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Development of Eco-Responsible Thermal Comfort Designs for the Valorization of the Traditional Malagasy House

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Abstract: *This study aims to provide any assistance in the design of a green thermal comfort solution that is aware of the current climate change and considers sustainable development. This concept is helpful to the environment and offers a possibility of popular use. The process results are reproducible to a maximum of eventuality in the thermal building field, but in this article, we discussed the cases of Malagasy thatched cottage with envelope in mud and roof in thatch and the case of an ordinary house of the popular Malagasy mass, with fired clay brick envelope, cement coating, galvanized corrugated iron roof. The approach is as follows: locate the study area, analyze the scenarios of ecological thermal solutions, carry out the heat balances according to the scenarios, and classify the optimal solution. To do this, METEONORM is used for geographical location, the heat balance is carried out using the THERMEXCEL tool, and the multi-criteria analysis is made by the PROMETHEE tool in the educational version.*

Keywords: *sustainable development; thermal comfort; heat transfers; heat balance; eco responsibility; multi-criteria analysis; bioclimatic*

I. Introduction

Due to the exponential growth of the world's population by a factor of four in one century, the demands on the earth's production capacity are increasing. This imbalance leads to the degradation of the natural environment, global warming, climate change, and major pollution problems, in short, devastating consequences for the whole of humanity. Developed countries, the main actors of increased industrial development and high-quality requirements, are currently concerned with eco-responsibility and sustainable development seriously. Aware that the globe is suffocating and needs some oxygen to maintain its existence, watches eco-responsible concepts for sustainable development are emerging over the years and are in constant evolution.

1.1 Issue

In terms of housing, global warming induces reflex solutions oriented to the use of air conditioning. In this field, we note that at present, "Comfortable Housing is Accessible to a Minority of the Population, it is Expensive, Ecologically and Financially and Sometimes, it is not Sustainable Development".

1.2 Assumptions and Objective

We consider that human comfort is the center of interest in the construction of one's habitat, and in terms of a fundamental right, everyone deserves to be on the same footing. In our hypothesis, this comfort is not necessarily dependent on financial means, it is multi-criteria, and, given the current ecological situation, it must be as responsible as possible.

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About this "eco-responsible comfort", it is interesting to focus on the thermal side because its control generally falls on energy-consuming and expensive solutions. With this in mind, our goal is to provide environmentally friendly thermal comfort solutions.

1.3 Questions

To contribute to the materialization of these assumptions and objectives, we will start with the following questions:

- On which philosophy and vision should we orientate the reflection about the "eco-responsible thermal comfort"?
- Which axes and means of technical interventions could be considered?
- What results could be achieved? What would be the opportunities, challenges and possible impacts?

As an answer to these questions, this study is entitled: "Thermal Solutions for an Eco-Responsible House, in a Sustainable Development Optic".

1.4 Approach to be Followed

To better understand our analysis, the methodology of work deals with the following elements:

- Systemic analysis: reflect on the philosophies, systems and methods related to eco-responsible lifestyles, ecological approaches in terms of housing as well as the human body and its thermal comfort.
- Technical analysis: Reflect on the systems and means for the implementation of an ecological thermal comfort treatment of a house. Focus on calculation and analysis referential.
- Discussions: Analyze the issues, challenges, and limits of the proposed solutions.

1.5 Expected Results

The expectations are as follows:

- To have multi-purpose technical supports for an eco-friendly thermal analysis,
- To prove the asset and the challenge that the solutions can bring.

1.6 Organization of the Presentation

To analyze the ins and outs, this article is divided into three parts:

- Firstly, an introduction, which talks about the foundations of sustainable development and the concept of eco-responsible, and the notion of efficient building.
- Secondly, we will talk about materials and methods. This part will focus on the basic theories of thermal comfort, the calculation and analysis tools to be used, the references to be exploited, as well as the existing technical solutions.
- Thirdly, a framework reserved for the results and discussions, in which a multi-criteria classification of the possible solutions will be issued. Also, we will discuss the level of efficiency of the proposed solutions, then, their footprints in the framework of contribution to sustainable development, and the possible blockages and limits of their applications.

II. Review of Literature

2.1 The Foundations of Sustainable Development and the Eco Responsible Concept

a. The Sustainable Development and Eco-Responsibility Context

1. Définitions and Generalities

"Sustainable development"**[ω1],[ω2]** was popularized in 1987 in the Brundtland Report, which defined it as: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It was through the 1992 Rio Declaration on Environment and Development ("Rio Declaration"), which took up this definition and identified the principles for its realization, that it received the endorsement of the international community. We can also mention the Johannesburg conference in 2002.

The "triptych of sustainable development" is based on three components, namely

- the economic component
- the social component
- the ecological component

2. The Three Pillars of Sustainable Development

Sustainable development is based on three pillars:

- economic efficiency
- social equity
- environmental quality

<u>Economic efficiency</u> **[ω2]**, is about ensuring sound and sustainable management, without harm to the environment and man. The economy is a pillar that occupies a prominent place in our consumer society. Sustainable development implies the modification of the modes of production and consumption by introducing actions so that economic growth is not done at the expense of the environment and the society.

<u>Social equity</u> **[ω2]** aims at satisfying the essential needs of humanity in housing, food, health and education, by reducing the inequalities between individuals, while respecting their cultures. Thus, we can say that sustainable development encompasses the fight against social exclusion, generalized access to goods and services, working conditions, improvement of employee training and their diversity, development of fair and local trade

<u>Environmental quality</u> **[ω2]** considers the preservation of natural resources in the long term. Sustainable development is often wrongly reduced to this single environmental dimension. It is true that in industrialized countries, the environment is one of the main concerns. We consume too much and produce too much waste. It is a question of rejecting acts that are harmful to our planet so that our ecosystem, biodiversity, fauna and flora can be preserved.

In short, the interdependence of the three pillars gives rise to interfaces whose balance and coherence make it possible to achieve the notion of sustainability for humans, their place of existence and their means of subsistence.

3. The 2030 Sustainable Development Goal (SDG)

The Sustainable Development Goals (SDGs) are the successor to the Millennium Development Goals (MDGs) which ended in 2015.

The Sustainable Development Goals (SDGs), also called Global Goals, are a global call to action to eradicate poverty, protect the planet and ensure that all human beings live in peace and prosperity. It has seventeen goals, however, we will choose among others the themes related to housing below:

- good health and well being
- measures related to the fight against climate change

4. The 2030 Sustainable Development Goal (SDG)

Around the concept of sustainable development, we can talk about other reflections and tools, among others:

- The development of the environmental economy
- The "green economy": green growth and the implementation of Agenda 21
- The Global Reporting Initiative (GRI): environmental and social reporting.

b. Eco-Responsibility

The eco-responsibility **[ω4]** of a human activity resides in the implementation of environment-friendly management. In other words, it is an approach that consists in integrating the stakes of sustainable development in all its daily activities.

Eco-responsibility **[ω5]** is the will to limit one's impact on the planet by taking into account the following elements in one's daily organization:

- Waste reduction and management,
- The control of energy consumption,
- The fight against water, air and land pollution,
- The reduction of greenhouse gas emissions,
- Reducing the consumption of non-renewable resources.

Beyond these environmental aspects, it is also a social and ethical commitment. It invites all citizens, companies and communities to think about the consequences of their actions on the environment. It encourages them to modify their behavior to include sustainable development issues. Thus, being eco-responsible means adapting one's behavior and acting to limit the impact of one's activities on the environment and society. We can thus speak of eco-responsible attitudes and gestures **[ω6]**.

Eco-responsibility applies to consumption, production, transportation and social interactions.

The expected result of an eco-responsible act is the minimization of the negative ecological impact following the execution of a given activity and/or project. For the eco-responsible individual, the result of his or her action is favorable, and the reflection of this result can (and should) serve others.

1. The Eco-Responsible Approach

The question of an eco-responsible approach often varies from one activity and/or project to another. However, the principle remains the same. Generally, the following points are considered:

- The diagnosis
- Delineation of the action area
- Action plan
- The execution
- Follow-up

2. Basic Eco-Responsible Gestures

The basic eco-responsible gestures are generally summarized by four acts, namely:

Favoring the ecological way of life at home

- To move in an eco-responsible way
- Buy ecologically responsible
- Manage your waste

In our theme, we will focus on the "ecological lifestyle at home"

- ✓ Search for ecological thermal comfort solutions, favoring bioclimatic solutions when designing a project.

- ✓ If the use of air conditioning and/or heating is unavoidable, use it in an ecologically responsible way

c. The Concept of a High-Performance Building

1. Generalities

The concept of the efficient building is currently a worldwide trend and even a regulatory obligation due to the accelerating depletion of fossil fuels, which account for a significant share of building consumption. Indeed, the goal is to minimize the consumption of primary energy **[6] [9]**.

In this concept, we can mention some key points, namely:

- The inertia of the building
- Watertightness
- The insulation
- The sanitary quality and comfort
- The control of ventilation
- Thermal management of the building
- Electricity management
- Energy management
- Water management
- Control of luminosity
- Integration of renewable energy in the system
- Maintainability
- Sustainability over time

2. Some Standards and Labels

From the energetic point of view, related to the thermal comfort, we could find the following labels in the literature:

- BEPOS Effinergie in France
- Minergie in Switzerland
- PassivHaus in Germany
- CasaClima/Klimahaus in Italy
- HPE and THPE labels

For other systems of analysis of criteria beyond the energy point of view, which aim at the relationship of the house with its environment, we can mention:

- The CASBEE method from Japan
- The LEED method of the United States of America
- The BREEAM method of the United Kingdom
- Canada's R-2000 standard

3. Types of Efficient Buildings According to the Energy Label

Following the energy label, the literature has allowed us to summarize the following concepts:

- The low-energy or low-energy building
- The "passive" building
- The energy-producing building
- The "zero energy" building
- The positive energy building
- The autonomous building

4. High-Performance Building Types by Other Criteria

Often, the other criteria are environmental or economic. We can mention the following concepts:

- The "zero utility cost house"
- The "Carbon Neutral House "
- The "green", "sustainable" or "ecological" building"
- The Intelligent Building

5. The "Green", "Sustainable" or "Ecological" Building

Known in English under the terms "green building". It is difficult to categorize a building according to this concept. We can say that it is a symbolic qualification.

