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Research Article

ENVIRONMENTAL IMPACT AND THERMO-ENERGY PERFORMANCE OF RECYCLED MATERIALS: LIFE CYCLE ASSESSMENT APPLIED TO OFFICE BUILDING IN BISKRA CITY, ALGERIA

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ABSTRACT

In order to reduce energy consumption of buildings and their environmental impacts, it’s important to improve their energy performance, and to have and evaluate sufficiently reliable multi-criteria tools, to highlight their origins, throughout the building life cycle. Such impacts may be resulting from their construction, during exploit, renovation and at the end of life.

This work relates to a part of this action and seeks to derive results from a life-cycle analysis comparing an office building envelope configuration, located in Biskra, a city south East Algeria characterized by hot and dry climate. Life Cycle Assesment method was applied according to a standardized protocol (ISO14000 &14040), promoting a better understanding of a building environmental impact throughout its life cycle. More, such method, allows designers to make the most appropriate choice (recycled materials, energy systems HVAC) in relation to their objectives.

Keywords: Sustainable building; life cycle assessment; energy optimization; environmental impact; thermal insulation system; recycled materials.

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1. INTRODUCTION

1.1. Building Energy Performance

The Brundtland Report [1] developed guiding principles for sustainable development applied to decision-making, requiring diverse and united actions in the various sectors of the economy, environment, health, agriculture, and especially construction. Also, Building is the most energy-intensive sector in the world, exceeding 45% of total energy consumption, with 50% of total exploited natural resources [2]. Emissions of building-related pollutants are also high; both in air (30% of total emissions of CO^2, greenhouse gases), and in water (a quarter of eutrophication discharges) with more than 40% of product waste [3]. This paper exposes, a life cycle assessment LCA carried about an office building in Biskra city (south East Algeria: lat. 34º 50' Nord; long.5º 43' East) to improve its energy performance, and to have adequate multi-criteria tools,tohighlight the sources of environmental impacts (greenhouse effect, radioactive waste, water consumption...), throughout its life cycle building, **"cradle to grave"** [4], allowing hence designers to make the most consistent choice (green building materials, recycled materials, passive systems for heating and cooling) in relation to their sustainable building objectives.

1.2 Energy, Economy and Building: Contribution of Thermal Insulation

The oil and the fossil fuels crisis, as well as certain phenomena affecting the environment have led to a desire to significantly reduce energy consumption [5], required for (Heating, Air Conditioning, and Lighting indoors) [6], through a recourse to good insulation and high performance sealing of the construction [7]. In this sense, this research work takles the matter of how to enable design of thermally efficient and, energy-saving building, within the limits of respect of environment by the means of environmentally friendly, ecological and recycled materials.

2. METHODOLOGY

Life Cycle Assessment (LCA) is an environmental impact assessment method EIAM, it's a scientifically recognized and standardized method used to assess the environmental impacts of a product, or a process, from the extraction of raw materials to its end-of-life treatment

“cradle to grave” [8].

LCA of a product is mainly associated to certification objectives, a diagnosis, an evaluation or/ and a frozen existing situation. However, the buildings life cycle assessment, will be oriented towards objectives of system evolution, analysis of public policy of housing, public buildings, etc...,decision aid and environmental impact assessment[9].

Life Cycle Assessment of building consists of four 04 phases [10] (Fig.1): construction, use, renovation, and end-of-life.

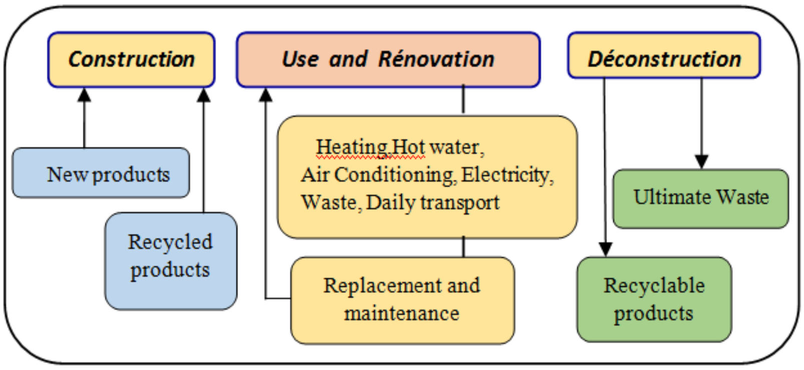

Fig.1. Life cycle Phases of building

This life-cycle analysis is based on 4 step approach (Fig.2), where results are leveraged by identifying directions for improvement proposals, strategic planning, public policy, marketing.

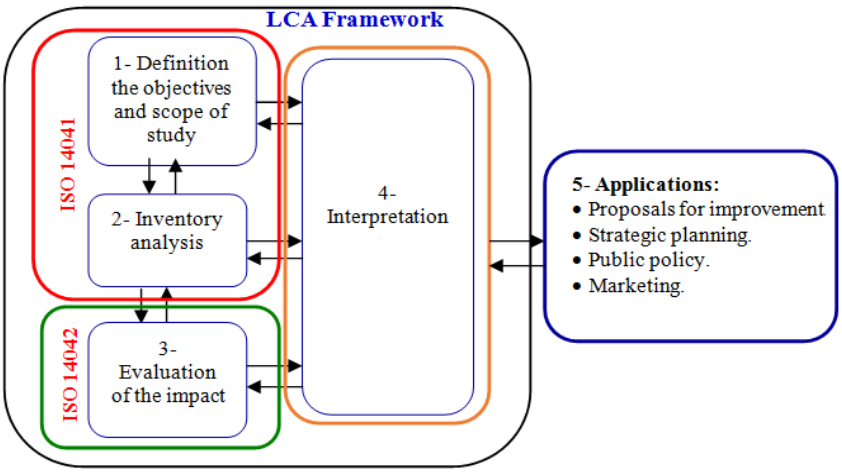

Fig.2. Life cycle analysis framework

2.1 Life cycle assesment objectives

The most important challenge of the Life Cycle Analysis approach [11] is to: identify, avoid, and eliminate the main sources of environmental impacts. This study aims to acquire results from a comparative life cycle analysis between several exterior wall configurations [12]. These make the energy optimization that determining all environmental impacts during building life cycle, and so allow to assess his environmental adaptation in relation to the hot and dry climate context.

