a typical summer week and the number of hours they exceed 28ºC over the year. Indoor conditions were evaluated in detail in three representative spaces (highlighted in Fig. 2): these were plotted during a typical summer week and compared with those outdoors and the thermal comfort criteria as defined by EN 16798 cat. II. Additionally, the authors calculated the energy demand for heating and cooling and the total carbon emissions including heating and cooling energy consumption over a 50-year period and the embodied footprint of any additional insulation added to the space.

4. RESULTS

4.1 Summer performance and overheating under free running conditions

Atelier Bas: indoor operative temperatures vary by up to 7K during the central hours of the day between the regulatory scenario and the other two scenarios (Fig. 7). The regulatory scenario has the highest indoor temperatures, which are 1 to 2K higher than outdoors and exceed the upper threshold of the comfort band every day for a few hours. Both the existing uninsulated condition and the adopted solution have indoor temperatures some 7K below outdoors during the warmest hours of the day and demonstrate the effectiveness of the existing thermal inertia in reducing indoor overheating. Indoor temperatures drop to a similar level in the early morning in the three scenarios, although it takes a



few hours longer for the regulatory one to cool down.

Figure 7: Operative temperatures in Atelier bas during a typical summer week.

Espace Moretti: indoor operative temperatures are very similar to those in Atelier bas and vary by up to 7K depending on the thermal insulation scenario (Fig. 8). As in Atelier bas, the regulatory insulated scenario has the highest indoor temperatures, which exceed the upper threshold of the comfort band every day and are above outdoors by some 4K during the early evenings. Similarly to Atelier bas, the existing uninsulated condition and adopted solution never exceed the upper threshold of the comfort band and only exceed 25ºC on very hot days when outdoor temperatures are above 32ºC.

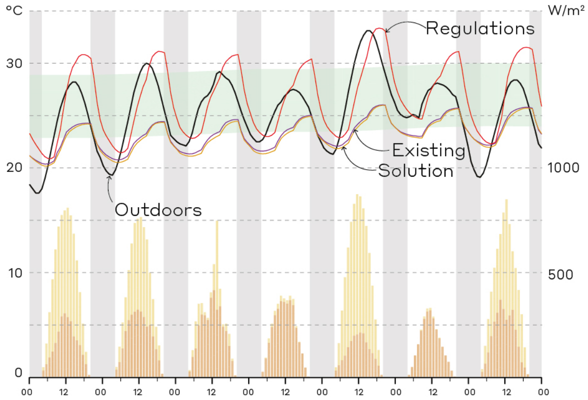


Figure 8: Operative temperatures in Espace Moretti during a typical summer week.

Cathedrale: Operative temperatures in this space are less affected by the thermal insulation scenario, but can still vary up to 5K (Fig. 9). As in the other two spaces, the fully insulated condition induces the highest indoor temperatures, although they are slightly lower in this space and only exceed the comfort band on three days. The adopted solution has the lowest temperatures, some 0.5 to 1 K lower than the existing condition during most of the time, especially at night: unlike the other spaces, Cathedrale's roof is directly exposed to outside.

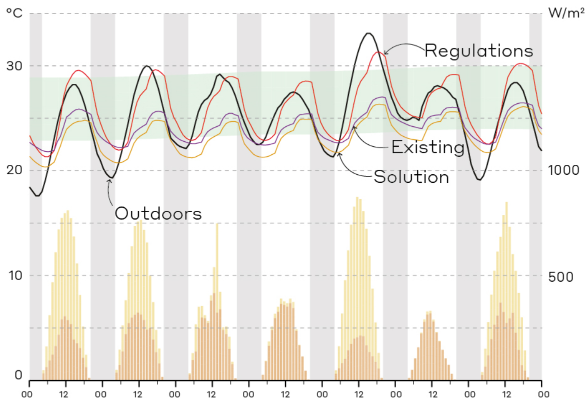


Figure 9: Operative temperatures in Cathedrale during a typical summer week.

The upper chart in Figure 10 shows the average number of hours above 28ºC for all the underground spaces in LD for each of the three scenarios previously described. Results are conclusive: the existing building does not have any overheating problem, which is only induced by insulating the entire envelope to meet regulations. The regulatory scenario has more than 400 hours above 28ºC, while both the existing building and the adopted solution keep the number of hours above 28ºC to 9 or less.

4.2 Energy demand and carbon emissions

A summary of the results from the thermal simulations can be seen on the graphs in Figure 10:

1) Heating and cooling annual demands are shown on the chart in the centre. Results for the existing building show heating and cooling demands of 20 and 6 kWh/m^2 respectively. Wrapping all the spaces in thermal insulation to meet regulations increases their cooling demand by 11 kWh/m^2 (+183%) while it only reduces their heating demand by 8 kWh/m^2 (-40%) when compared to the existing uninsulated condition.

In comparison to regulatory requirements, results for the adopted solution show the impact of removing the thermal insulation and keeping it only in the upper slab, the best performing scenario, as it reduces both heating and cooling demand to 9 and 6 kWh/m^2 respectively. This equals to a 55% reduction in heating demand, without increasing cooling needs.