In addition to the above qualifications in terms of efficient building, the green building is distinguished on its impact on the environment, for example, according to the choice of materials and its implementation.

d. The Human Body in Its Thermal Comfort

1. Thermodynamics of the Human Body

The central part of the human body (also called the nucleus) is "homeothermic" its temperature remains constant at 37°C and varies very little according to the outside temperature **[ω7]**. This temperature is necessary for the proper functioning of the body. The parts outside the core, called "envelopes" and "bark", consisting of the skin and subcutaneous tissues, can have a variable temperature, between 10 and 40°C, depending on the outside temperature. Between the two, is the vascular system which allows fast exchanges of heat between the central core and the external system.

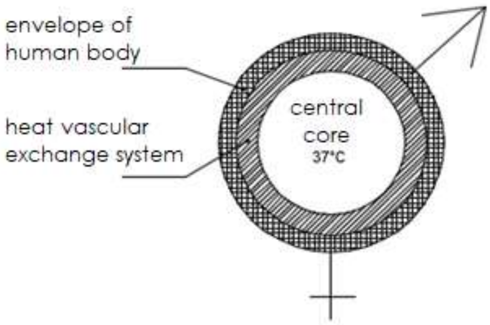


Figure 1. *Modeling the Human Body*

To maintain the temperature of the central core, the human body is in a perpetual thermodynamic exchange, there is a permanent balance between heat input and heat output. Even without exchange with the environment, the metabolism of the body provides heat.

When the heat input is greater than the heat output, the body temperature rises, when the heat output is greater than the heat input, the body temperature falls.

Reminder: The direction of heat exchange follows the law of thermodynamics: from the warmest to the coldest. Thus, if the temperature of the body is lower than that of the environment, the body receives heat from the outside, in the opposite case, the body loses it.

2. Thermoregulation of the Human Body

Thermoregulation represents all the processes allowing the man to maintain his internal temperature within normal limits whatever his metabolic level or the temperature of the surrounding environment **[ω7]**. It rests on a constant balance between the contributions and s losses of heat.

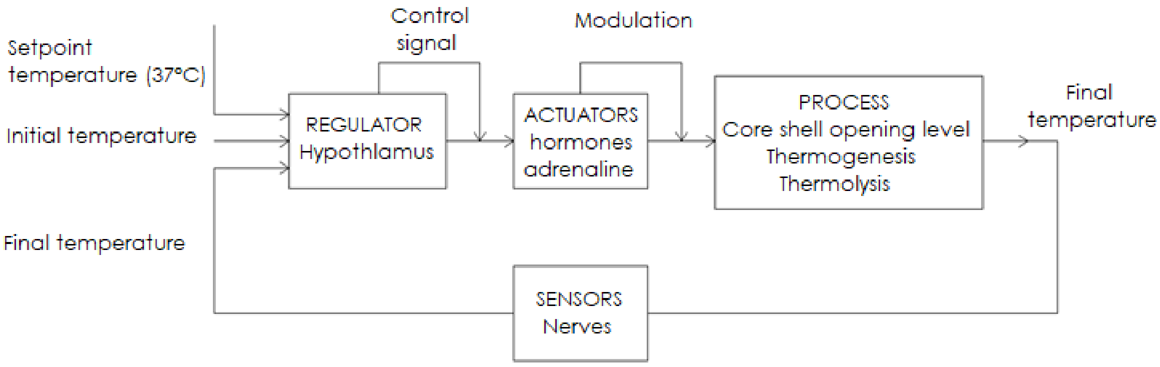


Figure 2. *Modeling the Thermoregulation of the Human Body*

The brain, mainly through the hypothalamus, compares the set temperature of the central core with the body temperature. The information is picked up by the nerves, which act as thermosensors.

Depending on the deviation of the temperature from the set point, the hypothalamus triggers a correction by sending a command signal to the hormones and adrenaline which act on the behavior of the nerves, subcutaneous tissues, skin and other organs (physiological reactions), so that the temperature of the central core is maintained.

3. The Behavior of the Body in the Cold

Faced with the cold, without any external contribution, the body can react by:

- Increasing its thermal insulation
- Increasing its thermogenesis

4. Increased Thermal Insulation

This is done by decreasing blood flow in the skin and subcutaneous cells which acts as a heat exchanger (less flow = less exchange), and through vasoconstriction: closing of the skin capillary loops to retain heat in the central core). The thermal conductance, thanks to vasoconstriction, can be reduced by half.

5. Increase in Thermogenesis

The increase in thermogenesis can be obtained by voluntary muscular contractions (physical exercises, taking a hot drink, exposure to a hot source...) or involuntary (shivering)

Note: the sensation of cold varies according to the wind speed of the environment where the subject is located.

6. The Behavior of the Body in the Heat

Faced with heat, without any external means, the body can react by:

- decreasing its thermal insulation and favoring its exchange with the surrounding environment
- carrying out thermolysis via sweating

7. Exchange with the Environment

This is done by increasing blood circulation in the skin and subcutaneous cells which acts as a heat exchanger (more flow = more exchange), and through vasodilation: opening of the capillary loops in the skin to allow the evacuation of heat into the central core). The thermal conductance thanks to vasodilation can be multiplied by five to six times.

8. Sweating

The mechanism is through the evaporation of the amount of water secreted in the skin through sweat. The thermolysis is done by latent vaporization.

The phenomenon follows the thermodynamic law: the drier the environment, the more efficient the evaporation and vice versa. A practical example is the feeling of heat before the rain falls. (Note: In the case where the temperature difference lasts in time, the use of other mechanical solutions is necessary (example: thermal treatment of the room by air conditioning or ventilation), or chemical solutions (example: taking medicine in case of illness).

e. Brief Overview of Thermal Comfort

1. Thermal Comfort Criteria

Briefly, the thermal comfort **[2] [3] [10]** inside the house must meet the requirements below:

- The degree of hygrometry. The relative humidity must be between 45 and 65%,
- The temperature must remain as stable as possible (no variation, neither important nor fast as with electric heating),
- The temperature level must be adapted to the needs of our body and our age.

However, the notion of thermal comfort is not limited to a temperature level, it is a function of ventilation (and therefore of wind speed), metabolism and the geographical location of the house.

2. The Relativity of Thermal Comfort

As we have seen in the previous paragraphs, the regulation of the temperature of the vital organs of the human body is carried out by the Hypothalamus. Mathematically, the order of magnitude of a comfort temperature of 21 to 25°C, however, the degree of satisfaction may be relative **[11]** from one individual to another. This relativity can serve as an interesting basis for our analysis of eco-friendly comfort.

In practice, the notion of thermal comfort is a function with six (6) parameters, four of which are dependent on the environment and two of which concern the individual directly. These six parameters are the following:

- The temperature of the air inside the room
- The radiation of the walls constituting the room
- The relative humidity (hygrometry) in the room
- The speed of the air in the room, also known as the wind temperature
- The level of activity of the occupant of the room, in other words, the metabolism
- The clothing

2.2 Materials and Methods: Heat Transfers, Calculation and Simulation Tools, Technologies

a. Heat Transfers

- Two bodies are said to be in thermal equilibrium if they have the same temperature. As soon as there is a thermal imbalance, the phenomenon of heat transfer **[4]** occurs, we have:
- Transfer by conduction: between two solids
- Transfer by convection: between two fluids, or between solid and fluid
- The transfer by radiation: heat transfer in the form of electromagnetic waves.

b. Conduction

The heat is transmitted from near to near throughout the solid. Our hypothesis is based on the conduction in a steady state.

c. Case of a Simple Wall

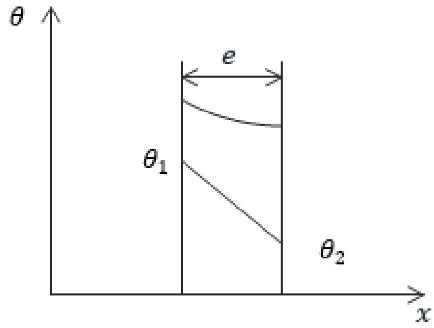


Figure 3. *Conduction in a Single Wall*

$$\frac{d\theta}{dx} = cte = a \; (1)$$
$$\theta = ax + b \; (2)$$
$$\varphi.R = \theta_1 - \theta_2 \; (3)$$
$$\emptyset_{cond} = \varphi.S \; (4)$$
$$R = e/\lambda \; (5)$$
$$K = 1/R \; (6)$$

θ: Temperature [°C] ou [°K]
θ_1: [°C] ou [°K]
θ_2: Temperature on wall surface 1 [°C] ou [°K]
φ: Heat flow through the wall [W/m²]
$\emptyset_{cond}$: Total heat flow through the wall surface [W]
R Thermal resistance of the wall [m²K/W]
e Wall thickness [m]
S Wall surface [m²]
λ Thermal conductivity of the wall [W/m.K]
K: Thermal conductance of the wall [W/m².K]

d. Case of a Wall Composed of n Layers

$$R = \sum_{j=1}^{n} \frac{e_j}{\lambda_j} \; (7)$$

$$\varphi.R = \theta_0 - \theta_n \; (8)$$

$$\varphi = \frac{\theta_0 - \theta_1}{R_1} = \frac{\theta_1 - \theta_2}{R_2} = \frac{\theta_{n-1} - \theta_n}{R_n} (9)$$

$$K.S = K_1 \,.\, S_1 + K_2 \,.\, S_2 + \cdots + K_n \,.\, S_n \; (10)$$

θ_0: Extreme wall surface temperature 1 [°C] ou [°K]
θ_n: Extreme wall surface temperature n [°C] ou [°K]

e. Case of a Hollow Cylinder

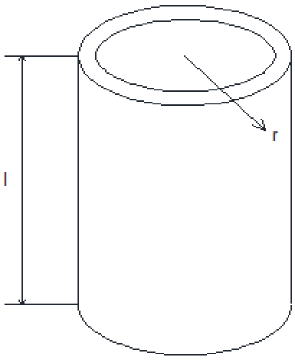


Figure 4. *Conduction in a Hollow Cylinder*

$$\theta(r) = \theta_1 + \frac{\theta_1 - \theta_2}{\ln(\frac{r_1}{r_2})}\ln(\frac{r}{r_1})\ (11)$$

$$\varphi(r) = -\lambda\frac{\theta_1 - \theta_2}{\ln\left(\frac{r_1}{r_2}\right)}1/r(12)$$

$$\emptyset = -2\pi\lambda l\frac{\theta_1 - \theta_2}{\ln\left(\frac{r_1}{r_2}\right)}(13)$$

$$R = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi\lambda l}(14)$$

r: Cylinder radius (variable)
r_1: Inner radius [m]
r_2: Outer radius [m]
θ_1: Temperature in r_1 [K]
θ_2:Temperature in r_2 [K]
l: Length of the cylinder [m]

f. Case of a hollow cylinder made of two different materials

$$R = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi\lambda_1 l} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{2\pi\lambda_2 l}(15)$$

$$\varphi.R = (\theta_3 - \theta_1)\ (16)$$

g. Convection

Generally, this is the mode of transfer between a fluid and a solid **[4]**. The fluid in contact with a solid of higher temperature warms up by taking the heat of the solid with it. The fluid then transfers heat to a solid of lower temperature than itself.

