International Journal of Applied Sciences: Current and Future Research Trends
(IJASCFRT)
ISSN: 2790-3990
https://ijascfrtjournal.isrra.org/index.php/Applied_Sciences_Journal

Energy Efficiency in Buildings Envelope

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Abstract

Morocco has a well-developed institutional and legal framework and an agile private sector. This is the basis for energy efficiency in buildings projects, especially in the residential and tertiary sector. Enforcement and development of further regulations and of financial mechanisms for residential housing .So this 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. The 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.

Keywords: Energy efficency (RTCM); Natural ventilation; Air infiltration; Building.

1. Introduction

The Energy efficiency is getting the maximum use from energy consumed.

Received: 3/24/2024
Accepted: 5/24/2024
Published: 6/2/2024

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This is a simple statement, yet characterizing energy efficiency is a complex task. Energy efficiency goes beyond a single product or policy. It encompasses a range of technologies, behaviors, designs, and industries, and it has relevant applications to most sectors of the economy and all U.S. geographies. It can respond to various market and policy signals and unlock financing strategies to achieve energy savings. The range of energy efficiency adds up to a massive, accessible, and low-cost, zero-carbon energy resource.

The energy efficiency of energy systems is classically assessed by looking at the energy conversion efficiency (η), (Greek letter Eta). The most common example of calculating energy efficiency is a conventional power plant where heat is converted into electricity by using a turbine and a generator. In such thermal power plants, energy input would refer to the heat fed into the process and the electricity produced as the useful output. Both elements are energy flows and can be quantified by using thermodynamic calculations which result in an absolute value for efficiency.

Unfortunately, such a straight forward procedure is not always applicable: For example modern light bulbs with LED technology are able to provide a light with brightness or more accurately, with visible light of 1000 lumen with electricity input of 20 Watt. On the other hand, the old incandescent light bulb technology needs five times more electricity input to provide the same brightness of visible light.

The LED uses the input resource in a more efficient way. However, we have to be aware that this comparison is only acceptable when the output or service is really the same in both technologies. In the case of a light bulb, some people might say that brightness is the only important factor, but others might argue, the LED provides a different light colour and therefore a different or less valuable service than the incandescent bulb. “Therefore, it is worth distinguishing between quality and quantity of output service. Evaluating the quality of services is generally difficult, especially when multiple services are provided by the system subject to analysis[8.9]“.

In addition, it is important to closely look at the denominator of the efficiency equation (the energy input).(3.4.6)When comparing different technologies with one another, not only the end use appliances (like a light bulb) might be changed but also the form of energy input. For example, changing a system in which power and heat are conventionally generated in separate generation cycles while waste heat remains unused to a a) more efficient system with heat reuse and heat recovery or b) even to a combined heat & power supply (co-generation facilities) system. Now the energy production itself should be incorporated into the evaluation of efficiency.

Figure 11: 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 theintroduction 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 ourreasoning for the impact that natural ventilation will be having by projection in other cities that need cooling .

The energy savings comparison table below details the energy savings and percentage reduction in energy demand for each transition between building cases:

Table 1: Energy Efficiency using Natural Ventilation

Simulation	Case	No NV (kWh)	NV (kWh)	Cooling Demand Reduction(%)
1	**Reference (No-RTCM)**	**182,178**	**180,074**	**1.15%**
1	**RTCM**	**195,346**	**184,308**	**5.65%**
2	**Reference (No-RTCM)**	**214,251**	**206,008**	**3.84%**
2	**RTCM**	**229,631**	**211,756**	**7.78%**
3	**Reference (No-RTCM)**	**330,802**	**323,019**	**2.35%**
3	**RTCM**	**343,993**	**329,136**	**4.31%**

We can see from table 5.4 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.

2. The Energy Efficiency – Global Dimension and Co-Benefits

The International Energy Efficiency Agency (IEEA) considers energy efficiency as "the world's first fuel". On global level more than half of the worldwide consumed primary energy is lost in production processes, by transport and general energy consumption. The resulting global high energy efficiency has hardly been captured. Facing this situation, energy efficiency has also gained high attention on the international political agenda: e.g.

energy efficiency is incorporated into the new global agenda of „Sustainable Development Goals" (SDGs), and as 2/3 of global Greenhouse Gas Emissions (GHG) derive from energy consumption (of power, fossil fuels etc.), energy efficiency is also a key for climate protection and will play a major role in international processes for realizing global climate goals (after COP21 in Paris). Besides high climate relevance, energy efficiency increase also addresses various so-called co-benefits (or multiple' benefits): security of energy supply, import improvements, increased productivity & economic growth, modernization of facilities and more.

Overview on common energy efficiency measures & technologies for agricultural value chains: As the agri-food sector heavily depends on fossil fuel inputs (for production, transport, processing, and distribution), and as this energy demand will even increase due to growing global food demand, opportunities for real energy savings are numerous along many agri-food chains – by increasing energy efficiency and using energy more wisely to avoid wasting it.

3. The indicators in this report highlight several key features of energy efficiency

The Energy efficiency delivers savings, creates jobs, and reduces emissions.

For decades energy efficiency has delivered savings by doubling economy-wide energy productivity, lowering per-capita energy consumption, and slashing carbon emissions and air pollutants. The investments are driven by a combination of markets and government programs and policies: research and development funding, building energy codes and appliance and fuel economy standards, utility programs and energy efficiency resource standards, certification and benchmarking programs, technical assistance, and financing tools. Investing in energy efficiency is not dependent on a single strategy, policy, or technology, but is available through a portfolio approach with tremendous diversity and breadth.

4. Energy efficiency works

As an energy resource, energy efficiency is proven, affordable and reliable. In our energy systems, we plan for it, count on it, and it helps to keep the lights on. Energy efficiency is recognized as a resource in capacity markets and integrated resource plans, and as an alternative to building new infrastructure. Governments, utilities, and corporations know, trust, and rely on energy efficiency, have done so for decades, and continue to do so now more than ever. And when compared with investments in supply-side generation, efficiency is often the least cost option, even as the electric grid becomes increasingly renewable. Energy efficiency is high-impact, large-scale, and growing to meet new needs.

Our energy efficiency potential is larger-scale and more powerful than generally realized, and new energy efficiency technologies, like electric vehicles, heat pumps, and connected devices and controls, are scaling up quickly, increasing this potential further. As these efficient technologies become increasingly effective and affordable, their usage can grow to meet today's challenges.

