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Common Sense Architecture – Harnessing Local Wisdom for Sustainable Future

Minimal retrofitting of a patrimonial dwelling

Evaluation of the thermal performance gap through pre- and post-intervention monitoring campaigns

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1. INTRODUCTION

The European Union's Renovation Wave Strategy, which aims to renovate 35 million buildings by 2030, addresses the urgent need to reduce emissions from the existing building stock. However, the acceleration of renovation rates risks encouraging standardized, out-of-the-box solutions that overlook the climatic, physical, and cultural specificity of individual buildings. Common practices, such as technical oversizing, mis-specified insulation, or the deployment of complex mechanical systems without clear contextual or performance justification, can result in maladaptation, increased embodied and operational carbon, the emergence of new building pathologies while attempting to address energy deficiencies, and the erosion of cultural value. Our objective is to emphasize the importance of minimal, well-calibrated architectural interventions, grounded in a holistic understanding of building behaviour, to reconcile energy renovation objectives with long-term environmental and conservation goals.

This paper presents the studies undertaken to inform the retrofitting of Maison Aubenas, a detached house constructed in 1970 in Ardèche, south-eastern France. Designed by a family member of the current occupants, the dwelling embodies the family's history and traditions, conferring patrimonial value through its architectural expression. The project pursued four objectives: (i) to define a minimal intervention strategy for the existing envelope that avoids loss of patrimonial significance and limits risks of maladaptation; (ii) to eliminate unnecessary energy losses and mitigate unavoidable energy use; (iii) to improve year-round occupant thermal comfort through passive means while enhancing climate resilience; and (iv) to replace the existing heat generation system to minimise reliance on fossil fuels. The retrofit began in October 2024 and was completed in May 2025.

2. METHODOLOGY

A detailed survey was carried out which included information provided by the occupants about construction characteristics, building services, patterns of use, and historical energy consumption. A first monitoring campaign was conducted pre-intervention during (winter 2023) to record indoor temperatures (dataloggers Testo 174H), complemented by thermal imaging surveys (FLIR Edge camera) of the building envelope. A thermal model of the house was developed using Ladybug Tools and EnergyPlus [1, 2] and calibrated against monitored data. The model of the existing house was run in both free-running mode, to calculate comfort levels and overheating hours, and active mode, to quantify heating demand. Various interventions were tested and the most relevant were combined and simulated to evaluate performance at the final design stage. Thermal comfort was evaluated against EN 16798 [3] category II for existing buildings in operation based on moderate occupant expectation (20°C - 26°C during the heating season). A second monitoring campaign was carried out post-intervention during the winter of 2026 to evaluate by comparison the impact of the interventions on the existing performance. Heating oil consumption was assessed from delivery invoices spanning 2018 to 2026 including five pre-retrofit heating periods against a single post-retrofit heating period. Tank level readings were not recorded at each delivery and consequently the delivery volume over time served as proxy to evaluate consumption. The analysis normalises each inter-delivery interval by its accumulated Heating Degree Days, computed daily as HDD = max(0, 18 − T)*30, where T is the monthly average minimum temperature from the nearest weather station (Meteociel). The resulting metric, litres per HDD, isolates thermal efficiency from both interval duration and variability of winter severity. Pre and post-renovation averages were computed as total litres divided by total HDD across valid intervals. The energy performance gap is quantified using the gap ratio, defined as measured energy consumption divided by calculated (simulated) consumption [6]:

$$\text{EPG ratio} = Em/Ep$$

where E_m is the measured and E_p the predicted demand (kWh/m²/y). A ratio below unity indicates that the model over-predicts consumption (measured use is lower than calculated); a ratio above unity indicates under-prediction.

3. THE CLIMATE

Aubenas lies at a latitude of 44.54 and longitude of 4.367. The local climate (Csb) is continental with Mediterranean influences, characterised by warm summers and mild winters. The average annual temperature is 14°C with a considerable average diurnal amplitude of 22° due to frequently clear sky conditions all year round. In summer temperatures average around 22°C and exceed frequently 32°C when incident solar radiation peaks slightly above 1000 Wh/m², driving a pronounced summer overheating risk. In winter, although temperatures have a mild average around 7°C, the region is exposed to the northerly katabatic wind (the "Mistral") blowing at an average of 3.6m/s, clears the sky and brings cold, dry air that causes temperatures drop regularly below 0°C, driving a genuine heating requirement.