h. NEWTON's Law: the Heat Flow Exchanged by Convection

$$\emptyset_{conv} = h.S.(\theta_s - \theta_f)$$

$\emptyset_{conv}$: Heat flow exchanged by convection between a solid and a fluid [W]
h: Convection coefficient [W/m².K] S: Exchange surface [m²]
θ_s: Surface temperature of the solid before contact with the fluid [K]
θ_f: Surface temperature of the fluid before contact with the solid [K]

i. VASCHY's Law

The thermal is of dimension four m, kg, S , ; In convection, seven quantities are involved: h, w, D,µ, λ, c, ρ

h : convection coefficient [W/m².K]

w : average fluid speed [m/s]

: length [m]

µ : dynamic viscosity [kg/m.s]

λ: thermal conductivity [W/m.K]

c mass heat capacity [J/kg.K] (also called « heat of mass » or « heat capacity »)

ρ : voluminal mass [kg/m³]

j. Dimensionless Numbers to Apply NEWTON's Law

The objective is to determine h for a given situation. These numbers are dimensionless, we quote:

- The Reynolds number (Re)
- The Nusselt number (Nu)
- The PraPrandtlmber (Pr)
- The Grashof number (Gr)

$$Re = \frac{w.D.\rho}{\mu}$$

$$Nu = \frac{h.D}{\lambda}$$

$$Pr = \frac{\mu.c}{\lambda}$$

$$Gr = \frac{\alpha.g.\Delta\theta.\rho^2 D^3}{\mu^2}$$

α: Coefficient of expansion by volume [K^{-1}]

g: Acceleration of gravity [m/s²]

$\Delta\theta$: Temperature difference [K]

k. Application of Dimensionless Numbers

- Gas flow in a duct

If 10 000 < Re < 120 000

$$Nu = 0{,}023.Re^{0,8}Pr^{0,4}$$

- Flow of liquids in a tube

If 10^4< Re (f) < 5. 10^6

If 0,6 < Pr (f) < 2500

$$Nu = 0{,}021.Re^{0,8}(f)\left(\frac{\Pr(f)}{\Pr(s)}\right)^{0,43}$$

- Flow of liquids in a coil

$$Nu = 0{,}021.Re^{0,8}(f)\left(\frac{\Pr(f)}{\Pr(s)}\right)^{0,43}\left(1+3{,}5\frac{D}{d}\right)$$

D: inner diameter of the coil tube

d: coil diameter

- Flow of a fluid around a tube

$$\text{If } 10^4 \leq \text{Re} \leq 10^3 ;\ Nu = 0{,}59.Re^{0{,}47}(f)\left(\frac{\Pr(f)}{\Pr(s)}\right)^{0{,}25}$$

$$\text{If } 10^3 < \text{Re} \leq 10^5 ;\ Nu = 0{,}21.Re^{0{,}62}(f)\left(\frac{\Pr(f)}{\Pr(s)}\right)^{0{,}25}$$

- Free convection
  - If $10^{-3} < \Pr.Gr \leq 5.10^2$; $Nu = 1{,}18.(Pr.Gr)^{0{,}25}$
  - If $5.10^2 < \Pr.Gr \leq 2.10^7$; $Nu = 0{,}54.(Pr.Gr)^{0{,}25}$
  - If $2.10^7 < \Pr.Gr \leq 10^{13}$; $Nu = 0{,}13.(Pr.Gr)^{0{,}25}$

l. The radiation

It is the heat of a surface of a body transformed into an electromagnetic wave that propagates in the air and even the vacuum **[4]**. Arriving on another body, these waves are decomposed into heat (absorbed wave), reflected wave and transmitted.

1. The Electromagnetic Spectrum

The thermal radiation is included in the ultraviolet and infrared spectra (including visible light 0.38 to 0.76 µm). Extended range from 0.01 to 100 µm. But most of it is in the infrared.

- Radiated flow: It is the thermal power source in the space that surrounds it. (In our case, it is the sun). Its unit is the watt [W].
- Emittance: the emittance (M) of an emitting surface is the thermal power emitted by this surface.

$$M = \frac{d\emptyset}{dS_{eme}}$$

M: Emittance [W/m²]

dS_{eme}: Emitting surface [m²]

- Enlightenment: enlightenment (E) of a receiving surface is the thermal power received by this surface.

$$E = \frac{d\emptyset}{dS_{rec}}$$

$enlightenment$ tment [W/m²]

dS_{rec}: Receiving surface [m²]

2. Absorption Factor (α), Reflection Factor (ρ), Transmission Factor (τ)

The incident flux $\emptyset_i$ (radiated flux) arriving in a given body is decomposed into absorbed flux $\emptyset_a$, reflected flux $\emptyset_r$ and transmitted flux $\emptyset_t$. The rates of these components are given by factors α, ρ and τ which represent their ratios to the incident flux, these factors are wavelength dependent.**[4]**

$$\alpha = \frac{d\emptyset_a}{d\emptyset_i}$$

$$\rho = \frac{d\emptyset_r}{d\emptyset_i}$$

$$\tau = \frac{d\emptyset_t}{d\emptyset_i}$$

$$\tau = e^{-\chi.e}$$

$$\alpha + \rho + \tau = 1$$

$d\varnothing_a$: absorbed flow [W]
$d\varnothing_r$: reflected flow [W]
$d\varnothing_t$: transmitted flow [W]
$d\varnothing_i$: incident flow [W]
χ: absorption coefficient of the body [m^{-1}]
e: body thickness [m]
If $\tau = 0$; the body is said to be opaque to radiation (no flow passes through the body)
If $\tau \neq 0$ the body is said to be transparent to radiation

If some of the energy is absorbed, but this part is constant regardless of the wavelength of the incident energy, the body is said to be grey (otherwise it is said to be colored.

If the proportion of absorbed energy is independent of the angle of incidence of the received radiation, the body is said to be matt (otherwise it is said to be polished).

3. The Notion of the Black Body, the Sun

If all the energy of the incident flux is absorbed by the body, regardless of the wavelength, we have a "black body" (also called "integral radiator"). The sun is considered a black body, its emittance is 6,5.10^7 W/m² (corresponding to yellow light); its temperature is at 5780K, and it emits the most for a wavelength λ=0.52µm. The maximum power of its radiation per unit area, called the "solar factor" is 1350 W/m² outside the atmosphere and 1000 W/m² in the earth's atmosphere; its value when it reaches the earth's surface varies according to the movement of the earth (daily, monthly).

4. The Generalized Heat Transfer

In practice, a wall is composed of n walls. The heat transfer occurring around and in the wall is mixed. We thus have the three modes of heat transfer that interact.

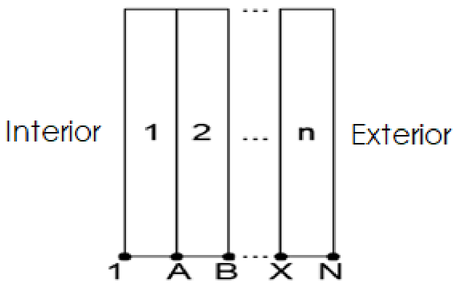


Figure 5. *Multilayer Wall*

Table 1. Matrix of a Multi-Layer Wall

Wall	Boundary	Thickness (m)	Conductance [W/m².K]	Thermal resistance [m²K/W]
1	1-A	e_1	λ_1	R_1
2	A-B	e_2	λ_2	R_2
….	….	….	….	….
n	X-N	e_n	λ_n	R_n

$$R_g = \frac{1}{h_i} + \sum_{j=1}^{n} R_j + \frac{1}{h_e} \quad \text{et} \quad K_g = \frac{1}{R_g}$$

$$\varnothing_g = (\theta_i - \theta_e) / R_g$$

R_g : Overall wall resistance $[m^2K/W]$

h_i : Convective heat transfer coefficient on the inside

h_e : Convective heat transfer coefficient on the outside

R_j : Wall strength j

K_g : Overall onductance

$\varnothing_g$: Overall flow through the compound wall

θ_i : indoor air temperature

θ_e : Outdoor air temperature

2.3 Ecoresponsible Thermal Study of a House

a. The Thermal Balance

The thermal balance of the building aims to control the thermal comfort of its occupant. It is a mandatory part of the HVAC (Heating, Ventilation, Air Conditioning) study of a building, as well as any construction related to the control and regulation of the indoor temperature.

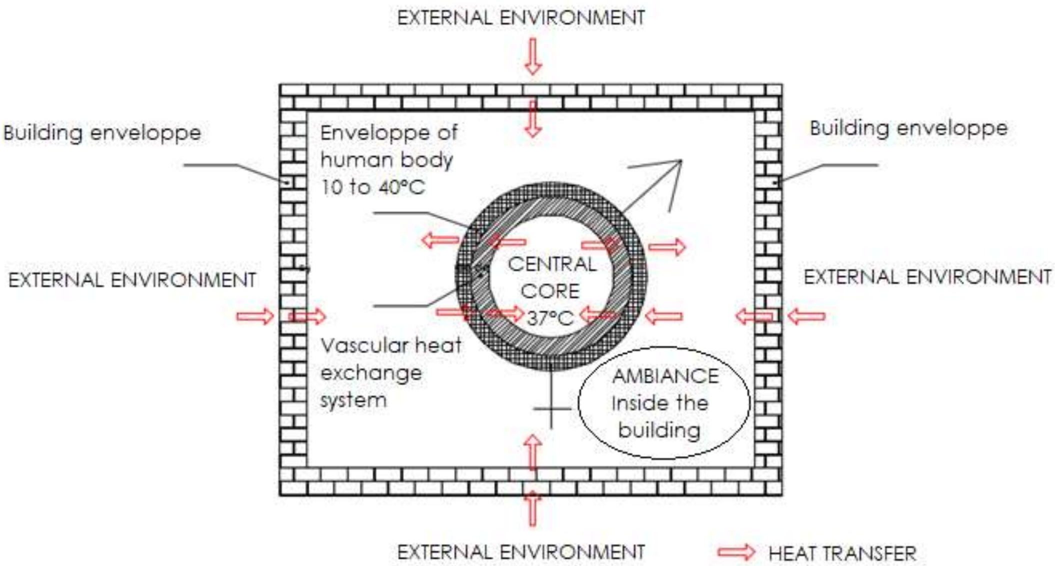


Figure 6. *Representation of the Human Body System in the Home in Summer*

b. A Brief Overview of Thermal Inputs

The thermal contributions in the house are illustrated by the figure below (note that during the summer, we fight against the apparition (heat coming from outside); during the winter, we fight against the déperditions (heat that is lost from inside).