5. Energy efficiency is a reliable and low-cost, distributed resource

Energy efficiency is the foundation of deep decarbonization and is also one of the best-established and most-implemented examples of a distributed and zero-carbon resource that usually does not require additional land use. Energy efficiency, together with grid integration technologies, also plays an important role in shaping electricity demand to match supply, features that make it an enabler in deploying variable renewable resources. However, the scale of energy efficiency required for deep decarbonization dwarfs the current size of energy efficiency investments.

6. Energy efficiency is a distributed and zero-carbon resource

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7. Energy efficiency can improve people’s lives

By reducing emissions and air pollutants, energy efficiency can deliver major public health benefits—such as avoided respiratory and cardiovascular illnesses, and avoided premature deaths—each year. Energy efficiency can also lower home energy costs, improve home comfort, increase grid reliability and resilience to weather disasters, and reduce the need for individuals to forego other necessities in order to pay their energy bills.

8. Energy efficiency is key to achieving tomorrow’s objectives

Whether we’re seeking to boost economic productivity, improve air quality or meet climate-related emissions reductions objectives, energy efficiency is a foundational tool to achieve these goals. Just as our progress to date has relied on extensive policy and programmatic support, ensuring we take full advantage of tomorrow’s energy efficiency will require sustained commitment to use our energy well.

9. Economic Analysis

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 2 : Economic Analysis Using Natural ventilation.

Simulation	Case	No NV Cost (MAD)	NV Cost (MAD)	Cost Savings (MAD)
1	Reference (No-RTCM)	273,267	270,111	3,156
1	RTCM	293,019	276,462	16,557
2	Reference (No-RTCM)	321,376.50	309,012	12,364.50
2	RTCM	344,446.50	317,634	26,812.50
3	Reference (No-RTCM)	496,203	484,528.50	11,674.50
3	RTCM	515,989.50	493,704	22,285.50

When comparing the real costs, we see from Table 2 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.

10. 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 CO2 emissions for each case transition.

To calculate the avoided CO2 emissions, we can multiply the energy savings (in kWh) by the emission factor of 0.715 kg CO2eq/kWh. This assumes that heating and cooling energy are sourced from the gridand use electricity:

Table 3: Environmental Analysis Using Natural Ventilation

Simulation	Case	No NV Emissions (kg CO2eq)	NV Emissions (kg CO2eq)	Avoided Emissions (kg CO2eq)
1	Reference (No-RTCM)	130,207.10	128,752.90	1,454.20
1	RTCM	139,572.90	131,820.20	7,752.70
2	Reference (No-RTCM)	153,139.65	147,405.70	5,733.95
2	RTCM	164,156.35	151,450.40	12,705.95
3	Reference (No-RTCM)	236,373.30	230,960.35	5,412.95
3	RTCM	245,760.05	235,317.20	10,442.85

These results indicate that implementing natural ventilation strategies can substantially reduce the building's environmental footprint. The avoided CO2 emissions range from 1,454.20 kg CO2eq to 12,705.95 kg CO2eq 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 CO2 emissions. This reduction in greenhouse gas emissions contributes to mitigating climate change and improving local air quality. It can be seen that Table 5.6 highlights the environmental benefitsof 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 CO2 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.

11. 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 CO2, 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 and his colleagues [62] reported a 42% CO2 reduction and a 78% VOC reduction in office buildings during winter. Li and his colleagues [63] found a 52% decrease in PM levels and a 67% reduction in radon levels in residential buildings. Wargocki and his colleagues [64] demonstrated an 8% improvement in cognitive performance and productivity, and a 20% reduction in sick building syndrome symptoms in office buildings. Natural ventilation effectivelyenhances 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.

12. Air Infiltration and Moroccan Thermal Construction

Regulation:Impact of the Simulation

Our Simulation conducted in Ifrane served to emphasize the significance of infiltration as a critical parameter in building energy performance assessments. Despite its importance, the Moroccan Thermal Construction Regulation (RTCM) does not currently account for infiltration, which, as evidenced by ourSimulation, could lead to inaccuracies in energy demand calculations, especially for heating and coolingsystems.

One potential explanation for the exclusion of infiltration in the RTCM is the variation in specific heating and cooling energy demands across Morocco's different climatic zones. Most climatic zones in the country have relatively similar climatic demands, which allows for a certain degree of infiltration to be tolerated in winter and even appreciated during the summer season.

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Table 4: Heating Demands and Increase due to Infiltration (kWh and %)

Simulation	Case	No Infiltration(kWh)	Infiltration(kWh)	Increase(%)
1	**Reference (No-RTCM)**	**414,018**	**640,018**	**54.6**
1	**RTCM**	**302,926**	**519,339**	**71.5**
2	**Reference (No-RTCM)**	**388,534**	**609,480**	**56.9**
2	**RTCM**	**279,500**	**491,599**	**75.8**
3	**Reference (No-RTCM)**	**412,204**	**641,744**	**55.7**
3	**RTCM**	**298,741**	**519,604**	**73.9**

Necessity of Including Air Infiltration in RTCM for Ifrane (Climatic Zone 4): Lessons from the Simulation

As highlighted in the Figure 1 below, mountainous regions like Ifrane have exceptional heating demands and relatively conditionally cooling demands, setting them apart from other climatic zones in Morocco. The absence of infiltration guidelines within the RTCM, as our simulation results indicated, leads to a lack of standardization and uniformity in the regulations applied across the country.