3. BISKRA, STUDY CONTEXT

Our choice of tertiary architecture for energy and environmental studies through a "life cycle assessment LCA of buildings" approach stems from reasons [13]:

a. The tertiary sector continues to grow globally, and Algeria is no exception.

b. Office buildings draw the urban silhouette, and will be our heritage for future.

c. It’s an energy user, with more than 42% of total energy consumption in Algeria, and also responsible for greenhouse, gas emissions, and other environmental impacts.

d. Implement the Energy/Economy/Environment report through a policy of energy management and reduction of emissions and environment impacts.

For some authors, Biskra is considered as representative of most Algerian cities of, arid regions[14]. It is distinguished by:

1. Maximum temperatures are recorded in summer, July and get to 45.2°C.
2. Minimum Temperatures are recorded in winter with 2.2°C in January.
3. The variant between day and night is 15°C.
4. Intense direct solar radiation up to 900 to 1100 W/m².
5. Relative humidity remains low at 27%.
6. Winds are strong and may exceed 80 km/h during the half-seasons.

The study office building (Urban Agency of Biskra refers to as AUB) is a new construction, using the locally widespread standards constructive technics systems (concrete structure, exterior masonry in terracotta bricks, coatings, wood, ceramics, plasters, etc.), together with, bay windows, and glazed walls integration. The building’s façades (S.E, S.W and W) are not conform to the guidelines recommended for architecture in an arid region [15] and are not equipped with appropriate sun protection devices. The building envelope composition is very varied (Fig.3) and comprises: single wall (15 cm); double wall (30 cm with 5 cm air blade); red wooden Moucharabieh and glazed wall. A very basic thermal insulation is realized and is, limited by a distributed insulation type or sandwich (double wall with a blade of air). For the others shell components, no insulation is built-in.

(a)

(b) (c)

Fig.3. The case study building.

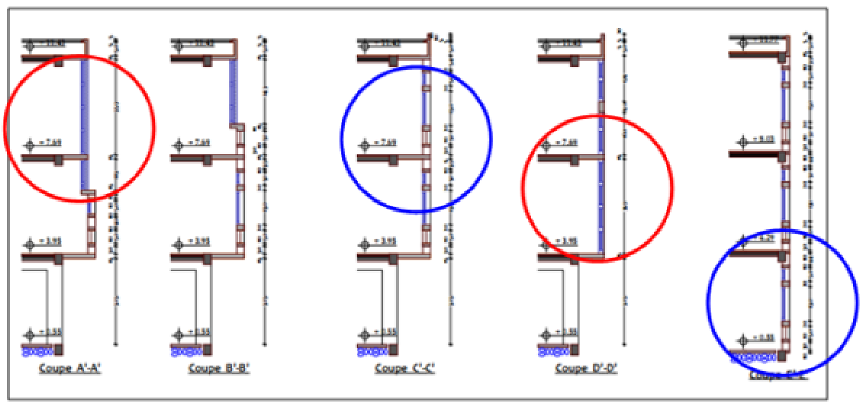

Fig.4. Details of the wall composition

4. SIMULATION

As cited previously, the LCA is an experimental study presented in this paper in the form of an informatics simulation. It is conducted using the **Comfie-Pleiades** 2016 dynamic heat behavior simulation software linked to the building environmental impact study software, **nova–Equer** 2016.

4.1 Simulation Tools

As input to the simulation, **Alcyone** software defines all the building data (geometry, materials...), the site data (orientation, neighborhood, environment, close masks), the weather data of study environment (Biskra) as well as the building thermal zones enclosing equivalent thermal behavior [16]. Also, **Comfie-Pleiades** are the dynamic thermal simulation **DTS** software for buildings [17]. Using data on building materials, occupancy scenarios and weather conditions, the software calculates the energy requirements for heating and cooling and lighting of the building for a given period of time (up to one year). The energy requirements once assessed are exported to **Nova-Equer**, which is the environmental impact assessment tool for buildings [18].

4.2 Simulation Protocol

The first simulation involves intervention at the origin, nature and type of insulation used for the building envelope or external walls (Expanded Polystyrene, Cellulose Wadding) [11].

The results from the thermal and environmental analysis allowed a comparison of the different configurations, and thus the validation of the insulation studied in this work [12].

The second involves intervention on the insulation technique of the building envelope (distributed insulation, by the exterior or by the interior insulation) (Fig.5).

