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Systematical Method for Zero-Energy Efficiency Buildings

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ABSTRACT

As a result of the impact of energy consumption, research on ultra-low energy, nearly zero-energy, and zero energy buildings has been conducted in Morocco. However, the design of the nearly zero-energy building is flexible; the traditional architectural design method is not fully applicable to nearly zero-energy buildings. The book proposed a performance-based design method based on overall energy consumption and progress for the nearly zero-energy building. The design process of the relevant cases was also analyzed. The factors of cold and heat sources, environment, and renewable energy were combined to make a comprehensive analysis to get the optimal scheme of the nearly zero-energy building in the case. In general, the performance-based design method has a certain guiding significance for the design of nearly zero-energy buildings and certainly promotes the expansion of the nearly zero-energy building industry. The study recommends prioritizing natural ventilation strategies and minimizing infiltration in building design and construction for building professionals, designers, and architects. It calls for regulatory authorities to revise building codes and regulations to better account for the effects of air infiltration and natural ventilation on energy performance. The research also encourages further investigation in the field of natural ventilation and infiltration to promote sustainable, energy-efficient, and bioclimatic building practices in the future.

Keywords: Energy efficiency; Moroccan Thermal Construction Regulation (RTCM); Natural ventilation; Nearly zero-energy building; Performance-based design method

INTRODUCTION

Global push towards sustainable development and energy efficiency has placed an increasing emphasis on the need for environmentally responsible building practices. As the building sector accounts for a significant portion of the world's energy consumption and greenhouse gas emissions, it has become an essential target for achieving energy efficiency improvements and promoting sustainable development [1,2]. In Morocco, the building sector is no exception, and the nation has made considerable efforts to promote energy-efficient and sustainable building practices.

The Moroccan Thermal Construction Regulation (RTCM) is a crucial tool in driving the adoption of these practices, aiming to improve energy efficiency and reduce greenhouse gas emissions in the building sector [3]. However, the current regulation does not comprehensively address the potential benefits of natural ventilation and air infiltration strategies [4]. This omission may lead to suboptimal energy performance and hinder the goal of achieving sustainable building practices in Morocco (**Figure 1**).

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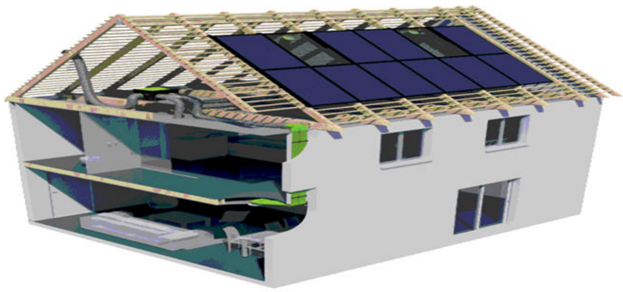

Figure 1: Zero-energy building.

In this context, the capstone project titled "revamping morocco's thermal regulation for construction: Energy efficiency and policy" aims to investigate the importance of natural ventilation and infiltration in improving energy efficiency, economic performance, and environmental sustainability in buildings, using Ifrane, Morocco, as a case study. The main objectives of this capstone project are:

- To examine the impact of natural ventilation and air infiltration on building energy performance and comfort levels.
- To assess the potential benefits and limitations of incorporating natural ventilation and air infiltration strategies in building design and construction.
- To provide recommendations for improving the RTCM and promoting sustainable building practices in Morocco.

The capstone project is organized into chapters that include Introduction, which covers background and context, and scope and objectives of the report; general context of the energy sector and energy efficiency in buildings in particular, discussing both international and Moroccan contexts, as well as legislative, institutional, and regulatory frameworks; Thermal Regulation of Constructions in Morocco (RTCM) and beyond, which evaluates international construction codes and the RTCM; integrating natural ventilation and infiltration in Morocco's thermal construction code, focusing on design principles and methodology; results and discussion, which presents simulation outcomes and analysis; STEEPLE analysis, offering a broader understanding of the project's impacts; potential engineering standards, reviewing relevant standards for the capstone work; and finally, conclusion, summarizing key findings, recommendations, and future work. The project explores natural ventilation and infiltration strategies in Moroccan buildings for improved energy efficiency and sustainability.

