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Dynamic Thermal Modeling and Energy Assessment of a Multi-Zone in F3

Apartment in an Arid Climate of Bechar, Algeria

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Abstract:

The extreme thermal conditions of arid climates, characterized by high daytime temperatures and significant diurnal variations, present a vital challenge for building energy efficiency. This paper presents a dynamic multi-zone thermal model of a standard residential apartment (F3 archetype) located in the hyper-arid region of Bechar, Algeria. Developed using the MATLAB/Simscape Thermal environment via the thermal Resistance-Capacitance (RC) analogy, the model simulates the transient temperature behavior and the precise cooling energy demand. The architecture couple's passive thermal elements (walls, inertia) with dynamic internal heat gains (time-varying occupancy, solar radiation) and an active thermostatic Heating, Ventilation, and Air Conditioning (HVAC) loop. Results demonstrate severe localized overheating under free-floating conditions; specifically, Bedroom 1 and the living room prove to be the most critical rooms reach temperature 46 °C. Therefore, in the primary living spaces (Bedrooms, Livingroom, and Kitchen) the with occupant exhibit distinct jagged peaks that perfectly mirror the dynamic occupancy schedules. Furthermore, the model evaluates the disaggregated daily energy consumption necessary to maintain a strict 25 °C setpoint, revealing that the living room alone requires up to 15.6011 kWh/day. This highlights the critical role of dynamic metabolic loads and solar orientation in arid building performance.

Keywords: Building Energy Simulation, Simscape Thermal, Arid Climate, RC Network Modeling, HVAC Energy Consumption, Dynamic Occupancy, Radiation solar (Lui&Jordan).

1. Introduction

The building sector is one of the largest consumers of energy worldwide, accounting for approximately 36% of global final energy use and nearly 40% of total CO₂ emissions, as reported by the International Energy Agency [1]. This share continues to grow, driven by urbanization, rising living standards, and the increasing demand for thermal comfort. Consequently, reducing energy consumption in buildings has become a central priority in national and international energy policies alike.

In arid and semi-arid regions, this challenge is particularly acute. The building sector accounts for a disproportionate share of regional energy consumption, largely driven by the demand for mechanical cooling [1, 14, 16, 17]. Cities such as Bechar, located in the southwestern Algerian Sahara, experience extreme summer conditions outdoor air temperatures regularly exceeding 44°C in July, combined with intense solar radiation exceeding 1000 W/m² imposing severe thermal loads on residential buildings. Under such conditions, air conditioning systems operate at or near full capacity for extended periods, making their efficient design and control a matter of both economic and environmental urgency. Algeria's national thermal building regulation [3] establishes minimum envelope performance requirements, yet compliance alone is often insufficient to prevent significant overheating in south-facing spaces under peak summer conditions.

To design efficient Heating, Ventilation, and Air Conditioning (HVAC) systems and optimize building envelopes for such climates, static thermal calculations are fundamentally insufficient. They fail to capture the transient behavior of thermal mass, inter-zonal heat redistribution, and the highly dynamic nature of internal loads such as occupancy and solar gain. Dynamic simulation approaches are therefore necessary [4]. While tools such as EnergyPlus [19] and TRNSYS [20] are widely adopted industry standards for whole-building energy modeling, lumped-parameter Resistance-Capacitance (RC) networks implemented natively in MATLAB/Simulink offer a complementary and often superior flexibility for

integrating advanced control algorithms - such as predictive control strategies and smart thermostat logic - directly with the physical thermal plant [5,13,15]. This co-simulation capability is particularly valuable when the objective is not merely to predict energy consumption, but to design and test control policies within the same modeling environment. Previous studies on residential buildings in hot arid climates have addressed thermal performance through either simplified steady-state methods [2] or full EnergyPlus simulations requiring detailed input datasets that are rarely available for standard Algerian housing stock. Few works have focused on the explicit coupling between multi-zone dynamic thermal models and zone-level electrical consumption integration under realistic occupancy dynamics, particularly for the F3 apartment typology that constitutes a large fraction of the Algerian residential building stock. Furthermore, comfort assessment in these studies has often been limited to peak temperature reporting, without quantifying the duration of comfort violations in relation to internationally recognized standards such as [6] or [7]. This study addresses these gaps by introducing a fully instrumented, multi-zone Simscape thermal model of a standard F3 apartment under the extreme summer climate of Bechar. The model explicitly represents six thermodynamic zones, each governed by RC-network heat balance equations accounting for conduction through multi-layer walls, convective exchange with indoor air, and direct solar gain through glazing. A localized on/off thermostat with hysteresis relay control, set to the comfort setpoint of 25 °C in accordance with [6] guidelines, governs the cooling output in each occupied zone.

2. Methodology and Model Description

2.1 Building Model

The modeled habitat is a standard F3 apartment comprising six distinct thermodynamic nodes (Figure 1): Living Room (South, 54 m³), Kitchen (South, 36 m³), two Bedrooms (East and West, 48 m³ each), Anteroom (South, 36 m³), and Bathroom (East, 18 m³). The southern

orientation of the Livingroom and Kitchen is of particular significance, as it exposes these spaces to direct solar irradiation throughout the peak hours of the day.

The external walls of all rooms are composed of three layers (total thickness 24 cm): cement mortar (2 cm), hollow brick (20 cm), and plaster (2 cm). Internal walls consist of three layers (14 cm total): hollow brick (10 cm) and plaster on both sides (2 cm). The roof is fiat and built from three layers (22 cm): concrete slab (5 cm), hollow brick (15 cm), and plaster (2 cm). All windows are simple single-glazed, representing the most common and thermally vulnerable glazing type in the Algerian residential stock.