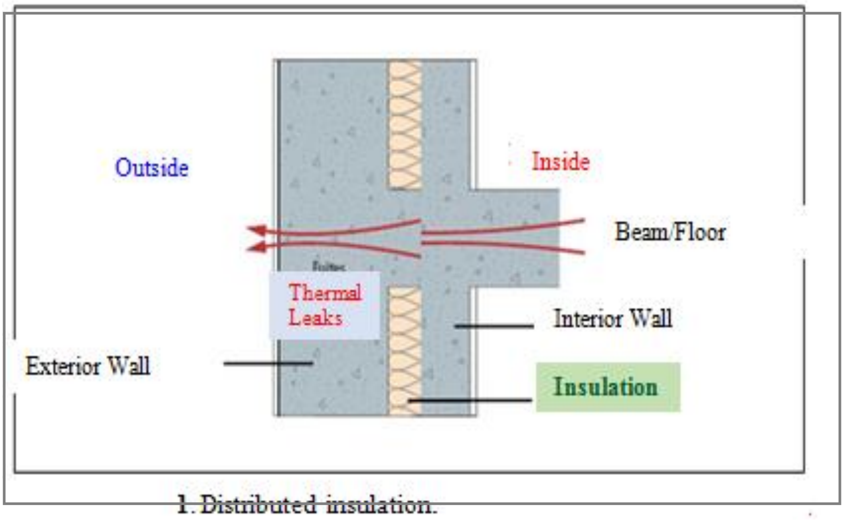

Fig.5 (a). Differents Insulations of exterior walls

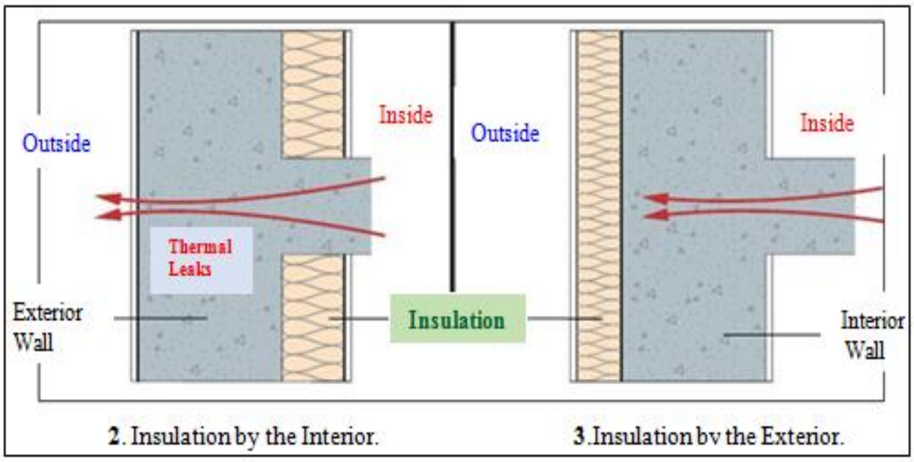

Fig.5 (b). Differents Insulations of exterior walls

Table1. Environmental Indicators Assessed.

Environmental Indicator	Unite
Greenhouse effect	t CO2 eq.
Acidification	kg SO2 eq.
Cumulative Energy Demand	GJ
Water used	m³
Inert waste produced	T
Exhaustion of ambiotic resources	kg E-15
Eutrophication	kg PO4 eq.
Ozone production photochemical	kg ethylene eq.
Aquatic ecotoxicity	m³
Radioactive waste	dm³
Human toxicity	Kg
Odor	m³ air

These drives include[19]:

a) The insulation technique that will determine the building thermal quality.

b) Energy optimizations.

c) Environmental impacts (Table1).

4.3 The Simulation Reasons

This work involves a modeling of the office building of concern in order to identify it's the optimal insulating materials (ecological materials, recycled materials, etc.) [20], which go into its envelope, and also to clarify the various techniques used to implement insulation. For this purpose, a functional unit was selected which is 1.00 m² of landscaped office area (Fig.6). This unit includes the elements of the concrete structure, the envelope materials, the interior partitions, the coatings and paints, the carpentry and the type of glazing, as well as the elements of the exterior layout (water space, vegetation, etc.) that affect the energy balance and the environmental impact [21].

4.3.1 Analysis of Insulation Type

This first level of simulation consists in studying the building in its initial state with all the technical solutions and the elements and treatments carried out (double wall, single glazing bays, structural and energy systems, etc.). It involves modifying the insulation of the building envelope without changing the initial composition (extern wall 15cm/ Insulation/ Intern wall 10cm). Others insulations were considered due to their outstanding thermal and environmental characteristics.