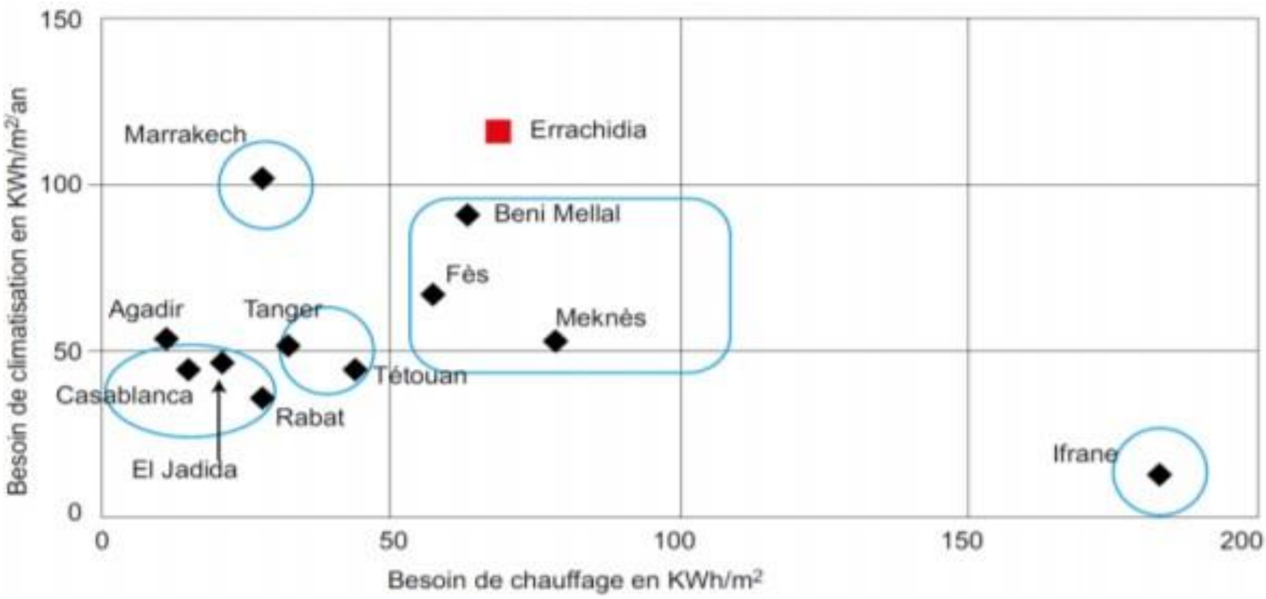

Figure 1: Heating demands in KWh/m2 in Morocco .

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 5: Additional Cost due to Infiltration (MAD)

Simulation	Case	No Infiltration	Infiltration	Additional Cost
1	**Reference (No-RTCM)**	**621,027**	**960,027**	**339,000**
1	**RTCM**	**454,389**	**779,008**	**324,619**
2	**Reference (No-RTCM)**	**582,801**	**913,731**	**330,930**
2	**RTCM**	**419,250**	**737,398**	**317,148**
3	**Reference (No-RTCM)**	**618,306**	**962,166**	**343,860**
3	**RTCM**	**448,111**	**779,403**	**331,292**

And we can als estimate the potential environmental benefits of considering infiltration in energy calculations. To do this, we can calculate the avoided CO2 emissions using energy savings and an emission factor. The following table shows the avoided CO2 emissions for each scenario using an emission factor of 0.6 kg CO2eq/kWh (assuming a mix of energy sources):

These results indicate that considering infiltration in energy demand calculations can lead to significant environmental benefits by reducing CO2 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.

Table 6: Avoided CO2 Emissions due to Infiltration (kg CO2eq)

Simulation	Case	No Infiltration(kWh)	Infiltration(kWh)	Avoided CO2 Emissions
1	Reference (No-RTCM)	248,410.8	384,010.8	135,600
1	RTCM	181,755.6	311,603.4	129,847.8
2	Reference (No-RTCM)	233,120.4	365,688	132,567.6
2	RTCM	167,700	294,959.4	127,259.4
3	Reference (No-RTCM)	247,322.4	384,646.4	137,324
3	RTCM	179,244.6	311,762.4	132,517.8

Basics of Energy Consumption Impacts

- **Economy:** U.S. total energy expenditures in 2020 were $1.01 trillion, or 4.8% of U.S. GDP, down from $1.22 trillion in 2019 (5.7% of GDP).12
- **Environment:** The combustion of fossil fuels is the primary source of greenhouse gas (GHG) emissions, including carbon dioxide (CO2), nitrogen oxides (NOx), sulfur dioxide (SO2), particulate matter, and other pollutants such as mercury. In 2020, 73% of total U.S. anthropogenic GHG emissions were due to combustion of fossil fuels.13
- **Energy volatility and costs:** Though the MOROCCO has been experiencing a period of low energy prices relative to previous periods, energy prices remain volatile. The day-to-day operations of energy-intensive industries are inextricably linked to energy prices, and these costs are often passed along to the consumer.

Efficiency Opportunities

Residential and commercial energy consumption primarily occurs indoors. Buildings are home to many energy efficiency opportunities (e.g., improving the building envelope, sourcing of construction materials, water efficiency, energy management systems, smart buildings) as well as energy-consuming products (e.g., appliances, plug loads, HVAC systems).

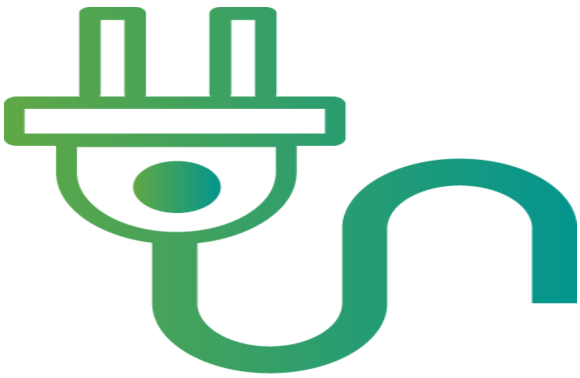

Figure12

In Morocco, annual energy consumption (all sources combined) averages 0.5 tonnes of oil equivalent per capita, and increases by 4.3% each year.

Indeed, Morocco faces two major energy challenges:

Energy dependence compared to abroad, 96.6% of energy is imported. Consumption of primary energy which increases by 5% / year.

The building sector is among the most energy-intensive sectors in Morocco with energy consumption of up to **33%, divided into 7% for commercial buildings and 26% for residential buildings**. This consumption is subject to increase given the demographic growth, the creation of new cities and the sustained use of air conditioning and heating systems that Morocco is experiencing.

Tools to Understand and Enhance Building Efficiency

Benchmarking; energy rating, such as through the Home Energy Rating System or Home Energy Score; and certification (including ENERGY STAR® and LEED) can drive efficiency in buildings. Zero net energy buildings and smart buildings are also growing rapidly.

The energy labeling standard for electrical products and appliances NM 14.2.302 relating to the requirements for air conditioners also defines the energy class of the air conditioner according to its SEER and SCOP depending on its type, as well as the different technical characteristics to be defined in the data sheets and the energy label of the air conditioner.