By examining the role of natural ventilation and infiltration in enhancing energy efficiency and environmental sustainability in the building sector, this capstone project aims to contribute to the ongoing efforts to promote sustainable building practices in Morocco and provide valuable insights for stakeholders in the building industry. The capstone will draw on existing research in the field of energy efficiency, ventilation strategies, and building regulations, providing a comprehensive understanding of the current state of knowledge and best practices in this area. The scope of the project includes evaluating different building scenarios using computational simulation tools, assessing the results, and identifying areas for potential improvement in the existing regulatory framework.

LITERATURE REVIEW

General Context of the Energy Sector and Energy Efficiency in Buildings in Particular

International context: Energy efficiency and thermal comfort in buildings have become increasingly important in recent years due to growing concerns about climate change, resource conservation, and occupant well-being. As a result, international standards have been developed to guide and regulate the design and operation of buildings with the goal of optimizing energy consumption, while providing comfortable and healthy indoor environments. This led to several key international standards and regulations to be introduced that play a significant role in shaping the energy performance and thermal comfort of buildings worldwide. By understanding and adhering to these standards, building professionals can contribute to a more sustainable and energy-efficient future.

Global energy consumption and climate impact: Access to energy represents a major challenge for our societies. According to the International Energy Agency (IEA), global energy consumption has more than doubled over the last 40 years, from nearly 6106 Mtoe in 1973 to 13,371 Mtoe in 2012. Fossil fuels currently account for more than 80% of this consumption, with oil as the leading source of energy, providing 31.4% of the world's needs, followed by coal (29%) and gas (21.3%). Renewable energies meet 13.5% of demand, while the share of nuclear power in primary energy consumption is 4.8%. These figures show the strong global dependence on fossil fuels, which contribute significantly to dangerous climate change for the planet [5]. Furthermore, the supply of these resources is subject to strong uncertainties and can be quickly disrupted by natural events, technical issues, or geopolitical factors [6]. The building sector is the most energy-intensive in the world, accounting for around 35% of final energy consumption [7]. This sector is also responsible for one-fifth of the world's greenhouse gas emissions, ranking ahead of the transport and energy sectors [8]. However, it is estimated that the potential for energy savings in this sector worldwide is around 40% through efficient and cost-effective measures. These global challenges must be addressed according to the conditions of each country or region, with energy policy choices differing accordingly (**Figure 2**) [9].

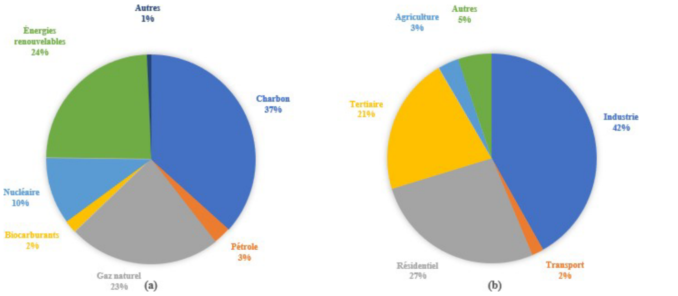

Figure 2: (a) The distribution of electricity production by energy source in 2019 and (b) The distribution of final electricity consumption by sector in 2019.

Mediterranean energy demands and opportunities: In the Mediterranean region, total energy demand has more than doubled between 1970 and 2010 [9]. This demand, which represents about 8.2% of global energy demand, is accompanied by an emission of 2152 $MtCO_2$ in 2010. Studies by the Mediterranean Energy Observatory (OME) indicate that energy demand in the Mediterranean could grow by more than 40% by 2030, reaching over 1400 Mtoe. This situation can only amplify energy and environmental problems in the region in the coming years.

The building industry in the Mediterranean region is responsible for more than a third of final energy consumption and could allow up to 60% of energy savings [10]. In response to housing demands, public policies in the Northern Mediterranean Countries (NMCs) tend to favor the rehabilitation of existing buildings, while the Southern and Eastern Mediterranean Countries (SEMCs) implement large-scale programs and regulatory frameworks for the construction of new buildings. The energy and environmental challenges must be addressed differently for the two sub-areas of the Mediterranean, with adaptations to the contexts of each economic sector in each country [11].

