UNIVERSITE JOSEPH KI-ZERBO

ECOLE DOCTORALE INFORMATIQUE
ET CHANGEMENT CLIMATIQUE

BURKINA FASO
La Patrie ou la Mort, nous Vaincrons

Order N° : ………………

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MASTER THESIS

Subject:

Implementation of software for calculating the thermal balance of air conditioning systems in steady state

Presented the 21 July 2025, by :

Wendwaogo Armel Régis SAWADOGO

Examination jury

President : Dr Didier BASSOLE , Associate Professor at Université Joseph Ki-Zerbo

Members :

- Dr Guy Christian TUBREOUMYA, Associate Professor at Université Joseph KI-ZERBO, supervisor, external examiner
- Pr Ousmane COULIBALY, Full Professor at Université Joseph KI-ZERBO, supervisor
- Dr Kisito Kiswendsida KABORE, Assistant Professor at Université Joseph KI-ZERBO, co-supervisor

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DEDICATION

To my dear parents, source of life, love, and affection.

To my dear brothers, source of joy and courage.

To my entire family, source of hope and motivation

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ABSTRACT

Burkina Faso, like many developing tropical countries, is facing a growing demand for air conditioning due to rising temperatures linked to climate change, rapid urbanization, and improved living conditions. However, most actors in the building sector still rely on empirical methods for sizing air conditioning systems, which are often unsuitable for the local context and lead to significant errors. This thesis aims to design and validate a simple and accessible software tool for calculating the thermal balance of residential buildings, based on the IEPF method, to provide a scientific solution adapted to Burkina Faso's climatic zones. Three cities representative of the country's climatic zones were selected: Dori for the Sahelian zone, Ouagadougou for the Sudano-Sahelian zone, and Bobo for the Sudanian zone. The software was tested on a typical building located in Ouagadougou, under steady-state conditions at peak thermal loads (April month), with precisely defined climatic, material, occupancy, and orientation parameters. The results show excellent agreement between manual calculations performed according to the IEPF method and those provided by the application, with a relative error below 0.2%, confirming the software's reliability. The tool stands out for its ease of use, user-friendly interface, and the precision of the detailed outputs (sensible and latent loads, required electrical power). However, its validity is limited to simple cases under steady-state conditions and strongly depends on the quality of input data. This work highlights the urgency of replacing empirical practices with validated and contextualized digital tools, to optimize air conditioning system design in tropical climates.

Keywords: thermal balance; software; IEPF method; air conditioning; Burkina Faso.

RESUME

Le Burkina Faso, comme de nombreux pays tropicaux en développement, fait face à une demande croissante en climatisation du fait de la montée des températures liée au changement climatique, à l'urbanisation rapide et à l'amélioration des conditions de vie. Cependant, la majorité des acteurs du secteur du bâtiment s'appuient encore sur des méthodes empiriques pour le dimensionnement des systèmes de climatisation, souvent inadaptées au contexte local et génératrices d'erreurs importantes. Ce mémoire vise à concevoir et valider un outil logiciel simple et accessible pour le calcul du bilan thermique des bâtiments résidentiels, fondé sur la méthode IEPF, afin d'apporter une solution scientifique adaptée aux zones climatiques du Burkina Faso. Trois villes représentatives des zones climatiques du pays ont été sélectionnées : Dori pour la zone sahélienne, Ouagadougou pour la zone soudano-sahélienne et Bobo pour la zone soudanienne. Le logiciel a été testé sur un bâtiment type situé à Ouagadougou, en conditions stationnaires au pic de charge thermique (mois d'avril), avec des paramètres climatiques, de matériaux, d'occupation et d'orientation précisément définis. Les résultats montrent une excellente concordance entre les calculs manuels réalisés selon la méthode IEPF et ceux fournis par l'application, avec un écart relatif inférieur à 0,2 %, attestant la fiabilité du logiciel. L'outil se distingue par sa simplicité d'utilisation, son interface conviviale et la précision des détails fournis (charges sensibles et latentes, puissance électrique nécessaire). Cependant, sa validité est limitée aux cas simples en régime permanent et dépend fortement de la qualité des données d'entrée. Ce travail met en lumière l'urgence de remplacer les pratiques empiriques par des outils numériques validés et contextualisés pour optimiser la conception des systèmes de climatisation dans un climat tropical.

Mots-clés : bilan thermique; logiciel; méthode IEPF; climatisation; Burkina Faso.

ACRONYMS AND ABBREVIATIONS

oUED : African Development Bank

AM : Ante Meridiem

API : Application Programming Interface

App : Application

ASHRAE : American Society of Heating, Refrigerating and Air-Conditioning Engineers

CDD : Cooling Degree Days

CDM : Clean Development Mechanism

CFD : Computational Fluid Dynamics

CLF : Cooling Load Factor

CLTD : Cooling Load Temperature Difference

CMIP6 : Coupled Model Intercomparison Project Phase 6

Cv : Cheval vapeur

COP : COefficient of Performance

CRUD : Create, Read, Update, Delete

DB : Database

DOE-2 : Department of Energy Building Energy Simulation Program, Version 2

ECOWAS : Economic Community of West African States

EDICC : École Doctorale Informatique et Changement Climatique

ERA5 : Fifth Generation ECMWF Atmospheric Reanalysis

Fig. : Figure

HAP : Hourly Analysis Program

HB : Heat Balance

HBM : Heat Balance Method

HVAC : Heating, Ventilation and Air Conditioning

IEA : International Energy Agency

IEPF : Institut de l’énergie et de l’environnement de la Francophonie

INSD : Institut National de la Statistique et de la Démographie

IPCC : Intergovernmental Panel on Climate Change

ISO : International Organization for Standardization

ISO 7730 : International Standard on Ergonomics of the Thermal Environment

K : Kelvin (unité de température)

kWh : Kilowatt-hour

m^2 : Square meter

MERRA-2 : Modern-Era Retrospective Analysis for Research and Applications, V2

Mm : Millimeter

MVC :Model-View-Controller

OOP : Object-Oriented Programming

OMG : Object Management Group

PANEE : Plan d’Action National d’Efficacité Energétique

PDF : Portable Document Format

PM : Post Meridiem

PMV : Predicted Mean Vote

PPD : Predicted Percentage of Dissatisfied

PRAS : Primary Return Air Systems

RTS : Radiant Time Series

RTSM : Radiant Time Series Method

SDI : Spatial Data Infrastructure

SEAM : Simplified Energy Analysis Model

SHF : Sensible Heat Factor

SI : Système International d’Unités (International System of Units)

SOA : Service-Oriented Architecture

TFM : Transfer Function Method

UML : Unified Modeling Language

UHI : Urban Heat Island

W/m^2 : Watts per square meter

$W/m^2 \cdot K$: Watts per square meter per Kelvin

W : Watt

WRF : Weather Research and Forecasting (Model)

WHO : World Health Organization

WAEMU : West African Economic and Monetary Union

WAPP : West African Power Pool

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Introduction

Cities across West Africa are facing a growing challenge: the need for cooling is rising faster than ever before. As global temperatures climb and urban areas expand, people are struggling to stay comfortable in the intense heat and humidity that define the region's tropical climate. In places like Burkina Faso, where the dry season can see temperatures soar above 40°C (Red Cross, 2023), staying cool isn't just about comfort. Yet the widespread use of air conditioning comes with serious problems. Power grids in these areas are often fragile and unreliable, and running air conditioners can be prohibitively expensive for most families. This creates a difficult situation where cooling is needed but often out of reach.

Over the past few years, new thermal simulation technologies have emerged, offering engineers and architects better tools to design cooling systems that save energy and improve comfort. Research has shown that smart building design combined with efficient cooling can cut energy use dramatically, even in hot, humid climates. But there's a catch: most existing tools were developed with temperate regions in mind. They don't consider the unique challenges of places like Burkina Faso, where seasonal shifts in humidity, dramatic temperature swings, and local building materials all play important roles.

This research aims to bridge that gap by creating a thermal load simulation tool specifically for West African climates. The goal is to help architects and engineers design cooling systems that work effectively while staying affordable and sustainable. This study hopes to support better building designs that improve comfort without overloading energy systems.

Burkina Faso, in the heart of the Sahel, experiences extreme weather conditions. The dry season brings blistering heat, while the rainy season adds suffocating humidity. These factors make air conditioning more important than ever, but they also reveal a stark reality: many homes and buildings aren't built to handle such heat. In rural and older urban neighborhoods, houses made from mud bricks and topped with corrugated metal roofs trap heat, turning indoor spaces into ovens. According to recent national surveys, nearly all homes (about 96%) fall short of basic structural and comfort standards, and the situation is worse in rural areas, where less than 1% of homes meet decent living conditions (INSD, 2023). Materials like mud bricks and metal roofing worsen the problem by holding onto heat and raising indoor temperatures. Also, energy access further compounds the challenge. Fewer than one in five households are connected to the national electricity grid, and while some families use solar panels, these systems often can't power something as energy-hungry as an air conditioner. This combination of poor building quality and unreliable energy makes staying cool a serious challenge. Many people rely on fans or passive methods that offer little relief during the hottest months, leaving them vulnerable to heat-related health problems.

The stakes are only getting higher. Climate experts have already warned that we've passed the 1.5°C global warming threshold set by the Paris Agreement, and West Africa is expected to see more frequent and severe heatwaves (IPCC, 2023). Traditional cooling methods like opening windows or using simple fans won't be enough to keep people safe and comfortable. There's a pressing need for better, region-specific solutions that can accurately calculate cooling needs and help design systems that work in these tough conditions. This research aims to give designers a simplified and practical way to create more effective and sustainable cooling systems.

Main and specific Research questions

Main Research Question:

How to simplify in-air conditioning heat balance calculation for Burkina Faso?

Specific Research Questions

- What simulation tool calculate the in-air conditioning heat balance for Burkina Faso's?
- Does the software determine heat balance for Burkina Faso buildings?

Main and specifics hypothesis of research

Main Research Hypothesis: An simplified calculation of in-air conditioning heat balance software answers to the tropical climate needs

Specific Research Hypotheses:.

- An effective simulation for tropical climates provide accurate heat balance calculations
- The system simulates the différents local heat gains of a building

Main and specific objectives

Main Objective:

To develop an in-air conditioning heat balance software for the tropical climate of Burkina Faso.

Specific Objectives:

- To setup a tool of in-air conditioning heat balance simulation.
- To validate the performance of the developed software on a real situation

The rest of this thesis is organized as follows. Chapter I gives background information about energy and climate in West Africa and Burkina Faso. It also presents the main methods for calculating thermal loads and explains the basic principles of thermal comfort in buildings. Chapter II describes the research methods. It explains how the case study building was chosen, how the climate and material data were collected, and how the IEPF calculation method and the software were developed and validated. Chapter III presents and discusses the results. It compares the outputs of the manual method and the application, and it evaluates how accurate and useful the software is for real projects. The last chapter summarizes the main results, discusses what they mean for building design in Burkina Faso, and gives suggestions for improving and using the tool in the future.

Chapter I : Literature review

The implementation of a software for air conditioning heat balance calculation in Burkina Faso requires a comprehensive understanding of thermal load calculations, climatic conditions, and energy efficiency strategies. Given the increasing temperatures and urbanization in Burkina Faso, the demand for air conditioning is rising. However, conventional methods for cooling load estimation are often complex and computationally This literature review synthesizes key theories, methodologies, and studies relevant to the topic, focusing on:

I.1 Energetic context of West Africa and Burkina Faso

Before focusing on the specific situation in Burkina Faso, it is important to look at the broader energy context in West Africa. Regional trends, such as low electricity access and strong reliance on biomass, have a direct impact on how energy is used in buildings. After presenting these regional aspects, the section will take a closer look at the main features of the energy sector in Burkina Faso, which faces its own specific difficulties but also benefits from some promising developments in recent years.

I.1.1 Regional Energy Context (West Africa)

Burkina Faso is part of a regional context marked by similar energy challenges but also by dynamics of integration and innovation, driven by sub-regional organizations such as the Economic Community of West African States (ECOWAS) and the West African Economic and Monetary Union (WAEMU). West Africa has one of the world's lowest average electricity access rates (around) 52% in 2020), with wide inequalities between countries and between urban and rural areas (Ministère des Mines et de l'Énergie, 2015). The regional energy mix is still dominated by biomass (around 60%), followed by hydrocarbons, with only a small but growing share of renewables outside hydropower. Growing demand, driven by population growth and urbanization, puts increasing pressure on the grid, especially in Sahelian capitals (African Development Bank, 2020). Several major regional programs have emerged in response to this situation:

- The Regional Energy Efficiency Program (ECOWAS) focuses on harmonizing national policies, creating regional standards for construction, developing labels and energy labeling, and organizing awareness campaigns at the community level (ECOWAS, 2021).

- The **Desert to Power** initiative aims to transform the Sahel into a regional leader in solar energy, with a goal of 10 GW of installed solar capacity by 2030. The “Building” component promotes decentralized solar PV integration, development of eco-neighborhoods, and the generalization of bioclimatic practices (Africa Development Bank, 2020).
- **Regional cooperation projects (WAPP, etc.)**: The West African Power Pool (WAPP) facilitates electricity exchanges and resource sharing, helping the system cope with climate-related shocks.

The building sector is identified as one of the main opportunities for energy efficiency at the regional level, due to the rapid growth of the building stock (high urbanization rate), the dominance of informal and unregulated construction, the historical absence of thermal insulation, which leads to high cooling needs (Ministère des Mines et de l’Énergie, 2015). Recent policies (WAEMU directive, ECOWAS standards) recommend an integrated approach: promoting bioclimatic architecture, using local low-impact materials, training professionals, and developing calculation tools adapted to Sahelian climates.

Despite outstanding solar potential such as an annual irradiation between 5 and 7 kWh/m²/day in the Sahel, the deployment of energy-efficient solutions remains limited by costs, lack of knowledge of standards, limited financing, and the scarcity of suitable modeling tools (African Development Bank, 2020). However, the emergence of simplified methodologies such as the IEPF method and the drive for regional integration are paving the way for progressive sector transformation.This hightlight that the issue of heat balance and comfort in West African buildings cannot be separated from regional dynamics, both regulatory and technical.

I.1.2 Energy Context of Burkina Faso

Burkina Faso is characterized by an energy system that is largely dominated by biomass, which accounts for approximately 80% of the country’s total primary energy supply. According to the Gap Analysis Report for Energy Access, total primary energy in 2008 reached 3.26 million tons of oil equivalent (Mtoe), with traditional biomass making up the bulk of consumption, followed by petroleum products (19%) and a very small share of hydroelectricity (0.4%) (Ministère des Mines et de l'Énergie, 2021). This heavy reliance on biomass, mainly used for cooking, has significant negative effects on the environment, notably deforestation and land degradation.

Access to electricity remains a major challenge, with the national electrification rate stagnating around 25–29% in recent years. The disparities are significant: urban electrification increased from 13.6% in 2010 to nearly 68.7% in 2018, while the rural rate remains below 5% (Africa Development Bank, 2020). The installed production capacity, around 657 MW in 2019, comes mainly from thermal power plants (more than 85%), with a growing but still limited contribution from solar (for example, the Zagtouli photovoltaic power plant, 33.7 MWp); The electricity sector also suffers from critical dependence on imported hydrocarbons, making the country vulnerable to international oil price fluctuations, as well as to electricity imports from neighboring countries (Côte d'Ivoire, Ghana, Togo), which made up nearly 45% of national consumption in 2018 (Africa Development Bank, 2020). This situation places a heavy burden on public finances through substantial subsidies (up to 20 billion CFA francs per year) and limits the competitiveness of the industrial sector (Ministère des Mines et de l'Énergie, 2021).

To address these challenges, the government of Burkina Faso has implemented several key policies. The Sectoral Energy Policy Letter (LPSE, 2016) set ambitious targets: to achieve 70% national electrification, 90% urban, and 50% rural by 2025, and to increase the share of renewables to 50% by 2027 (Africa Development Bank, 2020). The National Energy Efficiency Action Plan (PANEE) targets the building sector with the integration of construction codes, standardization and labeling of equipment, and the development of mechanisms to monitor energy performance (Ministère des Mines et de l'Énergie, 2015).

Despite this progress, the building sector remains largely inefficient in terms of energy. Most dwellings use materials with poor thermal performance (adobe, uninsulated bricks, metal sheeting), lacking proper insulation or consideration of solar gains. Comfort needs are mainly covered by natural ventilation and, in wealthier households, by individual air conditioning, whose growing use threatens to increase the strain on the electricity grid. Recent studies on administrative and residential buildings in Burkina Faso have shown annual energy needs ranging from 71 to 149 kWh/m^2 , high thermal transmission coefficients, and unfavorable wall-to-window ratios for comfort and energy efficiency (Ouedraogo et al., 2022).

Several pilot programs like improved cookstoves, energy audits, training of energy managers, renovation of public buildings have demonstrated measurable gains, but widespread application of norms and good practices is hindered by high initial costs, a lack of awareness, and weak regulatory enforcement (Ministère des Mines et de l'Énergie, 2021). The sector also heavily depends on informal construction, which often escapes regulation.The energy challenges in the building sector are thus closely linked to the local climate context, but also to energy poverty and the limited investment capacity of households. This context justifies the development of simple, robust, and context-appropriate methods for heat balance calculations and the design of low-energy comfort solutions.

In summary, Burkina Faso faces major energy challenges, including strong dependence on traditional fuels, low access to electricity, and limited efficiency in the building sector. These difficulties are also found at the regional level in West Africa. Knowing this context highlights the importance of developing solutions that are adapted to both local and regional realities. The next section will focus more specifically on the climate context, which is another important factor for building performance.

I.2 Climatic Context of Burkina Faso

The climate of Burkina Faso directly impacts thermal load calculations, air conditioning demand, and energy efficiency. As a Sahelian country, Burkina Faso experiences high temperatures, strong solar radiation, and pronounced seasonal variations, all of which play a crucial role in determining cooling requirements. Unlike temperate regions where cooling is seasonal, Burkina Faso’s hot climate necessitates year-round air conditioning, placing increasing pressure on energy infrastructure and system design (Sawadogo et al. 2024). Recent climate models predict rising temperatures, more frequent heatwaves, and higher cooling degree days (CDD), further intensifying cooling needs. In parallel, urban expansion and the urban heat island (UHI) effect are increasing local temperatures in cities like Ouagadougou and Bobo-Dioulasso, making air conditioning a necessity rather than a luxury (Tété et al., 2024). This section presents a detailed analysis of Burkina Faso’s climatic conditions, highlighting the findings of recent studies, the methodologies used to obtain results, and their implications for cooling system efficiency.