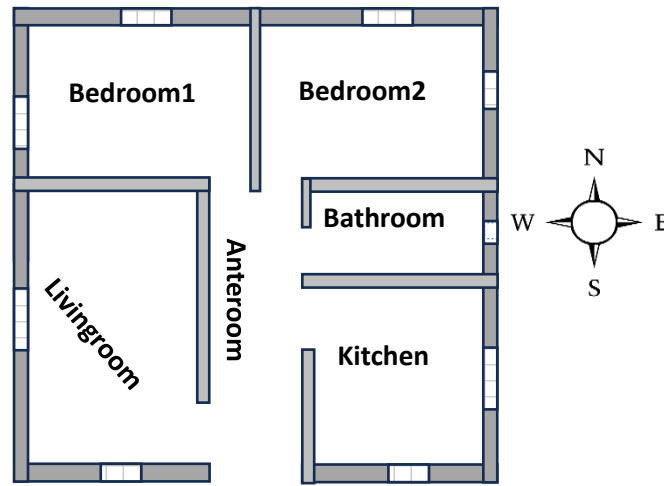


Fig.1 : Floor plan apartment (Six thermodynamic zones)

Table 1: Parameters associated with the materials of the evaluated wall types

Wall type	Layers	Thickness (cm)	Material	U-value (W/m ² K)
External wall	3	24	Cement mortar/ Hollow brick/ Plaster	0.8
Internal wall	3	14	Hollow brick / Plaster (both sides)	1.4
Roof (flat)	3	22	Concrete slab/ Hollow brick/	0.9

			Plaster	
Glazing	1	3	Simple single glazed window	5.8

2.2 Arid zone Climate

2.2.1 External Temperature

The measured outdoor air temperature in Bechar city exhibits a strongly periodic variation representative of a continental arid climate figure 2. The temperature data collected over the first three days of July was fitted to a sinusoidal model with a correlation coefficient of $R^2=0.96$, confirming the adequacy of the analytical approximation for the simulation period.

The outdoor temperature is expressed as:

$$T_{ext} = \frac{T_{max} - T_{min}}{2} \sin\left(\frac{2\pi t}{P} - \omega\right) + \frac{T_{max} + T_{min}}{2} \quad (3)$$

With $T_{max} = 44^\circ\text{C}$, $T_{min} = 28^\circ\text{C}$, $P = 24 \times 3600 \text{ s}$ and $\omega = \frac{4\pi}{5}$, The 16°C daily amplitude between the nocturnal minimum and the daytime peak represents one of the most thermally demanding residential environments in Algeria.

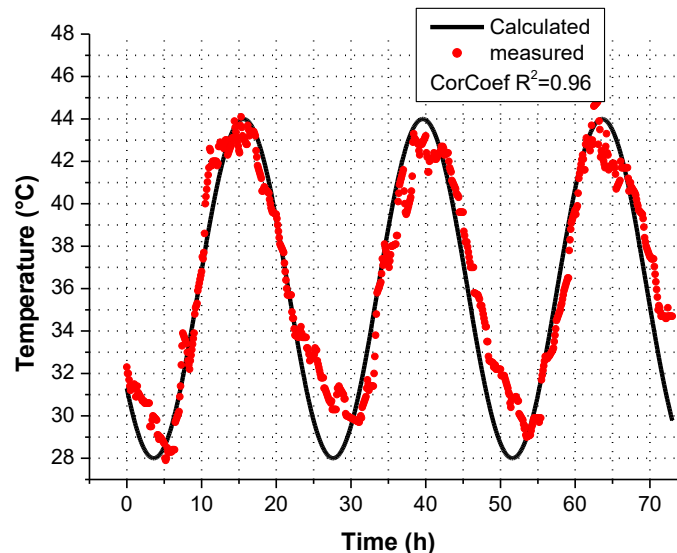


Fig.2: Outdoor temperature measured and calculated for three days of July ($R^2=0.96$)

2.2.2 Solar Irradiance Modeling (Liu & Jordan):

The solar radiation on the horizontal surface measured by the meteorological station of the ENERGARID laboratory of Bechar University in Algeria for July 1 is similar for the other days of the month of July so the radiation is calculated by the Liu & Jordan (1960) model (Eq.7) and simulated using Simulink/Matlab. Figure 3 represents the measured and calculated radiation of a typical day in July; the results show agreement between the measured and simulated values with a correlation coefficient of $R^2=0.96$. The solar radiation reaches a maximum of 1200 W/m^2 in the city of Bechar.

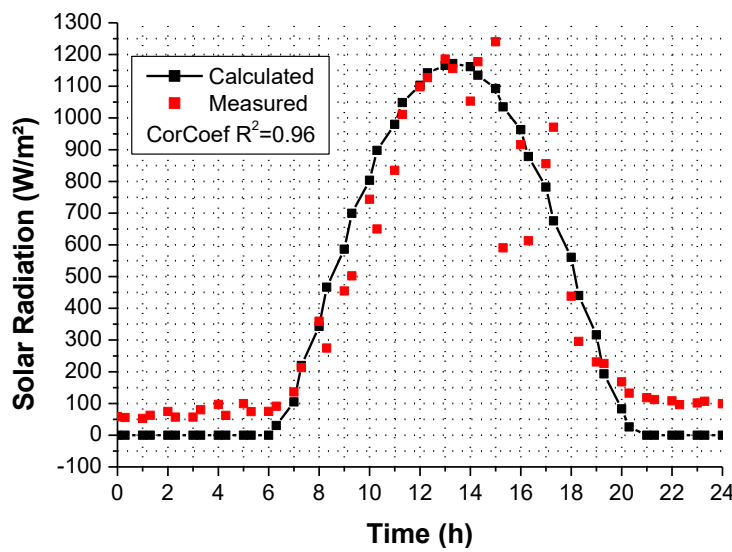


Fig. 3: Solar Radiation horizontal surface measured and calculated for one day in July ($R^2=0.96$)

2.3 Equation Model of Building Components

The building's structural elements - exterior walls, windows, interior walls and ceilings are modeled and simulated within the MATLAB/Simulink Simscape environment. The following assumptions are adopted:

- Each wall and the glazing are modeled using thermal capacity (1-node lumped model).
- The interior temperature of each room is spatially uniform.
- The ceiling temperature is also spatially uniform.
- Temperature measurements are instantaneous and minimally disturbed.
- The physical parameters of all subsystems are time-invariant.
- Heat transfer mechanisms considered: air convection ... walls, conduction

through walls, and solar radiation through glazing.