Energy efficiency standards: In the pursuit of sustainable development and energy efficiency, the construction industry has been focusing on creating buildings that not only reduce their environmental impact but also provide comfortable and healthy indoor spaces for occupants [12]. To achieve these goals, it is crucial to establish a set of guidelines and regulations that standardize best practices and set performance benchmarks for various aspects of building design, construction, and operation [13]. International standards have been developed to address these needs and provide a unified approach to energy efficiency and thermal comfort in buildings:

- **ASHRAE 90.1:** This standard, created by ANSI and released by ASHRAE, lays out the minimal standards for energy-efficient building design, with the exception of low-rise residential structures either the prescriptive approach (meeting minimum standards) or the performance path (demonstrating lower energy use than a baseline building) can be used to obtain compliance [14].
- **ISO 50001:** An international standard developed by ISO, aiming to improve energy performance in organizations [15]. It provides guidelines for a systematic energy management system focused on energy performance and is based on continuous improvement. The standard specifies requirements for energy use and consumption but does not prescribe energy-specific performance criteria.
- **ISO 7730:** This standard, which was created by ISO/TC 159, offers techniques for anticipating general thermal sensation and discomfort in people exposed to mild thermal settings. Using local thermal comfort criteria, PMV and PPD indices, and analytical analysis, it is possible to determine and interpret thermal comfort [16].

Moroccan Context

The context of energy efficiency in buildings can be broken down into three main national development agendas on which Morocco is working on [17] (**Figure 3**). These are:

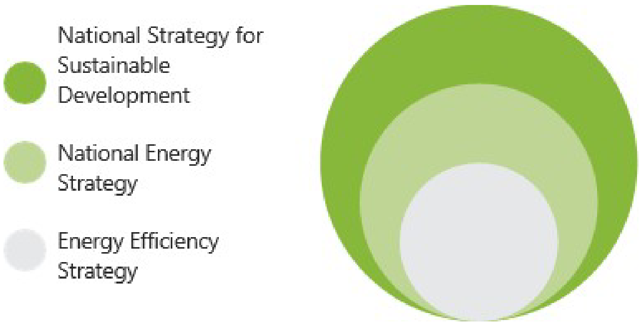

Figure 3: Main national development agenda of Morocco.

National Strategy for Sustainable Development (SNDD): Morocco's SNDD was adopted by the Council of Ministers in June 2017 to ensure a transition to a green and inclusive economy through 7 priority axes that all involve the building sector: Consolidation of sustainable development governance, supported by a stronger alignment of public policies and stimulation of the public sector's capacity for excellence. In this regard, the Ministry of Administration Reform and Civil Service's circular from August 3, 2018, calls for the adoption of energy-saving measures amounting to 20% and the incorporation of renewable energy amounts to 20%. Accelerating the implementation of energy efficiency and transitional measures and integrating sustainable development principles into urban planning are key components of a successful transition to a green economy. Improving conservation policies and biodiversity protection in order to better manage and develop natural resources [18,19].

The acceleration of the implementation of the national policy to fight against climate change, in a territorial approach.

- The particular vigilance to be granted to the sensitive territories, by the preservation and the valorization of the oasis, desert and mountain areas.
- The encouragement of human development and the lowering of social and geographic disparities.
- Supporting eco-citizenship, innovation, and research and development while promoting a culture of sustainable development.

Thus, the SNDD complies with Morocco's pledges to the international community to accomplish the 17 SDGs by 2030 and to contribute to the battle against climate change as outlined in the Nationally Determined Contribution (NDC).

METHODOLOGY

Simulation 1: Building in RTCM/Reference with no energy gain besides radiation (0 appliances in W/m² and 0 occupants).

Infiltration simulation scenarios: In this part of our study, we conducted infiltration simulations on the default building, which is the RTCM/with natural ventilation case. We aimed to investigate the impact of various Air Changes per Hour (ACH) values on the energy performance of the building. The infiltration scenarios are based on five different ACH values: 0.5, 0.6, 1, 1.4, and 1.6 (Table 1).

Table 1: The existence of limits of elementariness of thermal characteristics of requirements the envelope of regulatory buildings with characteristics use of thermal offices.