4. THE EXISTING DWELLING

Figure 1: Exterior photo taken from site entrance

Figure 2: Interior photo of the house taken in living room

The house (Fig. 1) is a rustic, multi-level stone-built structure with exposed timber beams (Fig. 2) and a tiled roof, characteristic of the Ardèche region. It is oriented predominantly to the east to maximise morning solar gains, get valley views, while remaining sheltered from the Mistral. The east façade has the largest windows(Fig. 3), followed by the west and south façades, while the north façade is more closed. Direct solar access to the west façade is limited due to surrounding context. In level 0 (Fig. 4), the living room faces south-east to capture morning sunlight, while bedrooms are north facing, At level -1 guest bedrooms are oriented north-east. Red zones indicate regularly heated spaces with a combined area of 142 m², pink zones are intermittently heated areas, and yellow zones correspond to rarely heated spaces.

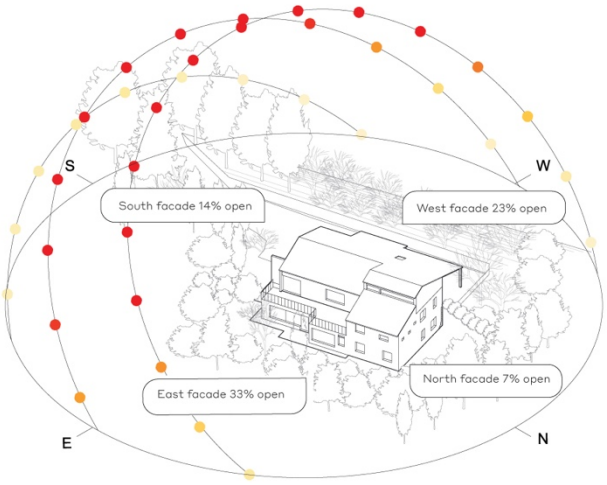

Figure 3: Solar geometry and façade opening

Figure 4: Floorplans of three levels -1, 0, 1

4.1 Use and occupant feedback

The house is occupied by only two people for most of the year and by around 6 to 8 people in summer. The main occupants are adapting their use to seasonal and daily climatic variations: in winter and the mid-season by sleeping in their main bedroom at level 0 leaving the

entire level -1 unheated, which results in an effective buffer zone; and in summer by sleeping in their secondary bedroom at level -1 to benefit from cooler temperatures. They systematically close shutters at night to insulate and open them in the morning to catch the sun and warm up. They only heat the spaces they occupy in the morning and regulate radiator valves throughout the day as needed and systematically turn the heating systems off when they leave the house.

4.2 Envelope

All existing fenestrations are single glazed (U 5.7 W/(m².K)) with loose frames that induce air infiltration. Some windows are protected by side-hung or sliding wooden shutters which are weathered and not easy to use. Walls are composed of uninsulated rendered concrete block, finished internally with local limewash plaster (U 2.8 W/(m².K)). Concrete slabs are covered with terracotta tiles, providing great thermal inertia. Eastern windows onto the terrace are equipped with awnings which are weathered and do not protect effectively from the sun. The roof originally had insulation (U 3.9 W/(m².K)) which is now degraded as revealed by the thermal camera.

4.3. Building services

Iron radiators are in good condition. An oil-fired boiler supplies the radiator and hot water which is intended to be replaced for an electrical heat pump. PV panels have yet to be installed to sustain power generation. In some of the intermittently occupied bedrooms there are façade-mounted air-conditioning units which compromise the visual character of the house.