- No inter-zone airflow is modeled (natural ventilation may be added in future work).

2.3.1 Indoor Air Balance Equation

The mathematical formulation of the RC network follows established grey-box modeling principles [4, 13, 21].

$$\rho_{\text{air}} c_{p,\text{air}} V \frac{dT_{\text{air}}}{dt} = \sum_{i=1}^{N_i} h_i A_i (T_i - T_{\text{air}}) + h_v A_v (T_v - T_{\text{air}}) + \dot{Q}_{\text{int}} + \dot{Q}_{\text{HVAC}} \quad (4)$$

Where: T_{air} : Indoor air temperature ($^{\circ}\text{C}$), T_i : Wall temperature ($^{\circ}\text{C}$), T_v : Glazing temperature ($^{\circ}\text{C}$), h_i : Convection coefficient air-wall ($\text{W}/\text{m}^2\cdot\text{K}$), h_v : Convection coefficient air-glass ($\text{W}/\text{m}^2\cdot\text{K}$), A_i : Wall area (m^2), A_v : Glass area (m^2), $\dot{Q}_{\text{int}}$: Internal contributions (occupants, equipment) (W), $\dot{Q}_{\text{HVAC}}$: Air conditioning power (W).

2.3.2 Equation of each wall (wall i)

$$C_i \frac{dT_i}{dt} = h_i A_i (T_{\text{air}} - T_i) + \frac{T_{\text{ext}} - T_i}{R_i} \quad (5)$$

Where: $C_i = \rho_i c_i V_i$: Thermal capacity of the wall,

R_i : Total thermal resistance of the wall $R_i = \sum_{k=1}^n \frac{e_k}{\lambda_k A_i}$

2.3.3 Glazing equation

The glazing node receives convection from indoor air, conduction from the outdoor environment and direct solar radiation:

$$C_v \frac{dT_v}{dt} = h_v A_v (T_{\text{air}} - T_v) + \frac{T_{\text{ext}} - T_v}{R_v} + \alpha_v A_v I_{\text{sol}} \quad (6)$$

Where $\alpha_v = 0.06$ the glass solar absorptivity and I_{sol} is the incident solar radiation (W/m^2) computed dynamically for each specific facade using the Liu & Jordan model (Eq. 7). The simple glazing represents the thermally weakest element of the envelope and is the primary solar gain pathway for south-facing rooms.

2.3.4 Solar Irradiance Modeling (Liu & Jordan):

To accurately capture the impact of building orientation and geographic location, the incident solar irradiance (I_{solar}) on each specific facade was dynamically modeled using the Liu & Jordan (1960) isotropic sky model [26, 27]. The total irradiation on any tilted surface is computed as the sum of direct, isotropic diffuse, and ground-reflected components:

$$I_{solar} = I_{direct} \cdot R_b + I_{diffuse} \cdot \left(\frac{1 + \cos(\beta)}{2} \right) + I_{global} \cdot \rho \cdot \left(\frac{1 - \cos(\beta)}{2} \right) \quad (7)$$

where β is the surface tilt angle, $\rho = 0.2$ is the ground albedo, and R_b is the geometric ratio of beam radiation on the tilted surface to that on a horizontal surface. The solar incidence angle is continuously resolved at each simulation step considering the site latitude, declination, and the facade's specific azimuth. This rigorous approach ensures a precise differentiation of solar gains across South, North, East, and West orientations, while numerical boundaries were implemented to prevent computational singularities at horizon transitions.

$$R_b = \frac{\cos(\delta)\sin(\phi)\cos(tilt)\cos(\omega) + \cos(\delta)\sin(tilt)\sin(\omega) - \sin(\delta)\cos(\phi)\cos(\omega)}{\cos(\delta)\cos(\phi)\cos(\omega) + \sin(\delta)\sin(\phi)} \quad (8)$$

where δ , ϕ , ω and $tilt$ are the declination angle, latitude angle, hour angle and surface azimuth angle, respectively [8].

2.3.5 Internal Gains and Dynamic Occupancy

Occupancy was modeled dynamically utilizing Simulink Signal Builder arrays driving Controlled Heat Flow Sources [12, 23]. The metabolic heat gain is given by:

$$Q_{occ}(t) = N_{occ}(t) \cdot \Phi_{metabolic} \quad (9)$$

where $N_{occ}(t)$ is the dynamic number of occupants, and $\Phi_{metabolic}$ is the base metabolic rate set to 100 W/person, consistent with the sedentary activity level in [6]: However, occupants are not simultaneously present in all zones throughout the day. A realistic hourly occupancy profile was constructed based on a typical south Algerian family schedule during summer.

188 The Living Room ($Q_{occ} = 800 \text{ W}$) absorbs peak loads in the evening, while the bedrooms
 189 ($Q_{occ} = 200 \text{ W}$) are engaged strictly at night.

190 **2.3.6 Mathematical Modeling of Air Conditioning and Energy**

191 **2.3.6.1 On/Off Thermostat with Hysteresis**

192 This transient logic is widely adopted in building energy control literature [15, 18]. The air
 193 conditioning system operates in closed-loop configuration. The cooling capacity injected
 194 into zone i is governed by a hysteresis relay control, set to the comfort on the setpoint
 195 $T_{setpoint} = 25^\circ\text{C}$:

$$196 \quad Q_{HVAC,i} = \begin{cases} -P_{max} & \text{if } T_i > T_{setpoint} + \left(\frac{\Delta T}{2}\right) \\ 0 & \text{if } T_i < T_{setpoint} - \left(\frac{\Delta T}{2}\right) \\ Q_{HVAC}(t) & \text{if } T_{setpoint} - \left(\frac{\Delta T}{2}\right) \leq T_i \leq T_{setpoint} + \left(\frac{\Delta T}{2}\right) \end{cases} \quad (10)$$

197 This nonlinear behavior ensures that the air conditioning compressor does not turn on and off
 198 too frequently, which would physically damage the equipment.

199 The hysteresis band of (relay active above 25.5°C , deactivated below 24.5°C) prevents
 200 excessively frequent compressor cycling, which would cause mechanical wear and reduce
 201 equipment lifespan.