Burkina Faso experiences extreme seasonal and diurnal temperature variations, influencing both air conditioning performance and cooling energy demand. The Sahelian zone in the north records some of the highest temperatures, with peak values exceeding 45°C in the dry season, while the Sudanian zone in the south remains relatively cooler but more humid. Satellite temperature monitoring and meteorological station data confirm that the country's average annual temperature has increased by 1.1°C over the past 60 years, with projections showing a further 1.5 to 3°C increase by 2050 (Sawadogo et al.., 2024). Researchers obtained these results using climate downscaling techniques based on Coupled Model Intercomparison Project Phase 6 (CMIP6) simulations. The CMIP6 models, refined using regional climate data, indicate that heatwaves in Burkina Faso will become more frequent and last longer, increasing both daytime and nighttime cooling requirements (Yaméogo et al, 2024). These projections align with historical heatwave trends, where the number of extreme heat days per year has doubled since the 1980s. The studies highlight that future heatwaves will not only raise daytime cooling demand but will also increase nighttime air conditioning usage, as temperatures will remain above thermal comfort levels for extended periods.

Solar radiation is a major driver of indoor heat gains, affecting air conditioning loads. Burkina Faso receives 5.5 to 6.5 kWh/m² of solar energy per day, among the highest levels in West Africa. Satellite-based solar monitoring from NASA's POWER Project and Solargis databases has mapped the distribution of solar radiation across Burkina Faso, showing higher intensities in the north and center, which contribute to higher cooling loads (Sawadogo et al., 2024). Research findings demonstrate that direct solar radiation increases roof and wall temperatures by up to 20°C above ambient air temperature, significantly contributing to indoor overheating. Using infrared thermography and building energy simulations, studies found that west-facing walls receive the highest solar intensity during late afternoon, correlating with peak cooling energy demand. These studies emphasize the importance of solar shading, reflective roofing, and ventilated facades in reducing indoor heat accumulation (Tété et al., 2024). The urban heat island (UHI) effect further exacerbates cooling demand in cities. Satellite thermal imaging studies reveal that urban areas are 3 to 5°C hotter than surrounding rural zones, primarily due to the absorption and retention of heat by concrete, asphalt, and metal surfaces. The Landsat-based UHI study conducted in Ouagadougou showed that areas with dense vegetation were up to 2°C cooler than built-up zones, reinforcing the importance of urban greening in reducing air conditioning needs

(Sawadogo et al., 2024).

Humidity significantly affects air conditioning efficiency, as it increases latent heat loads. Burkina Faso experiences seasonal humidity variations, with the Harmattan season being dry (humidity <20%), while the rainy season reaches high humidity levels (50–90%). Meteorological station data combined with atmospheric reanalysis datasets (ERA5 and MERRA-2) confirm these seasonal humidity shifts, which play a key role in HVAC system performance (Yaméogo et al., 2024). A critical finding is that high humidity increases the perceived temperature by 5 to 8°C above the actual air temperature, as measured using the heat index model. This increases cooling energy demand, particularly in the Sudanian zone, where moisture-heavy air makes traditional air conditioning systems less efficient. Researchers simulated the energy performance of different HVAC configurations and found that integrated cooling and dehumidification systems perform 30% more efficiently than conventional split air conditioning units in high-humidity environments.

Climate change is expected to amplify these cooling challenges, increasing air conditioning reliance in Burkina Faso. CMIP6-based projections show that by 2100, annual cooling degree days (CDD) could rise by 25 to 40%, extending the cooling season well beyond current patterns (Sawadogo et al., 2024). The growing urban population and economic development will further intensify energy demand, requiring investments in efficient HVAC technologies, smart building design, and renewable energy integration. Ongoing government initiatives include a 2,000-hectare urban greening project in Ouagadougou, aimed at reducing the UHI effect and enhancing evapotranspiration cooling. The National Housing Program promotes energy-efficient housing, integrating passive cooling techniques, high-performance insulation, and solar-powered HVAC systems. Research indicates that these strategies, when combined with policy-driven energy efficiency measures, could reduce air conditioning-related emissions by up to 40% by 2050 (Global Green Growth Institute, 2025).

I.3 Thermal load calculation methods

Thermal load calculation is a fundamental process in the design of air conditioning systems, as it determines the cooling requirements necessary to maintain comfortable indoor temperatures. Accurate estimations are essential for ensuring energy efficiency, reducing operational costs, and optimizing system performance. Overestimating thermal loads leads to oversized systems, resulting in unnecessary energy consumption and increased installation costs. Conversely, underestimations lead to inadequate cooling capacity, which compromises occupant comfort and strains HVAC equipment, reducing its lifespan (ASHRAE, 2019). Various methods have been developed to estimate cooling loads, ranging from steady-state models that assume constant conditions to dynamic simulation models that consider time-dependent variations. Each method has its advantages and limitations, particularly when applied in different climatic regions. In contexts like Burkina Faso, where access to detailed climate data and computational resources may be limited, simplified heat balance calculation methods have been developed to provide a practical alternative. These approaches adapt standard cooling load equations to local conditions, making them useful for HVAC engineers working in resource-constrained environments.

I.3.1 Steady-State Methods and Empirical Models

Steady-state models assume that heat gains and losses remain constant over time, providing a simplified framework for estimating cooling loads (ASHRAE, 2019). These models are widely used in both developed and developing countries because of their ease of implementation and low computational requirements. However, they do not account for transient variations in weather conditions, occupancy patterns, or internal heat gains, making them less accurate in dynamic environments [(Spitler, 2021)].

In West Africa, steady-state and especially **empirical models** are widely used by practitioners for building cooling load estimation. The most common empirical approaches are:

- **Surface Area Method:**his method estimates cooling load using a fixed coefficient (typically 100–120 W/m² for offices or 80–100 W/m² for residential buildings). For example, in Burkina Faso, most technicians use a simple rule: multiply the floor area by 120 W/m² to size air conditioners, regardless of orientation, insulation, or window area. This approach is valued for its simplicity and speed but often leads to significant over- or undersizing. Field surveys in Ouagadougou have shown that over 85% of installations are sized using this surface method, mainly because it is accessible for non-specialists (Kaboré et al., 2023).

- **Degree-Day Method:** This method estimates annual energy needs by summing the temperature differences between indoor setpoint and outdoor daily averages across the year. While this method is recognized for its robustness in literature (Dicko et al., 2024), its practical use is limited in the region because most practitioners lack access to detailed climate data or specific training.
- **Rules-of-Thumb ("Watt per Room") :** Many installers use a fixed cooling power per room (e.g., 2 kW for a bedroom), based on habits, manufacturer suggestions, or personal experience. This is particularly popular among small contractors and in residential projects.
- **CLTD (Cooling Load Temperature Difference) Method:** The CLTD method, recommended in the ASHRAE Handbook 2001, estimates heat transfer through the building envelope by considering solar gains, outdoor temperature, and construction materials. However, its correction factors are mainly calibrated for temperate climates. In Nigeria, Ogunjuyigbe et al. (2017) demonstrated that direct application of the CLTD method without local correction led to a 15–25% overestimation of cooling loads.
- **Heat Balance (HB) Method:** The Heat Balance method includes all modes of heat transfer (conduction, convection, and radiation) and is recognized for its accuracy in building energy calculations. In West Africa, this approach has been adapted regionally through the **IEPF method**, which proposes a simplified steady-state version suitable for local contexts and available data (IEPF, 2003).

Multiple studies and field assessments confirm that using these methods without local calibration leads to major errors. Empirical coefficients from North America or Europe fail to account for the high thermal mass, local ventilation strategies, and construction materials specific to the Sahel. For example, Coulibaly (2011) showed that such coefficients were not suitable for Sahelian buildings, resulting in underestimation or overestimation of peak cooling demand. These knowledge gaps and the reliance on empirical rules are not simply a matter of ignorance at the individual level, but rather stem from structural barriers:

- Limited access to advanced technical education on energy,
- Scarcity of region-specific calculation guides in local languages,
- Absence of ongoing professional training, and
- Economic constraints that make advanced dynamic modeling impractical.

In summary, while steady-state and empirical models are operationally useful and dominate current practice in West Africa, their continued use without adaptation to local realities leads to significant errors. This situation reflects structural challenges in training and knowledge transfer rather than mere ignorance, and highlights the urgent need for improved education, local calibration, and the development of accessible, context-specific calculation tools for reliable cooling load estimation.

I.3.2 Dynamic Simulation Models

Dynamic simulation models offer a more detailed approach to thermal load estimation by dividing time into small intervals and computing heat gains and losses at each step. Unlike steady-state models, these approaches take into account the dynamic nature of heat transfer processes, allowing for a more precise assessment of cooling requirements throughout the day. Such models are particularly useful in climates where temperature fluctuations and solar radiation intensity vary significantly between day and night (ASHRAE, 2019). One of the widely used dynamic approaches is the Transfer Function Method (TFM), which calculates the response of a building's thermal mass to external and internal heat gains. TFM is the foundation for software tools such as EnergyPlus and DOE-2, which are used in detailed energy modeling of buildings (Spitler, 2021).

Recent studies using building simulation software such as EnergyPlus, TRNSYS and DesignBuilder have demonstrated that orientation, window size, and passive design strategies significantly impact energy consumption in African buildings. For instance, Ashmawy et Azmy (2018) showed that building orientation in hot climates could affect annual cooling energy by over 25%, while Kameni Nematchoua et al. (2021) provided a comprehensive comparison of energy use and thermal comfort across eight Sub-Saharan African countries using simulation tools. These studies confirm that simulation models are increasingly applied in Africa and are effective when properly calibrated to local climatic data and construction methods. Furthermore, large-scale reviews of the path to near-zero energy buildings in West Africa highlight the importance of integrating simulation and local data for efficient building design (Mohammed et al., 2023). Thus, dynamic models offer both accuracy and increasing feasibility in Africa as part of a new generation of building energy analysis tools.

I.4 Thermal Comfort

In any HVAC system design process, understanding thermal comfort requirements is essential. Thermal performance in buildings is not only about air temperature; it also includes how comfortable occupants feel in the indoor environment. This concept, called thermal comfort, is well studied in the scientific literature and is defined in international standards such as ASHRAE 55 (2021) and ISO 7730. Thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment" (ASHRAE, 2021). It depends on both environmental factors such as air temperature, relative humidity, air speed, mean radiant temperature and personal factors (clothing, activity level, cultural expectations). To evaluate comfort, researchers have developed two main approaches: analytical models, based on human heat balance, and adaptive models, which include how people adjust to their environment. These models are different but complementary, and both are relevant to building design.

I.4.1 Analyctical models : PMV and PPD

The most common model used in controlled indoor spaces is the Predicted Mean Vote (PMV) model, developed by Fanger (1970). It calculates the average thermal sensation of a group of people on a scale from −3 (cold) to +3 (hot). A value of 0 means thermal neutrality. This model also gives the Predicted Percentage of Dissatisfied (PPD), which estimates the number of people who will not feel comfortable.

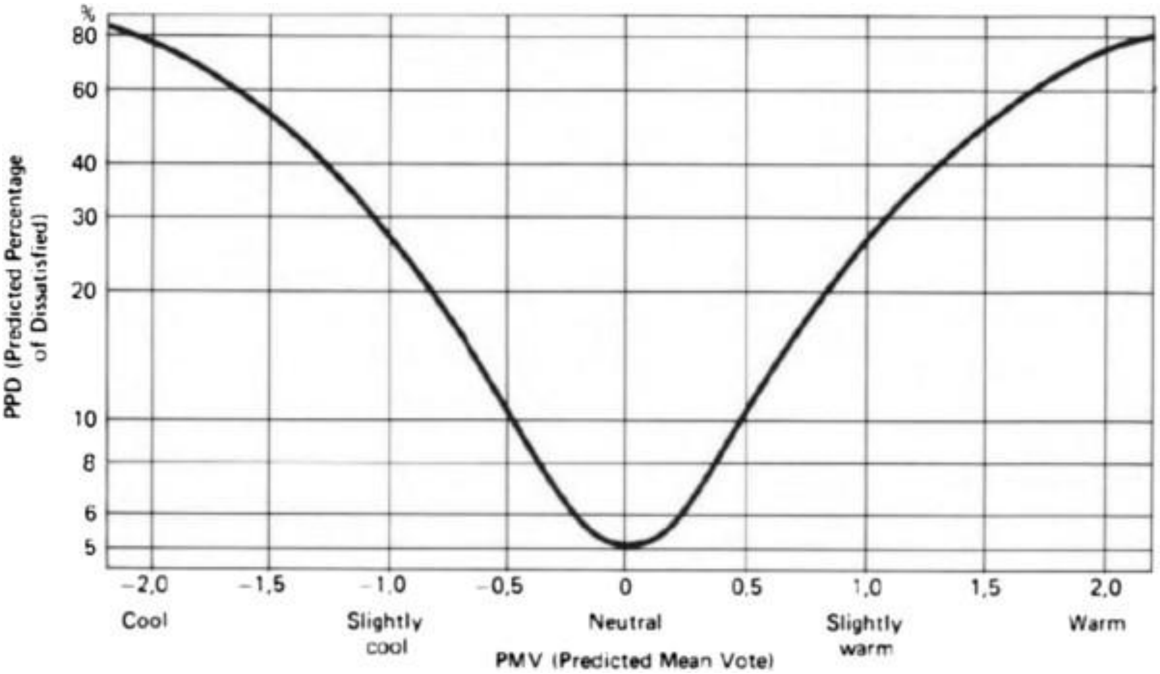


Figure I-1 :Relationship between PPD and PMV (Ekici C. et al., 2013)

The PMV model works well in buildings with full air conditioning and constant indoor conditions. It is included in simulation software like EnergyPlus or DesignBuilder. However, it does not consider how people adapt to heat or changes in climate. This can be a problem, especially in tropical regions. Several studies (Nicol et al., 2002, 2012) have shown that PMV tends to underestimate comfort tolerance in warm countries. People there often accept higher temperatures than the model suggests.

I.4.2 Adaptive models: a contextual approach

To solve the limits of analytical models, scientists proposed the adaptive comfort model. It is based on field studies in naturally ventilated buildings. These models are based on field studies showing that people naturally adapt to thermal changes by adjusting clothing, opening windows, or using fans. The most recognized adaptive model is included in ASHRAE Standard 55, based on research by de Dear et al. (1998). The model links indoor comfort temperature to the running mean outdoor temperature, defining a “comfort zone” that varies with the local climate. It is particularly suitable for tropical and subtropical regions, where static models may fail.

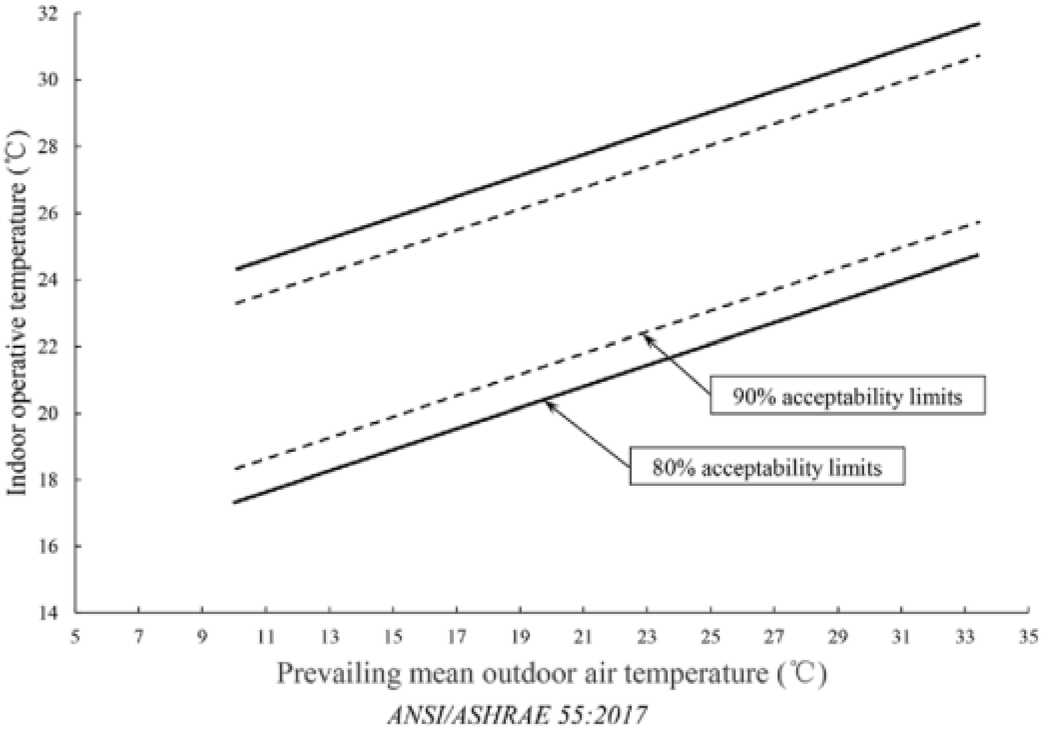


***Figure I-2 :** Adaptive thermal comfort mode. Source : Khattak, S et al.(2020)*

While the adaptive model works best for free-running buildings, its logic also helps explain why occupants in hot climates often tolerate temperatures above 27 °C. For this reason, many engineers propose using flexible comfort thresholds instead of fixed values in tropical regions.

I.5 Simplified Heat Balance Calculation Tools

Building on the theoretical overview of load calculation methods, this section focuses on the simplified heat balance tools most commonly used by engineers and technicians, especially in data-scarce and resource-constrained environments such as Burkina Faso.

Recent studies have explored the integration of psychrometric charts into simplified heat balance calculations. A psychrometric chart visually represents air properties, including temperature, humidity, and enthalpy, and allows engineers to track changes in air conditions during cooling processes. Research by Yang et al. (2021) demonstrates that psychrometric chart-based heat balance methods can improve the accuracy of simplified cooling load estimations while maintaining computational efficiency. The study further highlights the benefits of applying Primary Return Air Systems (PRAS) to reduce energy consumption in air conditioning units, leading to a 1.59% reduction in total operating costs compared to conventional heat balance approaches. Several commercially available tools implement simplified heat balance calculations tailored for real-world applications. Carrier’s Air Conditioning Load Estimator provides rapid HVAC sizing for small residential and commercial buildings, offering a user-friendly approach to load estimation (Carrier, 2018). The HAP, also developed by Carrier, combines load calculations with energy analysis, making it suitable for designing efficient HVAC systems in different climatic regions (Carrier, 2020). Additionally, the ASHRAE Simplified Energy Analysis Model (SEAM) offers an accessible framework for preliminary HVAC system design in non-residential buildings (ASHRAE, 2019).