5. FIELDWORK PRE-INTERVENTION

5.1. Temperature recordings

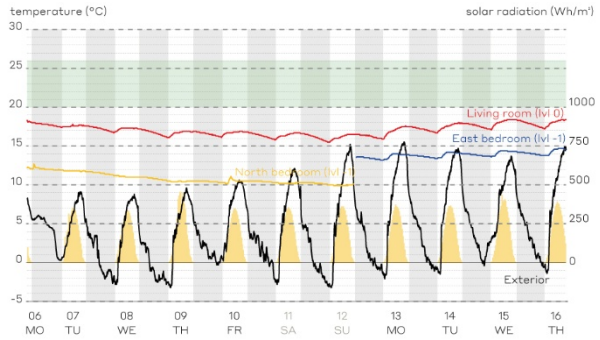

Figure 5: Winter temperature recordings from 6 to 16.02.2023

Indoor conditions are very stable, primarily due to the building's substantial thermal inertia. At level -1, direct contact with the ground further increases this inertia and enhances overall thermal stability. In the heated living room, indoor temperatures remain relatively steady, fluctuating between 15 and 18 °C over a ten-day period, despite outdoor temperatures varying widely from -3 to 15 °C. At level -1, temperatures in the unheated north-facing bedroom remain around 10 °C, while those in the unheated east-facing bedroom range between 13.5 and 15 °C. Nevertheless, during February, indoor temperatures generally fail to reach the thermal comfort range, even when space heating is in operation.

5.2. Thermal imaging

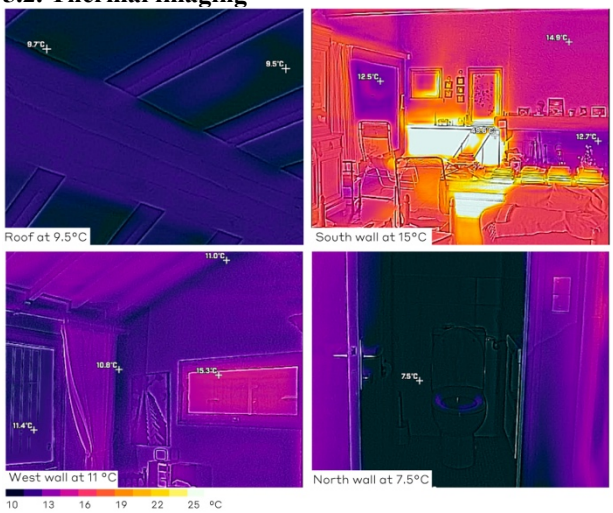

Figure 6: Thermal imaging with outdoor temperature at 6°C

When the outdoor temperature was 6°C, the north wall was the coldest surface of the house at 7.5°C, followed by the roof at 9.5°C and the west wall at 11°C, while the south wall reached 14.9°C. The thermal images confirm and spatially locate the loss paths inferred from the temperature recordings: the north wall and the degraded roof are the most intense, followed by the west wall, identifying these three surfaces as the priority for insulation. The east and south walls are markedly warmer, benefiting from direct solar exposure, and require no fabric intervention. This point in time thermal hierarchy further reinforces the minimal and targeted insulation strategy developed in Section 6, concentrating material where it is most needed rather than applying a standard practice everywhere.

Beyond the surface-by-surface comparison, the images reveal localised heat loss at the wall-to-wall and wall-to-roof junctions, pointing to thermal bridging that must be resolved through careful detailing rather than added insulation area alone. In the south wall image, the chimney shaft on the right shows a cold mass of air, indicating that the flue was most likely left open or insufficiently airtight.

5.3. Historical energy consumption

Table 1: Historical energy consumption and equivalent operational carbon footprint

	Pre-reno	BBC Effinergie benchmark	Gap
Primary energy (kWhEP/m²/y)	315	110	+186%
Fuel oil (heating + hot w.)	243		
Electricity	72		
Operation. CO_2 ($kgCO_2eq/m^2/y$)	77	11	+600%
Fuel oil (heating + hot w.)	76		
Electricity	1		

NB: Fuel oil calorific value (PCI) 9.96 kWh/L; fuel oil CO_2 factor 0.312 $kgCO_2/kWhep$; system efficiency 83%; domestic hot water (ADEME standard) 60L/day for 2 people.

Oil delivery records and electricity bills covering the five-year period 2018–2022 were averaged and normalised to the heated floor area (Table 1). 77% of the primary energy consumed is attributable to the fuel-oil boiler which serves both space heating and domestic hot water, while the remaining 23% are due to the electrical loads. Against the BBC Effinergie Rénovation 2024 threshold [4], the existing house consumes roughly three times the benchmark energy and emits seven times its carbon. Heat-pump deployment is not yet well established in the region and the dwelling is expected to continue running on fuel oil for some time. Reducing the heating demand therefore remains a priority, both as an immediate cut in operational emissions and as a precondition for any future heat-pump installation to be correctly sized rather than over-specified to a low performing envelope.