202 **2.3.6.2 Electrical Consumption (kWh)**

203 The cooling capacity removed from each zone translates into electrical power drawn from
 204 the grid via the Coefficient of Performance (COP) of the refrigeration unit:

$$205 \quad P_{elec}(t) = \frac{|Q_{HVAC}(t)|}{COP} \quad (11)$$

206 In this study, a COP value of 3.0 is adopted, which is consistent with the rated performance of
 207 standard split-unit air conditioners commonly installed in Algerian residential buildings. This
 208 value falls within the range of $COP = 2.5$ to 3.5 typically reported for inverter-type and fixed-
 209 speed split units operating under similar climatic conditions.

210 The total energy consumed by the apartment over the simulation period (in joules, then
 211 converted to kWh) is obtained by integrating this power over time:

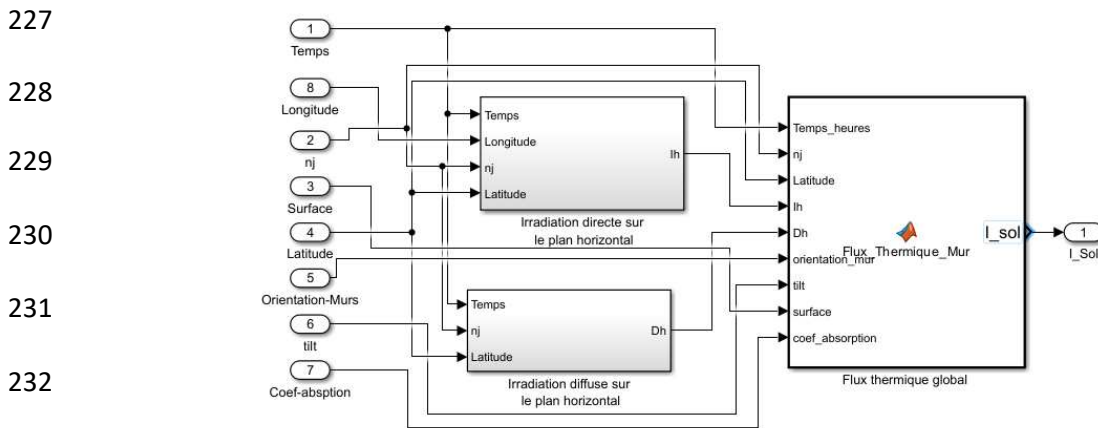
$$212 \quad E_{KWh} = \frac{1}{3.6 \times 10^6} \int_0^t P_{elec}(t) dt \quad (12)$$

213 This integration is performed numerically within the MATLAB/Simulink environment at each
 214 simulation timestep, enabling continuous tracking of cumulative energy consumption per zone
 215 throughout the 72-hour simulation window.

216 3. Simulation Procedure

217 The analysis of heat transfer across each zone is performed through dynamic model
 218 implementation in MATLAB/Simulink. The Simscape physical modeling library represents
 219 each room as an RC thermal circuit where resistance R and capacitance C encode the thermal
 220 properties of walls, ceiling, and glazing respectively. The electrical current analogy maps heat
 221 flux to current and temperature to electrical potential, yielding a state-space representation for
 222 each zone. All six zones are coupled through shared internal wall conductance. The Occupancy
 223 was modeled dynamically utilizing Simulink Signal Builder arrays driving Controlled Heat
 224 Flow Sources and each zone's AC unit is governed independently by its own hysteresis relay
 225 controller.

226 3.1 Simulation Parameters



233 Fig. 4: Simulink model for **Liu & Jordan** solar radiation

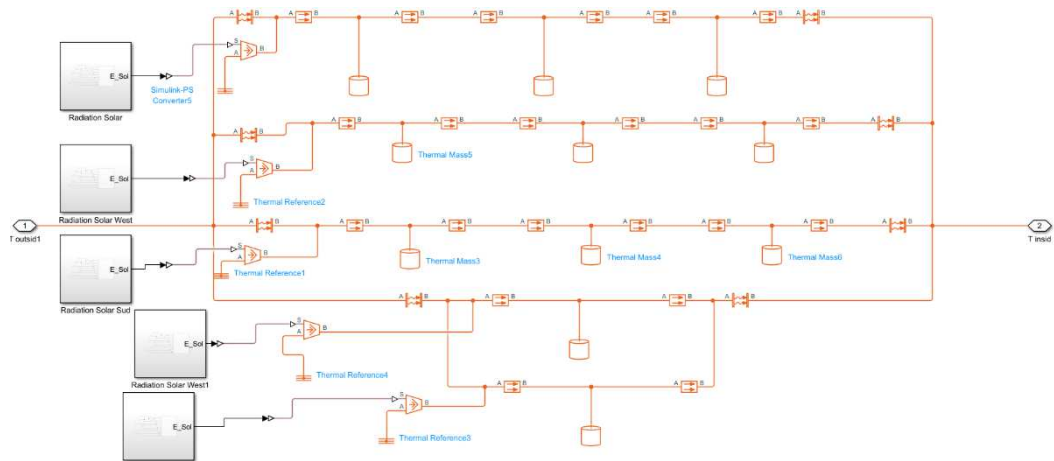


Fig. 5: Simulink model of external face thermal subsystem (Wall, ceiling, window)