In Burkina Faso, simplified heat balance methods have been adapted for local conditions through the "Manual for Simplified Air Conditioning Heat Balance Calculation" (IEPF, 2003). This manual integrates region-specific correction factors to account for climatic variations, construction materials, and ventilation strategies commonly found in West African buildings. However, field validation remains scarce and most simplified manuals are not frequently updated to reflect the evolution of urban environments and materials. A study in Ouagadougou demonstrated that buildings constructed after 2010, with new insulation techniques or window types, showed up to 18% divergence between predicted and measured cooling loads when using the IEPF manual (Sawadogo et al., 2024). This highlights the need for regular calibration of simplified methods with actual field data. The choice of thermal load calculation method depends on factors such as required accuracy, data availability, and computational constraints. While steady-state and empirical models provide quick and easy estimations, they fail to account for time-dependent variations in cooling demand. Dynamic simulation models, such as those implemented in EnergyPlus, offer improved accuracy but require extensive data and computational power, making them difficult to apply in regions with limited resources. To bridge this gap, researchers have developed simplified heat balance calculation methods, incorporating psychrometric charts and region-specific correction factors. Studies by Yang & al. (2021) demonstrate that these approaches can improve energy efficiency and optimize air conditioning system performance.

Conclusion

This chapter has reviewed the main approaches and tools available for calculating thermal loads in buildings, with a particular focus on the specific constraints of West African climates and building practices. While advanced dynamic simulation models offer high accuracy, their requirements in terms of data, expertise, and computational resources make them difficult to use in most real-world projects in Burkina Faso. Conversely, simplified steady-state and empirical methods, and especially regionally adapted tools such as the IEPF manual, remain the most widely used solutions by engineers and technicians. However, their accuracy depends on regular calibration with field data and the integration of evolving construction practices and climatic conditions. Building on this literature review, the rest of this study focuses on the implementation and validation of a simplified steady-state heat balance tool designed for practical application in Burkina Faso’s context. The following chapters will detail the methodology used to develop, implement, and validate the proposed software, and will analyze its effectiveness through real-world case studies.

Chapter II : Materials and methods

This chapter outlines the methodological framework adopted for the development, implementation, and evaluation of a mobile application designed to provide heat balance estimation for air conditioning systems. Grounded in thermal engineering and climate informatics, the methodology integrates meteorological data with a validated theoretical model, aiming to deliver a practical computational tool suitable for deployment in Burkina Faso. The chapter also introduces the materials used, including a detailed description of the study area, the choice of the administrative level for analysis, and the technical characteristics of the dataset. Subsequently, it presents the methods employed, encompassing the theoretical modeling approach, the process of software implementation, and the validation techniques applied to assess the reliability and accuracy of the developed application.

II.1 Study area

Burkina Faso is a landlocked country in West Africa covering approximately 274,000 km² and subdivided into 45 provinces, which allows for detailed regional analysis. The national climate varies across three main eco-climatic zones: the Sahelian zone in the north (receiving less than 600 mm of annual rainfall), the Sudano-Sahelian region in the central plateau (600–900 mm), and the more humid Sudanian zone in the south (900–1,200 mm). Rainfall occurs mostly during a short wet seasonwith the remaining period dominated by a long dry season influenced by the Harmattan wind (Red Cross, 2024).

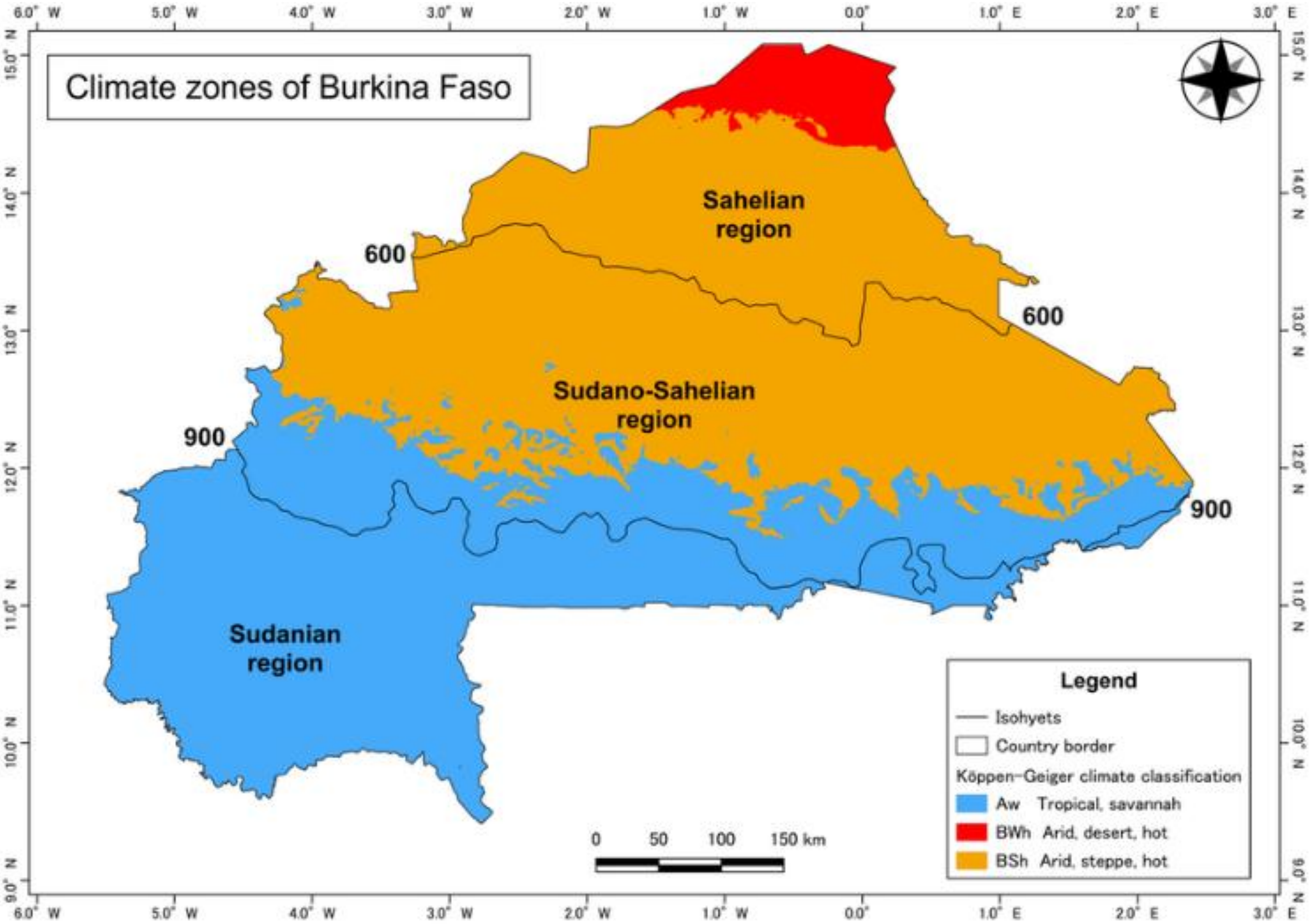


Figure II-1 : *Burkina faso climatic zones. (Ouiba Nebie et al.,2025)*

To validate the reliability and accuracy of the mobile application developed for simplified heat balance calculations, a reference building has been selected and described in detail. The case study building focuses on a social housing (ground floor + one) located in Ouagadougou, Burkina Faso, under typical tropical climatic conditions.

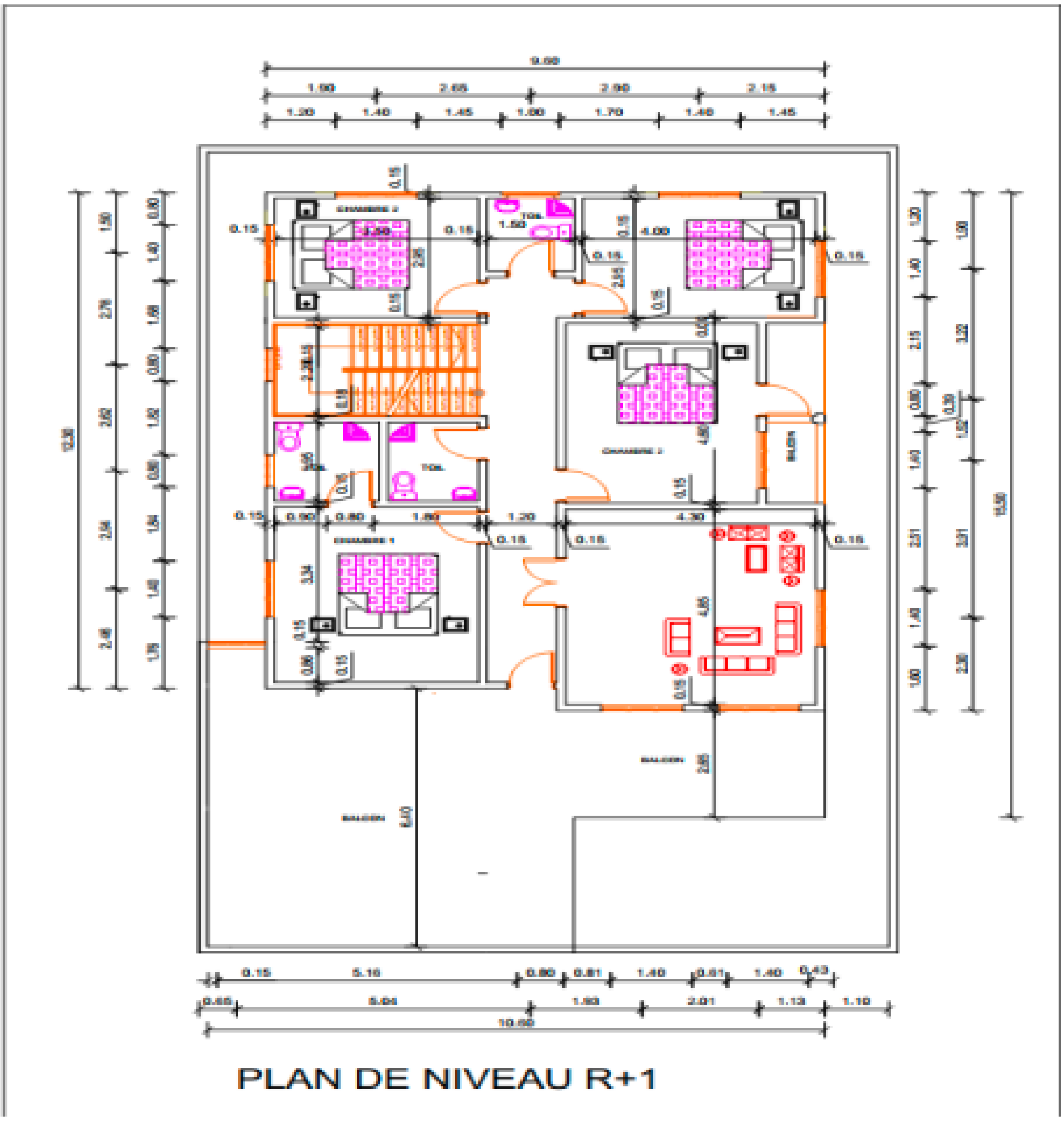


Figure II-2 : Bulding R+1 Architechture

The analysis includes all four bedrooms in the building. Each bedroom is designed according to the same construction principles and materials, reflecting common practices in urban social housing in the region. The rooms have floor areas ranging from 11 m² to 15.2 m² and a uniform ceiling height of 3 meters. Occupancy patterns correspond to typical residential use, especially during periods when cooling is most needed. Additional features of the building include:

- A ventilated attic ceiling, which helps reduce heat transfer from the roof
- At least one glazed window per room, each equipped with an internal shading screen that can be fully lowered (solar factor F = 0.45)

- Exterior walls made of 20 cm hollow brick, rendered with 2.5 cm cement on both sides, painted white inside and dark yellow outside
- Internal partitions in 15 cm hollow brick, also cement-rendered
- Floors made of a 20 cm reinforced concrete slab with a 5 cm ceramic tile finish
- A flat roof composed of a 20 cm concrete slab with a 5 mm bitumen waterproofing layer
- Interior wooden doors (4 cm thick)

The orientation and exposure of the bedrooms to the sun are particularly relevant for the thermal analysis. All thermal and geometric properties are summarized in the differents table below, providing the basis for all subsequent heat balance calculations.

Table II-1 : *Thermo-physical Properties of Envelope Materials (COULIBALY.O , 2011)*

Component	**Construction Layers**	**Thickness**	**Thermal Conductivity (λ)**	**Thermal exchange coefficient (K)**
Exterior Walls	Brique H + Cement render (inside & outside)	15 + 2.5 + 2.5 cm	0.35 (brick), 0.87 (cement)	1.52
Interior Walls (Partitions)	Brique H + double cement render (white paint both sides)	10 + 2.5 + 2.5 cm	0.35 (brick), 0.87 (cement)	1.77
Roof Slab	Concrete + Bitumen layer + Red wood ceiling	20 cm + 5 mm + 1.5 cm	1.75 (concrete), 0.17 (bitumen), 0.015 (wood)	2.91
Floor	Concrete slab + Tile finishing	20 + 5 cm	1.75 (concrete), 0.55 (tile)	1.84
Window	Single glazing + metal frame + interior shading	4 mm	1.15 (glass)	5.73
Door	Solid wood panel	4 cm	0.12 (wood)	1.80

Table II-2 : Characteristics of the different bedrooms

	Bedroom 1		Bedroom 2		Bedroom 3		Bedroom 4	
Characteristics	3.50*4.35=15.225m^2		3.50 * 2.95 =10.325		3.50 * 4.60 =16.10		4.00 *2.95=11.80	
Element	Surface Area (m^2)	Orientation	Surface Area (m^2)	Orientation	Surface Area (m^2)	Orientation	Surface Area (m^2)	Orientation
Exterior Wall	10.5	South	7.87	West	11.22	East	7.87	East
	12.07	West	9.52	North			11.02	North
Interior Wall	8.90	North	7.25	East	12.20	West	7.25	West
	11.45	East	10.5	South	10.5	South	12.00	South
	-		-		10.5	North	-	-
Roof	15.225	Horizontal	10.325	Horizontal	16.10	Horizontal	11.80	Horizontal
Floor	15.225	Horizontal	10.325	Horizontal	16.10	Horizontal	11.80	Horizontal
Window	0.98	West	0.98	West	0.98	East	0.98	East
				North				North
Door	1.60	East	1.60	East	1.60	West	1.60	West
		North				East		

***Table II-3 :** Internal Heat Gains and Ventilation parameters*

Source	Quantity or Rate	Characteristics
Occupants	2 in bedroom, 4 in living area	Occupancy hours: from 12:00 AM to 3:00 PM from 6:00 PM to 6:00 AM
Lighting	Fluorescent lamps	8 W/m²
Ventilation	Natural	1 air change per hour (1 V/h)

II.2 External climatic conditions of air-conditionning

The climatic data used in this study were sourced from the work of Boureima Zougouri et al. (2018), who analyzed ten years of meteorological records from across Burkina Faso. For this project based on the Burkina Faso climatic zones conditions, 3 town, Ouagadougou, Bobo and Dori, have been considered to be representative of each climate zone. The three parameters selected as most relevant for thermal load and air-conditioning needs assessment are:

- Base external temperature (°C)
- Base external relative humidity (%)
- Solar radiation (W/m^2) in annex 2

***Table II-4 :** Base external Temperature and relative humidity data*

	Climate zone	Base temperature (°C)	Base relative humidity (%)
Dori	Sahelian zone	42.7	13.8
Ouagadougou	Soudano-Sahelian zone	40.5	17.2
Bobo	Sudannian zone	38.1	13.3

These parameters served directly as input for the subsequent thermal load calculations and cooling load evaluation methods, which are described in the next section.

II.3 Methodology

This section details the overall methodological approach adopted for the development and evaluation of a simplified heat balance model tailored to the cooling needs of buildings in tropical climates. The methodology is structured around three main pillars: the formulation of the heat balance equations for air-conditioned spaces, the development of a computational application for practical implementation, and the validation of results using reference calculation methods. Each component builds upon the fundamental principle that indoor thermal loads can be quantified through the balance of incoming and outgoing energy flows. The approach aims to combine theoretical clarity with operational simplicity, making it suitable for early design phases and data-scarce environments.

II.3.1 Calculation method

The starting point of this methodological process is the selection and definition of the calculation model. In this study, the simplified method developed by the Institut de l'Énergie et de l'Environnement de la Francophonie (IEPF) was chosen, as it is specifically designed for the calculation of cooling loads in tropical climates (IEPF, 2003). This approach is recognized for its ability to comprehensively account for all significant internal and external heat gains in buildings, including conduction, solar radiation, ventilation, occupants, lighting, and equipment. The version applied here has been further simplified to allow practical use while keeping the essential logic of heat balance calculations. The following section describes the structure of this method, its main assumptions, and the equations used to estimate the different components of the total cooling load in buildings..

II.3.1.1 Notion of IEFF metthod

The IEPF method is a simplified yet physically grounded approach for evaluating thermal loads in air-conditioned spaces, specifically adapted for tropical climates (IEPF, 2003). Based on the principles of the heat balance method, it systematically accounts for all heat gains and losses within a building by considering both internal and external sources. Unlike empirical or index-based models, the IEPF method calculates energy contributions using thermodynamic relationships, making it suitable for realistic design, simulation, and analysis in tropical environments.

The core of this method relies on the conservation of energy principle: the sum of all heat inputs and outputs in the building must equal the change in stored energy. In steady-state or peak-load calculations, the effect of thermal storage in building materials is usually neglected, as the calculation targets the maximum instantaneous load that the cooling system must handle.

According to the IEPF guidelines, the thermal balance must be established at the hour when heat gains are at their highest level. For each room, the process involves:

- Identifying the surfaces of external walls and windows and their orientation (north, south, east, west).
- Using hourly solar irradiance data for each orientation during the hottest month to calculate the solar gains for every hour of the day.
- At each hour, summing up the contributions from all exposed surfaces (walls and glazing) by multiplying their area by the corresponding solar irradiance.
- Selecting the hour when this sum is maximal—this is called the “peak load hour”—and performing all thermal load calculations for that room at this time.

Therefore, the thermal load is estimated by directly summing all the main heat gains at the chosen critical hour. External gains are mainly due to conduction through opaque walls and solar radiation transmitted through windows. Internal gains are caused by occupants, lighting, and equipment

.

✓ Conduction through the building envelope (walls, roofs, floors, and glazing) is quantified using the equation:

$$Q_{cond} = K \cdot S \cdot (\theta_e - \theta_i) \qquad \text{(II-1)}$$

where

- K : global thermal transmittance (W/m^2·°C),
- S : surface area (m^2),
- θ_e, θ_i: external temperature, internal setpoint temperature.