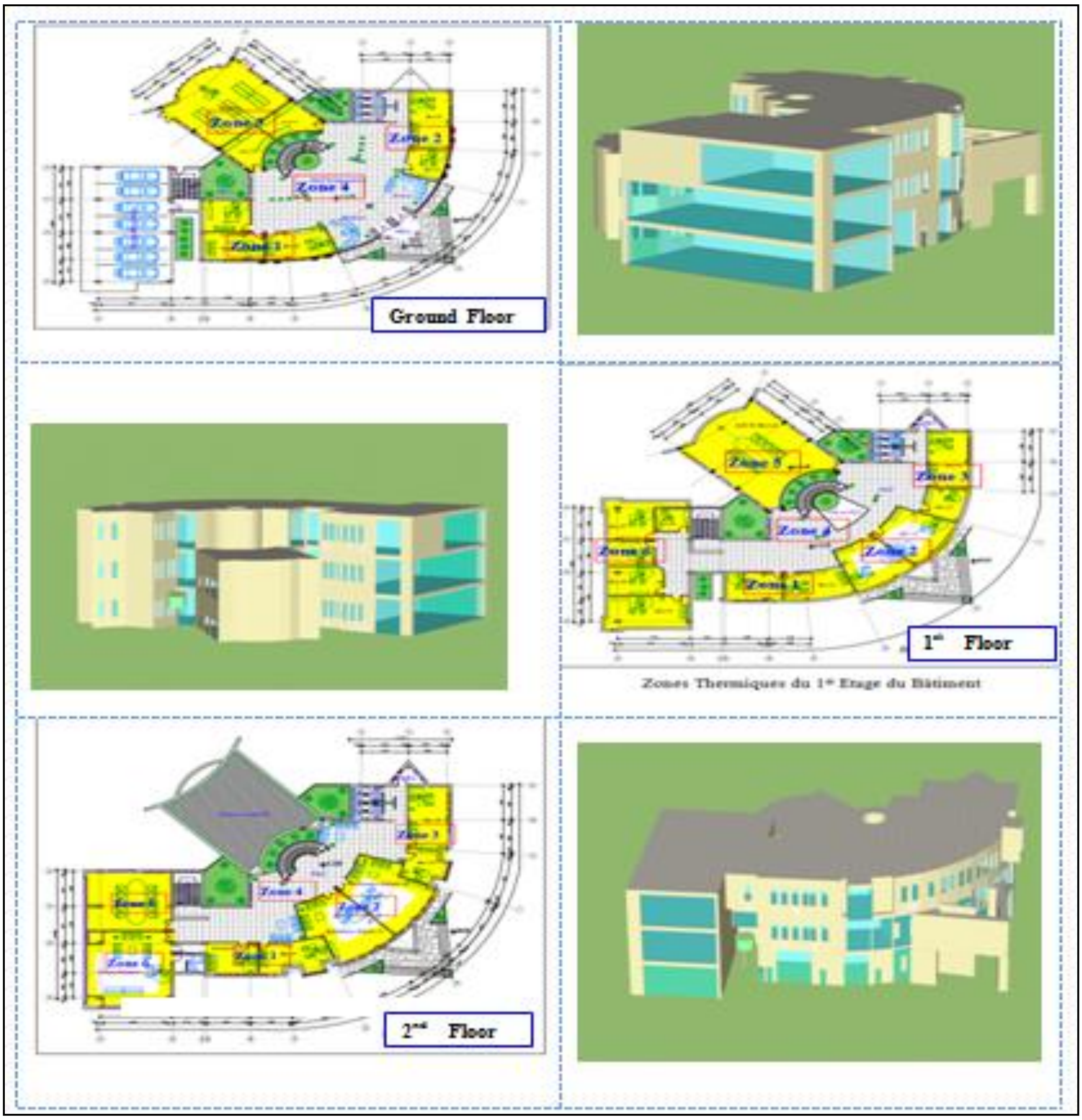

Fig.6. The Building zones thermals

The Expanded Polystyrene EPS (synthetic origin, widely used in the construction sector and very available on the national market with very accessible unit prices), and Cellulose Wadding Cwd (chosen for its outstanding technical, insulating and environmental characteristics, it is a material from recycling and 100% recyclable).

4.3.2 Analysis of Insulation Techniques

In second, it will be necessary to define the best systems for isolating the building envelope. Three (03) techniques for the installation of insulation are considered, and they are defined according to ministerial order approving the Regulatory Technical Document DTR- C3-T [22], of the Algerian Thermal Regulation of the Building, existing:

a. Distributed Insulation where it is placed between the two walls of the envelope.

b. Interior Insulation, where the insulation is placed adjacent to the interior space.

c. ExteriorInsulation; the insulation is placed in direct contact with the outside environment.

4.4 Occupancy and Use Scenarios

The main energy simulation conditions common to all building envelope configurations [23]:

1. Constant Temperature of 20°C.
2. Normal ventilation and over-ventilation in summer.
3. Heating Scenario: 20°C (and stop at night).
4. Scenario of Air Conditioning: 25°C (with stop at night).
5. Dissipated power scenario: 4100 W
6. Occupancy of offices 100% from 08.00AM to17.00PM, and 0% the rest of the time.

Also, the data required for the life cycle analysis of the building are structured into five main themes: Building materials; Energy (a gas heating system is considered, and an electric energy for air conditioning); Water; Waste; and User transport. Whith the conditions for the LCA are then defined as (Table2).

Table2. Conditions for the LCA of the building

	Building	**Carpentry**	**Equipments**	**Coatings**
Life (year)	80(default)	30	20	10

5. RESULTS AND DISCUSSION

By the technical, thermal and insulating characteristics of the materials (Table3), their respective environmental balances (Table 4), a first classification is established.

Produced from the recycling of paper and cardboard, Cellulose Wadding presents a [24], an ecological material, presents a positive environmental record (Table3).

It promotes excellent summer comfort, with a reduced amount of grey energy used 50kwh/m3, without any greenhouse effect and especially through its treatment at the end of life (100% recyclable) (Table04).

Table 3. Insulation technical characteristics.

Insulation \ Characteristics	Insulation Technical Characteristics					
	Thermal conductivity λ (W/m.K)	Density (kg/m3)	Specific heat (kJ/kg.K)	Resistance vapour diffusion (m)	Time of Phase Shift Hour	Hygroscopic capacity
Air blade	0.026	1	1000	0	03	No
EPS	0.032	10	1450	20	04	No
CWd	0.042	23	1900	2	12	normal

Table 4. Environmental characteristics of insulation.

Insulation \ Characteristics	Environmental Assessment				
	Grey energy Used(kWh/m^3)	Greenhouse effect (kgCO^2/UF)	End of-life treatment	Nature of the insulation	Comfort Summer Obtained
Air blade	/	/	/	/	6/20
EPS	450	10	100% in Landfill	Synthetic	9/20
CWd	50	-10	recyclable100%	From Recycling	18/20

Air blade1: Air b 1 Polystyrene Expansé2: EPS2 Cellulose Wadding3: CWd3

The dynamic thermal simulation has made it possible to define all the energy requirements; for heating, air conditioning, lighting, and the water used, to ensure the comfort of users, whatever the composition of the wall studied (Table5).