2) Total carbon emissions are shown on the graph in the bottom (Fig.10). Results show that the carbon footprint of the regulatory insulated case is the highest of them all: 1229 tCO_2 mostly caused by the embodied carbon of the thermal insulation (76%). Leaving the spaces as they are nowadays would reduce the overall carbon footprint by 789 tCO_2 (-64%): even if the operational emissions are higher by some 140 tCO_2 (440 tCO_2 in total), no carbon emissions arise from manufacturing any thermal insulation. The adopted solution has the lowest carbon emissions of them all: insulating the upper slab reduces the footprint by 924 tCO_2 as a very small amount of insulation installed on the right location reduces winter heat loss towards outdoors.

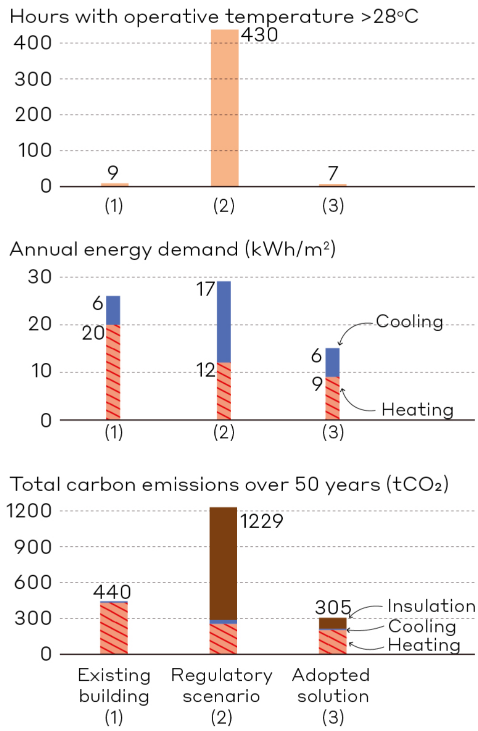


Figure 10: Graphs showing overheating hours (upper) heating and cooling energy demand (centre) and total carbon emissions (bottom) for the three scenarios.

It must be noted that any of the other project scenarios developed during the project and not included in this paper also had a lower carbon footprint than the regulatory one by some 300 to 900 tCO_2 (-25 to 75%). These included insulating only the lower slab, the walls on level -1, or all of the walls (level -1 and -2).

5. DISCUSSION

The analysis of the underground spaces of LD shows that despite the large investment in thermal insulation required by regulations (~€300k), this scenario: (i) has the highest carbon emissions of all the scenarios tested, even higher than not insulating at all, (ii) generates a large overheating problem (>400 hours above 28ºC, and indoor operative temperatures above the upper threshold of the comfort band every day) due to the lack of thermal inertia, a non-existent problem in any of the other scenarios, and (iii) retains heat indoors much longer during summer evenings: temperatures at 10pm are 3 to 5K higher than the other scenarios.

Considering the results and the architectural implications of covering all the internal elements with insulation, the team explored two alternative routes for compliance [7]: (i) ELAN law [8] and (ii) the exclusion list from RT-Existant[4], both unfruitful.

The ELAN law allows to derogate the requirements imposed by national regulations in France until 2025, as long as the objectives of these regulations are satisfied. However, the objectives of national French regulations are the reduction of operational energy consumption and the insulation of existing walls, rather than an overall improvement in the environmental performance of buildings and reduction of carbon emissions.

The exclusion list of French regulations (RT-Existant) [4] includes several typologies that do not require compliance, such as buildings for agricultural or industrial use, those without mechanical equipment other than fireplaces, or those that are usually open to outside. Only the latter one could be applicable to the underground spaces of LD and remains under evaluation, although it imposes certain restrictions to the overall functioning of the project, architecture, safety and HVAC design.

A new, more ambitious, French energy efficiency regulation for new buildings was rolled out in 2022, although its counterpart for existing buildings has not been announced at the time or writing. It is essential for the industry that this new regulation includes a performance-based compliance route, to avoid the pitfalls of prescriptive rules imposed on unconventional renovations described in this paper.

6. LESSONS EXTRACTED FOR UNCONVENTIONAL RENOVATIONS

1) Building regulations might be too focused on prescriptive rules and miss common performance trade-offs (operational vs embodied carbon, or heating vs overheating). Thus, they might create new overheating problems without completely solving the existing ones, especially in existing buildings where thermal inertia plays a key role (ie. churches, castles, ancient buildings, or concrete structures).
2) It must be emphasized that temperature monitoring carried out before the design of a building renovation and calibrated thermal modelling can provide valuable information and help identify existing issues. Accurate data extracted from the building and scenario modelling enables the design team to develop custom solutions for the project, rather than applying generic ones (ie. over insulation, or over reliance on mechanical equipment).
3) Leaving some elements of the building uninsulated could mitigate most of the newly created overheating problem without a large increase in heating demand. However, such specific solutions must be developed on a case-by-case basis, based on accurate modelling.

7. CONCLUSIONS

French energy efficiency regulations are unfit for unconventional building renovations due to their prescriptive approach: projects must meet generic insulation rules even if they induce higher energy demand, carbon emissions and generate overheating indoors. While the existing approach certainly suits many renovations, a performance-based alternative is required for the unconventional ones. With the large upcoming wave of building renovations, the current prescriptions risk locking in underperforming buildings that will undermine progress for decades.

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