6. ANALYTIC WORK

6.1. Calibrated thermal model

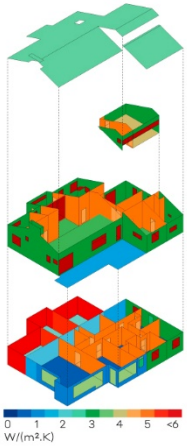

Figure 7: U values set in thermal model

The thermal model (Fig. 7) was calibrated against indoor temperatures recorded during the pre-intervention monitoring campaign in the two unheated bedrooms at level -1, whose free-running response provides the cleanest signal of the building fabric, unaffected by occupant heating. Material properties were adjusted to reproduce the observed thermal stability, infiltration rates were tuned to match the pattern of short-term fluctuations, and ground heat transfer was conditioned by pre-running the simulation for several days before the campaign so that the soil temperature reflected the building's prior thermal influence. In the north-facing bedroom the model follows the gradual cooling from approximately 12 to 10°C with a maximum deviation of about 1°C (Fig.8), while in the east-facing bedroom both curves hold within a narrow 13-14°C band with a residual offset of around 0.5°C.

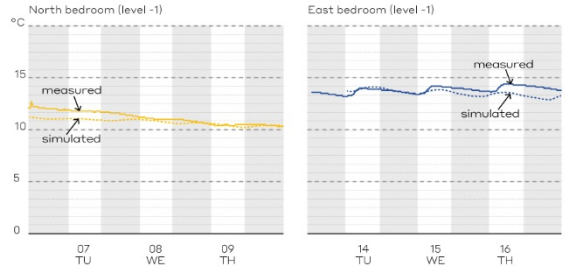

Figure 8: Calibration based on the unheated bedrooms

6.2. Iterations

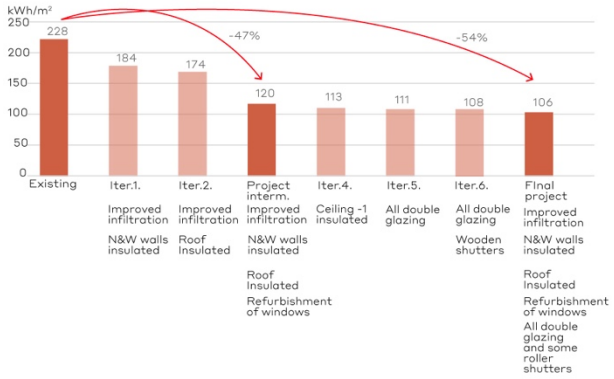

Figure 9: Heating demand iterative calculations

Insulating the roof with 24cm (mineral wool) is the most impactful intervention, followed by adding 12cm of external insulation (hemp wool) on both the north and west walls. Combined with reducing air infiltration by refurbishing existing windows, the intermediate project state already achieves -47% of heating demand. The subsequent iterations are beneficial but not substantial in terms of heating demand reduction (Fig.9). Cumulatively the final project state reaches 106 kWh/m² and pushes the reduction from 47% to 54%. The main interventions related to envelope insulation and air tightness are responsible for 88% of the total achievable saving.