Table 5. Energy requirements of wall composition

Energy equirements \ Variants	Distributed Insulation			Exterior Insulation		Interior Insulation	
	Air b.1	**EPS2**	**CWd3**	**EPS4**	**CWd5**	**EPS6**	**CWd7**
Energy Heating Kwh	10 082.00	888.00	9,327.00	9,327.00	**8,694.00**	9,344.00	**8,628.00**
Energy Heating/m² Kwh/ m²	19.00	**9.00**	18.00	18.00	**17.00**	18.00	**17.00**
Energy Air Condit Kwh	30 772.00	20 350.00	29,567.00	29,567.00	**28,774.00**	29 384.00	**28 851.00**
Energy Air Condit/m² Kwh/ m²	**59.00**	213.00	57.00	57.00	**55.00**	56.00	**55.00**

These results illustrate very remarkable differences in energy requirements, and allow a first classification of the different compositions of the wall.

The thermal criterion, and whatever variant is studied, opts for the use of Cellulose Wadding in the composition of the external wall. It has the lowest energy requirements relative to other insulating materials. In the second row we find Expanded Polystyrene, followed by the air blade (Table6).

Table 6. Environmental impacts of wall composition

Environmental Impact	Distributed Insulation			Exterior Insulation		Interior Insulation	
	Air b.1	EPS2	CWd3	EPS4	CWd5	EPS6	CWd7
Greenhouse effect (t CO2 eq.)	797.21	753.98	**751.46**	586.65	**533.69**	755.70	747.99
Acidification (kg SO2 eq.)	2,619.51	2,486.56	2,515.38	2,324.18	**2 125.00**	2,492.59	2,504.99
CumulativeEnergy Demand (GJ)	17,920.88	16,927.74	16 980.94	21,585.12	**19,808.80**	16,955.46	16,880.20
Water used (m³)	35 821.18	35,133.86	35,379.54	37,519.84	**35,975.52**	35,162.42	35,319.37
Inert waste produced (t)	476.58	470.60	471.93	453.43	**447.21**	470.85	471.46
Exhaustion of abiotic resources (kg E-15)	6.22	5.88	5.93	9.93	8.56	5.88	**5.89**
Eutrophication (kg PO4 eq.)	854.80	843.15	844.98	**820.81**	2 104.83	843.66	844.06
Ozone production Photochemical (kg ethylene eq.)	1,390.97	1,324.13	1,331.02	1,173.57	**1,074.94**	1,327.00	1,325.74
Aquatic ecotoxicity (m³)	4 916 261.98	14 066 767.68	14 308 094.30	13 908 914.16	**12 312 913.35**	14 105 868.40	14 241 240.52
Radioactive waste (dm³)	23.18	22.03	**22.43**	44.35	38.26	22.04	22.28
Human toxicity (kg)	3,413.08	3 249.66	3 283.02	3 007.39	**2,771.97**	3 257.05	3 270.15
Odor (m³ air)	8,570.37	8 060.43	7,894.46	4,845.60	**4,378.50**	8,077.86	7,852.38

The environment impact demonstrated by this study Life Cycle Assessment of the building (Table7). The results obtained (Table6) show that the ‘Cellulose Wadding insulated Wall’ has less impact on the environment than the ‘Expanded Polystyrene insulated Wall’ or the conventional wall insulated with an air blade, whatever the indicator is considered.

Also, the most important impact are: consumption of resources, cumulative energy demand, and water used followed by the eutrophication, and acidification (figures 9, 10).

Comparing the different phases of the building life cycle, the use phase is the one with the highest impact (fig.11).

Also, the construction phase (a shorter duration compared to the life cycle of the building) with impacts mainly in: acidification, cumulative demand for energy, water used, and release inert waste and odors (Table8). And the end-of-life phase has impacts on inert waste (Tables7, 8, 9 and10).

Table 7. Environmental Impacts by Life Cycle Phase.
EPS Exterior Insulation

Impact	Construction	Use	Renovation	Demolition	Total
Greenhouse effect (t CO2 eq.)	83.37	502.47	-0.96	1.76	586.65
Acidification (kg SO2 eq.)	346.98	1,956.59	0.48	20.14	2,324.18
Cumulative Energy Demand (GJ)	1,002.54	20,539.14	14.63	28.81	21,585.12
Water used (m^3)	562.84	36,941.85	1.64	13.51	37,519.84
Inert waste produced (t)	24.33	85.77	0.08	343.25	453.43
Exhaustion of abiotic resources (kg E-15)	0.29	9.63	0	0.01	9.93
Eutrophication (kg PO4 eq.)	37.92	779.66	0.08	3.15	820.81
Photochemical ozone production (kg ethylene eq.)	218.29	933.02	0.37	21.89	1,173.57
Aquatic eco-toxicity (m^3)	837,408.61	13 012 744.12	899.69	57,861.74	13 908 914.16
Radioactive waste (dm^3)	1.99	42.24	0.02	0.11	44.35
Human toxicity (kg)	494.33	2,486.80	2.05	24.21	3 007.39
Odor (Mm^3 air)	315.49	4,528.09	0.03	1.98	4,845.60

The study results (Figure7, radar diagrams) show that the cellulose wadding wall is the most interesting, from the point of view of energy and environmental optimization, relative to other wall.

Table 8. Environmental Impacts by Life Cycle Phase.
CWd Exterior Insulation .