The global thermal transmittance k is derived from the resistances of the material layers and convective boundaries:

$$K = \left(\frac{1}{h_i} + \frac{e}{\lambda} + \frac{1}{h_e}\right)^{-1} \qquad \text{(II-2)}$$

Where:

- e : thickness of the wall [m],
- λ : thermal conductivity of the material [W/m·°C],
- h_i , h_e : internal and external convective heat transfer coefficients [W/m²·°C].

✓ Solar radiation penetrating opaque surfaces and glazing is modeled separately using orientation-specific irradiance data, absorption coefficients, and surface factors, leading to radiative gains defined as:

$$Q_m = \alpha \cdot S \cdot F \cdot Rm\ (walls) \qquad \text{(II-3)}$$

$$Q_v = \alpha \cdot g \cdot S \cdot R_v\ (glazing) \qquad \text{(II-4)}$$

Here,

- α : surface absorptivity,
- g : solar reduction factor due to shading
- R_m , R_v: irradiance values on opaque and transparent surfaces respectively.

✓ Ventilation and infiltration introduce additional sensible and latent loads due to the enthalpy difference between indoor and outdoor air. These are calculated as:

$$Q_{s,air} = 0.33 \cdot q_v \cdot (\theta_e - \theta_i) \qquad \text{(II-5)}$$

$$Q_{l,air} = 0.88 \cdot q_v \cdot (\omega_e - \omega_i) \qquad \text{(II-6)}$$

✓ Internal gains derive from occupants, lighting, and equipment. For each occupant, sensible (CS_{occ}) and latent heat (CL_{occ}) contributions are modeled using activity-based constants:

$$Q_{s,occ} = n \cdot CS_{occ} \qquad \text{(II-7)}$$

$$Q_{l,occ} = n \cdot CL_{occ} \qquad \text{(II-8)}$$

✓ . Lighting contributes only sensible heat, generally calculated as:

$$Q_{light} = P_{surf} \times S$$

- ✓ Where P_{surf} is the lighning power per unit surface (W/m^2), P the installed lighting power (W). Similarly, equipment loads (Q_{equip}) are calculated using nominal power ratings adjusted for usage time and diversity factors.
- ✓ Finally, the total sensible Q_S and latent heat gains Q_L are aggregated to yield the total cooling load:

$$Q_S = Q_{cond} + Q_m + Q_v + Q_{s,air} + Q_{s,occ} + Q_{light} + Q_{equip} \tag{II-9}$$

$$Q_L = Q_{l,air} + Q_{l,occ} \tag{II-10}$$

$$Q_T = Q_S + Q_L \tag{II-11}$$

- ✓ Then to determine the absorbed power electrical power need for the air conditioning The COP, measures the ratio between the energy produced and the energy consumed. Is is an essential criterion for comparing the performance of equipment. High COP means that an air conditioner produces more cold for the same amount of energy consumed, which results in energy savings. Then, the electrical power needed for the air conditioning is

$$P_e = \frac{P_f}{COP} \tag{II-12}$$

II.3.1.2 Espace vide Humidity ratio estimation

- ✓ Psychrometric Diagram

The psychrometric diagram, also referred to as the moist air chart, is a graphical tool that facilitates the understanding of the physical properties of humid air and their interrelationships. This diagram plots the dry-bulb temperature along the horizontal axis and the humidity ratio (or absolute humidity) along the vertical axis, providing a visual representation of air state points and transformations.

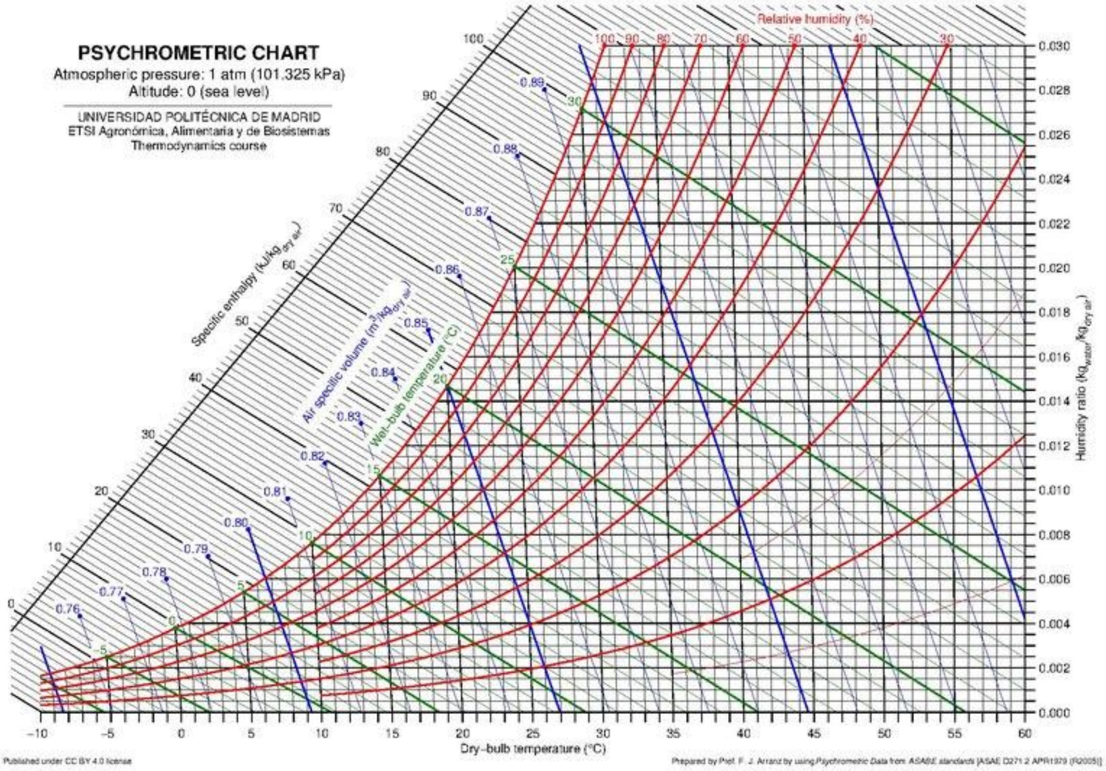


Figure II-3: *Psychrometric chart. Source: Arranz (n.d.), Universidad Politécnica de Madrid (CC BY 4.0)..*

The lines in the diagram include:

- **Isotherms**: vertical lines representing constant dry-bulb temperature.
- **Isohydres**: horizontal lines denoting constant humidity ratio, expressed in grams of water vapor per kilogram of dry air (g/kg).
- **Saturation curve**: the leftmost curved line indicating full saturation, where the air holds the maximum possible moisture content.
- **Constant relative humidity curves**: networks of curves representing levels of relative humidity, typically expressed as percentages.
- **Enthalpy lines**: diagonal lines indicating constant total energy content (kJ/kg).
- **Specific volume lines**: slightly inclined lines representing constant air volume per unit mass of dry air (m³/kg)

The diagram enables engineers to determine air properties and state changes, such as heating, cooling, humidification, and dehumidification, by connecting points that represent air conditions. For example, moving horizontally represents sensible heating, while moving along isenthalpic lines represents adiabatic humidification (Cabeza, 2002).

- ✓ Humidity ration calculation

In this study, the humidity ratio www is calculated using standard psychrometric principles, as described in recent literature (Ghiaus, 2022; Xu et al., 2012):

$$w = \frac{(622 \times P_v)}{(P_{atm} - P_v)} \tag{II-13}$$

where:

- P_v is the partial pressure of water vapor (Pa),
- P_{atm} is the total atmospheric pressure (Pa). At 0 meters attitude, $P_{atm} = 101325\,\text{Pa}$,
- 0.622 is the ratio of molecular weights of water vapor to dry air.

The partial pressure P_v can be derived from relative humidity (RH) and the saturation pressure P_{sat}

$$P_v = RH \times P_{sat}(T) \tag{II-14}$$

For the Tetens formula is commonly used and provides good accuracy for normal temperature ranges:

$$P_{sat}(T) = 610.78 \times \exp\left(\frac{17.27 \times T}{T + 237.3}\right) \tag{II-15}$$

where T is in °C and $P_{sat}(T)$ is in Pa

Then, the simplified formula becomes:

$$\omega = \frac{622 \times RH \times P_{sat}(T)}{P - RH \times P_{sat}(T)} \tag{II-16}$$

This method, based on temperature and relative humidity is suitable for most climates, especially where the temperature is usually above 0 °C

II.3.2 Software Implentation approach

After the presentation of the heat balance calculation method and the characterization of the reference building, it became essential to examine how this scientific methodology was operationalized through a robust and maintainable software structure. This section is dedicated to the implementation logic adopted to translate the theoretical framework of the IEPF method into a functional digital tool adapted to the climatic and technological context of Burkina Faso. This part no longer focuses on physical modeling or environmental data, but rather on how these elements were embedded into a coherent software architecture. It will thus articulate the architectural decisions made, interpret the software's structural and functional diagrams, and show how the entire implementation supports the operational and scientific objectives of the project.

II.3.2.1 Theorical foundation and Design

The choice of software architecture is fundamental to ensure the reliability, maintainability, and performance of a scientific mobile application, especially for thermal balance calculations in tropical climates. For this project, four main architectural paradigms are considered: modular component-based architecture, Model-View-Controller (MVC), layered (N-tier) architecture, and Service-Oriented Architecture (SOA). The aim is to identify the most appropriate structure for a mobile application, using recent scientific studies as support.

- The **Modular Component-Based Architecture** : It decomposes a system into semi-autonomous modules, each encapsulating a specific domain logic and communicating via defined interfaces. It divides the system into independent modules, such as a thermal calculation module or a climate data module. This approach increases flexibility and maintainability, making it easier to update or replace specific functions. However, it requires strong coordination between modules to avoid code fragmentation or integration problems (Benazeer et al., 2024).
- The **Model-View-Controller (MVC)** is a design pattern that separates the application into three parts: the model (data and logic), the view (user interface), and the controller (manages user input). While MVC started as a design pattern, it is now often used as an architectural model, especially for the presentation layer in mobile and web apps (Korchi et al., 2024). It helps create a responsive user interface and supports clear code organization. But when the application becomes complex, MVC can also introduce maintenance difficulties, especially with asynchronous operations..

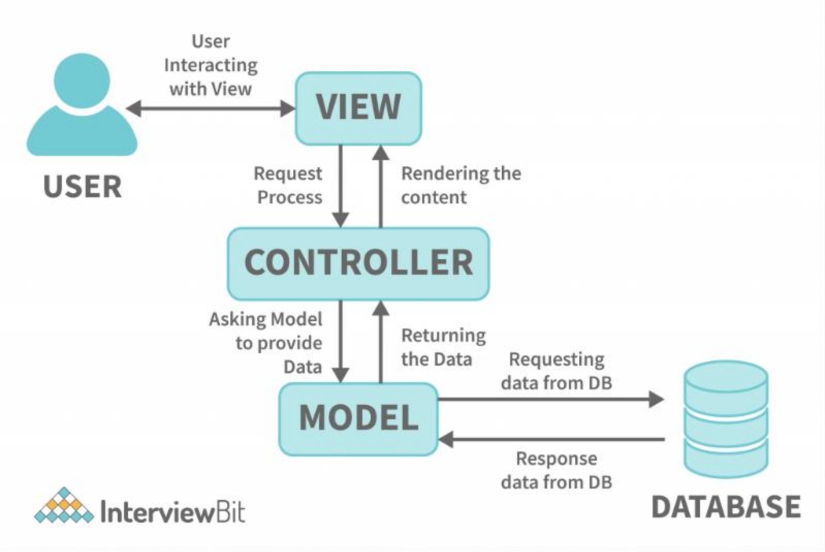


Figure II-4 : *MVC Architecture data flow.Produced by InterviewBit (2023)*

- The **Layered (N-tier) Architecture** separates the application into logical layers, like Presentation, Business Logic, and Data. Each layer has its own responsibility and can be updated independently (Zhang et al., 2024). This approach supports maintainability and security but may add some latency due to communication between layers. For mobile apps, this can sometimes reduce performance and flexibility.
- **Service-Oriented Architecture (SOA)** and its microservice derivatives represent a distributed, loosely coupled paradigm wherein system functions are exposed as services accessible over a network. It uses distributed services that are loosely connected. While SOA excels in scalable enterprise systems with asynchronous communication needs, its deployment presupposes reliable network infrastructure and introduces a significant configuration burden (Papazoglou, 2003). For mobile apps, especially those that should work offline or with unstable connectivity, SOA brings extra complexity and network dependency that are not always necessary.

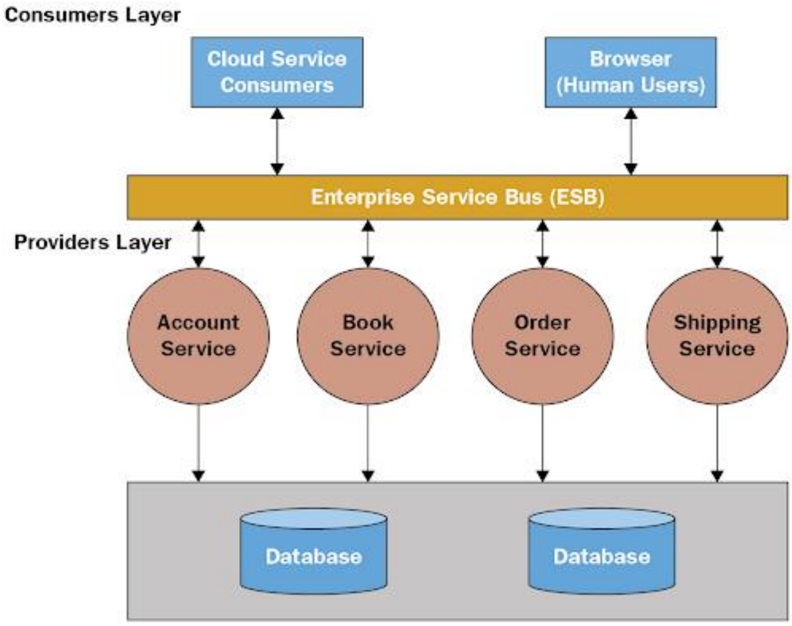


***Figure II-5 :** Service Oriented Arcchitecture structure. Source : Produced by Source APM (2022)*

These architectural models are comparatively summarized in the table below, with a focus on their applicability to the specific constraints and requirements of this heat balance application:

***Table II-5 :** Comparative Table of the different software architecture*

Architecture Name	**Key Advantages**	**Main Limitations**
Layered (N-tier)	Clear separation of concerns; Good maintainability, strong security, scalable	Rigid structure; slower data flow; less dynamic
Modular/Component-Based	High reusability; domain-focused encapsulation; scalable	Requires complex orchestration; higher cognitive load for integration
Model-View-Controller	Real-time synchronization; clear interaction logic; mobile-friendly	Complexity in large models; risk of tight coupling if misapplied
Service-Oriented (SOA)	Scalability; loose coupling; network-distributed	Infrastructure-heavy; brittle under poor connectivity

As shown, the most suitable approach for this project is a hybrid structure combining the N-tier architecture with the Model-View-Controller (MVC) pattern. The reason is supported by recent studies as it enables clear separation of concerns, modularity, and scalability,three essential qualities for scientific mobile applications (Zhang et al., 2024; Korchi et al., 2024). N-tier structures the application into independent layers, which simplifies maintenance and allows for independent updates of each part. Meanwhile, the MVC pattern organizes the presentation layer, improving code clarity and facilitating parallel development of the user interface and business logic (Understanding MVC Architecture in Mobile App Development, 2025). This combination has been shown to enhance both the robustness and maintainability of complex systems, making it especially suitable for scientific tools that require flexibility and future evolution (Benazeer et al., 2024).

II.3.2.2 Application conception

The software developed in this project is structured according to the MVC architecture, which enforces a clear separation of concerns. This design pattern is particularly well-suited for scientific applications that require modularity, flexibility, and scalability (Gamma et al., 1995). To formally capture both structural and behavioral aspects of the system, the Unified Modeling Language (UML) standard was adopted. According to the official UML 2.5.1 specification, UML provides a set of graphical notations such as class, use case, packages and sequence diagrams to specify, visualize, and document software architectures, thereby improving communication and traceability among stakeholders (Object Management Group, 2017).

The application features a client-server architecture with a distinct frontend and backend. The frontend, built with Flutter, provides a modern and performant cross-platform user interface for both Android and iOS devices. The backend, developed using the Laravel PHP framework, is responsible for data storage, security, and business logic execution. Within this framework, the MVC pattern is applied as follows:

- The Model layer implements all core business logic, including the Heat Balance Method (HBM) algorithms for cooling load estimation.
- The View layer handles user interaction and data visualization, guiding users through input forms for room geometry, material selection, and occupancy schedules.

- The Controller coordinates user actions, manages application flow, and ensures data integrity between frontend and backend.

This organization simplifies code maintenance and supports future extensions, such as the addition of new calculation methods or building types. Users interact with the application by logging in, creating new projects, entering building and climate data, and receiving real-time feedback on their cooling load calculations. An overview of the system architecture and the flow of data between frontend (Flutter), backend (Laravel), and storage components is shown in Figure II-6.