6.3. Summary of strategies

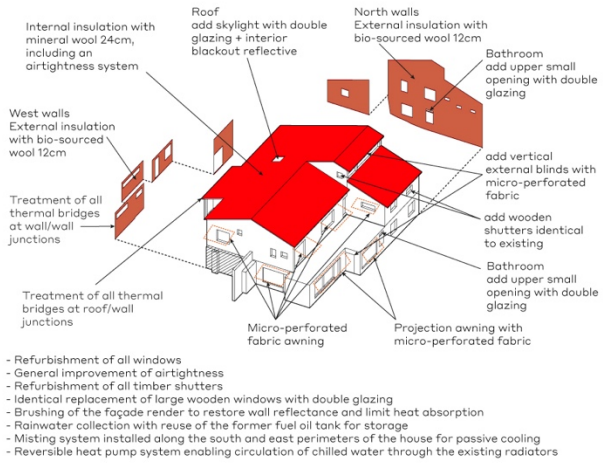

Figure 10: the minimal intervention

The retained strategies specify insulation where the net heat losses are the most intense: the roof followed by the north and west walls. This deliberately partial intervention covers roughly half the envelope area that a conventional full-wrap specification would have insulated, while addressing the bulk of the thermal balance problems. The insulation is applied externally, preserving the thermal mass of the heavyweight masonry on the inside of the lived spaces, which is responsible for the dwelling's exceptional indoor stability and avoiding any loss of usable floor area. All openings on sun-exposed orientations are equipped with either horizontal, tilted or vertical shading as needed (Fig. 10). The embodied-carbon implication is direct: with insulation material accounting for the largest share of a retrofit's embodied carbon emissions, halving the insulated area approximately halves the associated footprint. The refurbishment of all windows and shutters earns its place on two further grounds: it contributes to the overall airtightness improvement that underpins the headline saving, and it restores ease of operation to elements that the occupants, now elderly, use daily to manage the dwelling's adaptive comfort regime (Section 4.1).

6.4. Results

Table 2: Comparison of performance indicators

	Pre-reno.	Post-reno.
Calculated heating demand (kWh/m²)	228	106
Overheating degree-hours (°C.h)	736	232

Losses were dominated by opaque conduction (46%), glazing (25%), and infiltration (25%). Iterations demonstrated that roof insulation alone reduced heating demand by -43%, followed by west wall insulation (-13%), north wall insulation (-7%), double glazing (-10%), and chimney sealing (-1%). Solar gains accounted for 76% of summer overheating, highlighting the need for external shading and night ventilation. Together, these interventions are projected to cut heating demand by more than 53% and improve summer comfort by over 68%.

7. THE RENOVATED DWELLING

Figure 11: Exterior photo taken from site entrance

Figure 12: Insulated northern façade

Figure 13: Restoration of window frames, shutters, awnings
Figure 14: Preservation of the original roof wood structure

The executed works honour the dwelling's architectural character on both external and internal faces of the envelope. Externally, the 12 cm bio-sourced insulation wrap on the north and west façades required careful detailing at the openings so that the additional

thickness absorbed cleanly into the existing window reveals and the original wooden shutters could be restored and refitted in their original positions (Fig. 11, Fig. 12). The window frames themselves were refurbished rather than replaced, each rebuilt with identical wooden profiles upgraded to double glazing and with all opening mechanisms overhauled to operate smoothly. The roof eaves were extended in proportion to the new wall thickness, deflecting rain runoff clear of the insulated faces and protecting the finish from the streaking and darkening that would otherwise raise its solar absorptance over time. The principal east and south façades, which carry the dwelling's recognisable character are materially unchanged (Fig. 13). Internally, the patrimonial timber structure of the roof is fully retained: rather than dropping the 24 cm insulation below the rafters, which would have concealed the structure and lowered the ceiling, the entire roof was lifted to accommodate the insulation above the existing frame, leaving the timberwork visible from below exactly as it was (Fig. 14).

7.1. Temperature recordings

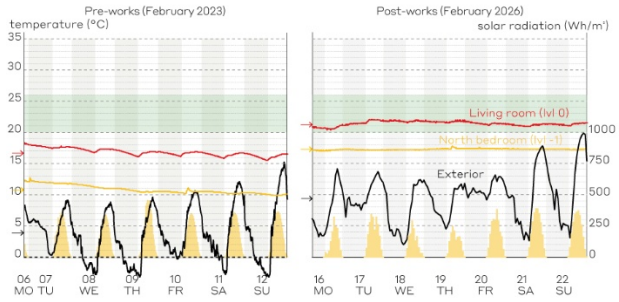

Figure 15: Comparison of winter temperature recordings before and after renovation works.

The winter of 2026, monitored after the renovation, was significantly milder than the 2023 baseline period, with an average outdoor temperature of 9.4°C compared to 3.9°C (Fig. 15). To assess the effect of the building fabric improvements, the unheated north bedroom provides the most reliable reference point because its temperature is less influenced by heating use.