Impact	Construction	Use	Renovation	Demolition	Total
Greenhouse effect (t CO2 eq.)	83.29	449.60	-0.96	1.76	533.69
Acidification (kg SO2 eq.)	345.99	1,758.43	0.48	20.10	2 125
Cumulative Energy Demand (GJ)	999.98	18,765.42	14.63	28.77	19,808.80
Water used (m^3)	562.50	35,397.89	1.64	13.49	35,975.52
Inert waste produced (t)	24.29	80.16	0.08	342.68	447.21
Exhaustion of abiotic resources (kg E-15)	0.29	8.26	0	0.01	8.56
Eutrophication (kg PO4 eq.)	37.83	2,063.78	0.08	3.14	2 104.83
Photochemical ozone production (kg ethylene eq.)	217.68	835.04	0.37	21.85	1,074.94
Aquatic eco-toxicity (m^3)	834 117.06	11 420 130.83	899.69	57,765.76	12 312 913.35
Radioactive waste (dm^3)	1.99	36.15	0.02	0.11	38.26
Human toxicity (kg)	492.97	2,252.78	2.05	24.17	2,771.97
Odor (Mm^3 air)	314.82	4,061.67	0.03	1.98	4,378.50

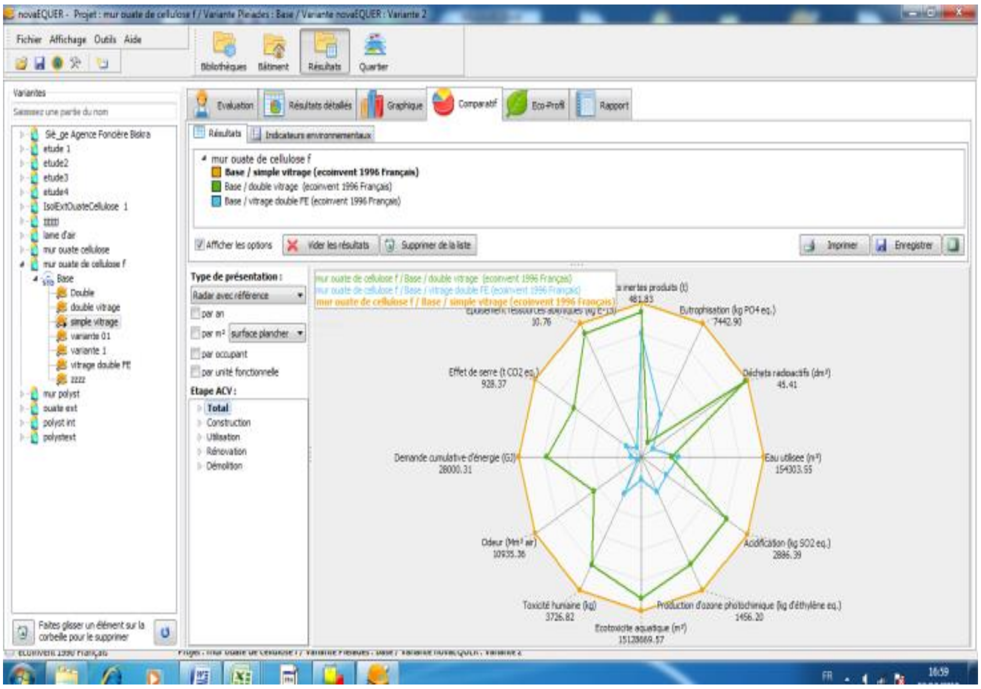

Fig.7. Radar Diagram of exterior walls insulation

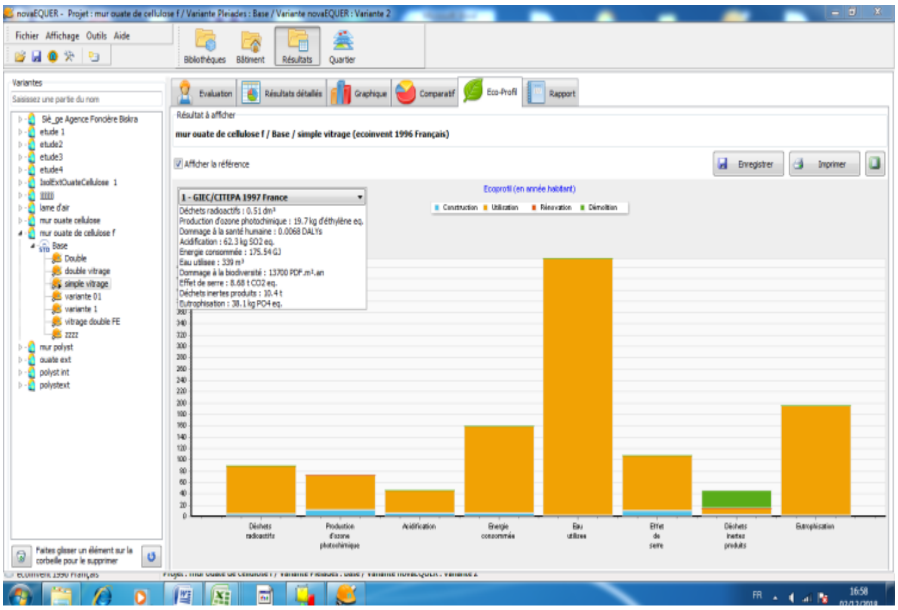

Fig.8. Ecoprofil of Impacts by life cycle of building

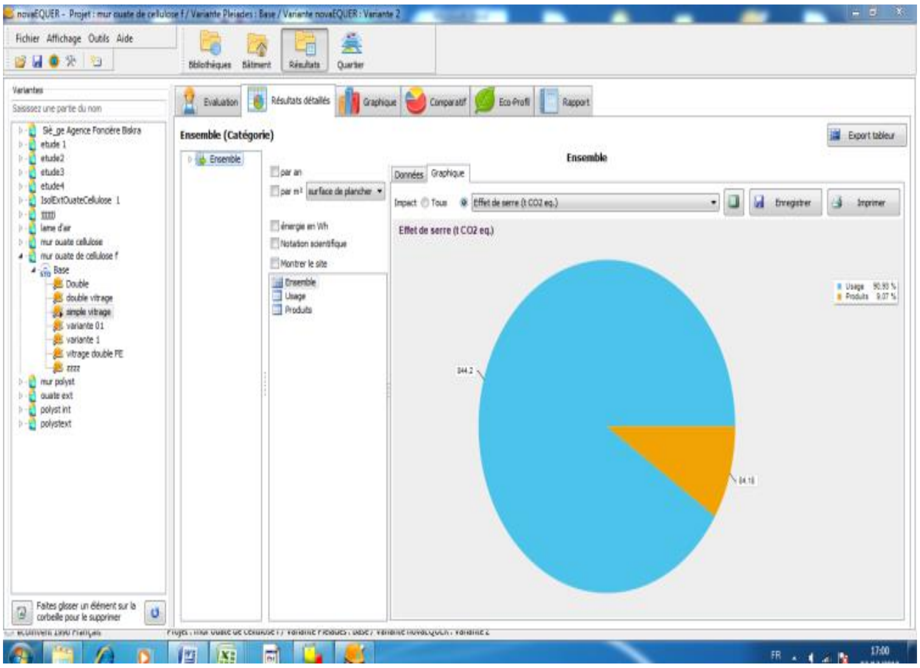

Fig.9. Greenhouse effect at Construction phase

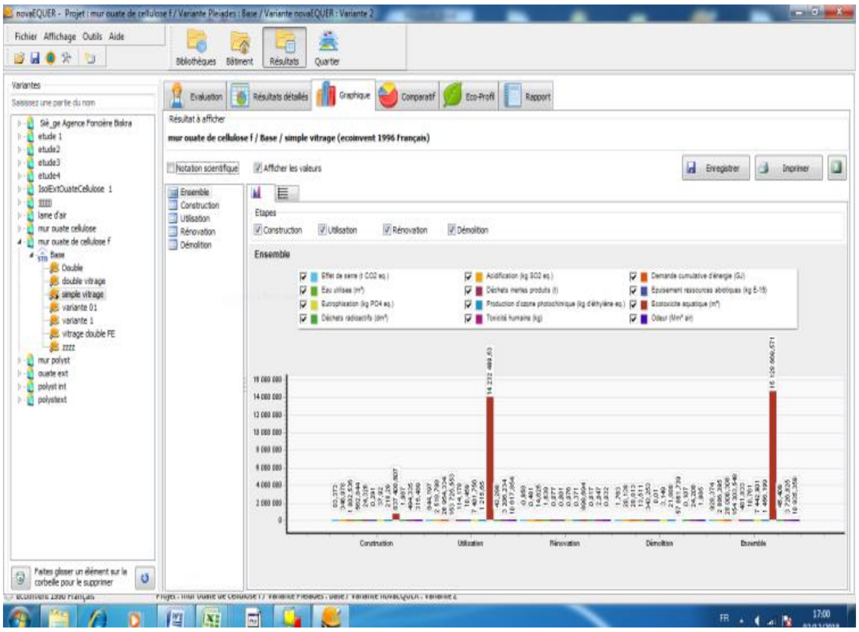

Fig.10. Numerical Impacts of the building exploit

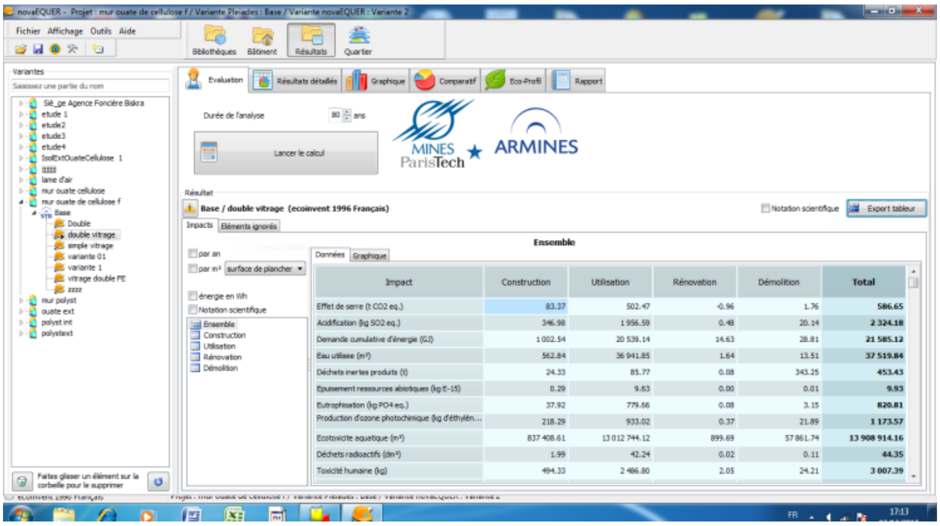

Fig.11. Environmental Impacts by Life Cycle phases

Table 9. Environmental Impacts by Life Cycle Phase of building

Impact	Construction	Utilisation	Rénovation	Démolition	Total
Effet de serre (t CO2 eq.)	83,37	502,47	-0,96	1,76	586,65
Acidification (kg SO2 eq.)	346,98	1 956,59	0,48	20,14	2 324,18
Demande cumulative d'énergie (GJ)	1 002,54	20 539,14	14,63	28,81	21 585,12
Eau utilisee (m³)	562,84	36 941,85	1,64	13,51	37 519,84
Déchets inertes produits (t)	24,33	85,77	0,08	343,25	453,43
Epuisement ressources abiotiques (kg E-15)	0,29	9,63	0	0,01	9,93
Eutrophisation (kg PO4 eq.)	37,92	779,66	0,08	3,15	820,81
Production d'ozone photochimique (kg d'éthy	218,29	933,02	0,37	21,89	1 173,57
Ecotoxicite aquatique (m³)	837 408,61	13 012 744,12	899,69	57 861,74	13 908 914,16
Déchets radioactifs (dm³)	1,99	42,24	0,02	0,11	44,35
Toxicité humaine (kg)	494,33	2 486,80	2,05	24,21	3 007,39
Odeur (Mm³ air)	315,49	4 528,09	0,03	1,98	4 845,60