Figure 3

Optimizing NV with an Automatic Control System Duct:

Integrating controllable natural ventilation smart systems in building design is an essential step towards harnessing the full potential of natural ventilation while addressing its limitations. These cutting-edge systems combine automatically operated vents with carbon dioxide and temperature sensors, optimizing the supply of fresh air according to occupants' needs and ensuring energy savings alongside improved comfort levels.

One effective method to maximize natural ventilation benefits during winter, without substantially raising heating demand, involves implementing an automatic control system. This system would regulate the window opening factor based on parameters such as outdoor temperature, indoor CO2 levels, and other factors. By utilizing live meteorological data, the system can adjust natural ventilation to open windows at the warmest times of the day, providing fresh air without significantly increasing heating demand. This approach ensures that natural ventilation primarily occurs when outdoor temperatures are most favorable. If CO2 levels dip below a specified threshold, however, the system prioritizes indoor air quality over temperature considerations and modifies the ventilation accordingly.

Supporting the effectiveness of such systems, research studies have demonstrated their feasibility and benefits. A study by Wang and his colleagues [66] found that an automatic control system for natural ventilation can reduce heating demand by 11% compared to manual operation while maintaining acceptable indoor air

quality and thermal comfort. Similarly, Zhang and his colleagues [67] proposed a fuzzy logic-based control strategyfor natural ventilation, achieving energy savings of up to 23% and improving indoor air quality by 15%.

Overall, the implementation of controllable natural ventilation smart systems in building design presents a groundbreaking approach to maximizing natural ventilation advantages while overcoming its limitations. By adopting these innovative systems, we contribute to energy efficiency and create sustainable, comfortable, and aesthetically pleasing spaces, paving the way for a more sustainable futurethat should take into consideration and encouraged in terms of implementation by the Moroccan Construction regulation. The integration of controllable natural ventilation smart systems in building design represents a groundbreaking approach to maximizing the advantages of natural ventilation while overcoming its limitations. As energy efficiency and sustainability become increasingly important in contemporary architecture, this innovative solution offers a fresh perspective on the design and construction of low-energy buildings

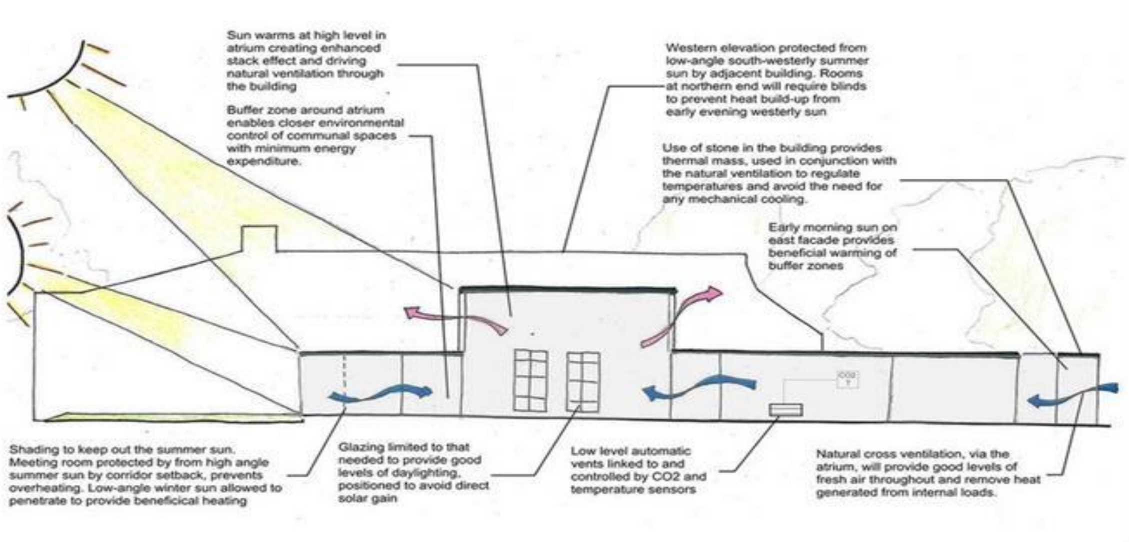

Figure 2: Optimizing NV with an Automatic Control System Duct: . [52]

By incorporating automatically operated vents linked to carbon dioxide and temperature sensors, these smart systems optimize the supply of fresh air based on the needs of the occupants. This added complexity, although deviating from the simplicity of traditional natural ventilation systems, provides significant energy savings and improved comfort levels, justifying the investment in advanced technology. As urban environments evolve, the primary sources of noise and pollution, such as gas-fired boilers and internal combustion engine vehicles, are expected to diminish. This will result in outdoor airbeing truly 'fresh,' making natural ventilation systems an even more attractive solution. Furthermore, the increasing global temperatures due to climate change necessitate the implementation of energy-efficient cooling strategies in building design. By designing naturally ventilated buildings that work in the summer, architects and engineers can utilize shading, buffer zones, and controlled cross ventilation enhanced by natural stack effect to maintain comfortable temperatures in low-energy building

Promoting Natural Ventilation: Guidelines for Moroccan BuildingStandards

In Morocco, a country characterized by diverse climatic conditions, the implementation of natural ventilation strategies is essential for reducing energy consumption and enhancing occupant comfort. A set of general guidelines outlining the basics, various design strategies, and types of natural ventilation systems, which can be embraced as recommendations within the Moroccan Thermal Construction Regulations (RTCM) is presented. These guidelines aim to provide a foundation for understanding and implementing natural ventilation principles, fostering a more sustainable and energy-efficient approach to building design in Morocco. An effective natural ventilation system must be designed to accommodate the various requirements imposed. David Etheridge [65] lists the steps to properly design a NV system:

E1. Feasibility: Ensure the technical feasibility of the NV and its integration withthe architectural design.

E2. Ventilation strategy: Define the ventilation strategy and the means of implementation.

E3. Design: Define optimal locations and sizes of openings.

E4. Modeling: Model the selected design and evaluate the comfort inside the building.

E5. Commissioning: of control systems, measurement packs, etc...

Feasibility and Adaptation:

For effective passive cooling, natural ventilation in Morocco must take into account:

- **RTCM climate Zone:** The indoor temperature must be higher than the outdoor temperature, which for effective cooling must be lower than the comfort temperature.