Although outdoor temperatures were on average 5.5 K higher after the renovation, the temperature difference between the north bedroom and the exterior increased from 6.8 K before the works to 8.0 K afterwards. This indicates that the bedroom remained, on average, 1.2 K warmer after the renovation with respect to outdoor conditions, demonstrating improved thermal performance of the building envelope.

Indoor temperatures also remained stable despite fluctuations in external conditions. During the monitoring period, the heated living room (Level 0) averaged 21.4°C, while the unheated north bedroom (Level -1) averaged 17.2°C. Both spaces maintained relatively constant temperatures while outdoor conditions varied between approximately 2°C and 14°C. The building's masonry structure, now protected by external insulation, continues to moderate daily temperature fluctuations, limiting indoor temperature swings to around 1°C.

The improvement is particularly evident when assessed against the EN 16798 [3] Category II thermal comfort criteria. In February 2023, indoor temperatures remained below the lower comfort threshold despite active heating. Following the renovation, the living room maintained an average temperature of 21.4°C, consistently within the comfort range throughout the monitoring period. The unheated north bedroom increased from 10.8°C to 17.2°C, bringing a previously cold and unheated space to within a few degrees of the recommended comfort range.

7.2. Post-renovation energy consumption

Table 3: Bill derived comparison of pre- and post-renovation energy consumption and equivalent operational carbon emissions

	Pre-reno.	Post-reno.	BBC Effinergie reno. benchmark	Change
Primary energy (kWhEP/m²/y)	315	229	110	-27%
Fuel oil (heating)	225	139		-38%
Fuel oil (hot water)	18	18		constant
Electricity	72	72		constant
Operational CO_2 ($kgCO_2eq/m^2/y$)	77	51	11	-35%
Fuel oil (heating)	70	44		-38%
Fuel oil (hot water)	6	6		constant
Electricity	1	1		constant

The envelope retrofit reduced space-heating primary energy and the associated operational carbon by 38% (225 to 139 kWhEP/m²/y; 70 to 44 $kgCO_2eq/m^2/y$), consistent with its scope of roof and north-façade insulation and double glazing. At whole-building scale the reductions are more modest, 27% in primary energy and 35% in carbon, because domestic hot water and electricity form a fixed load unaffected by the works. The building nonetheless remains well above the BBC Effinergie Rénovation benchmarks: roughly double the primary-energy threshold (229 against 110 kWhEP/m²/y) and around five times the carbon threshold (51 against 11 $kgCO_2eq/m^2/y$). This residual carbon is determined by the fuel-oil source rather than the building fabric; reaching the benchmark would require fuel switching, most plausibly a heat pump, for which the completed envelope improvement is a necessary precondition to correct system sizing.

Table 4: Heating demand analysis

Heating demand (kWh/m²/y)	Pre-reno.	Post-reno.	Change
Calculated (thermal model)	228	106	-54%
Bill derived demand (assumed 83% efficiency)	187	116	-38%
Energy Performance Gap ratio	0.82	1.09	

Before renovation the calibrated model over-predicts demand (a gap ratio of 0.82; 187 measured against 228 calculated kWh/m²/y): its standardised assumptions overstate the energy use of a dwelling that the occupants in practice heat only partially and intermittently, retreating to a warm core and leaving the periphery as a buffer. After renovation the relationship reverses to a slight under-prediction (1.09; 116 against 106), the model now marginally optimistic relative to the as-built fabric. Both gaps are of reasonable magnitude, though several limitations bear on them (section 8.2). Crucially, the two methods agree on what matters: a measured reduction in heating demand of 38% against a modelled 54%. The simulation figure should therefore be read as an upper bound on the savings achievable under idealised operation, and the bill-derived 38% as the more reliable estimate of what the building and its occupants actually deliver.

This inversion of the gap is not unique to our case but a documented pattern. Large studies comparing measured and calculated consumption find that inefficient buildings consume less than predicted, the "prebound" effect, in which occupants of poorly performing buildings under-heat, while efficient buildings consume slightly more than predicted. A Swiss study of 1,172 buildings assessed before and after retrofit reports a gap ratio of 0.77 beforehand and 1.02 after [5]; our results trace the same inversion, from 0.82 before the works to 1.09 after. Set against the 0.5–2.5 range reported for residential case studies [6], a post-retrofit ratio of 1.09 represents unusually close agreement, which we attribute to calibration against monitored data and to the designer's continued involvement through construction and operation.