Table 10. Environmental Impacts at the **Use** Phase of building

Impact	Chauffage	ECS	Eau	Electricité spécifique	Climatisation	Transport	Total
Effet de serre (t CO2 eq.)	18,16	52,15	12,09	140,23	264,39	15,44	502,47
Acidification (kg SO2 eq.)	21,54	61,84	76,93	595,32	1 094,87	106,08	1 956,59
Demande cumulative d'énergie (GJ	337,10	967,92	387,14	11 577,70	7 015,31	253,97	20 539,14
Eau utilisee (m³)	22,42	64,36	24 282,19	5 965,46	6 483,52	123,90	36 941,85
Déchets inertes produits (t)	1,48	4,24	2,07	27,96	45,20	4,83	85,77
Epuisement ressources abiotiques (	0,09	0,27	0,07	6,39	2,68	0,12	9,63
Eutrophisation (kg PO4 eq.)	2,56	7,36	620,63	48,80	90,40	9,91	779,66
Production d'ozone photochimique	18,23	52,35	21,58	264,34	489,72	86,79	933,02
Ecotoxicite aquatique (m³)	80 855,32	232 164,51	312 562,33	4 401 319,53	7 474 072,85	511 769,60	13 012 744,12
Déchets radioactifs (dm³)	0,11	0,33	0,87	29,72	10,95	0,26	42,24
Toxicité humaine (kg)	28,93	83,06	102,63	729,41	1 334,43	208,33	2 486,80
Odeur (Mm³ air)	344,67	989,67	30,97	1 089,41	2 050,89	22,50	4 528,09

According to life cycle assessment LCA, the energy criterion associated with the environmental balance is favourable for the benefit of external insulation (Table7). This last is easy to implement, very fast, eliminates thermal bridges and benefits from the thermal inertia of the walls. Interior insulation has disadvantages: it favour's thermal bridges and condensation points, deprives the walls of thermal inertia, and reduces interior space, and also additional energy consumption. Also, distributed insulation, ensures a level of comfort but with very high energy consumption over the entire life cycle of the building (figure7).

6. CONCLUSION

The environmental assessment method used is Life Cycle Assessment LCA, combined different building materials and assemblies within the building envelope, using the Eco-Invent database and based on the life cycle analysis software, connected to dynamic thermal simulation software. The results of this study, it can be seen that for all impacts, Cellulose Wadding is a more environmentally friendly material than other insulating materials. Expanded polystyrene gives very acceptable thermal