	Rate of bay windows TGBV	U of exposed roofs	U of exterior walls (W/m^2.k)	U of glazing (W/m^2.k)	Minimum R of floors on ground (m^2 .k/W)	Solar factor FS* of glazing
Regulatory climatic zone Z1	≤ 15%	≤ 0,75	≤ 1,20	≤ 5,80	NE	NE
	16-25%	≤ 0,65	≤ 1,20	≤ 5,80	NE	Nord: NE Autres: ≤ 0,7
	26-35%	≤ 0,65	≤ 1,20	≤ 3,30	NE	Nord: NE Autres: ≤ 0,5
	36-45%	≤ 0,55	≤ 1,20	≤ 3,30	NE	Nord: ≤ 0,7 Autres: ≤ 0,3
Regulatory climatic zone Z2	≤ 15%	≤ 0,65	≤ 0,80	≤ 5,80	NE	NE
	16-25%	≤ 0,65	≤ 0,80	≤ 3,30	NE	Nord: NE Autres: ≤ 0,7
	26-35%	≤ 0,65	≤ 0,60	≤ 3,30	NE	Nord:NE Autres: ≤ 0,5
	36-45%	≤ 0,55	≤ 0,60	≤ 2,60	NE	Nord: ≤ 0,7 Autres: 0,3
	≤ 15%	≤ 0,65	≤ 0,80	≤ 3,30	≥ 0,75	NE
Regulatory climatic zone Z3	16-25%	≤ 0,65	≤ 0,80	≤ 3,30	≥ 0,75	Nord: NE Autres: ≤ 0,7
	26-35%	≤ 0,55	≤ 0,70	≤ 2,60	≥ 0,75	Nord: NE Autres: ≤ 0,5
	36-45%	≤ 0,49	≤ 0,60	≤ 1,90	≥ 0,75	Nord: ≤ 0,7 Autres: ≤ 0,5
Regulatory climatic zone Z4	≤ 15%	≤ 0,55	≤ 0,60	≤ 3,30	≥ 1,25	NE
	16-25%	≤ 0,55	≤ 0,60	≤ 3,30	≥ 1,25	Nord: NE Autres: ≤ 0,7
	26-35%	≤ 0,49	≤ 0,60	≤ 2,60	≥ 1,25	Nord: ≤ 0,7 Autres: ≤ 0,6
	36-45%	≤ 0,49	≤ 0,55	≤ 1,90	≥ 1,25	Nord : ≤ 0,6 Autres: ≤ 0,5
Regulatory climatic zone Z5	≤ 15%	≤ 0,65	≤ 0,80	≤ 3,30	≥ 1,00	NE
	16-25%	≤ 0,65	≤ 0,70	≤ 3,30	≥ 1,00	Nord: NE Autres: ≤ 0,7

	26-35%	≤ 0,55	≤ 0,60	≤ 2,60	≥ 1,00	Nord M: ≤ 0,6 Autres: ≤ 0,4
	36-45%	≤ 0,49	≤ 0,55	≤ 1,90	≥ 1,00	Nord: ≤ 0,5 Autres: ≤ 0,3
Regulatory climatic zone Z6	≤ 15%	≤ 0,65	≤ 0,80	≤ 3,30	≥ 1,00	NE
	16-25%	≤ 0,65	≤ 0,70	≤ 3,30	≥ 1,00	Nord NE Autres: ≤ 0,7
	26-35%	≤ 0,55	≤ 0,60	≤ 2,60	≥ 1,00	Nord: ≤ 0,6 Autres: ≤ 0,4
	36-45%	≤ 0,49	≤ 0,55	≤ 1,90	≥ 1,00	Nord: ≤ 0,5 Autres: ≤ 0,3

For our reference building, we chose an ACH value of 1 as the default infiltration rate. This decision was made based on ASHRAE standard 62.1 ("ventilation and acceptable indoor air quality in residential buildings"), which recommends that tertiary buildings should receive no less than 1 air change per hour to maintain an acceptable indoor air quality. By choosing an ACH of 1 as our reference, we aimed to represent a median airflow rate for the building in accordance with the ASHRAE standard.

In each of the five infiltration scenarios, we simulated the energy performance of the building with the specified ACH value while keeping all other building characteristics consistent with the RTCM/with natural ventilation case. This approach allowed us to isolate the impact of varying infiltration rates on the building's energy consumption and efficiency.

Processing Weather Data for Seasonal Variations

To accurately account for the seasonal variations in Ifrane's weather conditions, we processed our weather data to consider both the winter and summer periods. Typically, meteorologists define winter as the three calendar months with the lowest average temperatures. In the Northern hemisphere, this corresponds to December, January, and February. However, due to CASABLANCA's unique climate, we extended the winter period to include the months from October to April. During this winter period, we processed our weather data to align with an energy set-point of 20°C for heating, as recommended by the RTCM. For the summer period, we processed the weather data to work according to a cooling set point of 26°C, which is also in accordance with the RTCM guidelines. This approach allowed us to better understand and analyze the energy performance of the building under study, considering the specific climate conditions of CASABLANCA and the seasonal variations in temperature and radiation levels.