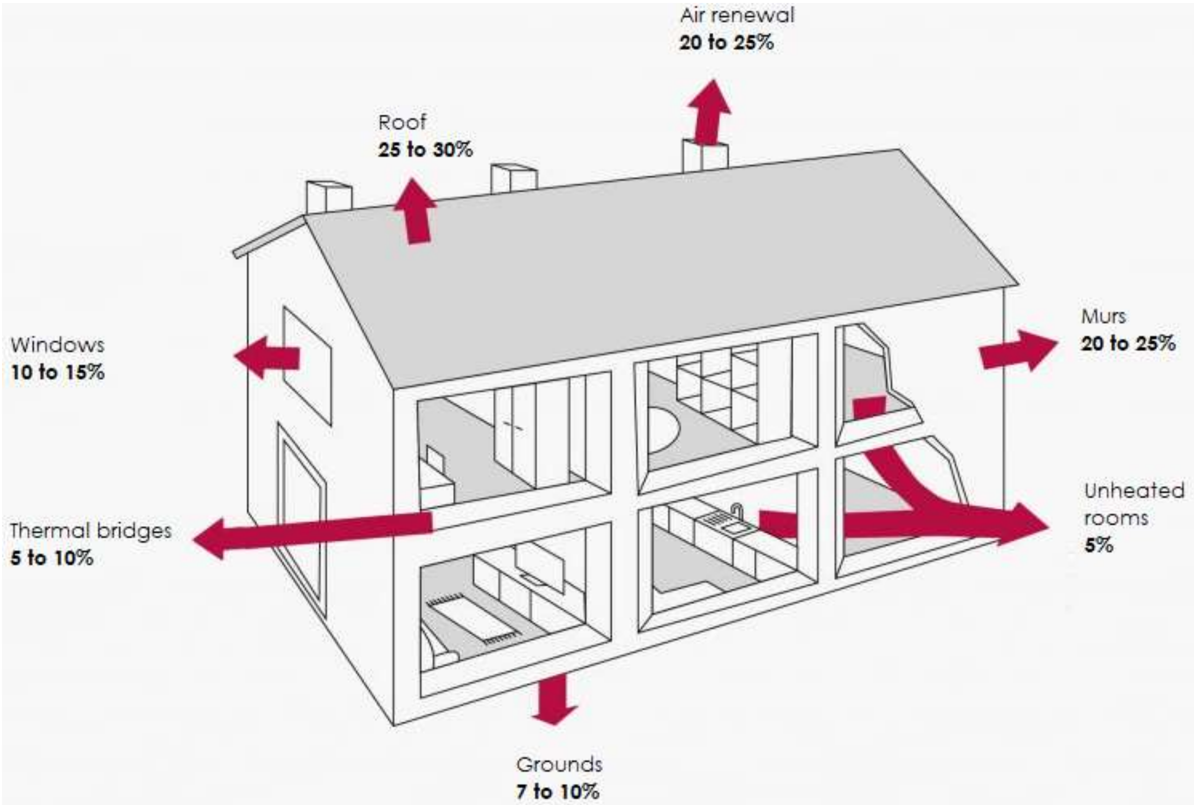


Figure 7. *Heat Input from Building Components*

c. Heat Balance Calculation Tool

Among the usual tools, we have selected for our simulation is the "Thermexcel" tool. It is an interactive heat balance calculation tool on Excel with programs under Visual Basic. We chose it because it is a professional tool respecting the norm, having a rather affordable cost compared to other tools and software of the same kind.

In the heat balance calculation, one must introduce:

- The selected climatic conditions of the area where the house is located
- The thermal contributions of radiation
- The thermal contributions by conduction
- Heat gains by convection
- Heat gains by air renewal
- Internal gains corresponding to the activity and operation of each room concerned.

Once the entries have been made, the tool directly outputs the results by station and the total balance in Watt. It remains to check possible anomalies before choosing the appropriate equipment for the thermal comfort of the house. Usually air conditioning and/or heating equipment.

Note:

In our approach, we do not limit ourselves to the choice of air conditioning equipment, but the way to limit the thermal loads to be compensated and to reduce the losses. In other words, the design of the house, the roofing materials and the envelope. Also, the logic of design and choice of equipment is focused on environmentally responsible solutions.

d. Optimization of Thermal Comfort

1. Thermal Comfort Solutions

For the optimization of the thermal comfort (cooling), we quote the following solutions:

- GCT1: the bioclimatic design of the house,

- GCT2: the use of thermal screens (blinds, sunshades)
- GCT3 the use of reinforced thermal insulation,
- GCT4 the use of high inertia materials,
- GCT5 the use of natural convection
- GCT6 the optimized use of the VMC,
- GCT7: geo cooling,
- GCT8 energy recovery systems,
- GCT9 Opting for cooling instead of air conditioning,
- GCT10 Standard air conditioning
- GCT11: co air conditioners (air conditioners with "Inverter" technology with high COP and EER, solar air conditioners).

2. Classification Criteria

The criteria to be applied are the following:

- Feasibility and accessibility
- Efficiency
- Ecological value
- Cost
- Sustainability

3. Qualitative Indicators of Solutions

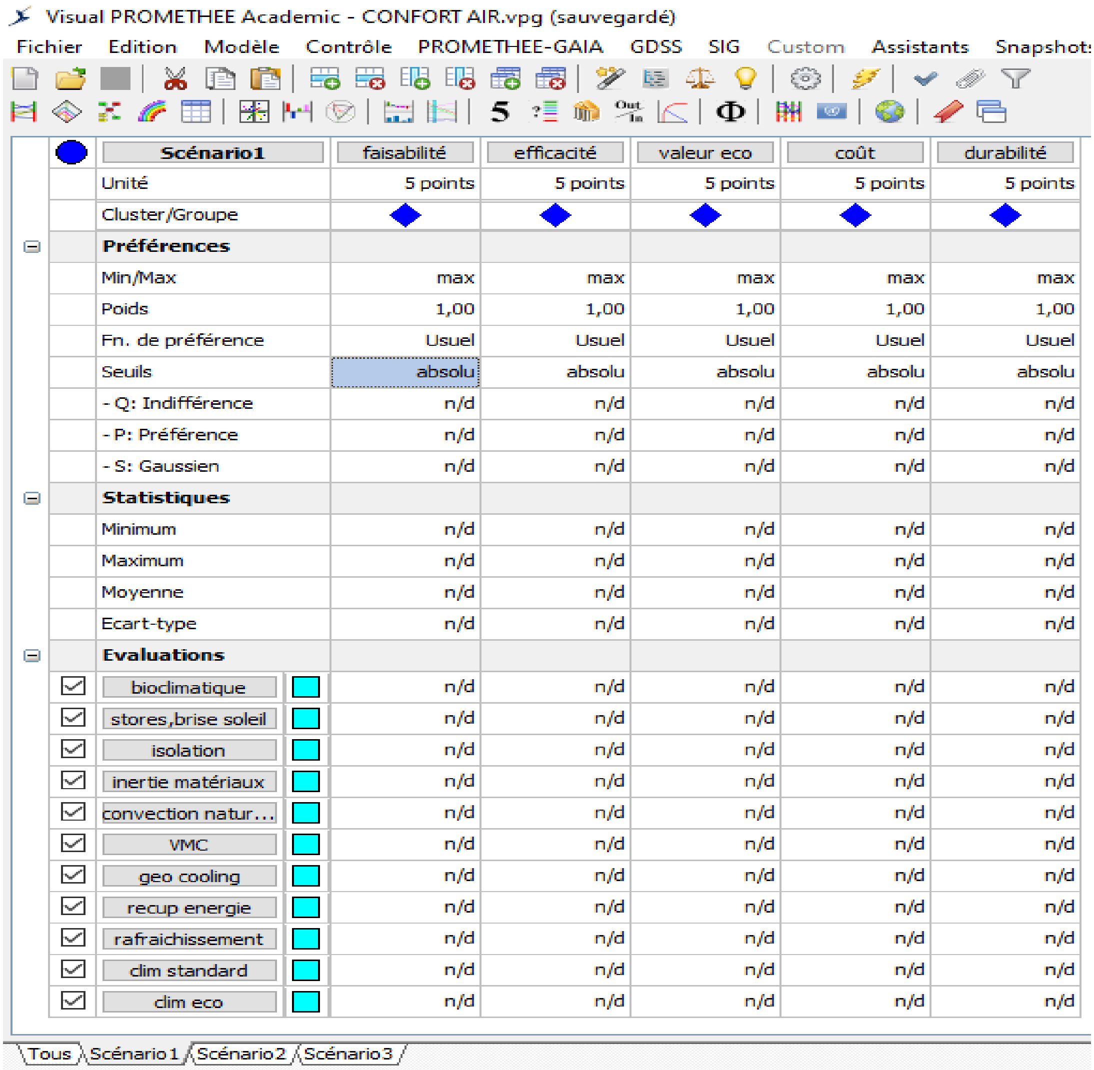
The values assigned to the evaluation criteria are: Very bad, Bad, Average, Good, Very good.

4. The Multi-Criteria Analysis Tool

To outperform the best solution in a given situation, we propose the use of the multi-criteria analysis tool PROMETHEE **[7]**.

The version used is a version dedicated to education and learning. It can be downloaded **[ω8]** after registration of a free license. Our tool is called “COMFORT AIR ".