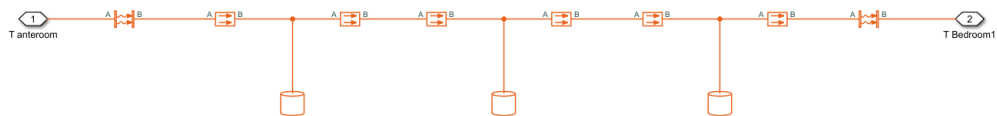


Fig. 6 : Simulink model of internal wall thermal subsystem

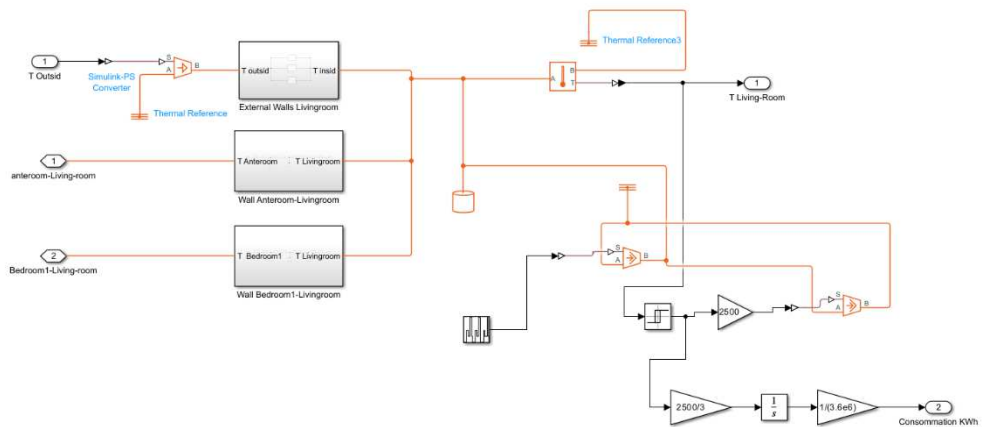


Fig.7 : Simulink model of Room thermal subsystem

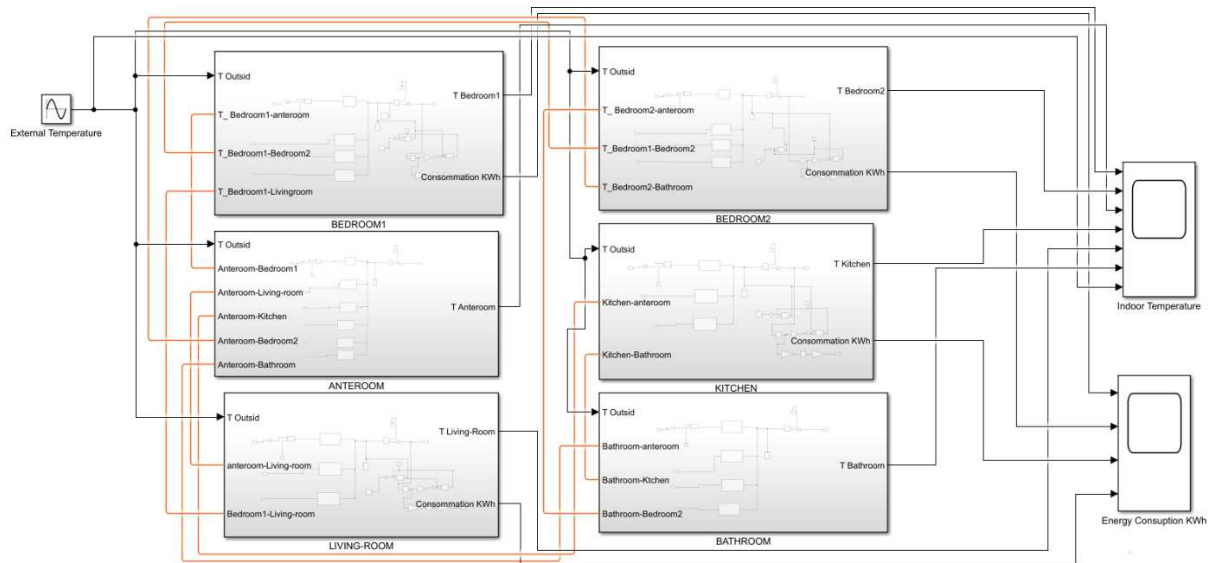


Fig. 8: Overall Simulink block diagram of the apartment thermal system

4. Results and Discussion

This study presented a fully instrumented, multi-zone dynamic thermal model of a standard F3 apartment located in Bechar, Algeria. Built natively within the MATLAB/Simulink Simscape environment, the model couples RC-network heat balance equations for six distinct thermodynamic zones with a localized on/off hysteresis AC relay-control strategy and a continuous zone-level electrical consumption integrator. The explicit incorporation of a realistic hourly occupancy profile, reflecting typical south Algerian summer family behavior, allowed the model to capture the non-linear transient thermal dynamics that simplified steady-state methods fundamentally cannot reproduce.

4.1 Natural Thermal Dynamics (Without Occupant and Air conditioning)

A simulation lasting 604800 seconds (7 days) without active cooling and occupant were conducted to characterize the building's natural thermal resilience under the July climate of Bechar. Results are presented in Figure 9. All six zones experienced severe overheating and significant thermal inertia well above the ASHRAE 55 comfort threshold of 25 °C throughout the simulation.

The figure clearly shows a warm-up phase over the first 3 days ($t=0$ to $t=72h$). The solid concrete structure absorbs the intense solar load during the day but does not have time to fully release it at night. This thermal accumulation causes the base temperature to rise day after day until it reaches a saturated periodic regime. This time lag confirms the significant inertial mass of the building materials. Bedroom 1 and the living room prove to be the most critical rooms in the building (reaching the highest peaks, nearly 46°C). With no occupants present, this overheating is due to their west-facing facades being subjected to very aggressive low-angle solar radiation in the late afternoon, at the exact time when the outside air temperature has already reached its daily maximum. This combination (hot air + solar radiation) significantly exacerbates the overheating. In contrast, bedroom 2 (northeast) and the Kitchen (southeast) receive the bulk of their direct solar radiation early in the morning. At this time, the outdoor air is coolest, and the structural thermal mass has been partially dissipated overnight. Their cooling curves and peaks therefore remain slightly lower than their western counterparts; thus, bedroom 2, which has one more window than the kitchen, explains the higher peak. The Anteroom and Bathroom effectively acted as interior thermal buffers, mitigating peak temperatures to approximately 43°C , consistent with their position as transitional spaces without direct external wall exposure to solar radiation.

Quantifying the thermal phase lag between the outdoor signal and each room, the indoor peaks trail the outdoor maximum by approximately 1 to 2 hours, this is a purely physical phenomenon, caused by the thermal resistance and thermal capacity (RC network) of the walls. It represents the time it takes for the outdoor heat wave to pass through the building envelope.