Thermal insulation: The most important requirement for passive cooling to

work is to keep the heat out. This requires, first of all, good thermal insulation of the building and efficient solar protection. Secondly, the natural ventilation during the day must be reduced to avoid the infiltration of warm air.

- **Solar protection:** It is important to specify that effective solar protection is donefrom the outside. In addition, it must be controlled so that it meets the needs of the user (Contribution of lighting / Reduction of heat gain).
- **Limit internal gains:** Electrical installations and appliances, artificial lighting and computers are major sources of heat, limiting the use of these devices is veryimportant. Natural lighting must be favored because of the energy gain it allows.In addition, it must be controlled to avoid heat gain.
- **Thermal inertia:** The thermal inertia of the envelope limits the increase of the internal temperature due to internal heat gain. An envelope with good thermal inertia is composed of materials with the ability to store heat and release it in cold weather **[**65].

Ventilation Strategies:

Air inlet/outlet by ventilation:

Wind and thermal draft are the primary driving forces of natural ventilation, natural ventilation strategies relying on both air sources are

<u>One-sided ventilation:</u>

The cooling of a room in a building is achieved by the entry of air through an opening. This movement is due to the pressure difference created by the wind or thermal draught in case the inside temperature is higher than the outside temperature. The internal thermal draft (in the room) facilitates the entry of fresh air through the lower part of the opening and the exit of warm air through the upper part of the same opening. . **[**65**].**

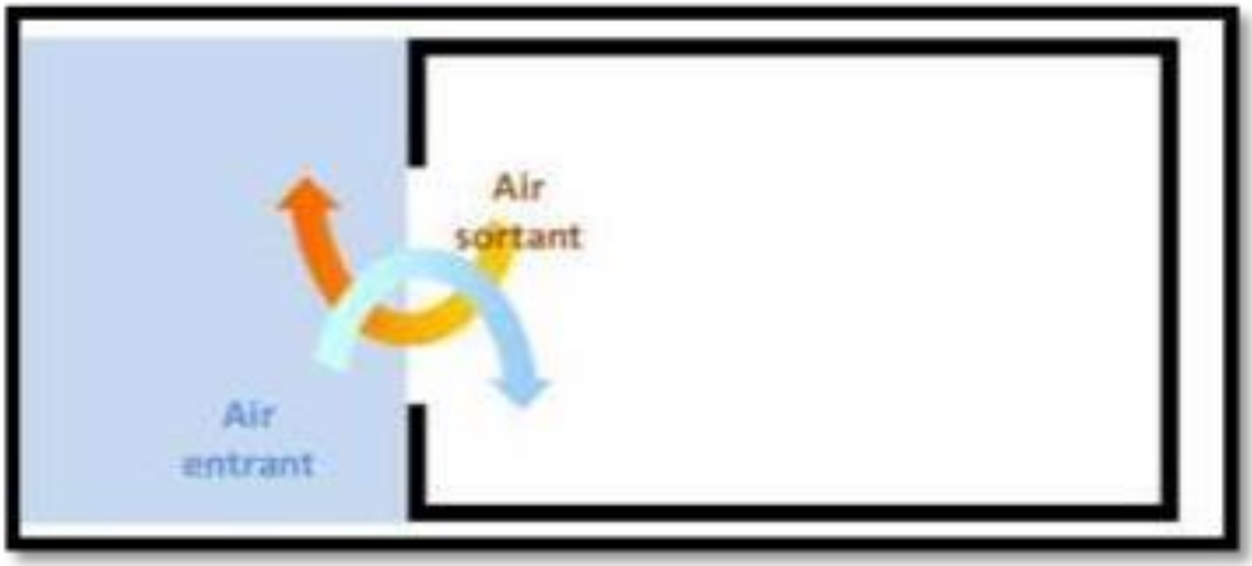

Figure 3: Schematization of the NV by effect of the thermal draft [68]

a. Through-ventilation by wind effect:

The wind passing through the building creates a pressure difference, which induces a cross ventilation flow. This results in air entering on one side and leaving on the other, sweeping across the room.In an open area (without mask effect), we can assume that the wind pressurerequired for this type of ventilation i s 10 Pa. In an urban area the pressure is much lower than this value. Therefore, the envelope must present less resistance through large openings.

This type of ventilation has many disadvantages:

- It depends on the wind direction and its speed: the change o f one of these two parameters can induce a pressure drop and thus the natural ventilation does not fulfill its role.
- It allows the propagation of pollutants.

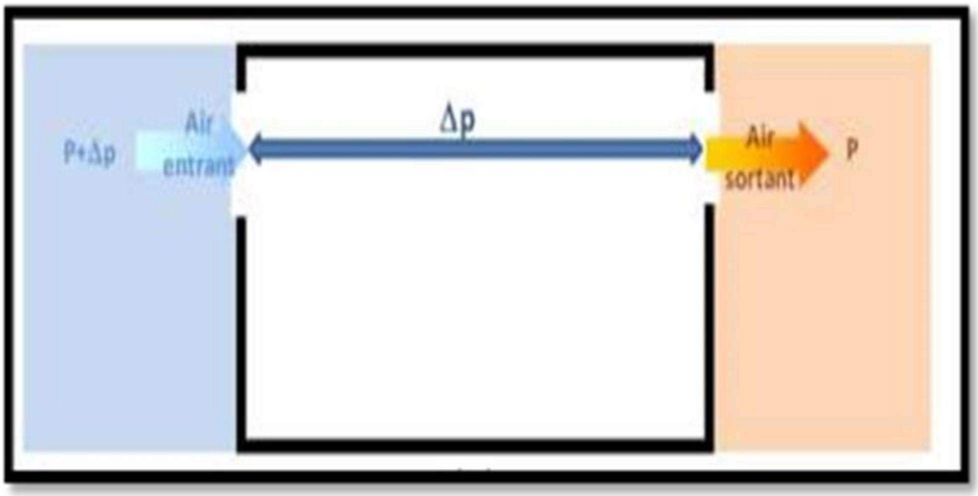

Figure 4: Schematic of the NV by wind effect [68]

b. Stacked thermal draft ventilation:

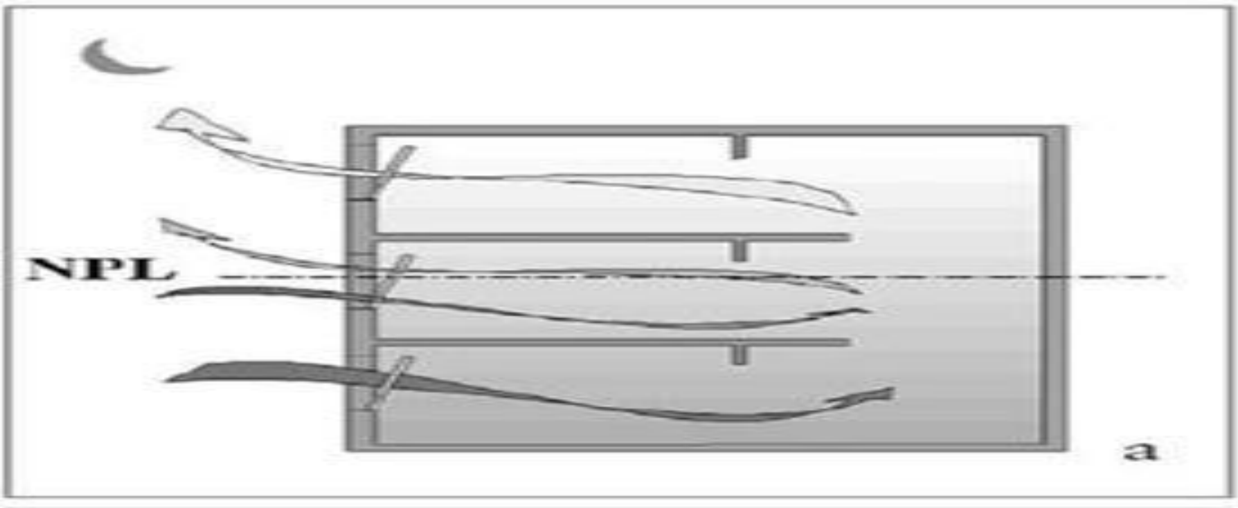

Figure 6: Diagram of the Balanced Stacked Ventilation [69]

The outside atmosphere is colder than the inside of the building, so the introduction of outside air through the lower openings allows the warm air to be moved upwards and extracted through the upper openings. This process requires large openings to guarantee a good air introduction. The incoming air flow rate increases with the temperature difference and the vertical distance between openings. For a correct design of natural ventilation, it is necessary to introduce the concept of the NPL (Neutral Pressure Level); it is defined as the level for which the incoming and outgoing airflow are balanced. Above the NPL, air cannot be introduced under any circumstances. On this basis, the exhaust openings must be large so that the NPL is as high aspossible. This strategy is well suited to the high rise building **[**68**].**

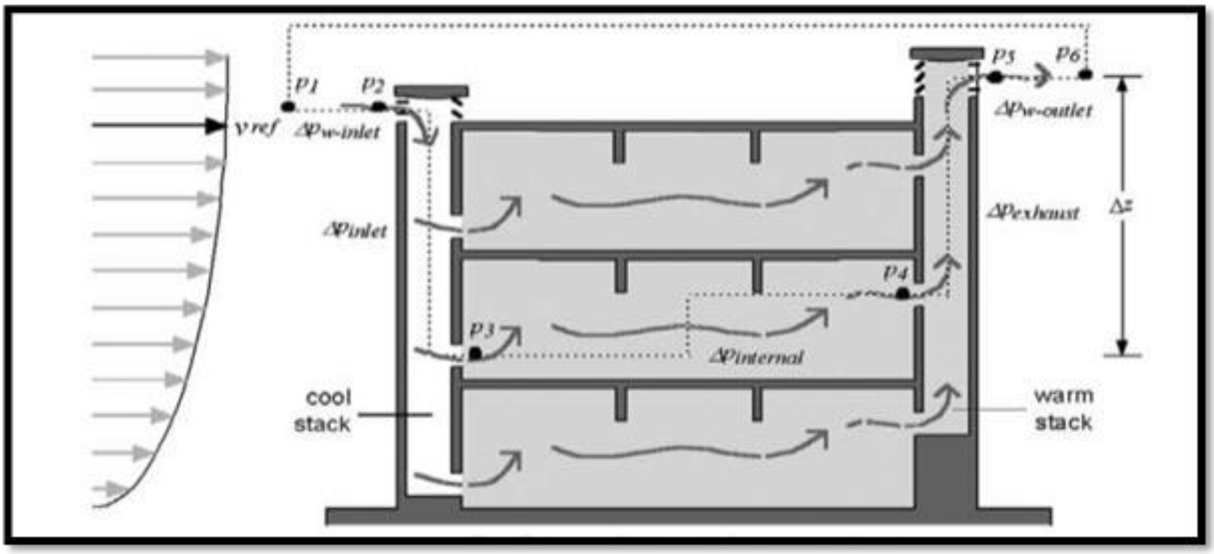

Figure 5 : Diagram of the NV by stacked thermal draft effect [69]

c. Balanced stacked ventilation:

The fresh air is introduced through a chimney that divides the incoming air flow amongthe

different floors, while the extraction of the air flow is done through another chimney. This method requires additional devices such as chimney pipes and sensors of wind **[56].**

Double skin facade:

This process consists of using two skins for the façade, with fresh air introduced through the space between the two skins. It has the advantage of reducing heat loss. Indeed, it allows, in winter, to introduce air preheated by solar radiation. In summer, this quality becomes a major drawback since it induces an overheating of the introduced air, which can be avoided by opting for a solar protection in system (Par reflexion). In addition, it allows secure night ventilation since the external skin protectsthe interior from the violent wind and the showers. Air circuit inside the building [70].

d. Sweep ventilation:

The principle of the ventilation by sweeping consists in introducing, in a permanent way, the new air in the main rooms of the dwelling and in extracting it in the service rooms. The new air enters through openings (windows, ventilators,...), and transits in the rest of the building via the undercutting under the doors or the transit grilles. The stale air is extracted in the service rooms (W.C., S.D.B, Kitchen,...) by openings (Windows or extract units). In conclusion, the transfer of air is from the less polluted areas to the polluted areas.