By inserting all the elements of multi-criteria analysis, we have our “COMFORT AIR " interface.



Scénario1	faisabilité	efficacité	valeur eco	coût	durabilité
Unité	5 points	5 points	5 points	5 points	5 points
Cluster/Groupe					
Préférences					
Min/Max	max	max	max	max	max
Poids	1,00	1,00	1,00	1,00	1,00
Fn. de préférence	Usuel	Usuel	Usuel	Usuel	Usuel
Seuils	absolu	absolu	absolu	absolu	absolu
- Q: Indifférence	n/d	n/d	n/d	n/d	n/d
- P: Préférence	n/d	n/d	n/d	n/d	n/d
- S: Gaussien	n/d	n/d	n/d	n/d	n/d
Statistiques					
Minimum	n/d	n/d	n/d	n/d	n/d
Maximum	n/d	n/d	n/d	n/d	n/d
Moyenne	n/d	n/d	n/d	n/d	n/d
Ecart-type	n/d	n/d	n/d	n/d	n/d
Evaluations					
bioclimatique	n/d	n/d	n/d	n/d	n/d
stores,brise soleil	n/d	n/d	n/d	n/d	n/d
isolation	n/d	n/d	n/d	n/d	n/d
inertie matériaux	n/d	n/d	n/d	n/d	n/d
convection natur...	n/d	n/d	n/d	n/d	n/d
VMC	n/d	n/d	n/d	n/d	n/d
geo cooling	n/d	n/d	n/d	n/d	n/d
recup energie	n/d	n/d	n/d	n/d	n/d
rafraichissement	n/d	n/d	n/d	n/d	n/d
clim standard	n/d	n/d	n/d	n/d	n/d
clim eco	n/d	n/d	n/d	n/d	n/d

Tous / Scénario1 / Scénario2 / Scénario3

Figure 8. *Multi-Criteria Analysis Tool*

5. Measurement Tools

We used thermo-recorders type FI84ED and the adapted software "Data Logger" for simultaneous measurements of indoor and outdoor temperatures.

Figure 9. *Localization of the Site*

III. Discussion

3.1 Comparison of a Traditional and an Ordinary Housing Unit
a. Presentation of the Models to be Simulated
1. Geographic Location

The simulations are conducted in the Fokontany Amboniandrefana, Commune of Ambalavao, District of Antananarivo Atsimondrano; located 27.5 km from the National Road n°7

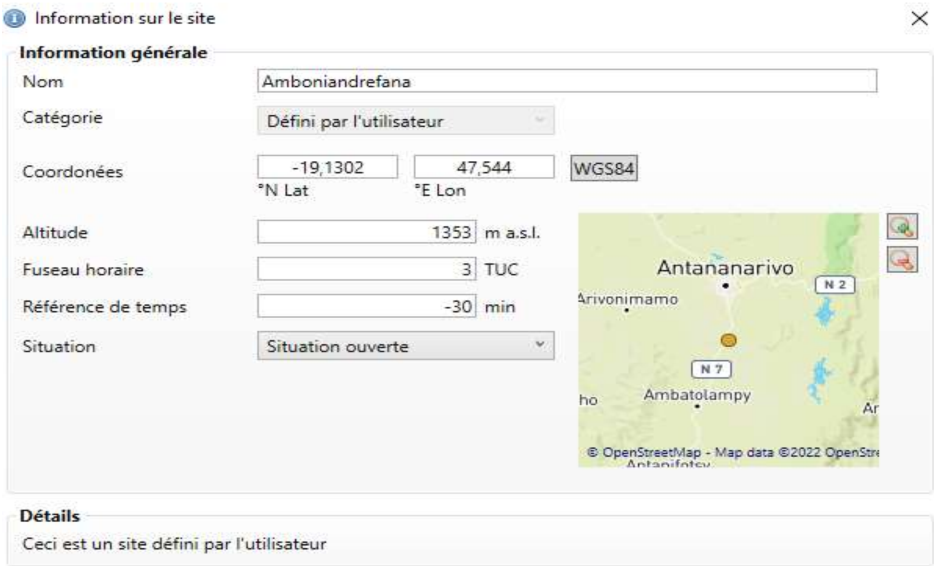


Figure 10. *Site Location*

2. Models to be Simulated

In this experiment, we compare two housing models of the Malagasy popular mass: the traditional house model and the current ordinary house model.

3. The Traditional House Model

The traditional house model is a mud-brick house with a thatched roof and earthen floor covered with matting; it is indicated by the red arrow.

Figure 11. *Country Village in Mud and Baked Clay, Thatched Roof*

This house is built to experiment, it represents the dwelling of the current Malagasy popular mass.

b. The Ordinary Case Model to be Processed

This model of simulation is built to represent an ordinary house of the Malagasy popular mass. It will be the object of simulations for optimal solutions in terms of eco-responsible comfort.

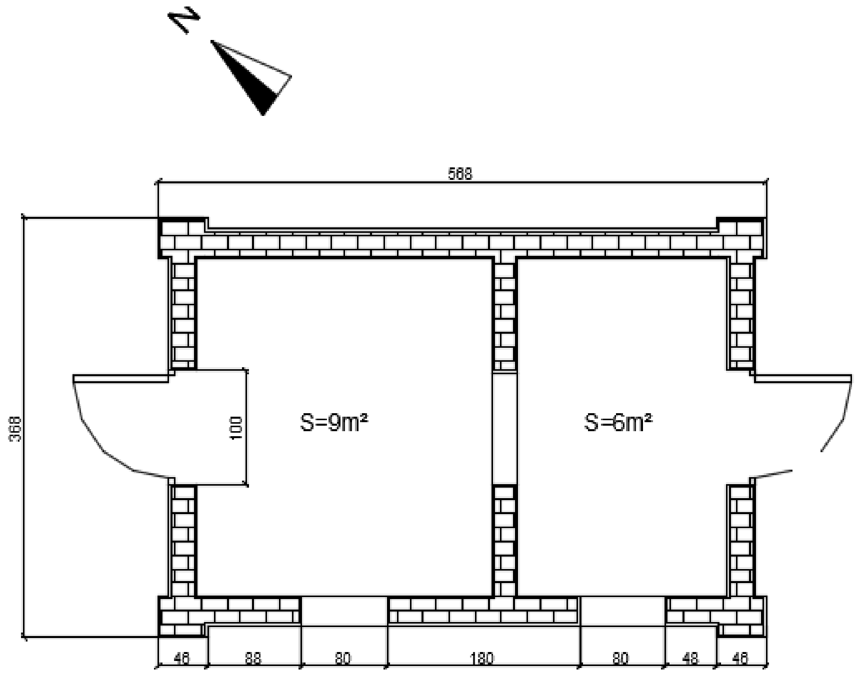


Figure 12. *Principle Plan of the Basic Ordinary House*

Figure 13. *Basic Ordinary House Model*

3.2 Basic Heat Balance

a. The Specifications for Thermal Comfort

The thermal comfort specifications **[1] [5] [8]** take into account the six thermal comfort parameters as well as the thermal contributions through the envelopes induced by the operation of the room. The latter are listed below:

- Dry summer indoor temperature: 24°C +/-1
- Dry winter indoor temperature: 20°C+/-1
- Or difference between indoor and outdoor temperature: 3°C
- Occupancy rate: the number of people per room or per square meter of living space
- Sensible heat input: 68W per person; Latent heat input 34W per person (we consider moderate physical activities)
- Heat input from computers (if any): 100W per computer
- Heat release from lighting fixtures: 10W/m².

- Glazed surfaces considered for thermal calculation: to be inserted (to be considered: geographical exposure, contribution by radiation through the glazings, contribution by conduction through the glazings)
- Wall surfaces (envelopes) considered for thermal calculation: to be inserted (to be considered: geographical exposure, contribution by convection through the walls)
- Surface of roofs (envelopes) considered for thermal calculation: to be inserted (to be considered: solar exposure, contribution by convection, contribution by radiation)
- Loss by air renewal: to be inserted, we will consider the conditions stipulated by the French regulations: The decree of March 24, 1982 and October 28, 1983 and the DTU 68-3

b. The Balance Sheet of the Traditional House

Table 2. Radiation Heat Gain from the Traditional House

5	Menu Bilan thermique			Identification du local : Traditionnelle							
6	Divers			Base de sélection calcul			Position du soleil		Condition climatique	Eté	Hiver
7	- Altitude	1353m		- Latitude		47,5°	altitude solaire :	26,9°	- Température sèche été	30,0°C	5,0°C
8	- Pression atmosphérique	860,92	kPa	- Longitude (facultatif)		-19,1°	azimuth (N) :	209,4°	- humidité relative	80,00%	
9	Eclairages			- Mois de référence :	Fév	2	Localisation site		- Ecart moyen sur 24h	10,0°C	
10	- Heure d'allumage	6,0h		- Jour choisi :		21	Amboniandrefana		Condition climatique ambiance		
11	Condidion climatique			- heure solaire choisie :		14,0h	15 Heure locale		- température sèche	24,0°C	20,0°C
12	Temp. extérieure à 14h	28,2°C		- Facteur trouble (facultatif)		0,9			- humidité relative	65%	

15	PAROIS VITREES EXTERIEURES - GAINS SOLAIRES											SC		Apports été (W)		Déperdi
16	Désignation	Orientation		Ouvrants				Facteur	Facteur solaire (Fs)			Rayonnement		sensibles	latents	W
17	vitrages	Désig.	Azimut	Longueur	Hauteur	Surf.	Surface	chassis	Sans store	Avec store		inclinai	solaire			
18			degré	m	m	m2	m2	%	SC	SC	% ouvert	degré	W/m2			
19		N	1°					0,85	0,8			90°	26,4		-------	-------
20		NE	45°					0,85	0,8			90°	26,4		-------	-------
21		E	90°					0,85	0,8			90°	26,4		-------	-------
22		E/SE	113°					0,85	0,8			90°	26,4			
23		SE	135°					0,85	0,8			90°	205,1		-------	-------
24		S/SE	158°					0,85	0,8			90°	437,8		-------	-------
25		S	180°					0,85	0,8			90°	600,0		-------	-------
26		S/SO	203°					0,85	0,8			90°	680,5		-------	-------
27		SO	225°					0,85	0,8			90°	660,5		-------	-------
28	- Vitrage vertical	O/SO	248°	1,6m	1,6m		2,56	0,85	0,8			90°	541,5	942,6	-------	-------
29		O	270°					0,85	0,8			90°	351,0		-------	-------
30		O/NO	293°					0,85	0,8			90°	102,3			
31		NO	315°					0,85	0,8			90°	26,4		-------	-------
32	- Elément vitré toiture	horizontal						0,85	0,8				390,6		-------	-------
33		horizontal						0,85	0,8				390,6		-------	-------