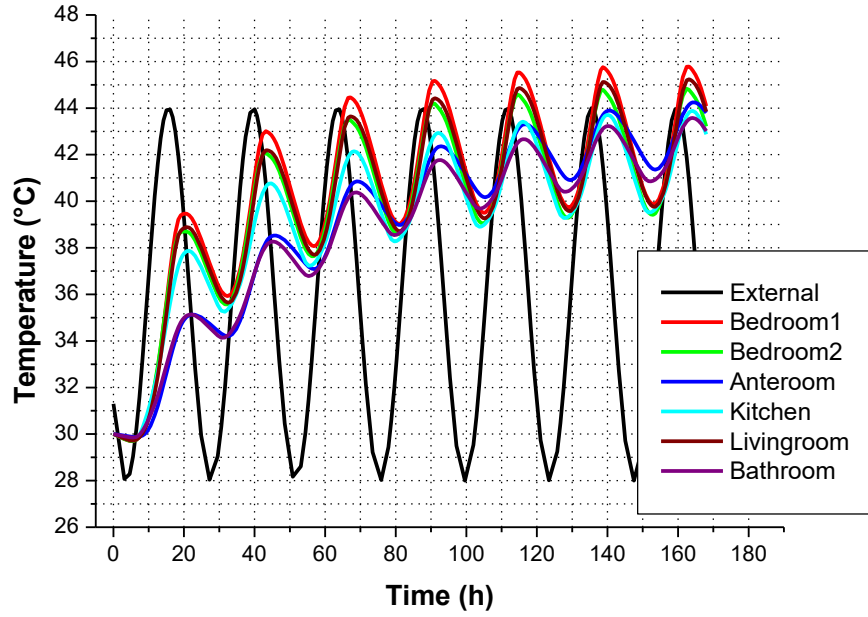


Fig 9: Interior temperatures of the apartment's rooms

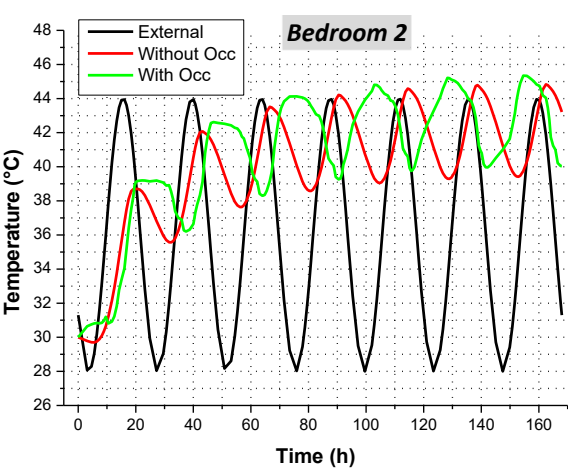
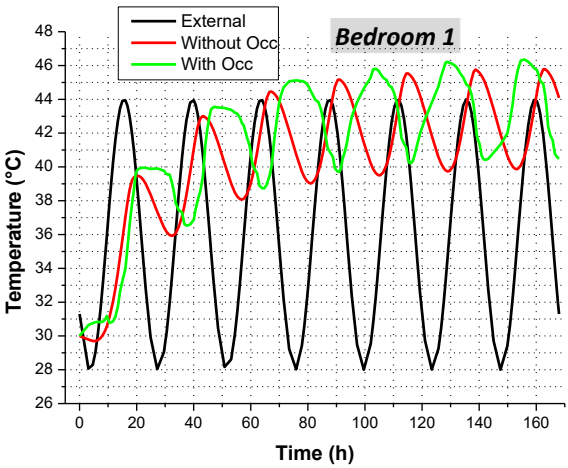
4.2 Impact of Dynamic Occupancy Profiles

Figure 10 presents a comparative analysis of the indoor temperatures with and without internal occupant loads across all six thermal zones. The results demonstrate the profound impact of metabolic heat generation on the building's thermal performance. As governed by thermodynamic principles, the inclusion of occupants strictly increases the baseline temperature in all zones. In the primary living spaces (Bedrooms, Livingroom, and Kitchen), the With Occupant curves exhibit distinct jagged peaks that perfectly mirror the dynamic occupancy schedules. For instance, the bedrooms show exacerbated overheating during the night when continuous metabolic heat is trapped within their small volume. Interestingly, even the un-occupied buffer zones (Anteroom and Bathroom) experience a slight, smooth temperature rise in the 'With Occupant' scenario. This phenomenological response is due to bidirectional conductive heat transfer through the internal partition walls from the adjacent occupied rooms, thereby highly validating the accuracy and the physical connectivity of the proposed multi-zone RC network.

Furthermore, an occupancy-induced dynamic phase shift is clearly visible on the green curves. This is not a delay caused by the building envelope's thermal inertia, but rather an artificial shift of the temperature peak toward the evening (7:00–9:00 p.m.). This secondary peak is strictly caused by the sudden release of metabolic heat usage as occupants return home.

Table 2: Peak Temperature Shift and time lag

Zones	External peak (°C)	Internal peak with occupants (°C)	Differences (°C)	time lag (h)
Bedroom 1	44	46.2	2.2	8
Bedroom 2	44	45.3	1.5	8
Livingroom	44	47	3	4
Kitchen	44	45	1	5
Anteroom	44	44.1	0.1	8
Bathroom	44	44	0	6