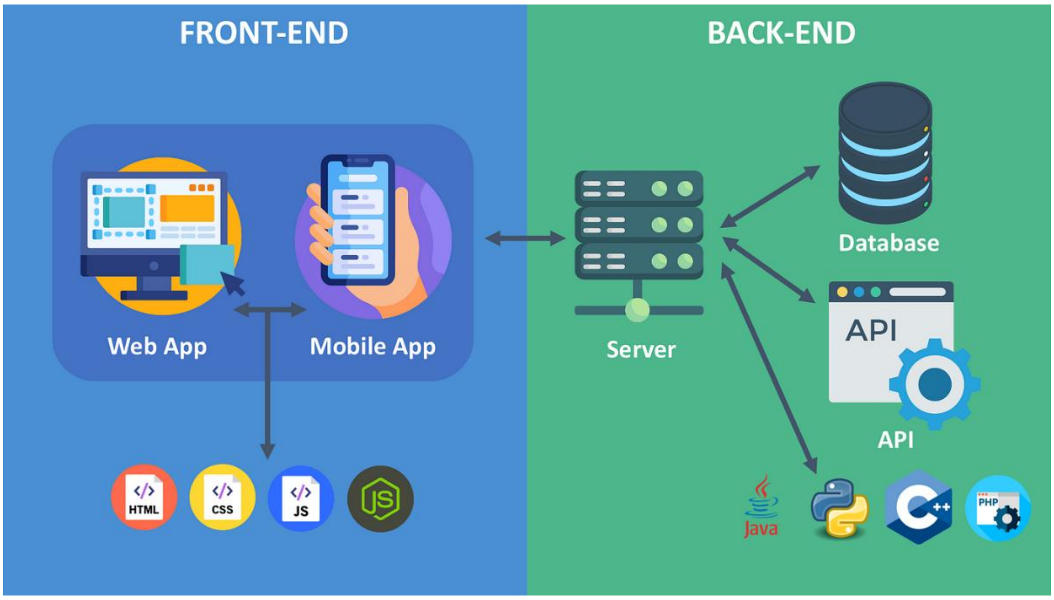


***Figure II-6 :** Overview of the backend-frontend principle. Produced by mobileLIVE (2023)*

In this section, we first present the explicit functional requirements of the application, structured as a formal bullet list to facilitate traceability with the corresponding diagrams. We then analyze each UML diagram used to model the software system, interpreting them as representations of the application's architectural logic and execution behavior. Each diagram is embedded in the text at the appropriate point and receives detailed commentary on its role, structure, and implementation implications. The main functionalities expected from the application include:

- User authentication

- Ability to create and store multiple simulation projects.
- Including wall types, materials, thickness, surface areas, orientation, and associated thermophysical properties.
- Input of occupancy and internal loads
- Input and selection of climatic data
- Execution of heat balance computation using simplified HBM logic.
- Visualization of the results in clear, structured format.
- Export of simulation results in PDF or image formats for reporting and archiving.

To clearly visualise the conception of the future solfware, several UML diagrams have bean done. These diagrams are commented below.

Figure II-7 : Use Case Diagram

This diagram identifies the interactions between users and system functions. The primary actor, "AppUser," can register and log in. Once authenticated, the user gains access to all core functions: managing irradiation data, calculating the heat balance, and exporting the results. The diagram clearly defines dependencies between use cases, such as the inclusion of the authentication process before any other actions. This structure ensures that user data is protected and associated with personal simulations, aligning with mobile security practices. The figure also suggests modular treatment of the application's logic, as each use case corresponds to a self-contained functionality that can be extended or updated independently.

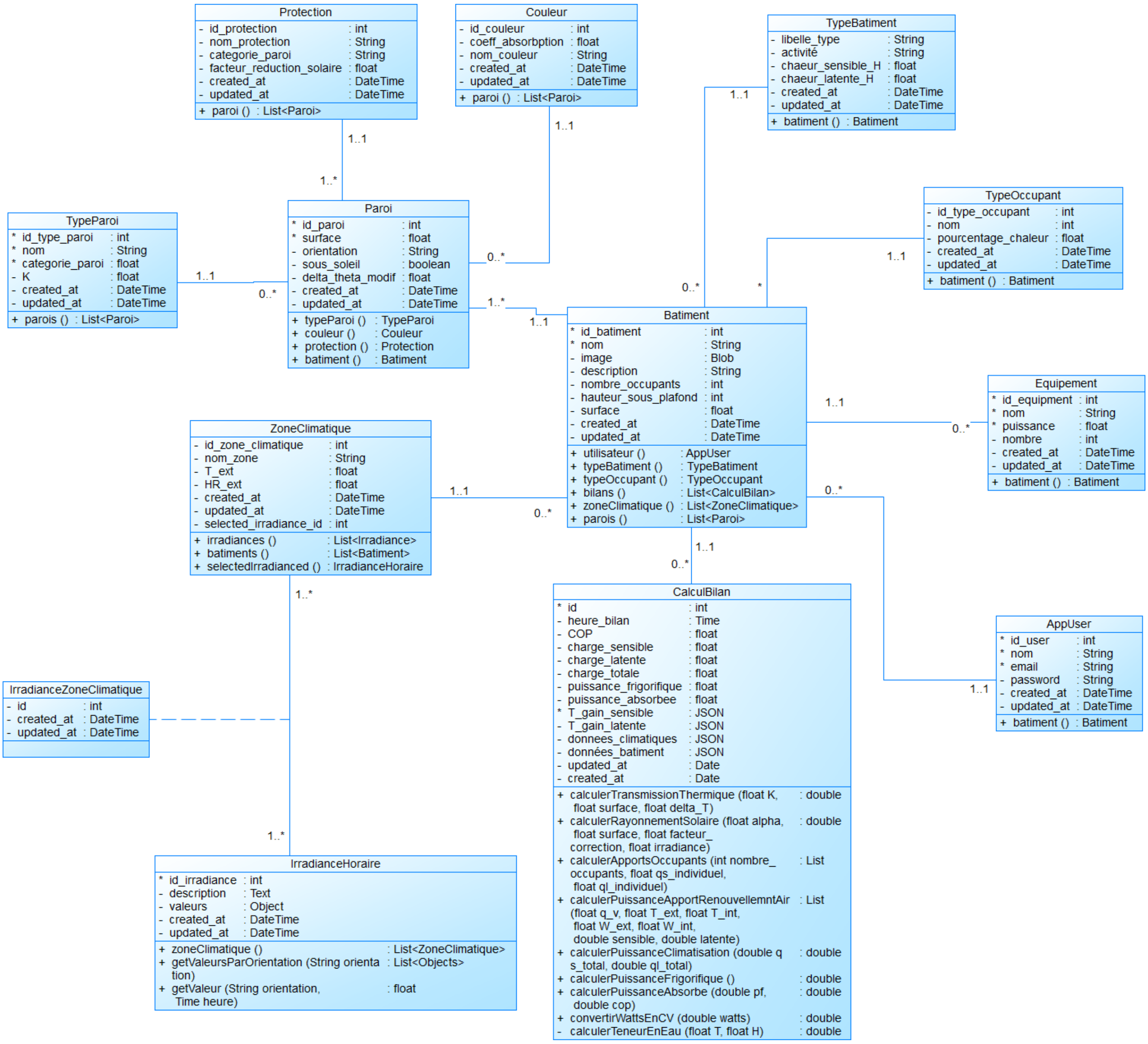


Figure II-8 : Class Diagramm

The class diagram reflects the core data structures of the application. It shows entities such as AppUser, Projet, Batiment, Paroi, Irradiance, and CalculBilan. Each class encapsulates attributes and relations. For instance, Projet aggregates a Batiment and a climatic profile (Irradiance), showing how simulations are context-specific. The central class CalculBilan manages the heat balance computation by accessing surface-level and climatic inputs. Relations between classes are implemented with associations, aggregations, and inheritance where appropriate. This modular data organization facilitates updates, such as the inclusion of new material types or climatic profiles, without reconfiguring the core algorithm. The diagram adheres strictly to object-oriented principles and supports MVC's separation between models and controllers.

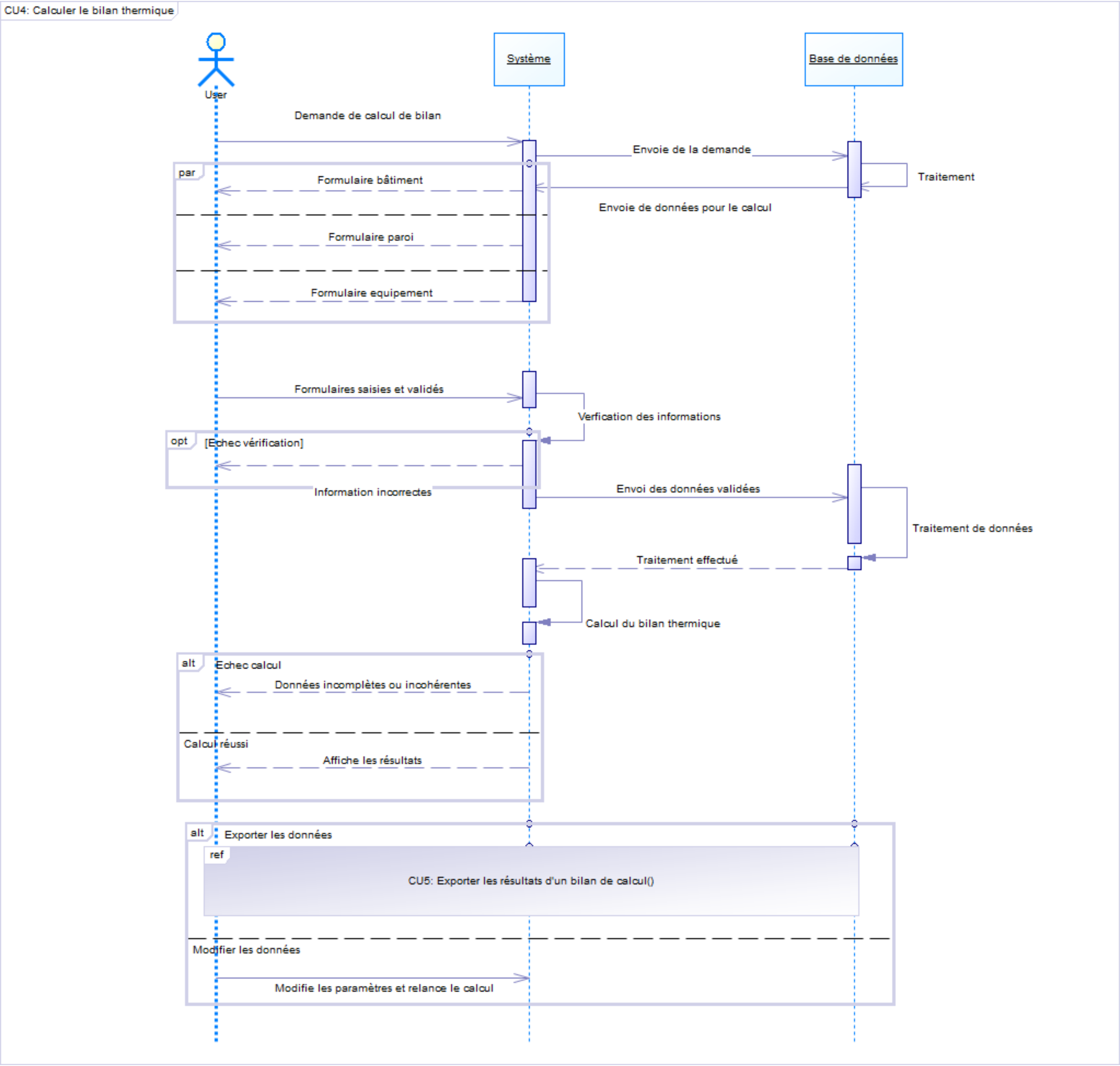


__Figure II-9__ : Sequence Diagram – Execution of the Heat Balance Calculation

This diagram is critical, as it models the core logic of the software. Once all data is entered, the user triggers the computation. The controller verifies input completeness and invokes the CalculBilan module, which fetches relevant data (irradiance, materials, occupancy, etc.), processes it, and returns thermal balance results. These are then displayed and can be exported. The step-by-step representation confirms that the system adheres to the principles of decoupling computation logic from presentation, essential for debugging and for ensuring consistent results across different devices or updates.

Together, these diagrams provide a complete visual and logical representation of the software's structure and dynamics. They demonstrate that the application's logic is tightly aligned with its intended use cases, from user interaction to climatic input management and final report generation. The use of standardized UML diagrams provides clarity and maintainability for future developers and ensures transparency in the scientific logic embedded in the software.

II.3.3 Methods for validation

Following the presentation of the adopted heat balance method and the development process of the mobile application, it is essential to assess the accuracy and reliability of the tool. To ensure that the results generated by the developed software are both reliable and accurate, I used a validation process directly based on the simplified thermal load calculation method published by the IEPF. This method, already described in detail in Chapter 2, was chosen because it is specifically adapted to the realities of buildings in tropical climates and is recognized by professionals across Francophone Africa.

The validation consisted of two main steps, both using the IEPF method applied to the reference room by collecting all the required architectural and usage data: surface areas, dimensions, orientations, types of walls, windows, and doors, as well as internal loads like lighting, equipment, and occupancy. The calculation followed the official IEPF guidelines, strictly respecting the steps and formulas for each heat gain component:

- Sensible gains through conduction (walls, roof, floor, windows, doors)
- Sensible gains from direct solar radiation (accounting for orientation and color of external surfaces)
- Sensible and latent gains due to ventilation and air infiltration
- Internal gains from people, lighting, and appliances

In accordance with the IEPF methodology, all manual and software calculations were performed at the specific hour of peak cooling demand for each room, rather than at a fixed time of day. The peak hour was determined for every bedroom by identifying when the sum of solar gains through all exposed walls and windows was greatest, ensuring that the thermal load calculations reflect the most critical conditions for each space.

The software and the manual result were then directly compared. The comparison focused on the total cooling load. Any differences between the two results were investigated, to check whether they were due to data entry mistakes, misinterpretation of the method, or simple rounding errors. In all cases, the goal was to ensure that both approaches, when given the same inputs and following the same IEPF logic, produced the same or very similar results. If a difference larger than 10% appeared, I systematically went back through each step of the process to find and correct the source of the error. This careful, transparent validation procedure is essential for building confidence in the new software, especially since the IEPF method is widely used by engineers and technicians in West Africa. Showing that the software produces results consistent with both manual calculations and trusted spreadsheet tools gives end users confidence that they can rely on the software for practical design work.

In summary, validation of the software was achieved by manually applying the IEPF method using the same building and climate data. This dual approach makes it possible to rigorously check the accuracy of the software and to ensure that the tool will be truly useful in the context of building design in Burkina Faso and similar regions.

Conclusion

To conclude, This chapter has explained the main theories and the calculation methods chosen for evaluating thermal loads in air-conditioned buildings under tropical conditions. The IEPF method, together with the selected parameters and assumptions, provides a solid foundation for both the software and its validation. The next chapter will focus on the results. It will show how the manual method and the software performed in practice, and will offer a critical analysis of their accuracy

Chapter III: Results and discussion

This chapter is dedicated to the presentation and discussion of the results obtained from the thermal load calculations for the case study building. Because the building is located in Ouagadougou in the soudano-sahelian zone, all climatic data used for both manual and software-based calculations correspond to this city. The chapter first presents the results generated by the different calculation methods, followed by a comparison between the manual approach and the developed app. Finally, a critical discussion is provided to assess the accuracy and applicability of the tool in the local context.

III.1 Results

This section presents the results of the cooling load calculations performed for the four bedrooms of the reference building, using the different methods introduced in Chapter II. The objective is to compare the performance, consistency, and applicability of each estimation method under typical tropical conditions.

In accordance with the IEPF guide, all calculations were carried out for the actual peak hour of cooling demand in each bedroom, as identified by the sum of hourly solar gains on exposed surfaces (see methodology section II.3.3). This means that the hour was determined individually for each room, based on the orientation and area of external walls and windows. The climatic parameters applied for each case were:

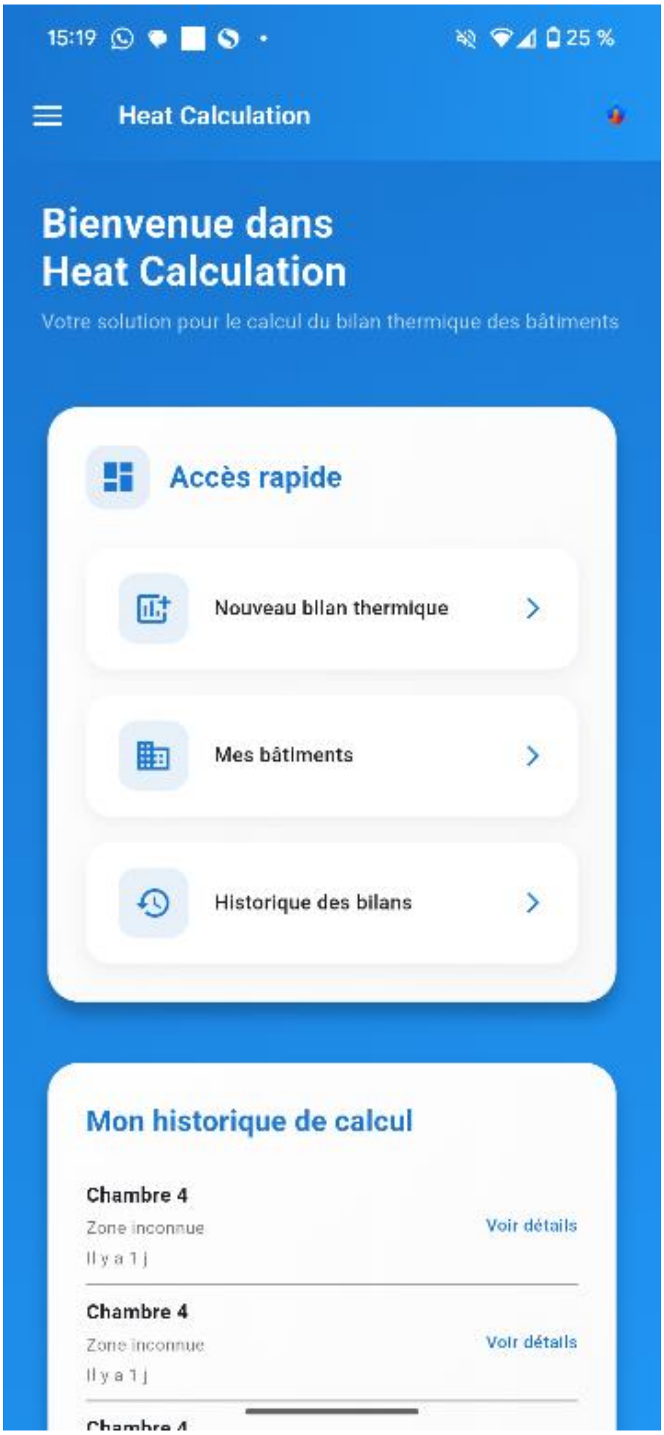
- **Outdoor air temperature (T_{out}) :** 40.5 °C
- **Indoor setpoint temperature (T_{int}) :** 24 °C
- **Outdoor relative humidity (RH_{out}) :** 17.2 %
- **Indoor relative humidity (RH_{int}) :** 50 %
- **Outdoor humidity ration :** 8.1
- **Indoor humidity ration :** 9.3 g/kg
- **Solar irradiance at the peak hour** (see Annex 2)

For both methods, the COP is settled to 3.

III.1.1 Software results

This application was built to make thermal load calculations easier and more accessible, especially in Burkina Faso where most engineers don’t use complex simulation tools. When the app opens, the user sees a very simple home screen with just three options:

create a new project, view saved buildings, or check past results. It was important that nothing looks intimidating, just clear buttons and direct access.