Table 3. Conductive Heat Input from the Traditional House

	PAROIS OPAQUES ET VITREES - TRANSFERT PAR CONDUCTION															
35		Orientation		Dimensionnement parois					Coef.	Absorption		T.équivalente				
36	Parois extérieures	Désig.	Azimut	Masse	Long.	Largeur	Surface	Surf. réell	U	Facteur	Teinte	Inclinai	au soleil			
37			degré	kg/m2	m	m	m2	m2	W/m2 °C	Valeur		degré	°C			
38	- Parois verticales	N		1500kg					2,00	0,75	moyen	90°	4,2°C		------	
39	- Parois verticales	NE	45°	1500kg	5,7m	2,4m		13,68	2,00	0,75	moyen	90°	4,2°C	113,8	------	410,4
40		E	90°	1500kg					2,00	0,75	moyen	90°	4,2°C		------	
41	- Parois verticales	SE+E/SE	135°	1500kg	3,7m	2,5m		9,25	2,00	0,75	moyen	90°	15,0°C	278,0	------	277,5
42		S	180°	1500kg					2,00	0,75	moyen	90°	21,7°C		------	
43	- Parois verticales	SO+S/SO	225°	1500kg	5,7m	2,5m		14,20	2,00	0,75	moyen	90°	18,0°C	512,1	------	426,0
44		O	270°	1500kg					2,00	0,75	moyen	90°	6,3°C		------	
45	- Parois verticales	NO+O/NO	315°	1500kg	3,7m	2,5m		9,20	2,00	0,75	moyen	90°	4,2°C	76,5	------	276,0
46	- toiture terrasse			30kg	-----	-----	22,00	22,00	0,70	0,9	foncée	----	8,2°C	125,6	------	231,0
47	- toiture terrasse			30kg	-----	-----			0,70	0,9	foncée	----	8,2°C		------	
48	- Vitrage vertical			----	-----	-----	-----	2,56	5,00	-----	-----	----	4,2°C	53,2	------	192,0
49	- Vitrage horizontal			----	-----	-----	-----		5,00	-----	-----	----	4,2°C		------	
50	- Coefficients linéiques			----		-----	-----	-----	0,15	-----	-----	----	4,2°C			
51	- Coefficients linéiques			----		-----	-----	-----	0,18	-----	-----	----	4,2°C			
52	Parois intérieures				Long.	Largeur	Surface	Surf. réell	U	Delta T (hiver)		delta T (été)				
53	- refend			----	3,7m	2,5m		9,20	2,2	-----	2,0°C	----	3,0°C	60,7	------	40,5
54	- plancher			----	5,5m	3,5m		18,89	3	-----	2,0°C	----	3,0°C	170,0	------	113,3
55	- cloison			----					2,7	-----	2,0°C	----	3,0°C		------	

Table 4. Heat Balance of the Traditional House

56	GAINS PAR RENOUVELLEMENT D'AIR															
57		Dimensions local		Débit air Q (à 20°C/1013mb)				Extérieur		Intérieur		Delta valeurs				
58				Unit	Nbre	Volumiq	Massiqu	Ts	Humidité	Tempér	Humidité	Tempé	Humidité			
59		Surf.	Haut	m3	U	m3/h	kg/h	°C	g/h kg	°C	g/h kg	°K	g/h kg			
60	- Air hygiénique occup	19m2	2,5m	47	1	47	48	28,2°C	25,53	24,0°C	14,33	4,2°C	11,19	56,1	361,6	240,8
61	- Infiltration d'air							28,2°C	25,53	24,0°C	14,33	4,2°C	11,19			
62	- Renouvellement air							28,2°C	25,53	24,0°C	14,33	4,2°C	11,19			
63	GAINS INTERNES (W/h)															
64						Surf.	Occupation (pers/m2 or personnes)					Sensi.	Latent			
65	OCCUPANTS		Type d'activité			m2	pers/m2	Pers	Simulta	Correct	pers	W	W			
66	- Assis sans activité, au repos		(théatre)							1		68	34			------
67	- Assis, marche lente, travail lé		(bureaux, magasin)			19	0,3			1	5,70	71	46	404,8	260,9	------
68	- Travail facile		(atelier, restaurant)							1		82	80			------
69	- Danse		(discothèque)							1		95	162			------
70	- Travail difficile		(usine)							1		154	270			------
71	ECLAIRAGE		Type d'éclairage			Surf.	ratio/m2	Quant	Simulta	Puis	balast	Amortissement				
72						m2	w/unit	U		w/h	corect.	h. écou	coéf.			
73	- Eclairage (non encastré)		à incandescence									8,0h	0,97		------	------
74	- Eclairage (non encastré)		fluorescent				10w	2u		20	1,25	8,0h	0,97	24,2	------	------
75	- Eclairage (encastré)		à incandescence								1,25	8,0h	0,97		------	------
76	DIVERS					m2	w/unit	Quant.	Simulta	-----	-----	-----	------			
77	- Ordinateur :														------	------
78	- Divers						100w								------	------
79	- Vapeur d'eau dégagée dans local (679 x Q (kg/h))					---	---		---					------		------
80	TOTAL BILAN THERMIQUE DU LOCAL (W) :													2818	623	2208

PG | standard | traditionnelle

c. The Balance Sheet of the Ordinary House

Table 5. Radiation Heat Input for the Malagasy Ordinary Basic House

5	Menu Bilan thermique		Identification du local : Standard						
6	**Divers**		**Base de sélection calcul**		**Position du soleil**		**Condition climatique**	Eté	Hiver
7	- Altitude	1353m	- Latitude	47,5°	altitude solaire :	26,9°	- Température sèche été	30,0°C	5,0°C
8	- Pression atmosphérique	860,32 kPa	- Longitude (facultatif)	-19,1°	azimuth (N) :	209,4°	- humidité relative	80,00%	
9	**Eclairages**		- Mois de référence : Fév	2	**Localisation site**		- Ecart moyen sur 24h	10,0°C	
10	- Heure d'allumage	6,0h	- Jour choisi :	21	Amboniandrefana		**Condition climatique ambiance**		
11	**Condidion climatique**		- heure solaire choisie :	14,0h	15 Heure locale		- température sèche	24,0°C	20,0°C
12	Temp. extérieure à 14h	28,2°C	- Facteur trouble (facultatif)	0,9			- humidité relative	65%	

15	PAROIS VITREES EXTERIEURES - GAINS SOLAIRES													SC	Apports été (W)	Déperdi
16	Désignation	Orientation		Ouvrants				Facteur	Facteur solaire (Fs)			Rayonnement		sensibles	latents	W
17	vitrages	Désig.	Azimut	Longueur	Hauteur	Surf.	Surface	chassis	Sans store	Avec store		inclinai	solaire			
18			degré	m	m	m2	m2	%	SC	SC	% ouvert	degré	W/m2			
19		N	1°					0,85	0,8			90°	26,4		------	------
20		NE	45°					0,85	0,8			90°	26,4		------	------
21		E	90°					0,85	0,8			90°	26,4		------	------
22		E/SE	113°					0,85	0,8			90°	26,4			
23		SE	135°					0,85	0,8			90°	205,1		------	------
24		S/SE	158°					0,85	0,8			90°	437,8		------	------
25		S	180°					0,85	0,8			90°	600,0		------	------
26		S/SO	203°					0,85	0,8			90°	680,5		------	------
27		SO	225°					0,85	0,8			90°	660,5		------	------
28	- Vitrage vertical	O/SO	248°	1,6m	1,6m		2,56	0,85	0,8			90°	541,5	942,6	------	------
29		O	270°					0,85	0,8			90°	351,0		------	------
30		O/NO	293°					0,85	0,8			90°	102,3			
31		NO	315°					0,85	0,8			90°	26,4		------	------
32	- Elément vitré toiture	horizontal						0,85	0,8				390,6		------	------
33		horizontal						0,85	0,8				390,6		------	------

Table 6. Conduction Heat Input for the Mmalagasyordinary Basic House

34	PAROIS OPAQUES ET VITREES - TRANSFERT PAR CONDUCTION															
35		Orientation		Dimensionnement parois					Coef.	Absorption		T.équivalente				
36	Parois extérieures	Désig.	Azimut	Masse	Long.	Largeur	Surface	Surf. réell	U	Facteur	Teinte	Inclinai	au soleil			
37			degré	kg/m2	m	m	m2	m2	W/m2 °C	Valeur		degré	°C			
38	- Parois verticales	N		450kg					2,50	0,75	moyen	90°	4,2°C		------	
39	- Parois verticales	NE	45°	450kg	5,7m	2,4m		13,68	2,50	0,75	moyen	90°	4,2°C	142,2	------	513,0
40		E	90°	450kg					2,50	0,75	moyen	90°	4,2°C		------	
41	- Parois verticales	SE+E/SE	135°	450kg	3,7m	2,5m		9,25	2,50	0,75	moyen	90°	12,5°C	288,5	------	346,9
42		S	180°	450kg					2,50	0,75	moyen	90°	17,5°C		------	
43	- Parois verticales	SO+S/SO	225°	450kg	5,7m	2,5m		14,20	2,50	0,75	moyen	90°	14,8°C	524,4	------	532,5
44		O	270°	450kg					2,50	0,75	moyen	90°	5,8°C		------	
45	- Parois verticales	NO+O/NO	315°	450kg	3,7m	2,5m		9,20	2,50	0,75	moyen	90°	4,2°C	95,6	------	345,0
46	- toiture terrasse			10kg	-----	-----	22,00	22,00	3,50	0,9	foncée	----	8,3°C	636,0	------	1155,0
47	- toiture terrasse			10kg	-----	-----			3,50	0,9	foncée	----	8,3°C		------	
48	- Vitrage vertical			----	-----	-----	-----	2,56	5,00	-----	-----	----	4,2°C	53,2	------	192,0
49	- Vitrage horizontal			----	-----	-----	-----		5,00	-----	-----	----	4,2°C		------	
50	- Coefficients linéiques			----		-----	-----	-----	0,15	-----	-----	----	4,2°C			
51	- Coefficients linéiques			----		-----	-----	-----	0,18	-----	-----	----	4,2°C			
52	Parois intérieures				Long.	Largeur	Surface	Surf. réell	U	Delta T (hiver)		delta T (été)				
53	- refend			----	3,7m	2,5m		9,20	2,2	-----	2,0°C	----	3,0°C	60,7	------	40,5
54	- plancher			----	5,5m	3,5m		18,89	3	-----	2,0°C	----	3,0°C	170,0	------	113,3
55	- cloison			----					2,7	-----	2,0°C	----	3,0°C		------	