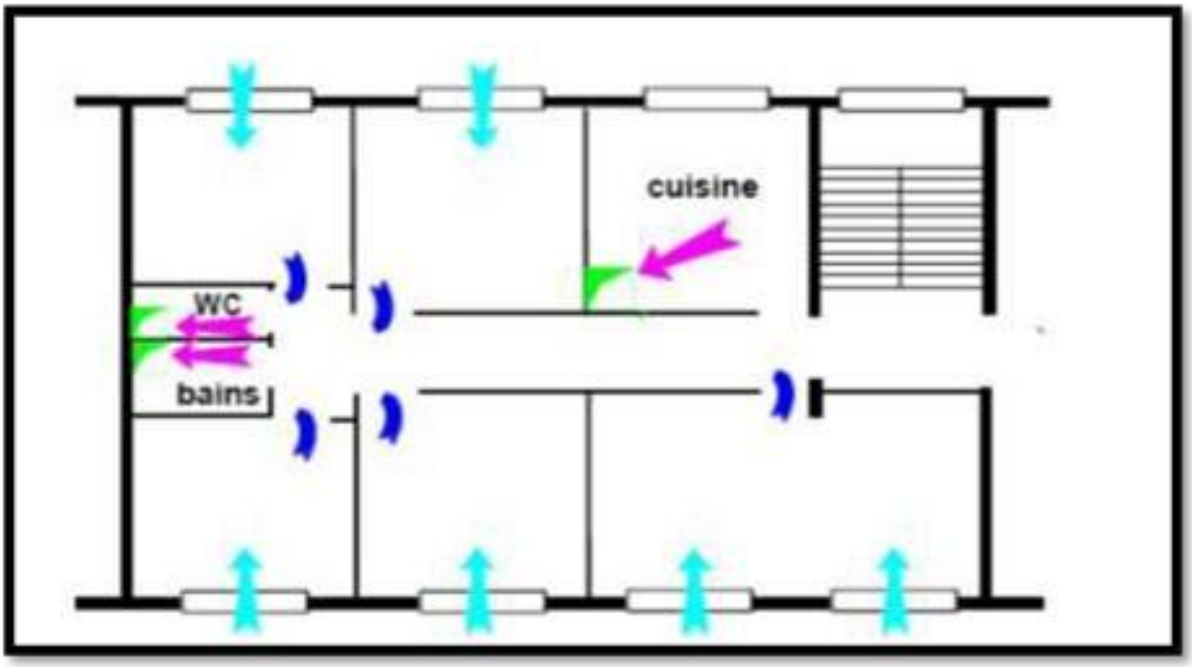

Figure 7: Schematic of the ventilation by sweeping [70].

Ventilation by separate rooms :

The air intake and exhaust are in the same room:

- ✓ Through a single large orifice such as windows.
- ✓ Either by two openings in the façade, or by an opening in the façade and a naturaldraft duct.
- ✓ Or, finally, by a mechanical system ensuring in the same room the supply o f freshair and the extraction of polluted air (double flow syst

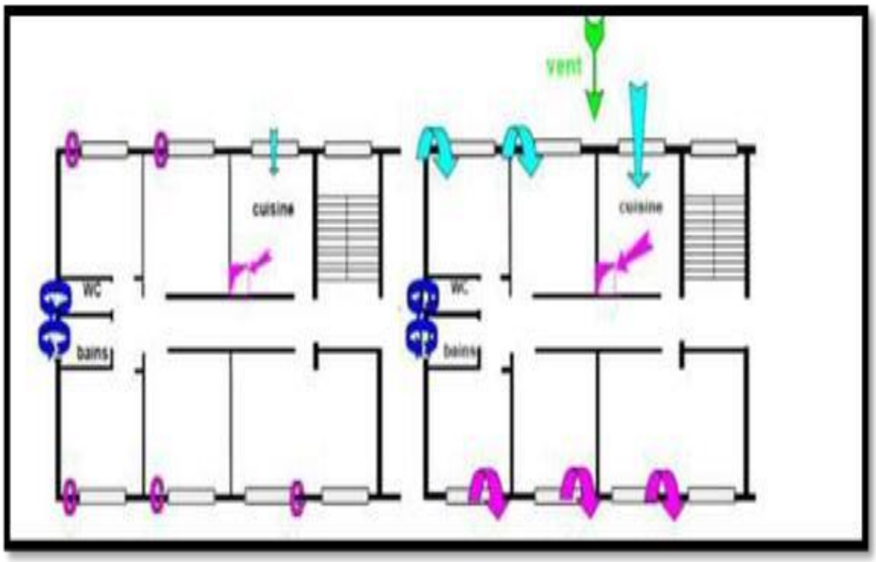

Figure 8: Schematic of the ventilation by separate rooms [70].

e. Partial sweep ventilation:

It is a hybrid principle between scavenging and separate room ventilation. The air inlets are located in different rooms from where the exhaust takes place, however, the airflow is not really controlled.

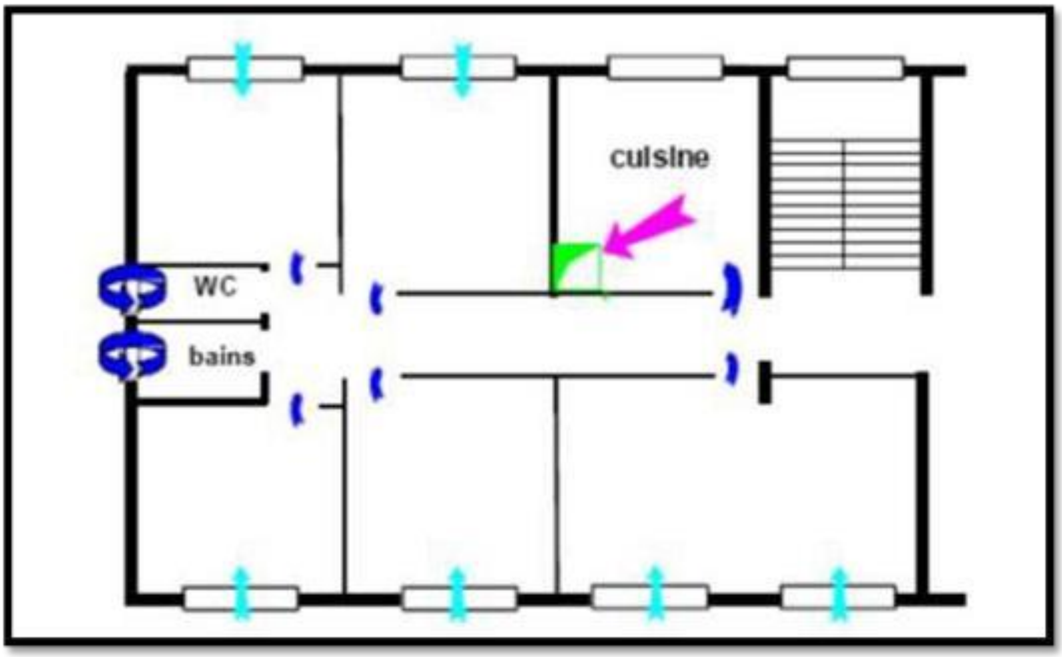

Figure 9: Schematic of the partial sweep ventilation [70].

e. Partial sweep ventilation:

It is a hybrid principle between scavenging and separate room ventilation. The air inlets are located in different rooms from where the exhaust takes place, however, the airflow is not really controlled.