results, but very impactful on the environment. Also, insulation techniques play a very decisive role in the energy aspect, closely linked to the environmental impacts generated. Then, exterior insulation is the most effective and has less impact than distributed insulation. And the interior insulation has more energy disadvantages than thermal advantages. Therefore, the exterior insulation is the most efficient as it eliminates in particular the thermal bridges, and allows to benefit from the thermal inertia of the walls. It would also be more interesting to opt for this technique of insulation by the outside for more energy savings and less environmental impacts. Also, Cellulose Wadding should be used more in construction as an ecological material resulting from recovery and recycling, and no longer as waste.

The results of this research can be used as an inventory of strategies for a sustainable building, including energy retrofits. It is an ecological approach, which helps to fight earth warming, the reduction of greenhouse gas emissions, and environmental impact.

Also, life cycle assessment LCA is a strategy, and a decision-making tool, to contribute to this heavy environmental issue resulting from poor building design.

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NOMENCLATURE

Abbreviations	Full Name
Λ	Thermal conductivity, $W.m^{-1}. K^{-1}$
AP	Acidification Potential
ADP	Abiotic Depletion Potential
C2C	Cradle to Grave
CWd	Cellulose Wadding
CDW	Construction and Demolition Waste
CED	Cumulative Energy Demand
Cp	Specific heat , j
D	Densité,kg/m^3
DTS	Dynamic thermal simulation
DTR	Regulatory technical document.
EIAM	Environmental Impact Assessment Method
EP	Eutrophication Potential
EPS	Expanded Polystyrene
Ge	Greenhouse effect, kg/CO_2 /UF
G E use	Grey energy use,kwh/m^3
GWP	Global Warming Potential
HVAC	Heating, ventilation, air conditioning
LCA	Life Cycle Assessment
ODP	Ozone (stratospheric) Depletion Potential
POCP	Photochemical Ozone Creation Potential
ODP	Ozone (stratospheric) Depletion Potential
Sd	Ressistance to water vapour difusion,m
XPS	Extruded Polystyrene

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