Table 7. Thermal Balance for the Malagasy Ordinary Basic House

56	GAINS PAR RENOUVELLEMENT D'AIR															
57		Dimensions local		Débit air Q (à 20°C/1013mb)				Extérieur		Intérieur		Delta valeurs				
58				Unit	Nbre	Volumiq	Massiqu	Ts	Humidité	Tempér	Humidité	Tempé	Humidité			
59		Surf.	Haut	m3	U	m3/h	kg/h	°C	g/h kg	°C	g/h kg	°K	g/h kg			
60	- Air hygiénique occup	19m2	2,5m	47	1	47	46	28,2°C	25,53	24,0°C	14,33	4,2°C	11,19	56,1	361,6	240,8
61	- Infiltration d'air							28,2°C	25,53	24,0°C	14,33	4,2°C	11,19			
62	- Renouvellement air							28,2°C	25,53	24,0°C	14,33	4,2°C	11,19			
63	GAINS INTERNES (W/h)															
64						Surf.	Occupation (pers/m2 or personnes)					Sensi.	Latent			
65	OCCUPANTS		Type d'activité			m2	pers/m2	Pers	Simulta	Correct	pers	W	W			
66	- Assis sans activité, au repos		(théatre)							1		68	34			------
67	- Assis, marche lente, travail lé		(bureaux, magasin)			19	0,3			1	5,70	71	46	404,8	260,9	------
68	- Travail facile		(atelier, restaurant)							1		82	80			------
69	- Danse		(discothèque)							1		95	162			------
70	- Travail difficile		(usine)							1		154	270			------
71	ECLAIRAGE		Type d'éclairage			Surf.	ratio/m2	Quant	Simulta	Puis	balast	Amortissement				
72						m2	w/unit	U		w/h	corect.	h. écou	coéf.			
73	- Eclairage (non encastré)		à incandescence									8,0h	0,97		------	------
74	- Eclairage (non encastré)		fluorescent				10w	2u		20	1,25	8,0h	0,97	24,2	------	------
75	- Eclairage (encastré)		à incandescence								1,25	8,0h	0,97		------	------
76	DIVERS					m2	w/unit	Quant.	Simulta	-----	-----	-----	-------			
77	- Ordinateur :														------	------
78	- Divers						100w								------	------
79	- Vapeur d'eau dégagée dans local (679 x Q (kg/h))					---	---		---					------		------
80	TOTAL BILAN THERMIQUE DU LOCAL (W) :													3398	623	3479

d. Resultats Et Discussions

1. Bilan Thermique Comparatif

The matrix below summarizes the heat balance of the two models.

Table 8. Heat Balance of the Two Models

	Traditional house	Basic standard house
Latent heat [W]	2818	3398
Sensitive heat [W]	623	623
Wastage [W]	2208	3479
Total [W]	**5649**	**7500**

It can be confirmed that in terms of thermal comfort, a traditional house is more viable than the basic standard house of the Malagasy population. Indeed, for the same geographical and climatic conditions, the traditional house allows saving in 1851[W].

2. Comparison of Room Temperatures

The measurements were taken between 12:00 and 4:00 p.m. We have the interior and exterior temperatures in the two models. We notice that the temperatures are not taken on the same days for the two models, on the other hand, what interests us, is the delta between the inside and outside temperatures.

3. Interior Temperature of the Traditional House

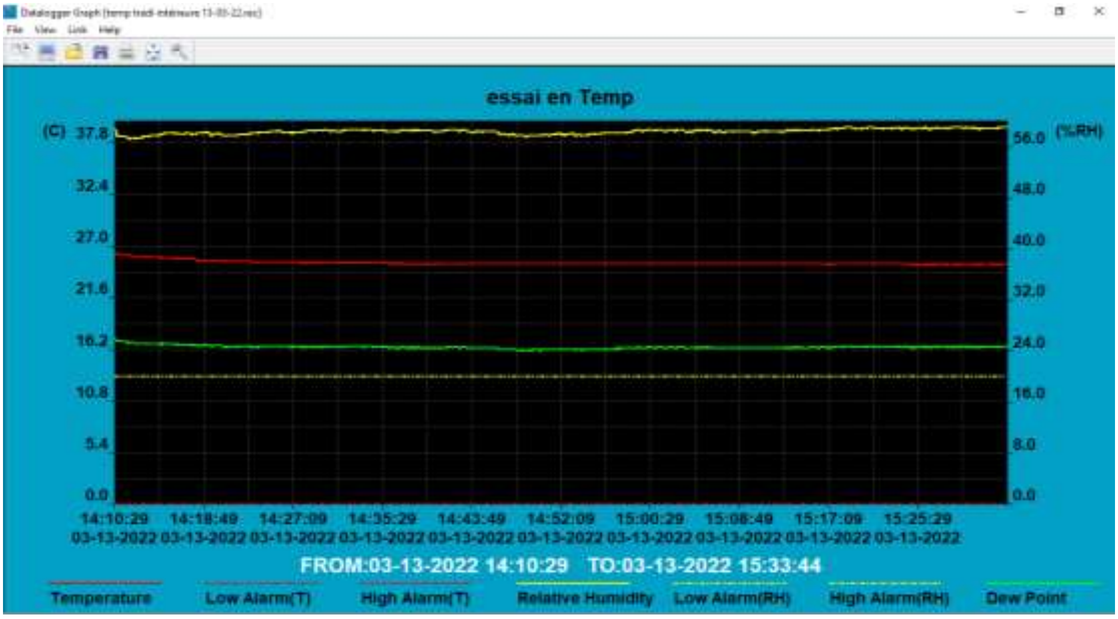


Figure 12. *Indoor Temperature of the Traditional House*

4. Outside Temperature of the Traditional House (Temperature Taken at the Level of the North-West Façade at the Same Level of the Roof; Windows Facing North-West)

Figure 13. *Indoor Temperature of the Traditional House*

5. Conclusion

For the traditional house, we can confirm a difference in indoor and outdoor temperature very close to that recommended by the specifications.

6. The Interior Temperature of the Basic Standard Box Model

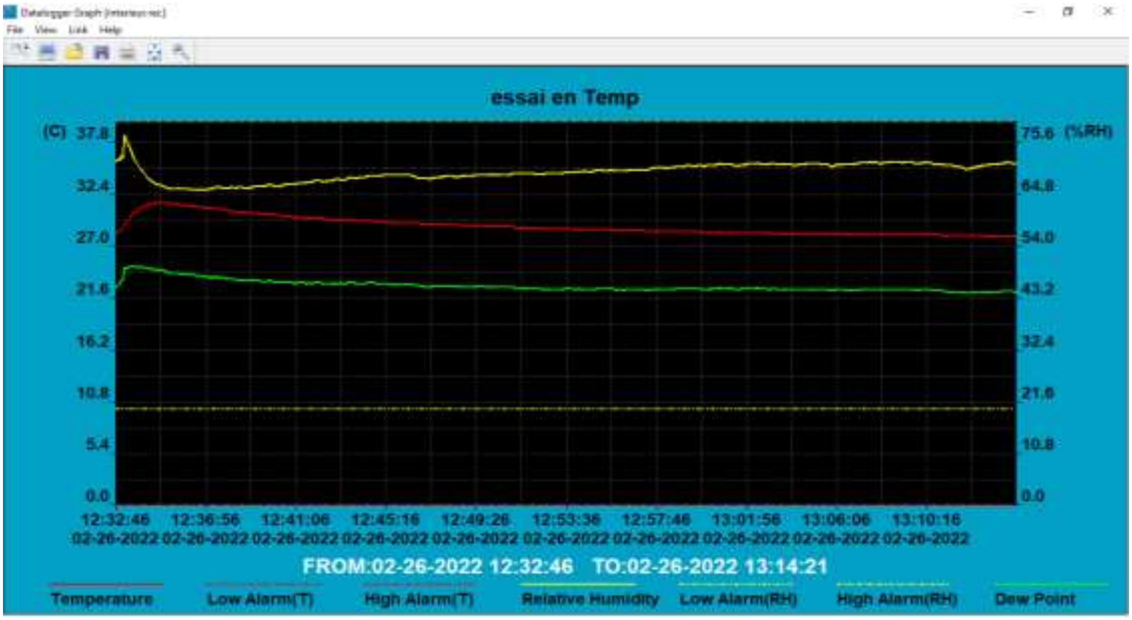


Figure 14. *Interior Temperature of the Basic Standard House Model*

7. Outdoor Temperature at the Ordinary Basic House Model (Temperature Taken at the Southwest Façade at the Same Level as the Roof; Windows Facing Southwest)

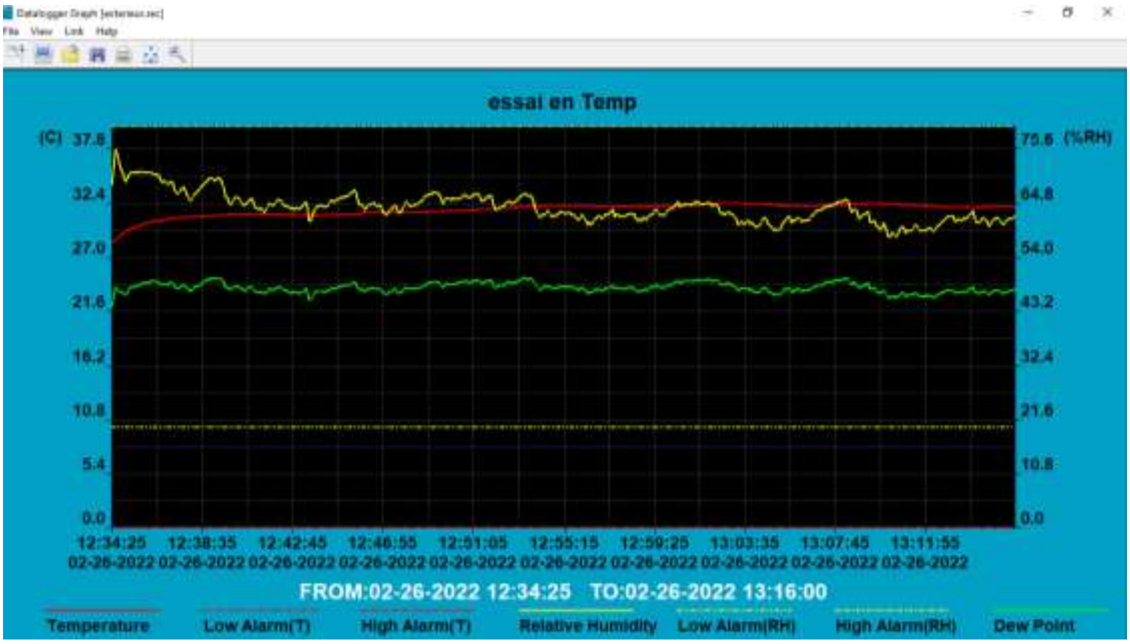


Figure 15. *Interior Temperature of the Basic Standard Box Model*

8. Conclusion

The temperature difference between the interior and exterior is around 3.5°C, but the interior exceeds the temperature specified in the specifications by more than 3°C. A solution is therefore needed for the comfort heat treatment.