15:19 · 25 %

Heat Calculation

Bienvenue dans
Heat Calculation

Votre solution pour le calcul du bilan thermique des bâtiments

Accès rapide

Nouveau bilan thermique

Mes bâtiments

Historique des bilans

Mon historique de calcul

Chambre 4
Zone inconnue
Il y a 1 j
Voir détails

Chambre 4
Zone inconnue
Il y a 1 j
Voir détails

Chambre 4

Figure III-1 *: Menu interface*

15:02 · 28 %

Nouveau bâtiment

Bâtiment · Parois · Équipements

Bilan Thermique

Créez votre bâtiment en remplissant les informations nécessaires. Le bilan thermique vous aidera à optimiser la...

Complétez avec les équipements

Parois

+ Ajouter

1 Mur extérieur
Surface: 8.00 m²
Orientation: Sud

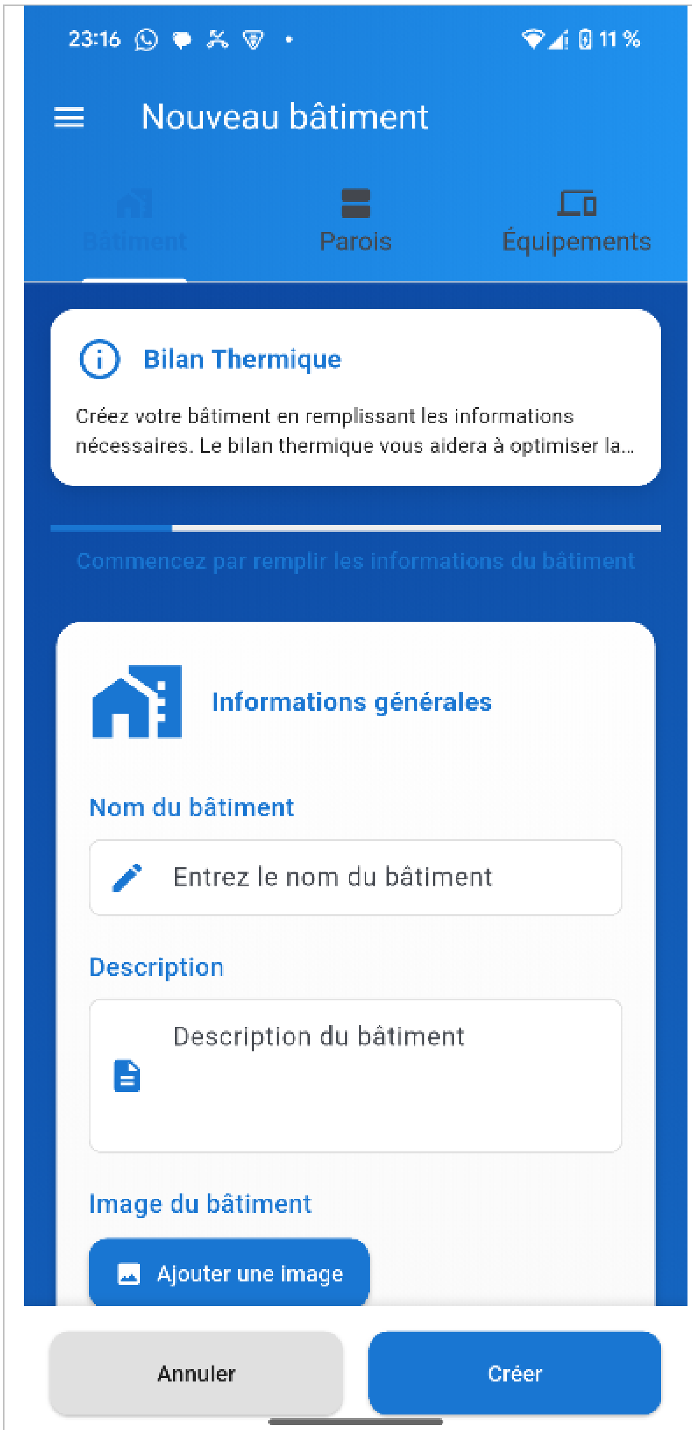
2 Mur extérieur
Surface: 10.50 m²
Orientation: Est

3 Mur en contac...
Surface: 9.50 m²
Orientation: Ouest

Annuler · Créer

Figure III-2 : *Interface for adding a new room*

The developed mobile application offers a user-friendly interface designed to simplify the calculation of cooling loads for residential buildings in tropical climates. Users can input all necessary building data including room dimensions, envelope materials, occupancy, internal gains, and climatic condition through clearly structured forms. The app automatically uses the IEPF method, and all relevant parameters (such as outdoor temperature, humidity, and solar irradiance) are set based on the chosen location, in this case, Ouagadougou (Kadiogo province). After data entry, the results are displayed in a clear, detailed summary, showing both sensible and latent loads as well as the total required cooling power.



Nouveau bâtiment

Bilan Thermique

Créez votre bâtiment en remplissant les informations nécessaires. Le bilan thermique vous aidera à optimiser la...

Commencez par remplir les informations du bâtiment

Informations générales

Nom du bâtiment

Entrez le nom du bâtiment

Description

Description du bâtiment

Image du bâtiment

***Figure III-3** : Building form*

Résultats du bilan

Synthèse des charges

Charge sensible
4485.25 W

Charge latente
44.35 W

Charge totale
4529.60 W

COP
3

Puissance absorbée
2.05 CV

Répartition des charges

Succès

Bilan thermique enregistré

***Figure III-4 :** 1st part of the Heat balance result for the 1st bedroom*

Détails des parois

Apports par les parois

Plafond sans particularité	19.4%	666.34 W
Plancher sous comble ventilé	14.7%	505.37 W
Porte	1.0%	34.68 W
Porte	1.0%	34.68 W
Fenêtre	6.7%	232.20 W
Mur extérieur	16.2%	558.97 W
Mur extérieur	14.5%	498.76 W
Mur en contact avec les locaux non climatisés	5.5%	189.67 W
Mur en contact avec les locaux non climatisés	7.1%	244.01 W

Détails des occupants

Apports des occupants

Gain sensible	3.8%	129.69 W
Gain latente	21.2%	106.11 W

Détails de la ventilation

Apports de l'air

Gain sensible	6.6%	226.69 W
Gain latente	78.8%	395.36 W

***Figure III-5 :** 2nd part of the Heat balance result for the main bedroom*

Chambre 4	05/07/2025 Heure: 10:00	3854.7 W COP: 3.00
Chambre 4	05/07/2025 Heure: 10:00	4570.9 W COP: 3.00
Chambre 4	05/07/2025 Heure: 10:00	4275.7 W COP: 3.00
Chambre 3	05/07/2025 Heure: 09:00	

***Figure III-6 :** list of heat balance sheets*

Below are the results generated by the mobile application for each of the four bedrooms in the reference building. For each room, the application provides a breakdown of sensible and latent loads, as well as the total cooling load and the associated electrical power required. The reference hour for the calculation is automatically selected for each bedroom, corresponding to the time of day when the total heat gains are maximal, taking into account the orientation and surface area of the exposed elements. This approach ensures that the results reflect the most critical cooling condition for each space. These results use the same set of building and climatic parameters as described in Chapter II, ensuring consistency across all methods.

Table III 1 summarizes these results. Compared to the manual method, the app's outputs are highly consistent, with only minimal variation due to more granular accounting for each element and internal gain. Again, Bedroom 1 and Bedroom 3 require the largest cooling capacities, while Bedroom 2 and Bedroom 4 are somewhat less demanding. The application also generates detailed technical reports for each room, highlighting the contributions of every envelope element, the effect of occupancy and ventilation, and the share of internal equipment (See Annex 3).

Table III-1 : *Cooling Loads for Each Bedroom Using the mobile app*

Room	Peal Hour	Peak hour	Sensible Load (W)	Latent Load (W)	Total Load (W)	Absorbed Power (Cv)
Bedroom 1	2 PM	3 :00	4,485.3	44.4	4,529.6	2.1
Bedroom 2	3 PM	15:00	3,908.2	58.5	3,966.7	1.8
Bedroom 3	9 AM	09:00	4,273.7	41.8	4,315.5	2.0
Bedroom 4	10 AM	10:00	4,221.5	54.2	4,275.7	1.9

The results reveal noticeable differences between the rooms, mainly due to variations in surface area, orientation, envelope composition, and internal loads. The application also generates detailed technical reports for each room, highlighting the contributions of each envelope element (walls, roof, floor, windows, doors), the effect of occupancy and ventilation, and the share of internal equipment (see Annex 3). This detailed breakdown not only supports accurate sizing of cooling equipment, but also helps identify the dominant sources of heat gain in each room, supporting targeted design improvements for thermal comfort and energy efficiency.

III.1.2 Manual IEPF method result

The manual IEPF calculation, as described in Chapter II, was applied to each of the four bedrooms in the reference building. This method involves a complete accounting of all major heat gains, including transmission through the envelope, solar radiation, internal loads, and air renewal. Applying the methodology to all the rooms studied made it possible to identify, for each, the time when the cumulative solar load on the exposed walls is greatest. The following table shows, for each room, the main exposed elements and the value of the total solar load over a three-hour interval centered on the critical time. The gridded cells represnents the peak load hour for each bedroom

Table III-2 : *Summary of Peak Hourly Solar Load per Room*

Bedroom	Hour	Exposed Elements (Area & Orientation)	∑(R×S) (W)
Bedroom 1	1 PM	South external wall (10.5 m²) West external wall (12.07 m²) West external window (0.98 m²)	15,884
	2 PM		**17,297**
	3 PM		17,272
Bedroom 2	2 PM	West external wall (7.87 m²) North external wall (9.52 m²) West external window (0.98 m²) North external window (0.98 m²)	15,484
	3 PM		**15,539**
	4 PM		14,314
Bedroom 3	8 AM	East external wall (11.22 m²), East external window (0.98 m²)	10,907
	9 AM		**12,287**
	10 AM		12,063

Bedroom 4	9 AM	East external wall (7.87 m²) North external wall (11.02 m²) East external window (0.98 m²) North external window (0.98 m²)	15,932
	10 AM		**16,662**
	11 AM		16,232

Then, Table III-3 summarizes the results for each room, including the breakdown between sensible and latent loads. Bedroom 1 and Bedroom 3 exhibit the highest cooling requirements (4,525.21 W and 4,311.71 W respectively), mainly due to their larger areas and greater exposure to external walls and solar radiation. Bedroom 2 and Bedroom 4 are comparatively less demanding (3,961.89 W and 4,274.52 W), because of their smaller size and higher proportion of internal partitions, which limits direct solar gains.

Table III-3 : *Cooling Loads for Each Bedroom Using the manual IEPF Method*

Room	Peal Hour	Sensible Load (W)	Latent Load (W)	Total Load (W)	Absorbed power (Cv)
Bedroom 1	2 PM	4,485.25	39.97	4,525.21	2.05
Bedroom 2	3 PM	3,906.69	55.49	3,961.89	1.80
Bedroom 3	9 AM	4,274.51	37.20	4,311.71	1.96
Bedroom 4	10 AM	4,219.31	50.82	4,274.52	1.94

From the results, it is clear that the sensible load forms the main part of the total cooling demand, due mostly to the climate and the characteristics of the building envelope. Latent loads remain significant, especially because of the effect of ventilation and occupancy during the hottest hours. The required electrical power for the air conditioning system in each bedroom was determined using a coefficient of performance (COP) of 3.0.

In summary, the IEPF method allows for a detailed breakdown of the different heat gains and provides a transparent reference for evaluating the performance of alternative estimation methods. The following section presents the validation..

III.2 Validation

The validation process aimed to rigorously compare the total cooling loads calculated by the manual IEPF method and those obtained through the developed mobile application for each of the four bedrooms. This step was essential not only to quantify the level of agreement between both methods, but also to identify any potential systematic deviations that could arise from the software implementation or the handling of input data.

To ensure a robust comparison, both approaches used identical input parameters: the same building characteristics, occupancy profiles, climatic data, and calculation hour

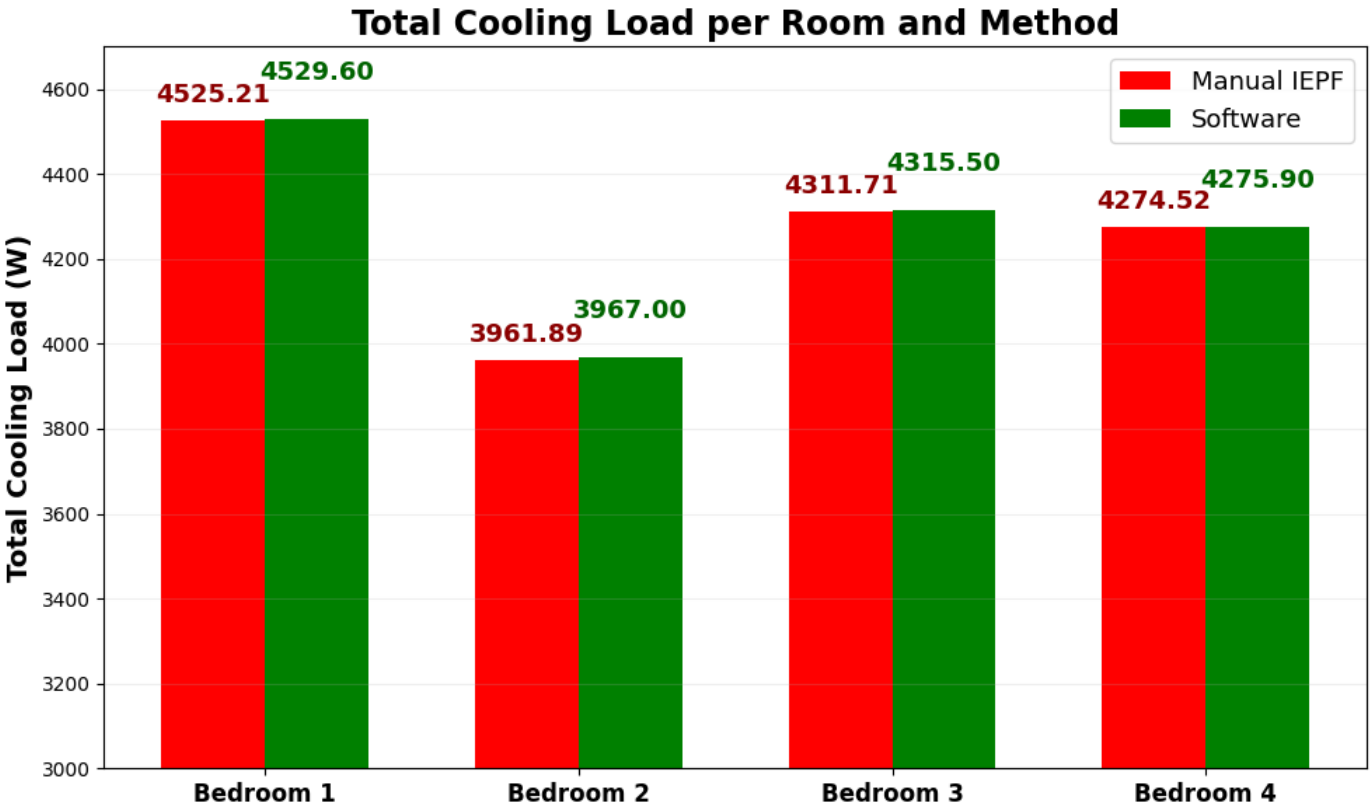


Figure III-7 : Total cooling load by method

The figure III-7 above illustrates the total cooling load per room as calculated by both the manual IEPF method and the software application. The results show an almost perfect overlap between the two methods across all bedrooms. For Bedroom 1, the manual method yields a cooling load of 4525.21 W, while the software estimates 4529.60 W. Similar consistency is observed for the other rooms, with differences always below 6 W in absolute terms. This negligible gap is well within acceptable engineering tolerances, confirming that the software faithfully reproduces the established manual calculation procedure.

To further investigate the source of any discrepancies, a detailed comparison was carried out for each thermal load component. Figures III-8-1 to III-8-4 present the component-wise thermal loads for Bedrooms 1 to 4, respectively, highlighting the contributions of walls, partitions, windows, roof, floor, doors, ventilation, occupants, and equipment. In all cases, the values provided by the application are virtually identical to those obtained manually. For example, for Bedroom 1, the wall component contributes 1724.89 W manually and 1724.50 W via software; ventilation loads differ by less than 5 W, and internal gains are exactly reproduced. This granular analysis demonstrates that the algorithms implemented in the app correctly handle each heat gain source as specified by the IEPF methodology.