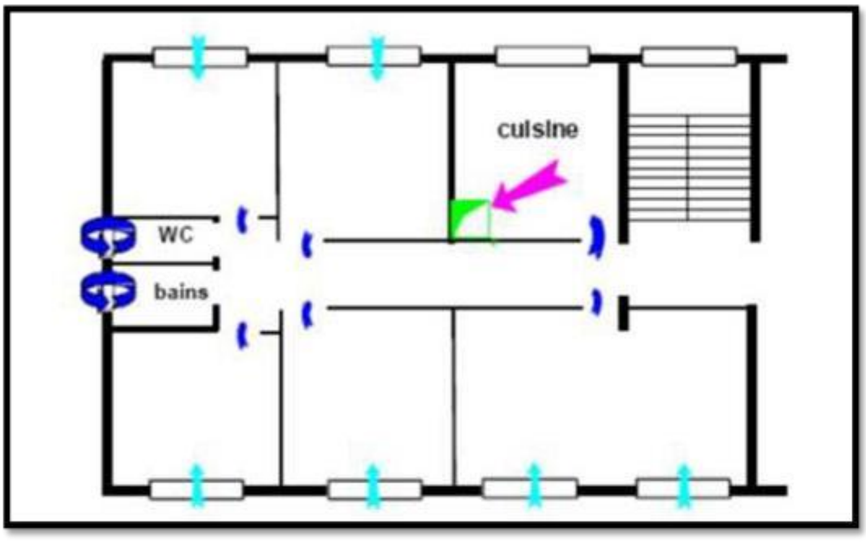

Figure 10: Schematic of the partial sweep ventilation [70].

13. STEEPLE Analysis

- **Social impact:**

Implementing energy efficiency measures in the building sector, including the incorporation of natural ventilation and addressing air infiltration, can improve living conditions, reduce energy poverty, and promote community engagement in sustainability initiatives. Public awareness campaigns and capacity-building programs can lead to a greater understanding and adoption ofenergy-efficient practices.

- **Technological impact:**

Technological advancements play a crucial role in the development and implementation of energy-efficient systems and solutions, such as smart natural ventilation systems. By investing in research and development, Morocco can foster innovation and accelerate the adoption of cutting-edge technologies in its building sector.

- **Environmental impact:**

Enhanced energy efficiency in buildings, including the optimization of natural ventilation and infiltration strategies, can significantly reduce greenhouse gas emissions, contributing to Morocco's climate change mitigation efforts. Moreover, it can help reduce air pollution, decrease waste generation, and promote the conservation of natural resources.

- **Economic impact:**

Energy efficiency improvements, such as the incorporation of natural ventilation, can result in cost savings for building owners, residents, and businesses through reduced energyconsumption. Additionally, they can stimulate job creation in the green construction, audit andretrofitting industries.

- **Political impact:**

Morocco's commitment to international climate agreements and national energy efficiency goals reflects the importance of political will in driving the adoption of sustainable building practices. Enhanced cooperation between government entities and stakeholders, including the revision of building codes to include natural ventilation and infiltration guidelines, can help develop and enforce effective policies and regulations.

- **Legal impact:**

By updating and strengthening building codes and regulations to include natural ventilation and air infiltration considerations, Morocco can create a supportive legal framework for energy- efficient buildings. Ensuring compliance with these standards is crucial for achieving national energy efficiency targets.

- **Ethical impact:**

Promoting energy efficiency, including the optimization of natural ventilation and addressing infiltration, aligns with ethical principles of sustainability, environmental stewardship, and social responsibility. Ensuring access to affordable, clean, and efficient energy for all citizens is a crucial aspect of addressing social and economic inequalitie

Overview of relevant engineering standards for the capstone designwork

- Several engineering standards have been identified as applicable to energy efficiency, natural ventilation, and infiltration in the building sector, including:
- *ASHRAE Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings*
- *ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality*
- *ISO 50001: Energy Management Systems*
- *ISO 13790: Energy Performance of Buildings - Calculation of Energy Use for Space Heatingand Cooling*
- *EN 15232: Energy Performance of Buildings - Impact of Building Automation, Controls, and Building Management*
- *Eurocode 5: Design of Timber Structures*
- *ASHRAE Standard 62.2: Ventilation and Acceptable Indoor Air Quality in Residential Buildings*

Incorporation of these standards in the project

By incorporating the identified engineering standards into the capstone design work, the project can ensure alignment with international best practices and promote the adoption of energy-efficient building systems, natural ventilation strategies, and air infiltration management in Morocco. These standards will guide the design, implementation, and assessment of energy-efficient building practices, providing a robust framework for evaluating and comparing different approaches to building energy efficiency, ventilation, and infiltration.

Importance of staying current with new standards and practicesin the field

Since engineering standards are frequently updated to keep pace with new technological developments and evolving best practices, it is crucial for engineering designers to stay current with new standards and practices relevant to their field and design work. Staying informed of the latest standards ensures that the capstone project remains relevant, effective, and aligned with industry expectations. It also helps identify new opportunities for innovation and improvement in energy efficiency, natural ventilation, and infiltration management within the building sector.

14. Conclusion

This capstone project 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.

Acknowledgement

The technical inputs of Mr MOUHIB TAOUFIQ of Physical Engineering Department are acknowledged.

15. Conflict of Interest

The authors declare that there are no conflicts of interest.

16. Compliance with Ethical Standards:

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

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