9. Ranking of Adapted Eco-Responsible Solutions
a. Case of the Traditional House

Table 9. Eco-Responsible Analysis for Traditional House

Visual PROMETHEE Academic - CONFORT AIR.vpg (sauvegardé)

Fichier Edition Modèle Contrôle PROMETHEE-GAIA GDSS SIG Custom Assistants Snapshot:

case traditionnelle	faisabilité	efficacité	valeur eco	coût	durabilité
Unité	5 points	5 points	5 points	5 points	5 points
Cluster/Groupe	◆	◆	◆	◆	◆
Préférences					
Min/Max	max	max	max	max	max
Poids	1,00	1,00	1,00	1,00	1,00
Fn. de préférence	Usuel	Usuel	Usuel	Usuel	Usuel
Seuils	absolu	absolu	absolu	absolu	absolu
- Q: Indifférence	n/d	n/d	n/d	n/d	n/d
- P: Préférence	n/d	n/d	n/d	n/d	n/d
- S: Gaussien	n/d	n/d	n/d	n/d	n/d
Statistiques					
Minimum	3	3	1	1	2
Maximum	4	5	5	5	5
Moyenne	4	4	3	3	4
Ecart-type	0	1	1	1	1
Evaluations					
bioclimatique	bon	moyen	très bon	très bon	bon
stores,brise soleil	n/d	bon	moyen	moyen	moyen
isolation	n/d	très bon	mauvais	mauvais	bon
inertie matériaux	bon	bon	très bon	bon	très bon
convection natur…	moyen	moyen	très bon	très bon	bon
VMC	n/d	bon	mauvais	mauvais	bon
geo cooling	n/d	moyen	très bon	moyen	bon
recup energie	n/d	bon	très bon	très mauvais	moyen
rafraichissement	n/d	moyen	moyen	mauvais	moyen
clim standard	n/d	très bon	très mauvais	mauvais	mauvais
clim eco	n/d	très bon	mauvais	très mauvais	moyen

All | case traditionnelle | standard basique | Scénario3

b. Case of the Basic Ordinary House

Table 10. Eco-Responsible Analysis for Ordinary Basic House

Visual PROMETHEE Academic - CONFORT AIR.vpg (sauvegardé)

Fichier Edition Modèle Contrôle PROMETHEE-GAIA GDSS SIG Custom Assistants Snapshot

	standard basique	faisabilité	efficacité	valeur eco	coût	durabilité
	Unité	5 points	5 points	5 points	5 points	5 points
	Cluster/Groupe	◆	◆	◆	◆	◆
	Préférences					
	Min/Max	max	max	max	max	max
	Poids	1,00	1,00	1,00	1,00	1,00
	Fn. de préférence	Usuel	Usuel	Usuel	Usuel	Usuel
	Seuils	absolu	absolu	absolu	absolu	absolu
	- Q: Indifférence	n/d	n/d	n/d	n/d	n/d
	- P: Préférence	n/d	n/d	n/d	n/d	n/d
	- S: Gaussien	n/d	n/d	n/d	n/d	n/d
	Statistiques					
	Minimum	2	2	1	1	2
	Maximum	3	5	5	5	5
	Moyenne	3	4	4	3	3
	Ecart-type	1	1	2	1	1
	Evaluations					
☑	biodimatique	mauvais	moyen	très bon	bon	bon
☑	stores,brise soleil	n/d	bon	n/d	moyen	mauvais
☑	isolation	n/d	bon	mauvais	bon	moyen
☑	inertie matériaux	n/d	mauvais	très bon	moyen	moyen
☑	convection natur…	moyen	moyen	très bon	très bon	très bon
☑	VMC	n/d	bon	mauvais	moyen	moyen
☑	geo cooling	n/d	moyen	très bon	moyen	moyen
☑	recup energie	n/d	moyen	très bon	très mauvais	moyen
☑	rafraichissement	n/d	moyen	moyen	mauvais	moyen
☑	clim standard	n/d	très bon	très mauvais	mauvais	moyen
☑	clim eco	n/d	très bon	mauvais	très mauvais	moyen

All / case traditionnelle / standard basique / Scénario3

c. Comparison of Suitable Solutions for the Two Cases

The advantageous solutions are colored in green.

Table 10. Eco-Responsible Suitable Solutions Comparison for the Two Houses Models (Left: for the Traditional House Model, Right: Basic Ordinary House Model)

PROMETHEE V

Contraintes | Solution

Etat : Terminé! RAZ

Actions		Flux Net	Optimal	Comparai
		Total:	1,1200	1,1200
bioclimatique		0,2600	oui	oui
stores,brise so...		-0,0400	non	non
isolation		0,0600	oui	oui
inertie matéria...		0,4800	oui	oui
convection nat...		0,2000	oui	oui
VMC		-0,0800	non	non
geo cooling		0,1200	oui	oui
recup energie		-0,1400	non	non
rafraichisseme...		-0,3200	non	non
clim standard		-0,3000	non	non
clim eco		-0,2400	non	non

PROMETHEE V

Contraintes | Solution

Etat : Terminé! RAZ

Actions		Flux Net	Optimal	Comparai
		Total:	0,8600	0,8600
bioclimatique		0,3000	oui	oui
stores,brise so...		-0,1000	non	non
isolation		0,1000	oui	oui
inertie matéria...		-0,1000	non	non
convection nat...		0,4400	oui	oui
VMC		-0,0200	non	non
geo cooling		0,0200	oui	oui
recup energie		-0,1800	non	non
rafraichisseme...		-0,2200	non	non
clim standard		-0,1200	non	non
clim eco		-0,1200	non	non

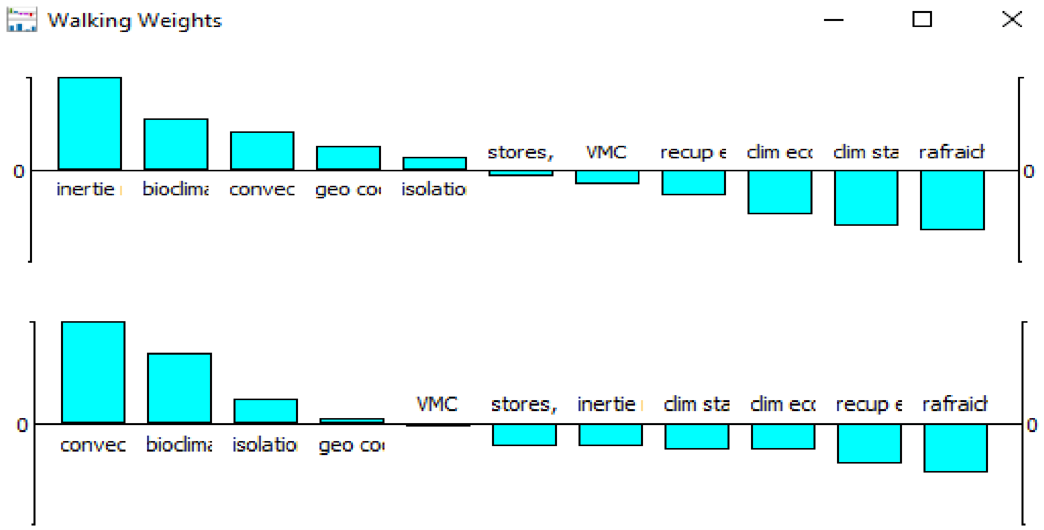


__Figure 14.__ Suitable Solutions Ranking for the Two Models (Top: Traditional Model; Bottom: Ordinary Basic Model)

Comparing the graphs of the adapted solutions, we notice that bioclimatic design, natural convection and geo-cooling play key roles in both cases.

In terms of inertia, fired clay bricks are not good elements. We will have more of a tendency toward insulation, so another analysis in this sense should follow this study in an optic of improving the thermal comfort of the ordinary basic house. For more or less natural insulation solutions, the following points will be discussed:

- The creation of air gaps in the envelopes (compound walls)
- The use of vegetated walls
- The use of insulating roofs and roofs with low albedo (thatch, vegetated roofs)

IV. Conclusion

In short, through this study, we were able to put thermal comfort at the heart of systemic analysis. We looked at it from another angle than the usual air conditioning solution. Moreover, according to the eco-responsible value, the use of mechanical solutions is far from natural solutions. These solutions should not be used only when ecological solutions are not feasible.

Also, we could demonstrate that the design of the traditional mud house and a thatched roof has an exploitable value in terms of eco-responsible comfort. We underline our interest in this theme in technological watches and innovations in the thermal field of the building. The key elements are bioclimatic design, materials with high thermal inertia, insulation (but in the natural trend), ventilation and geo cooling.

In terms of stakes and challenges for the future, within the framework of the current environmental situation, this study is well aligned with the energy control required by the environmental standards, if we only mention those mentioned in the paragraph on efficient buildings, or the RT2020.

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