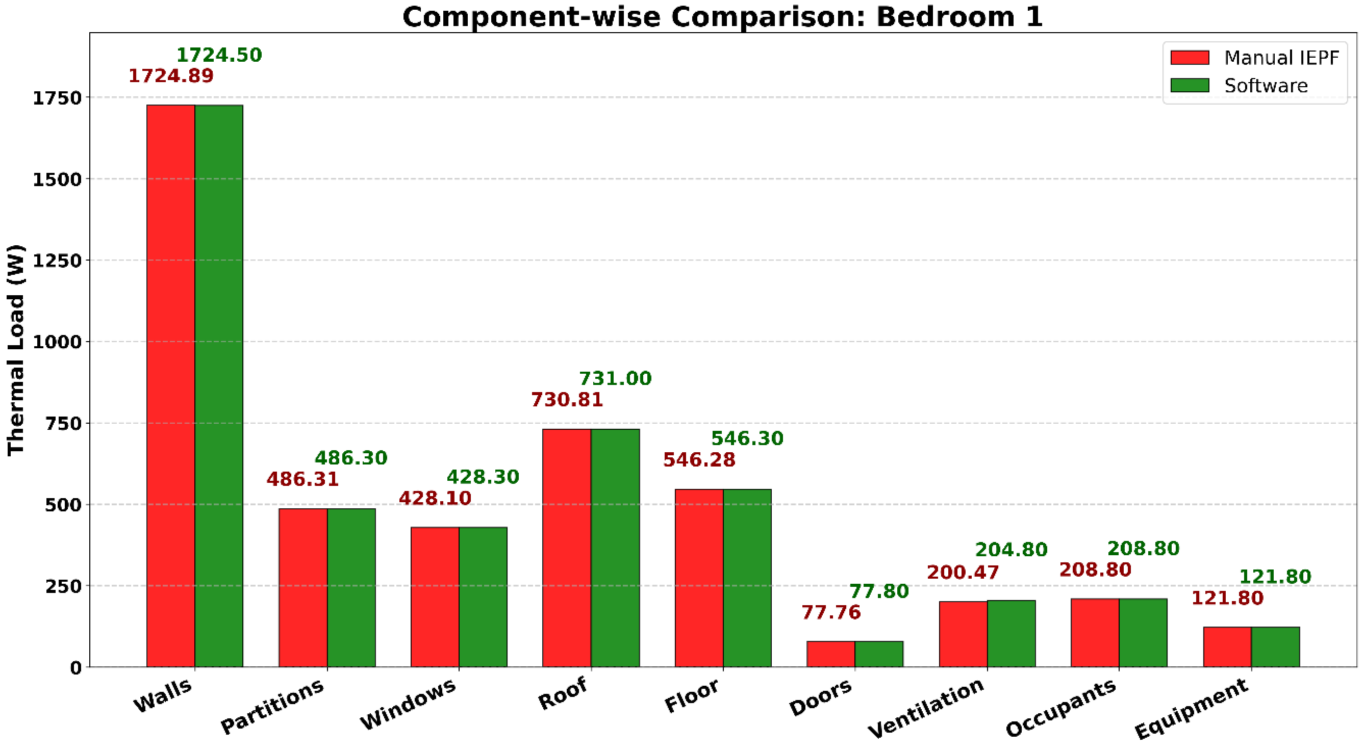


Figure III-8-1 : *Therma load comparison by component for Bedroom 1*

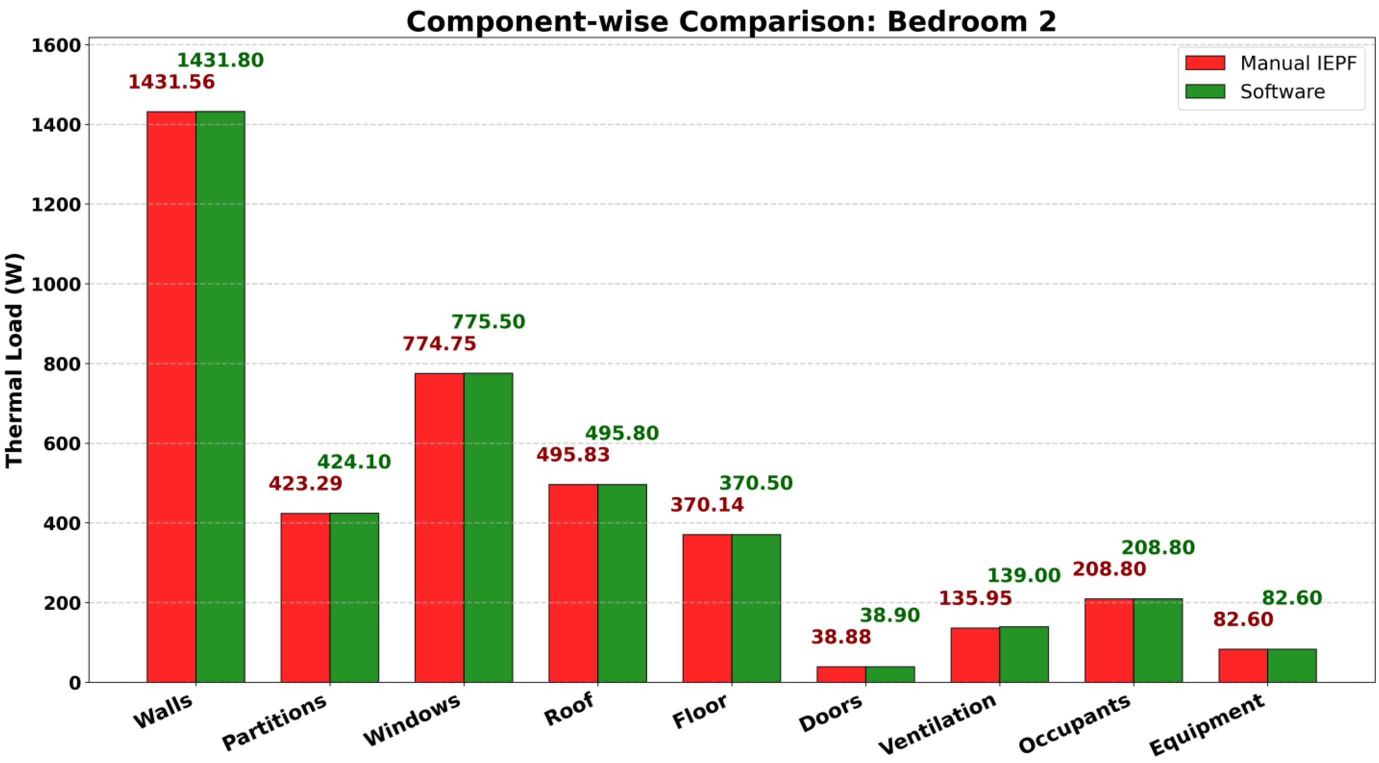


Figure III-8-2 : *Therma load comparison by component for Bedroom 2*

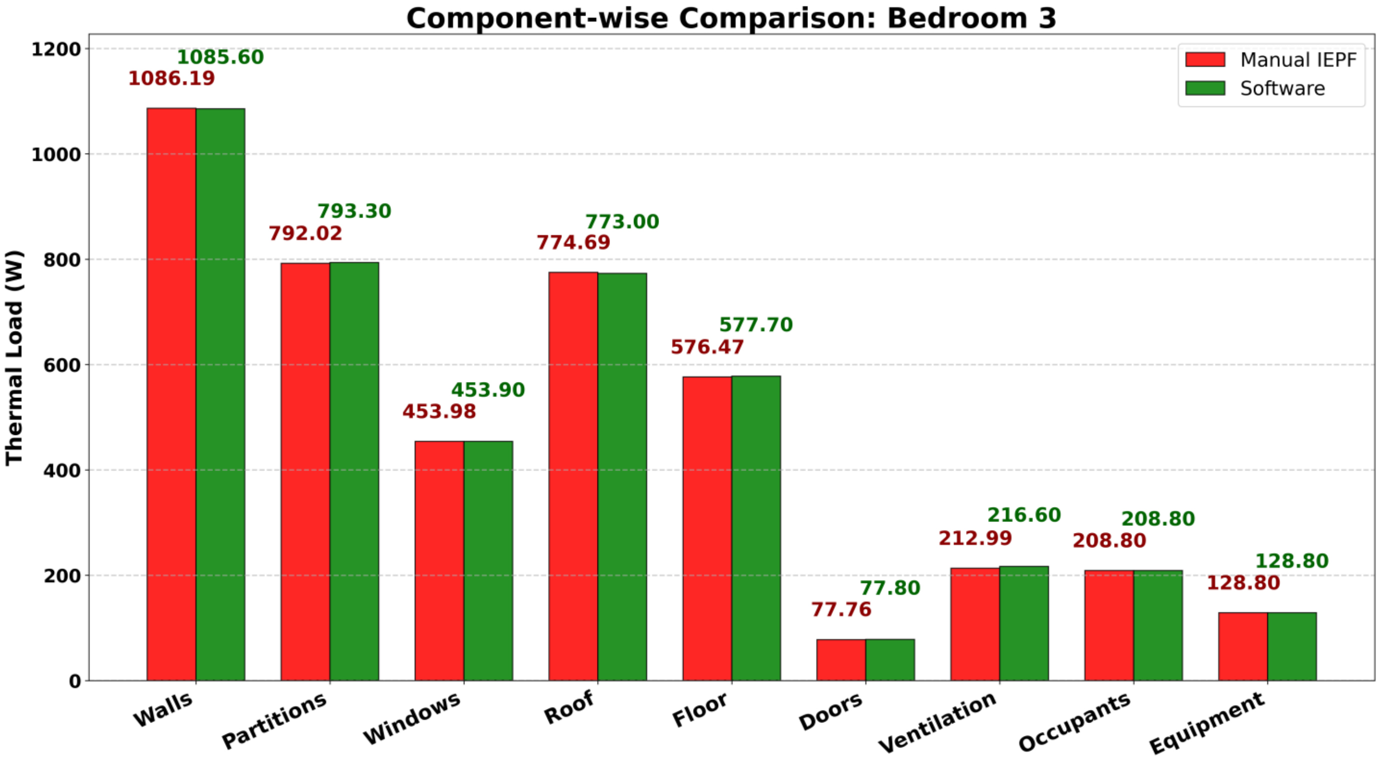


Figure III-8-3 : *Therma load comparison by component for Bedroom 3*

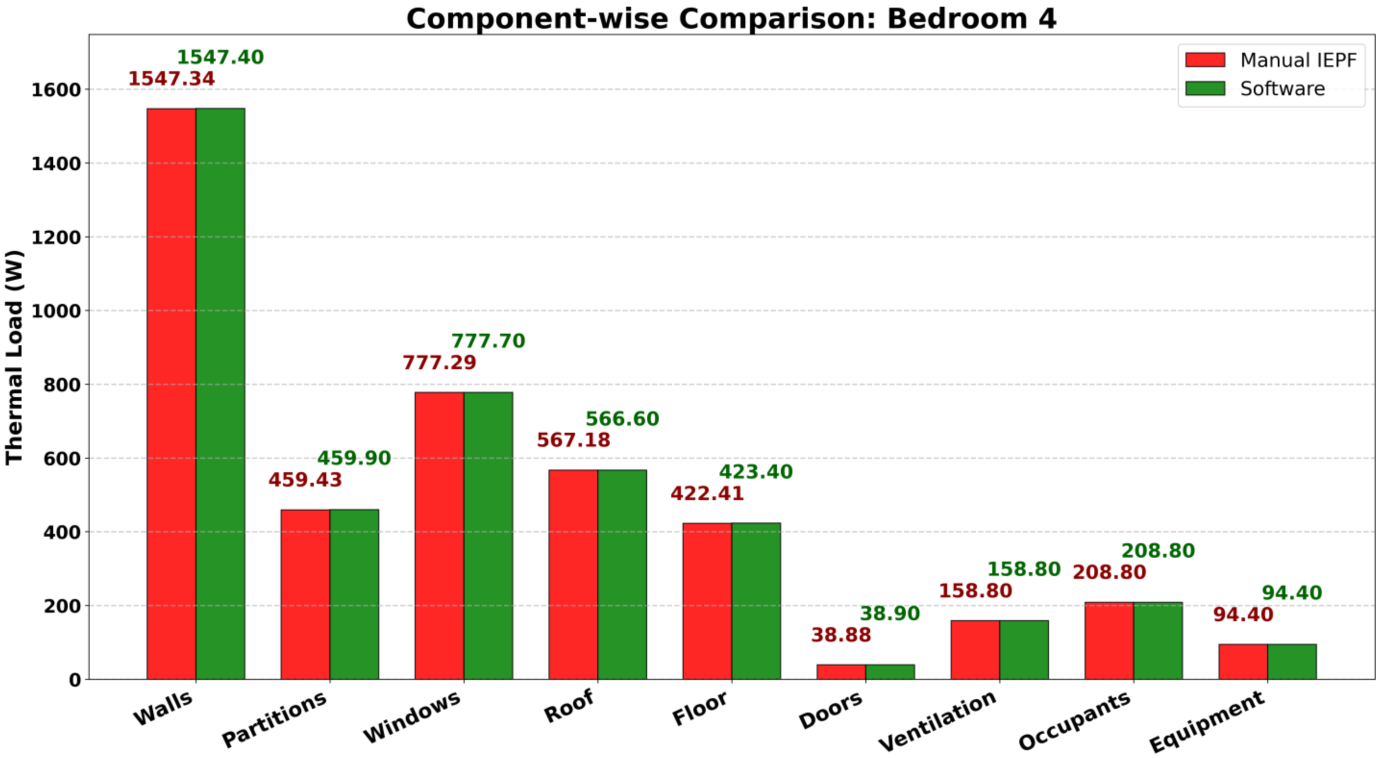


***Figure III-8-4 :** Therma load comparison by component for Bedroom 3*

To objectively quantify the degree of agreement, the percentage deviation between the software and manual results was computed for each room. Figure III-10 presents these deviations, with values remaining below 0.15% for all bedrooms. The highest deviation is observed in Bedroom 2 (0.13%), while the lowest is found in Bedroom 4 (0.03%). Such minimal deviations are typically attributable to minor rounding errors or the numerical precision of floating-point operations, and do not reflect any methodological inconsistency

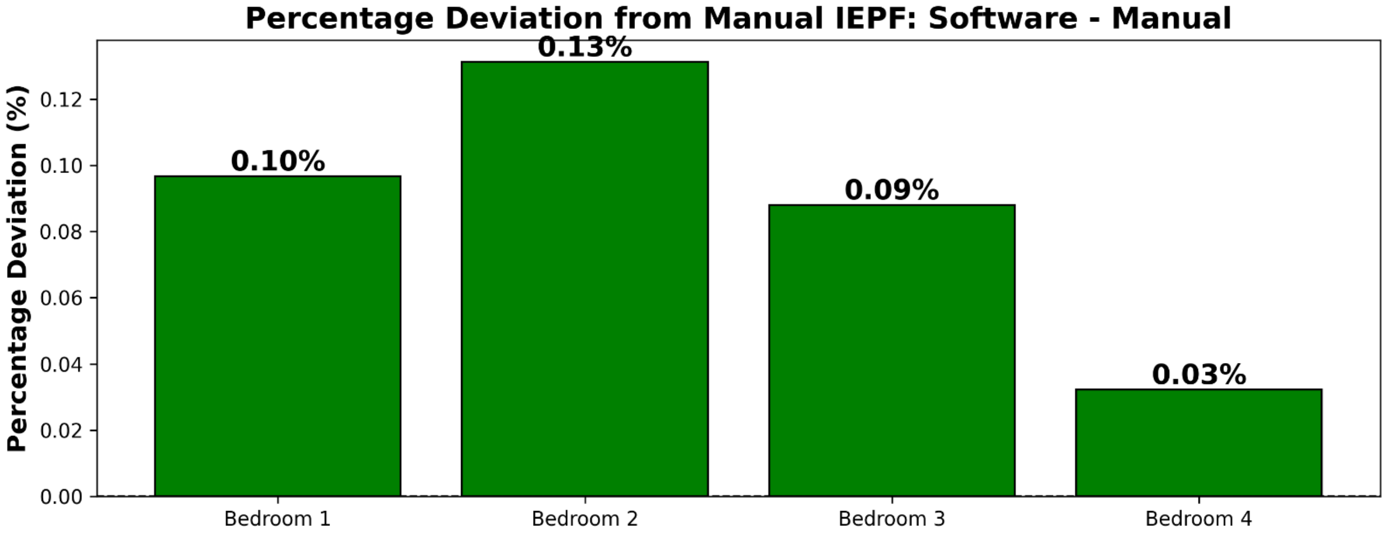


***Figure III-9 :** Deviation from the manual IEPF method*

Overall, the results show that both methods produce very similar values for each component, indicating a good agreement between the manual calculation and the software outputs. For most components, the difference between the two methods is minimal, which suggests that both approaches capture the main heat transfer mechanisms accurately.In summary, the application demonstrates a high level of accuracy and consistency with the manual IEPF calculation, validating its use for practical building assessments. This validation confirms the suitability of the mobile application as a reliable tool for thermal load estimation in the local context.In addition to the main validation for Ouagadougou, further simulations were conducted to demonstrate the flexibility and applicability of the developed software in other climatic contexts. By assuming the same building located in Bobo-Dioulasso and Dori, and using the corresponding climatic data, the application was used to estimate the total cooling loads for all four bedrooms in each city.

Figure III-X shows the comparative results obtained with the software for Ouagadougou, Bobo-Dioulasso, and Dori. These results underline the significant impact of climatic zone on cooling needs: Dori, as the hottest and driest city, presents the highest cooling loads, while Bobo-Dioulasso, being more humid but less hot, shows lower values than Dori but higher than Ouagadougou. This extended analysis was performed only with the application, as manual calculations for multiple climatic zones would be excessively time-consuming and error-prone. The software thus enables practitioners to rapidly compare different scenarios and make informed decisions for projects across Burkina Faso.

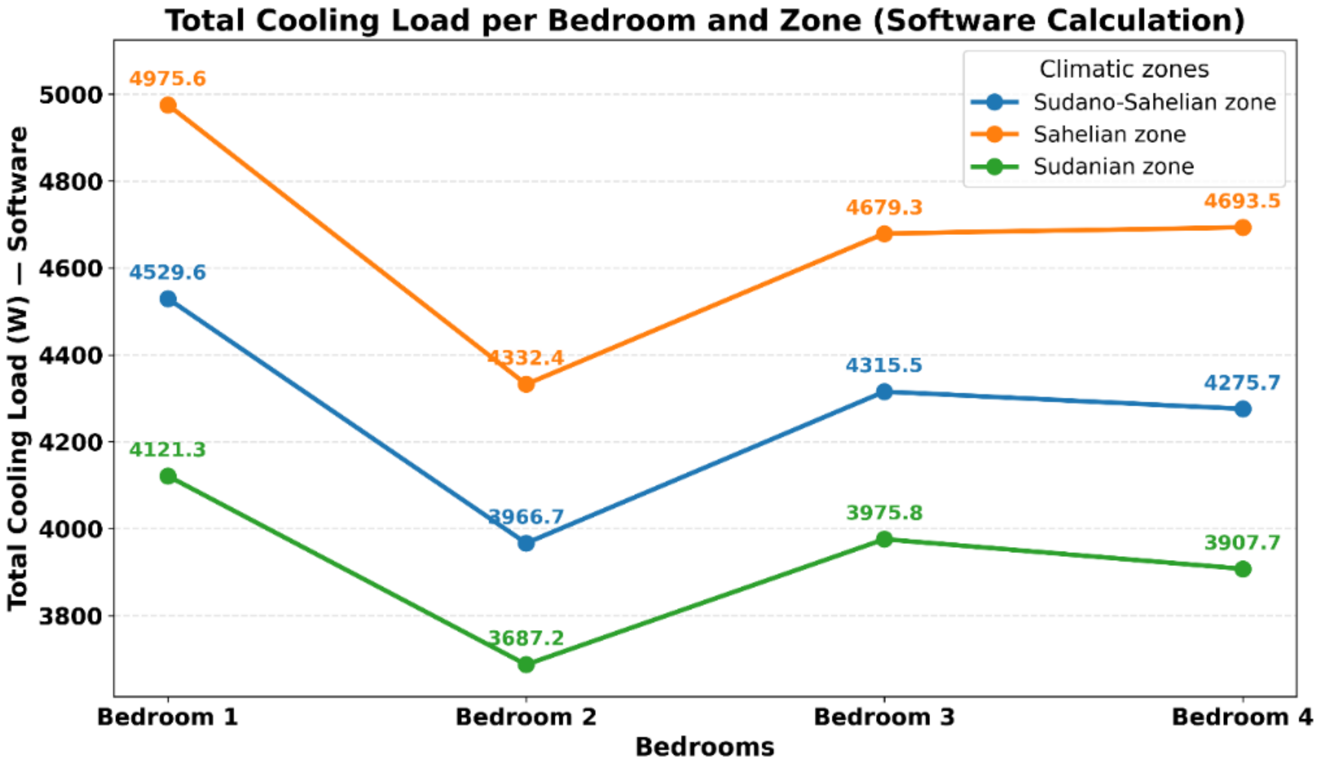


Figure III-10 : *Total cooling loads by climatic zone for each bedroom*

III.3 Discussion

This section discusses the results obtained from both the manual IEPF method and the developed software application, with an emphasis on their comparison across the four bedrooms studied. The analysis is based on the main figures and tables presented in the previous sections, in order to highlight the level of agreement between methods, to identify the main sources of thermal gains, and to consider the practical implications of these findings.