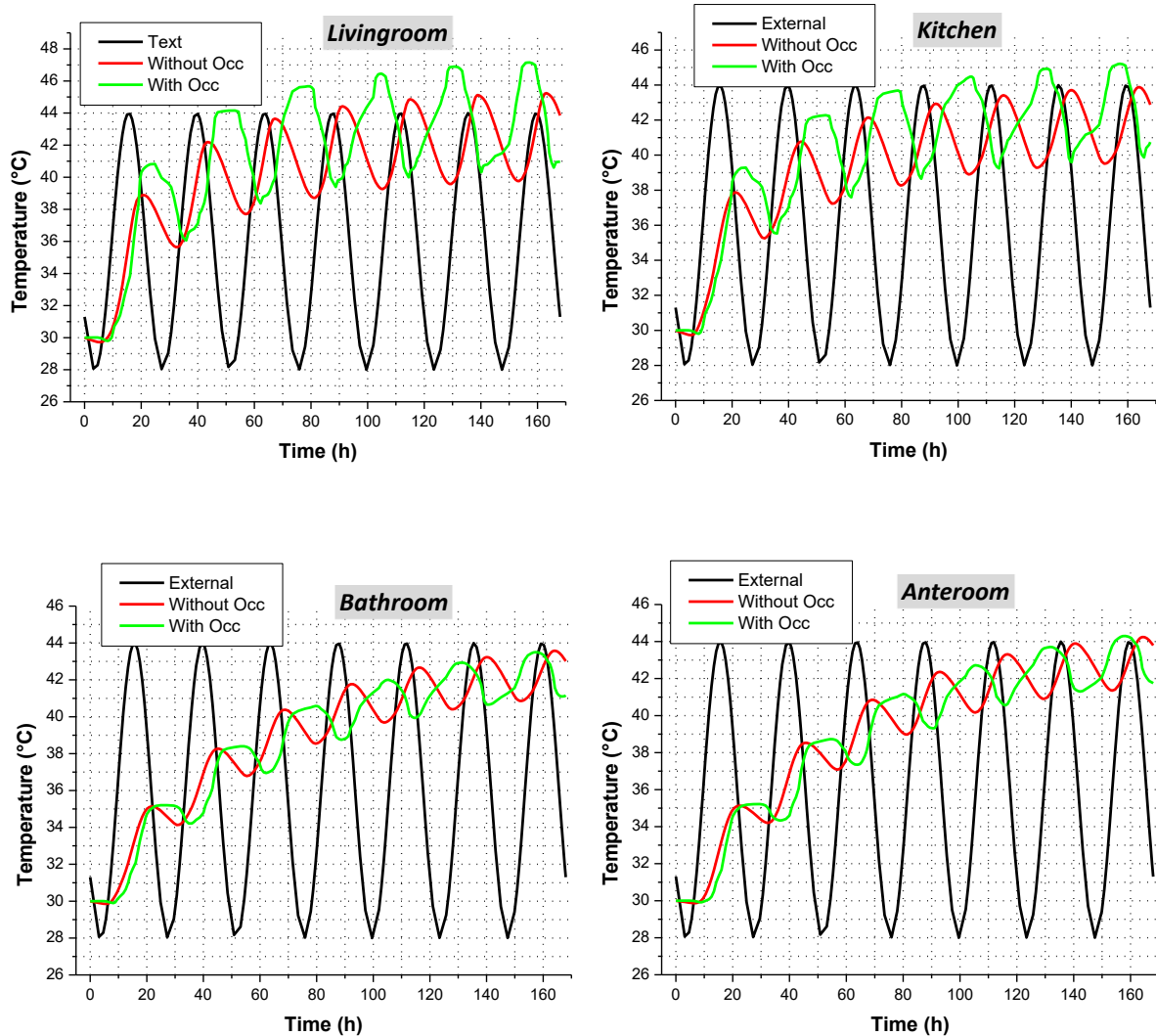


Fig. 10: Indoor temperatures with and without internal occupant

4.3 Controlled Thermal Dynamics (With Air Conditioning)

With the HVAC relay loop engaged, zone temperatures were successfully constrained within the 24.5-25.5 °C comfort envelope defined by the ± 0.5 °C hysteresis band. The daily cumulative energy required to condition the entire apartment reached approximately 53.77 kWh. The monthly total electrical consumption reached 1613.26 kWh across the four AC-equipped zones (Bedroom 1, Bedroom 2, Kitchen, Livingroom). The Anteroom and Bathroom are not independently conditioned in this mode (figure 11).

Energy consumption disaggregated by zone reveals a strong correlation with orientation and occupancy dynamics rather than room volume alone. The Livingroom, despite being the

largest zone at 54 m³, does not dominate solely because of its size: its south-west facing orientation, large glazed area, and sustained afternoon occupancy together drive a disproportionate cooling load. At 29% of the monthly total (468.033 kWh). Bedroom 1 and Bedroom 2 each account for 25% (408.345 kWh), while Kitchen accounts for 21% (344.064 kWh), reflecting slightly higher nighttime metabolic loads due to its occupancy profile.