DISCUSSION

Infiltration Simulations

In simulation 1 and as showcase in **Figure 4** below, where the building has no energy gain besides radiation, the winter heating demands show significant differences when infiltration is taken into account.

Reference case (No-RTCM): The heating demand increases by 54.6% when infiltration is considered, rising from 414,018 kWh to 640,018 kWh. As the building does not follow RTCM standards and lacks natural ventilation, this figure represents the energy consumption for heating without any energy-efficient measures in place.

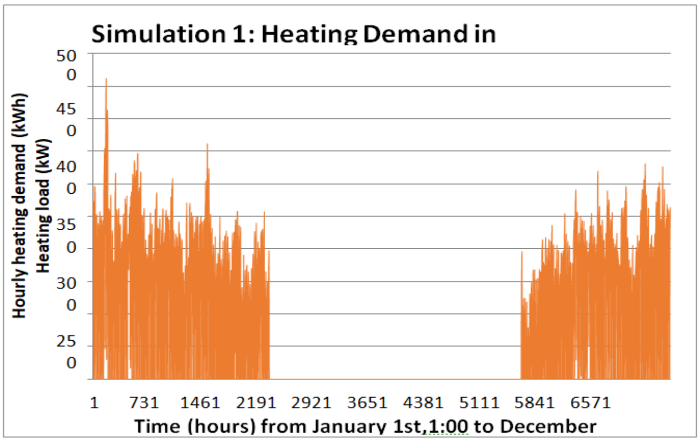

Figure 4: Heating demand for reference case.

RTCM case: The heating demand increases by 71.5% when infiltration is considered, rising from 302,926 kWh to 519,339 kWh (**Figure 5**).

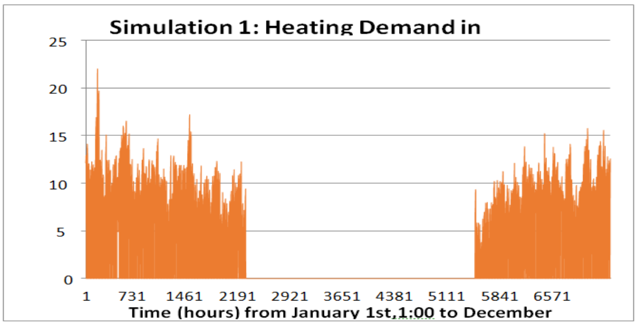

Figure 5: Heating demand for RTCM with no natural ventilation 6-simulation.

These results indicate the importance of considering infiltration in the building energy performance analysis. The RTCM case demonstrates better energy performance compared to the reference case, with a 26.9% reduction in heating demand without infiltration and an 18.8% reduction with infiltration considered (**Table 2**).

Table 2: Comparison between simulations 1 case.

Winter heating demands	Reference case No-RTCM	RCTM
No infiltration taken into account	414018	302926
Infiltration Taken into account	640018	519338

Cooling Energy Demand in Summer per Scenario

The following is a result analysis of the summer cooling energy demands for the three simulations with two case studies (Reference Case No-RTCM and RTCM), considering the impact of Natural Ventilation (NV) as a cooling strategy (**Table 3**).

Table 3: Simulation 2: Air infiltration cooling demand reduction.

Case	No NV (kWh)	NV (kWh)	Cooling demand reduction (%)
Reference (No-RTCM)	1,82,178	1,80,074	1.15%
RTCM	1,95,346	1,84,308	5.65%

In simulation 1, when NV is taken into account, the cooling demand for the reference case No-RTCM is reduced by 1.15% (from 182,178 kWh to 180,074 kWh). In the RTCM case, the cooling demand is reduced by 5.65% (from 195,346 kWh to 184,308 kWh). NV proves to be more beneficial in the RTCM case for this simulation as seen in **Figure 3**.

Infiltration Simulations

In the infiltration simulation results, we examined five different scenarios with varying ACH values: 0.5, 0.6, 1 (reference case), 1.4, and 1.6. The main focus of our analysis was the impact of these different ACH values on the yearly space heating and cooling energy demands. When the ACH value was set to 0.5, the yearly space heating energy demand was found to be significantly lower at 489,409 kWh compared to the reference ACH value of 1. However, the yearly space cooling energy demand increased to 776,774 kWh, which was higher than the reference case. In the scenario with an ACH value of 0.6, the yearly space heating energy demand was still lower than the reference case at 514,128 kWh. Similarly, the yearly space cooling energy demand was higher, registering at 768,433 kWh (**Figure 6**).