8. DISCUSSION

8.1. Occupant feedback and adaptive behaviour

The occupants' engagement with the building is central to its measured performance. Post-renovation, they report no longer needing the air-conditioning units, with the interior now running some 10°C cooler than outside in summer. Their established winter regime persists: heating only occupied rooms, only when needed, and turning the system off on leaving. This adaptive operation, which the pre-renovation monitoring first revealed, is now better supported by the upgraded fabric and restored shutters.

Two caveats temper the measured figures, however. First, during the post-renovation heating season one occupant was unwell, specifically requiring more continuous heating of a larger portion of the dwelling than the household's habitual pattern; the single measured season therefore reflects atypically high demand, which partly explains why the bill-derived consumption sits at the upper end of expectation and the gap ratio tips slightly above unity. Second, the heat-generation system has not yet been replaced, so the boiler still responds to a single thermostat in the entrance hall. Although every radiator carries a manual thermostatic valve, control remains coarse and dependent on occupant attention; a zoned system with smart per-room valves would allow the heating to track the household's selective, room-by-room occupancy far more closely, and would likely narrow the residual gap between the partial heating the occupants intend and the whole-house response the current control delivers.

8.2. Limitations

Several limitations qualify these findings. The post-renovation metric rests on a single delivery interval (October 2025 – April 2026), so no inter-annual spread can be estimated and the value may reflect atypical conditions; all post-renovation figures are therefore indicative rather than established. Moreover, the tank capacity and its fill level at each delivery were never known, so delivery volumes are an imperfect proxy for actual consumption; to mitigate this, consumption was normalised by heating degree days (HDD) accumulated between consecutive deliveries, isolating thermal performance from both interval length and winter severity. The bill-derived demand further assumes a fixed boiler efficiency of 83%, which is an assumption. Per-area metrics rely on a typical occupancy scenario including 142 m². It represents a likely source of the residual discrepancy between modelled and measured demand. The analysis also assumes that the works were executed as specified, with insulation thicknesses, material properties, and thermal-bridge treatment matching the prescribed values; any deviation in workmanship or as-built detailing would alter the modelled performance. Finally, the pre-renovation simulation over-predicted demand (a gap ratio of 0.82), reflecting the difficulty of calibrating ground heat-transfer effects, occupancy-dependent manual valve operation and frequently varying set-point temperatures to fire-up the boiler as described by the occupants.

9. CONCLUSION

A scientifically justified, minimal-intervention retrofit can deliver significant energy and comfort improvements while preserving the architectural and cultural integrity of a patrimonial dwelling. At Maison Aubenas, insulating only where the monitored losses were most intense, the roof and the north and west walls, together with window refurbishment and external shading, was projected to roughly halve heating demand, using approximately half the insulation a conventional full-wrap specification would have added. The first post-renovation heating season broadly confirms this: a measured 38% reduction in heating demand against a modelled 54%, with comfort raised from below the lower threshold to within the target band, and the principal façades and roof structure left visibly unchanged.

The two-campaign structure also exposes the limits of relying on simulation alone. The model over-predicted demand before the works and slightly under-predicted it after, an inversion consistent with the documented prebound effect and with the household's frugal, adaptive operation. The headline modelled saving should therefore be read as an upper bound under idealised conditions, and the bill-derived figure as the more honest estimate. The post-retrofit gap ratio settled at 1.09 (unusually close as per the standards of the published literature) is attributed to the calibration against monitored data and to the occupant’s commitment to a relatively frugal lifestyle.

Two conclusions follow for practice. First, the residual operational carbon is now structurally determined by the fuel-oil source rather than the fabric; the completed envelope is the necessary precondition for a cleaner and correctly sized heat production alternative, which remains the decisive step toward the regulatory benchmark. Second, the value of doing less but verifying it, diagnosing with measurement, intervening where physics shows it matters, and confirming the result through monitoring, offers a more defensible route to decarbonising the existing stock than the reflex to always specify more and of the same everywhere. Minimal intervention, in this reading, is not a concession on ambition but its most rigorous expression: every element of fabric is made to earn its place against measured evidence.

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