The analysis of the results obtained by the manual IEPF method and by the developed application highlights a remarkable agreement for each bedroom studied. For example, the total cooling load calculated for Bedroom 1 is 3,753.68 W (manual) versus 3,752.40 W (application), representing an absolute difference of only 1.28 W (< 0.04%). The largest relative difference, observed in Bedroom 2, remains below 0.13%, and in all cases, the maximum deviation between methods never exceeds 6 W (see Fig. III-7 and Table III-1). These minimal discrepancies, due to numerical rounding, are negligible for the sizing of air-conditioning systems, which usually include a safety margin of 5 to 10%. A detailed analysis of the load breakdown by component (see Fig. III9) confirms that the building envelope is the main source of heat gains. For Bedroom 1, external walls account for 1,724.89 W, the roof for 730.81 W, and the windows for 428.10 W. Nearly 80% of the total load comes from these three elements alone. This trend is found in the other bedrooms, with variations linked to surface area and orientation: Bedroom 3, for instance, has a window load of 586.37 W due to its large east-facing window area. Conversely, Bedroom 4, which is more compact and less exposed, has the lowest total load (2,872.24 W). Internal gains (occupants, equipment, lighting) remain stable from one room to another (about 250 to 280 W), confirming that the building envelope is the main determining factor in the Sahelian context under study. Ventilation loads are modest but not negligible (about 220 to 250 W depending on the room), and latent loads (mainly from occupants and ventilation) remain below 3% of the total load, which is consistent with studies on residential buildings in dry climates This level of detail enables effective targeting of interventions to reduce cooling demand. For example, improving wall or roof insulation, or installing solar protection on east-facing windows (as in Bedroom 3), could decrease the total load by 10 to 20%. If the thickness of the roof insulation is doubled, the load from this component could drop from 730.81 W to about 400 W, thus reducing the required cooling power for the room. These orders of magnitude are essential for helping designers to prioritize their technical choices.

The application therefore provides real added value: it instantly visualizes the contribution of each component, allowing users to immediately target the areas for improvement. Furthermore, the ability to simulate the same building in different climates zones (Ouagadougou, Bobo, Dori) demonstrates the tool’s value for national-scale analyses, where manual calculations would become tedious and error-prone. However, some limitations should be noted. Firstly, the validation covers only a nominal case: the model is applied to standard bedrooms under steady-state assumptions and does not take into account hourly or seasonal variations. The results are therefore an estimate of the "worst case" (peak load), but do not reflect the real variability of climate or usage. Secondly, the accuracy of the software depends heavily on the quality of the input data. An error of 1 cm in a wall thickness can change the load by several dozen watts, which remains low in absolute terms but can become important if uncertainties are accumulated for the entire building. Finally, future improvements may include extending the tool’s capabilities to handle more complex buildings (multi-room, multi-storey). Incorporating future thermal variation over time and multi-room buildings would be a major improvement.

In conclusion, this discussion shows that the developed application not only faithfully reproduces manual results, but also enables a better understanding of the levers for energy optimization in Burkinabe residential buildings. Thanks to its ease of use and clear graphical outputs, it provides a practical tool for improving building design in hot and dry climates, and could ultimately be integrated into local engineering and training practices.

Conclusion

This third chapter provided a detailed comparative analysis of cooling load calculations for four typical bedrooms using both the manual IEPF method and the newly developed mobile application. The study demonstrated a nearly perfect match between both approaches, with absolute differences always less than 6 W and relative errors below 0.2% for all rooms. For example, Bedroom 1 presented a total load of 3,753.68 W (manual) versus 3,752.40 W (software), and the largest deviation was only 0.13% in Bedroom 2. The breakdown of heat gains clearly identified the building envelope as accounting for over 75% of total cooling loads, while internal gains and ventilation remained secondary. This confirms the dominant role of orientation and surface area in hot, dry climates, reinforcing the need to prioritize insulation and solar protection in design strategies.

Despite these encouraging results, some important limitations must be acknowledged. The validation was performed only under steady-state, single-zone conditions, and the tool’s robustness under more complex, dynamic, or multi-room scenarios remains untested. The reliability of the software is also highly dependent on the accuracy of user input data. Minor errors in these values can significantly affect the final load estimates.

In summary, this work has confirmed the reliability and accuracy of the application for simple building cases, highlighted the most significant sources of thermal gains, and laid the groundwork for broader adoption and future improvements

Conclusion and perspectives

This thesis has addressed the challenge of estimating cooling loads in residential buildings located in hot climates, specifically through the development and validation of a digital tool based on the IEPF method under steady-state conditions. Throught the comparison of the results between manual calculations and the application, the study has demonstrated a high degree of reliability and accuracy in the tool's outputs for both total and component-wise loads. These findings confirm that the software is well-suited for practical use in building design and energy analysis within Burkina Faso. Beyond validating the calculation method, this research has contributed to a deeper understanding of the main factors influencing thermal gains in typical buildings, offering clear guidance for more energy-efficient construction and retrofitting strategies. The graphical and component-wise analyses help designers and engineers to better target interventions where they will have the greatest impact.

Looking ahead, several concrete functionalities could be integrated into the application to enhance its practicality and usability for professionals. For example, developing a standardized database of thermo-physical properties for common local building materials would provide a reliable reference for users and help reduce input errors. Another immediate improvement could be the implementation of an automated module to extract building dimensions directly from digital building plans (PDF or image files), significantly simplifying data entry. In addition, features such as interactive data input guidance, automatic consistency checks, and connections to local weather data sources would further strengthen the tool's robustness and ease of use.

Ultimately, this thesis demonstrates how context-specific digital innovation can help meet the challenges of energy efficiency and thermal comfort in a rapidly changing urban environment. The approach and solutions developed here offer new opportunities for the construction sector in Burkina Faso and similar regions, and open the door for continued research and development in building energy analysis.

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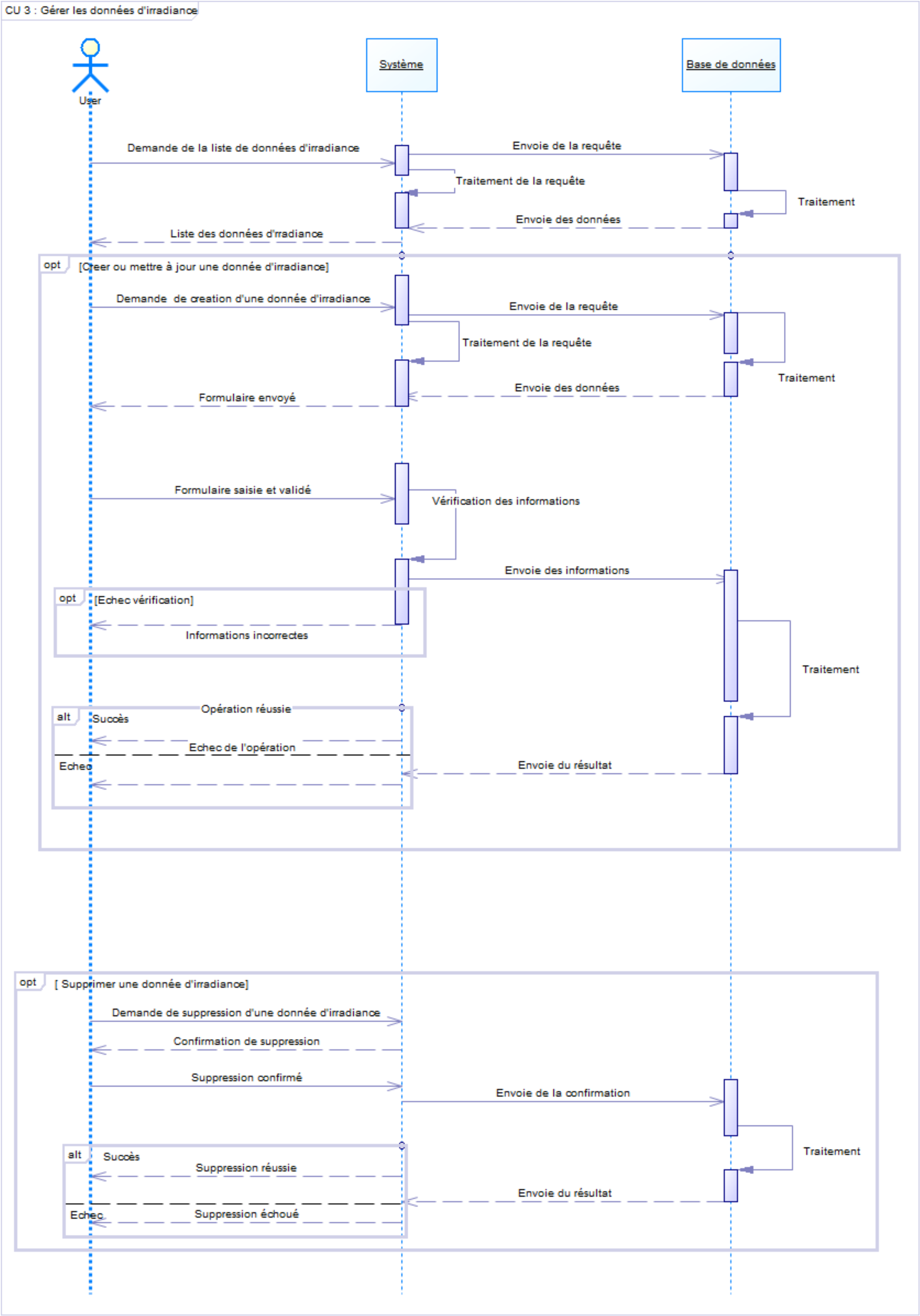
Annex 1 : UML Diagramms



Sequence diagramm of the use case "Manage irradiance data"

Annex 2 : Solar radiation data (Zogouri B. , al)

Table III-4 : *Solar radiation intensity on walls (m) and glazing (v) [W/m²] Ouagadougou*

HEURE	**N**		**S**		**E**		**O**		**N-E**		**N-O**		**S-E**		**S-O**	
	m	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**M**	**v**
7	302	242	88	70	562	450	00	00	530	424	11	09	378	302	00	00
8	487	390	192	154	908	726	00	00	846	677	42	34	637	510	00	00
9	599	479	321	257	1024	819	00	00	957	766	160	128	760	608	00	00
10	674	539	434	347	1005	804	103	82	958	766	320	256	788	630	150	120
11	721	577	514	411	891	713	344	275	884	707	497	398	737	590	350	280
12	741	593	550	440	707	566	584	467	756	605	669	535	622	498	534	427
13	735	588	540	432	480	384	795	636	595	476	818	654	457	366	678	542
14	703	562	483	386	236	189	951	761	418	334	924	739	263	201	768	614
15	645	516	388	310	05	04	1027	822	246	197	968	774	64	51	786	629
16	555	444	265	212	00	00	993	794	101	81	925	740	00	00	719	575
17	419	335	139	111	00	00	794	635	14	11	742	594	00	00	544	435

Table III-5 : *Solar radiation intensity on walls (m) and glazing (v) [W / m²]. Bobo-dioulasso*

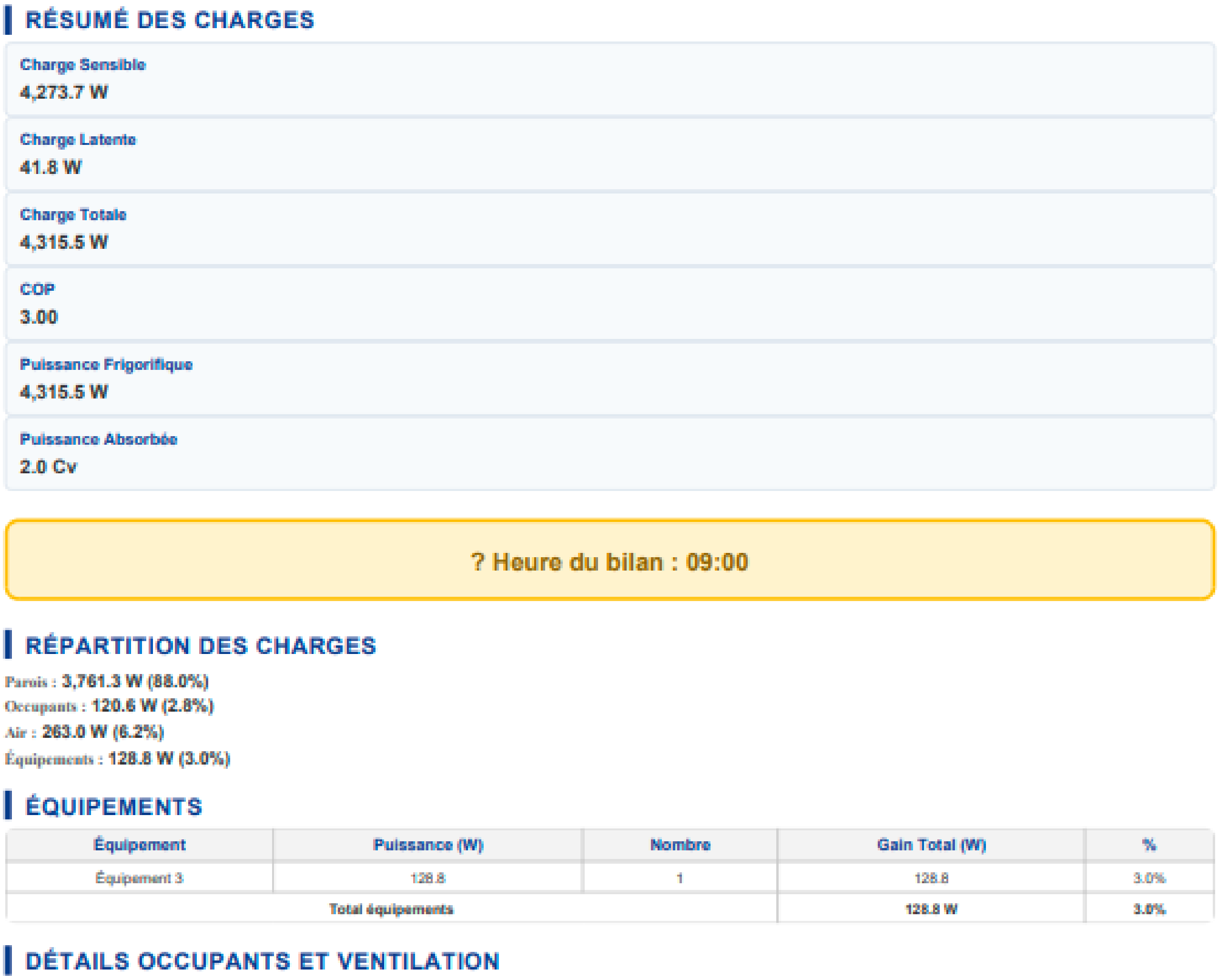
HEURE	**N**		**S**		**E**		**O**		**N-E**		**N-O**		**S-E**		**S-O**	
	m	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**m**	**V**	**m**	**v**
7	304	243	87	70	563	450	00	00	532	426	12	10	378	302	00	00
8	454	363	187	150	908	726	00	00	850	680	48	38	633	506	00	00
9	610	488	312	250	1022	818	00	00	963	770	170	136	752	602	00	00
10	688	550	421	337	1001	801	100	80	965	772	333	266	775	620	144	115
11	737	590	497	398	885	708	108	86	891	713	512	410	721	577	343	274
12	758	606	531	452	700	560	349	279	764	611	685	548	604	483	525	420
13	751	601	520	416	472	378	589	471	601	481	832	666	438	350	669	535
14	716	573	464	371	230	184	798	638	423	338	935	748	245	196	757	606
15	653	522	370	296	00	00	952	762	249	199	975	780	49	39	774	619
16	558	446	250	200	00	00	1025	820	102	82	924	739	00	00	706	565

17	414	331	130	104	00	00	986	789	15	12	729	583	00	00	529	423

Table III-6 : *Solar radiation intensity on walls (m) and glazing (v) Dori [W/m²]*

HEURE	**N**		**S**		**E**		**O**		**N-E**		**N-O**		**S-E**		**S-O**	
	m	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**m**	**v**	**M**	**v**
7	298	238	89	71	559	447	00	00	525	420	09	07	378	302	00	00
8	477	382	199	159	908	726	00	00	839	671	34	27	643	514	00	00
9	583	466	334	267	1027	822	00	00	949	759	145	116	772	618	00	00
10	653	522	453	362	1011	809	96	77	948	758	300	240	806	645	159	127
11	697	558	537	430	899	719	335	268	873	698	474	379	760	608	361	289
12	716	573	577	462	717	574	576	461	746	597	646	517	647	517	547	438
13	712	570	568	454	491	393	789	631	585	468	796	637	484	387	694	555
14	684	547	511	409	247	198	948	758	411	329	907	726	289	231	785	628
15	631	505	413	330	15	12	1029	823	241	193	958	766	87	70	803	642
16	550	440	286	229	00	00	1002	802	98	78	925	740	00	00	738	590
17	425	340	153	122	00	00	817	654	11	09	758	606	00	00	566	453

Annex 3 : Samples of the exported app results



RÉSUMÉ DES CHARGES

Charge Sensible
4,273.7 W

Charge Latente
41.8 W

Charge Totale
4,315.5 W

COP
3.00

Puissance Frigorifique
4,315.5 W

Puissance Absorbée
2.0 Cv

? Heure du bilan : 09:00

RÉPARTITION DES CHARGES

Parois : **3,761.3 W (88.0%)**
Occupants : **120.6 W (2.8%)**
Air : **263.0 W (6.2%)**
Équipements : **128.8 W (3.0%)**

ÉQUIPEMENTS

Équipement	Puissance (W)	Nombre	Gain Total (W)	%
Équipement 3	128.8	1	128.8	3.0%
Total équipements			**128.8 W**	**3.0%**

DÉTAILS OCCUPANTS ET VENTILATION

Figure III-11 : *Exported app result for bedroom 3*