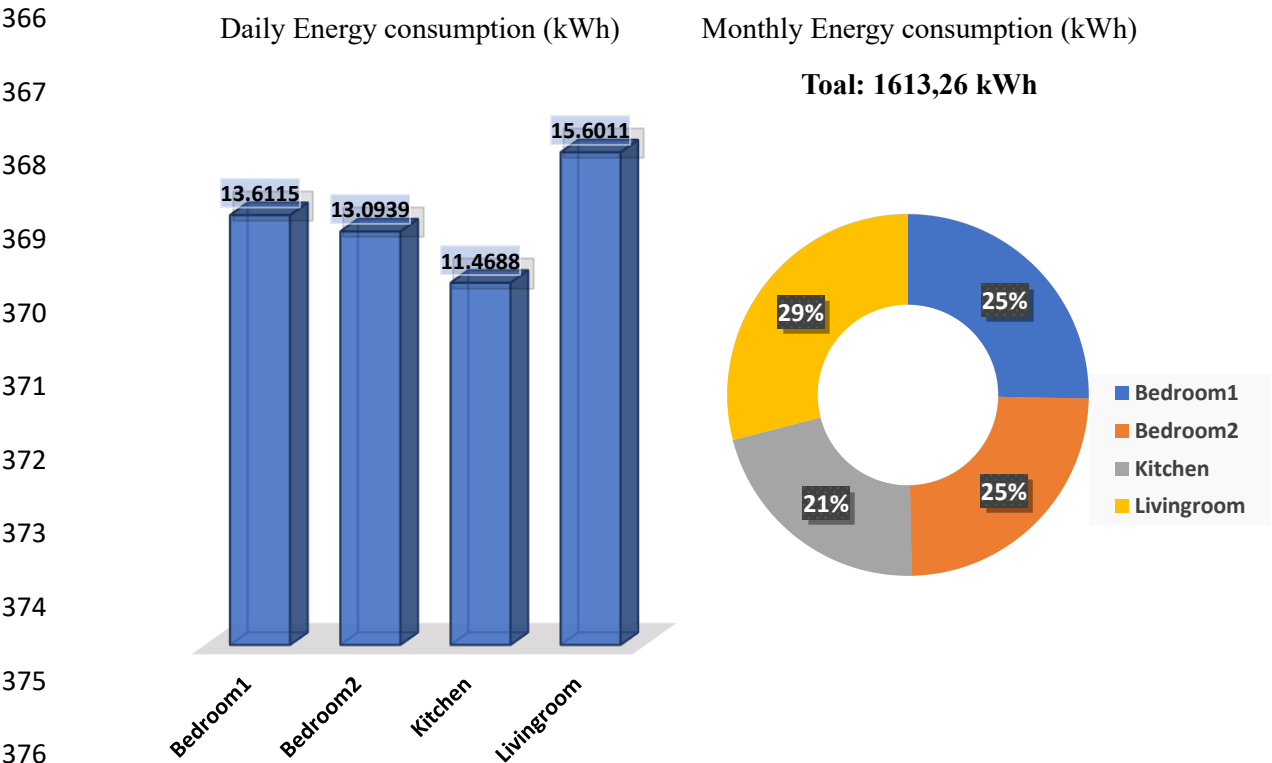


Fig. 11: Energy consumption (kWh) in apartment

4.4 Sensitivity Analysis of AC Coefficient of Performance (COP)

The initial monthly electrical consumption was evaluated using a baseline COP of 3.0. A sensitivity analysis was conducted to assess the potential energy impact of utilizing high-efficiency inverter units (COP = 3.5) versus older or degraded standard units (COP = 2.5). As demonstrated in Table 3, upgrading the HVAC system from an average COP of 3.0 to 3.5 results in an immediate 14.3% reduction in electrical demand across all active thermal zones. Conversely, a degraded unit operates with a +20% penalty on total consumption, highlighting

the critical economic and environmental role of equipment selection in extreme hyper-arid climates.

Table 3: Monthly electrical energy consumption (kWh) and percentage impact relative to the baseline COP across all conditioned zones.

Thermal Zone	COP = 2.5 (+20%)	Baseline COP = 3.0	COP = 3.5 (-14.3%)
Livingroom	561.64	468.03	401.17
Bedroom 1	490.01	408.34	350.01
Bedroom 2	471.38	392.82	336.70
Kitchen	412.88	344.06	294.91
TOTAL (kWh)	1935.91	1613.26	1382.79

5. Conclusion

This study successfully developed and validated a fully dynamic, multi-zone RC thermal model of a standard F3 residential apartment in the extremely arid climate of Béchar, Algeria, utilizing MATLAB/Simscape. By directly coupling behavioral occupancy patterns with building thermophysics, the model accurately captured both the severe free-floating thermal risks and the precise electrical load distribution required for mechanical cooling.

The quantitative simulations revealed critical vulnerabilities in current architectural standards. Under unconditioned (free-floating) scenarios, the apartment experiences extreme localized overheating, with bedrooms reaching up to 46 °C and the south-facing Living Room peaking at 47 °C during high-occupancy evening hours. When governed by a strict 25 °C HVAC thermostatic control, the cumulative electrical demand surges, culminating in a massive total monthly consumption of 1613.26 kWh (assuming a baseline COP of 3.0). The south-facing Living Room acts as the primary thermal sink, demanding over 468 kWh alone due to the combined effect of direct solar irradiation and dense metabolic heat gains.

404 These findings confirm that the current building envelope (hollow brick walls, flat roof without
405 insulation, simple single glazing) is insufficient for passive thermal protection under Bechar's
406 climate. Based on the simulation results, the following practical recommendations are
407 proposed:

- 408 • **External shading on the south façade:** Overhangs or adjustable louvers targeting the
409 Livingroom and Kitchen windows would directly reduce the dominant solar gain
410 component.
- 411 • **Glazing upgrade:** Replacing single-glazed windows with low-emissivity double
412 glazing could reduce solar heat gain in south-facing rooms.
- 413 • **Wall and roof insulation:** Adding an external insulation layer would increase thermal
414 resistance, reduce indoor temperature swings, and lower the AC duty cycle.
- 415 • **Night ventilation strategy:** A timed ventilation schedule during the cool nocturnal
416 hours (28 °C. 22h00-06h00) could pre-cool the building's thermal mass and reduce
417 morning starting temperatures, potentially cutting daily energy consumption.
- 418 • **High-efficiency AC units:** As demonstrated in the sensitivity analysis, selecting
419 inverter type units with a rated COP of 3.5 and ensuring regular maintenance
420 immediately yields over 14% real world electrical consumption savings.

421 **Declarations**

- 422 • **Ethics approval and consent to participate**
423 Not applicable.
- 424 • **Consent for publication**
425 Not applicable.
- 426 • **Availability of data and material**
427 The datasets generated and/or analysed during the current study are available from the
428 corresponding author on reasonable request.

429 • **Competing interests**

430 The authors declare that they have no competing interests.

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432 No funding was received for conducting this study.

433 • **Authors' contributions**

434 **A. Missoum:** Conceptualization, methodology, thermal modelling, numerical
435 simulation, data analysis, and writing of the original manuscript.

436 **M. Elmir:** Supervision, methodology, validation, and review and editing of the
437 manuscript.

438 **R. Mehdaoui:** Validation, data analysis, and review and editing of the manuscript.

439 **M. Tamali:** Supervision, validation, and review and editing of the manuscript.

440 **M. Rebhi:** Data analysis and review and editing of the manuscript.

441 **M. Nabou:** Supervision and review and editing of the manuscript.

442 All authors read and approved the final manuscript.

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444 Not applicable.

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