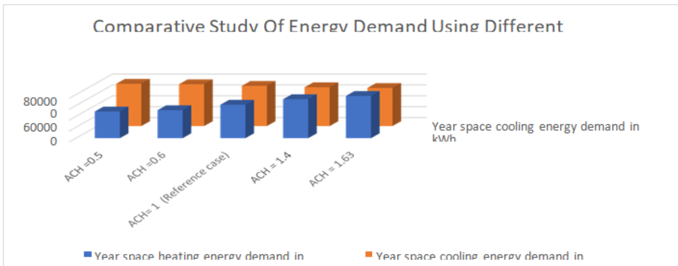

Figure 6: Comparative study of energy demand using different ACH.

For the reference case with an ACH value of 1, the yearly space heating energy demand was 614,082 kWh, while the yearly space cooling energy demand was 738,250 kWh. When we increased the ACH value to 1.4, the yearly space heating energy demand rose to 716,088 kWh, which was higher than the reference case. On the other hand, the yearly space cooling energy demand slightly decreased to 712,518 kWh. Lastly, with an ACH value of 1.6, the yearly space heating energy demand reached its highest point among all considered ACH values, totaling 775,643 kWh. The yearly space cooling energy demand was at its lowest point, measuring 699,514 kWh. Through this analysis, it became evident that as the ACH value increases, the space heating energy demand also increases, while the space cooling energy demand decreases.

These findings emphasize the importance of selecting an appropriate infiltration rate to optimize a building's energy performance (**Figure 7**).

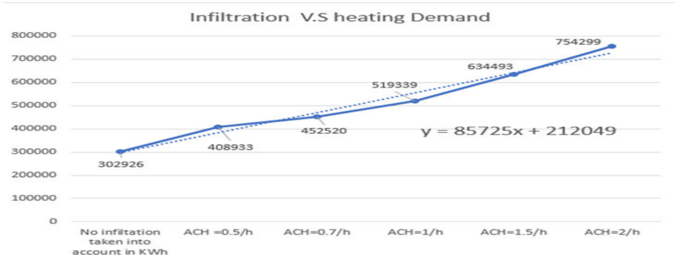

Figure 7: Linear fit for correlation between air infiltration and heating demand

Energy Efficiency using Natural Ventilation

Implementing natural ventilation has shown remarkable improvements in the energy efficiency of buildings. When analyzing the three building cases with the different simulations we can see how the introduction of natural ventilation impacts the cooling energy demand for a city such as Ifrane: The climatic structure of Ifrane minimally need cooling compared to other climatic zones. This supports our reasoning for the impact that natural ventilation will be having by projection in other cities that need cooling (**Table 4**). The energy savings comparison table below details the energy savings and percentage reduction in energy demand for each transition between building cases:

Table 4: Energy efficiency using natural ventilation.

Simulation	Case	No NV (kWh)	NV (kWh)	Cooling demand reduction (%)
1	Reference (No-RTCM)	1,82,178	1,80,074	1.15%
1	RTCM	1,95,346	1,84,308	5.65%
2	Reference (No-RTCM)	2,14,251	2,06,008	3.84%
2	RTCM	2,29,631	2,11,756	7.78%
3	Reference (No-RTCM)	3,30,802	3,23,019	2.35%
3	RTCM	3,43,993	3,29,136	4.31%

We can see from **Table 4** that incorporating NV into the building designs results in cooling demand reductions ranging from 1.15% to 7.78%. This translates into improved energy efficiency across all scenarios, with more significant benefits observed in the RTCM cases.

The economic analysis for the three simulation in different 2 cases (reference case, RTCM/No natural ventilation) highlight the financial benefits of implementing natural ventilation strategies in building design. First, let's examine the real cost of energy consumption for each case. By multiplying the total energy demand (in kWh) by the price cost per kWh (1.5 MAD) which is the tariff implemented by ONEE (Reference), we can calculate the real cost for each scenario (**Table 5**).

Table 5: Economic analysis using natural ventilation.

Simulation	Case	No NV cost (MAD)	NV cost (MAD)	Cost savings (MAD)
1	Reference (No-RTCM)	2,73,267	2,70,111	3,156
1	RTCM	2,93,019	2,76,462	16,557
2	Reference (No-RTCM)	3,21,376.50	3,09,012	12,364.50
2	RTCM	3,44,446.50	3,17,634	26,812.50
3	Reference (No-RTCM)	4,96,203	4,84,528.50	11,674.50
3	RTCM	5,15,989.50	4,93,704	22,285.50

When comparing the real costs, we see from **Table 5** demonstrates that incorporating NV leads to cost savings in all scenarios. The savings range from 3,156 MAD to 26,812.50 MAD, with the most significant savings observed in the RTCM cases.

The analysis indicates that incorporating natural ventilation in building design can lead to substantial cost savings. The energy cost savings resulting from the implementation of natural ventilation can be further invested in other energy efficiency measures or channeled into other areas of the building's operation and maintenance.

Environmental analysis: Incorporating natural ventilation in building design not only leads to energy and cost savings but also contributes to reducing the environmental impact through lower greenhouse gas emissions. In this analysis, we consider the environmental benefits of implementing natural ventilation strategies by estimating the avoided CO_2 emissions for each case transition (Table 6).

To calculate the avoided CO_2 emissions, we can multiply the energy savings (in kWh) by the emission factor of 0.715 kg CO_2 eq/kWh. This assumes that heating and cooling energy are sourced from the grid and use electricity.

Table 6: Environmental analysis using natural ventilation.

Simulation	Case	No NV emissions (kg CO_2 eq)	NV emissions (kg CO_2 eq)	Avoided emissions (kg CO_2 eq)
1	Reference (No-RTCM)	1,30,207.10	1,28,752.90	1,454.20
1	RTCM	1,39,572.90	1,31,820.20	7,752.70
2	Reference (No-RTCM)	1,53,139.65	1,47,405.70	5,733.95
2	RTCM	1,64,156.35	1,51,450.40	12,705.95
3	Reference (No-RTCM)	2,36,373.30	2,30,960.35	5,412.95
3	RTCM	2,45,760.05	2,35,317.20	10,442.85

These results indicate that implementing natural ventilation strategies can substantially reduce the building's environmental footprint. The avoided CO_2 emissions range from 1,454.20 kg CO_2 eq to 12,705.95 kg CO_2 eq across all scenarios. The most significant emission reduction occurs when transitioning from the reference case to RTCM/with no natural ventilation, resulting in a 16.03% decrease in CO_2 emissions. This reduction in greenhouse gas emissions contributes to mitigating climate change and improving local air quality. It can be seen that Table 6 highlights the environmental benefits of incorporating NV into building designs. This indicates that incorporating NV as a cooling strategy contributes to a more sustainable and eco-friendly building design, with the most significant benefits observed in the RTCM cases. Furthermore, the environmental benefits of natural ventilation extend beyond CO_2 emission reductions. By promoting air circulation and reducing reliance on mechanical ventilation systems, natural ventilation can contribute to improved indoor air quality, fostering a healthier environment for building occupants. Moreover, reducing the need for energy-intensive heating and cooling systems can lead to lower demand for electricity generation, thus decreasing the pressure on power plants and promoting a more sustainable energy infrastructure.

Importance of Natural Ventilation in Cold Climate-Winter

Natural ventilation is often overlooked or avoided in cold climates during winter, as it is perceived to result in heat loss and increased energy consumption. While this is true, natural ventilation offers numerous benefits to both occupants and buildings during winter. One key advantage is improved indoor air quality, reducing exposure to harmful pollutants. Indoor air quality is crucial for health and well-being, particularly in winter when people spend more time inside airtight buildings designed for energy efficiency. These structures can trap pollutants like CO_2, VOCs, PM, radon, mold, and bacteria, which can adversely affect health, cognitive performance, productivity, mood, and comfort. Natural ventilation can alleviate these issues by introducing fresh outdoor air and removing stale indoor air, thereby reducing pollutant concentration and improving oxygen levels and humidity balance. Studies have shown natural ventilation's positive effects on indoor air quality and health. For instance, Zhang et al. reported a 42% CO_2 reduction and a 78% VOC reduction in office buildings during winter. Li et al. found a 52% decrease in PM levels and a 67% reduction in radon levels in residential buildings. Wargocki et al. demonstrated an 8% improvement in cognitive performance and productivity, and a 20% reduction in sick building syndrome symptoms in office buildings. Natural ventilation effectively enhances indoor air quality, health, and overall comfort during winter. However, it faces challenges and limitations related to weather conditions, noise levels, security issues, or building design constraints, and may require occupants to adjust their behaviors for optimal performance. These concerns will be addressed in the following sections of this report.

IN RTCM to ensure more accurate energy demand calculations and the implementation of appropriate energy efficiency measures (Table 7 and Figure 8).

Our simulation results demonstrate the significant impact of infiltration on heating demands, highlighting the importance of considering infiltration in energy calculations.

Table 7: Heating demands and increase due to Infiltration (kWh and %)

Simulation	Case	No infiltration(kWh)	Infiltration (kWh)	Increase (%)
1	Reference (No-RTCM)	4,14,018	6,40,018	54.6
1	RTCM	3,02,926	5,19,339	71.5
2	Reference (No-RTCM)	3,88,534	6,09,480	56.9
2	RTCM	2,79,500	4,91,599	75.8
3	Reference (No-RTCM)	4,12,204	6,41,744	55.7
3	RTCM	2,98,741	5,19,604	73.9

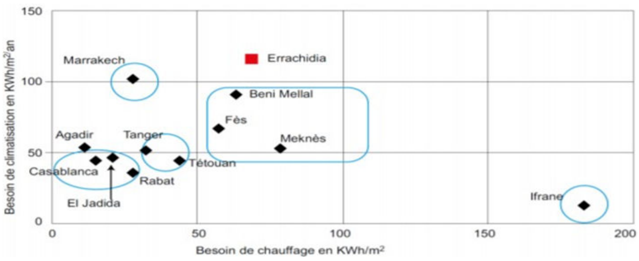

Figure 8: Heating demands in KWh/m^2 in Morocco.

By using the additional energy consumption due to infiltration, we can calculate the additional costs incurred. These figures highlight the substantial economic impact of not accounting for infiltration in energy demand calculations. The following table shows the additional cost for each scenario (**Table 8**).

Table 8: Additional cost due to infiltration (MAD).

Simulation	Case	No infiltration	Infiltration	Additional cost
1	Reference (No-RTCM)	6,21,027	9,60,027	3,39,000
1	RTCM	4,54,389	7,79,008	3,24,619
2	Reference (No-RTCM)	5,82,801	9,13,731	3,30,930
2	RTCM	4,19,250	7,37,398	3,17,148
3	Reference (No-RTCM)	6,18,306	9,62,166	3,43,860
3	RTCM	4,48,111	7,79,403	3,31,292

And we can als estimate the potential environmental benefits of considering infiltration in energy calculations. To do this, we can calculate the avoided CO_2 emissions using energy savings and an emission factor.

The following Table 9 shows the avoided CO_2 emissions for each scenario using an emission factor of 0.6 kg CO_2 eq/kWh (assuming a mix of energy sources) (**Table 9**).

Table 9: Avoided CO_2 emissions due to infiltration (kg CO_2 eq).

Simulation	Case	No infiltration (kWh)	Infiltration (kWh)	Avoided CO_2 emissions
1	Reference (No-RTCM)	2,48,410.80	3,84,010.80	1,35,600
1	RTCM	1,81,755.60	3,11,603.40	1,29,847.80
2	Reference (No-RTCM)	2,33,120.40	3,65,688	1,32,567.60
2	RTCM	1,67,700	2,94,959.40	1,27,259.40
3	Reference (No-RTCM)	2,47,322.40	3,84,646.40	1,37,324
3	RTCM	1,79,244.60	3,11,762.40	1,32,517.80

These results indicate that considering infiltration in energy demand calculations can lead to significant environmental benefits by reducing CO_2 emissions. The data emphasizes the importance of including infiltration in energy calculations for a more comprehensive understanding of a building's energy performance and environmental impact.

CONCLUSION

This article has conducted an in-depth investigation of natural ventilation and infiltration strategies in the context of the Moroccan Thermal Regulation for Construction (RTCM) and the specific climate conditions of Ifrane, Morocco. The study has examined the impact of these strategies on energy efficiency, economic performance, and environmental sustainability of buildings. A comprehensive analysis of data collected from simulations based on three building scenarios and various Air Change per Hour (ACH) values has provided valuable insights into the effectiveness of various natural ventilation and infiltration strategies in enhancing building performance.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

COMPLIANCE WITH ETHICAL STANDARDS

This article does not contain any studies involving human or animal subjects.

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