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Application of the Building Height Concept to Energy-Efficient Heating and Cooling for Saharan Buildings

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ABSTRACT

The compactness of a building depends on its shape, its size and its contact properties. The main objective of this contribution is to investigate the impact of the building' height on energy needs. The assessment criteria will be based on a well-defined lifestyle and occupancy scenario, the indoor comfort temperature and the required energy consumption. The results obtained from the regression models and their relative simplicity allows them to be used as a tool for estimating energy needs, energy savings and investment-return time. The absence of insulation would result in an energy saving of exactly 26.77%, by raising a single house to one-storey building. It will be more substantial savings (more than 40%) by exceeding the fourth floor. In the case of an insulating layer of 10 cm, an energy gain of 21.17% can be saved by varying a single house to one-storey building. The reduction in energy needs exceeds 35% but remains below 38.5% for buildings which are over three storeys high. Generally, the investment-return time is between 49 months and 44 months, and it is inversely proportional to the number of storeys in the dwelling. It is therefore necessary to favor large buildings to rationalize energy consumption.

1. INTRODUCTION

The intensive use of energies from exhaustible natural resources has motivated some scientists to propose experimental environmental works on atmospheric emissions in urban areas [1]. In this context, the geometry of thermal structures is an essential factor in determining the reached comfort. The shape factor is a measure of the building's compactness. According to a literature review, several contributions have revealed that the building design has a significant effect on both the thermal performance and energy needs. Martaa and Belinda [2] have proposed a simplified model to expect heating and cooling energy needs for a building subject to a Spanish climate. They reported that the compactness factor is one of the determining and preponderant factors. Li et al. [3] have provided some guidelines which enable to compute shape compactness based on the inertia moment. As expected in reference [4], it is proved that the stated concepts that have a direct link with the geometric properties can improve the energy efficiency in buildings. In 2012, on the basis of the research studies achieved by Parasonis et al. [5], it has been indicated that the relationship between the building shape and its energy performance was significant. On the one hand, the geometric efficiency depends both on its dimensions and proportions; on the other hand heat losses through the envelope elements constitute a large part of the total energy needs. However, in some Algerian sites, such as Algiers and Ghardaïa, optimal compactness is an additional measure to consider; increasing the compactness index has a contrasting effect, negative for the heating and positive for the cooling, meanwhile, the savings for cooling needs are larger than the disadvantage of increased heating needs [6]. Other research work, conducted by Ourghi et al. [7] allowed us to obtain an analysis tool to predict the effect of the geometric shape for an office on its annual cooling and total energy use. The same objective was addressed by AlAnzi et al. [8]. The studies take into account several building forms including rectangular, L-shape, U-shape, and H-shape. For this purpose, a compactness index was used to assess the impact of shape on the energy efficiency of office buildings. Furthermore, in previous work, Danielski et al. [9] have shown that designing buildings with lower shape factor will result in lower specific heat demand; the impact of this parameter factor varies significantly as function of different thermal envelope properties for different climate circumstances. For an appropriate occupation scenario, the change in specific heat demand varied from 12 to 52 kWh/m^2/year. The shape factor has a sensible impact on this specific heat demand with lower thermal properties and for cold climates.

Additionally, a large number of contributions have used only roof area to calculate the energy saving of green roofs. The main objective pursued by Park [10] was to conclude the most effective building to install green roofs in Harrisburg. All finding results demonstrated that indoor temperature of buildings and energy demands are affected by building shapes. An experimental study was carried out to determine the relationship between building compactness and indoor temperature after the integration of green roofs during the summer season. The approach adopted was based on four physical models tested for 54 days. Indoor temperatures can be reduced by 8.1 °C for a less compact building compared to a more compact building (4.6 °C). These results are more apparent on warm days. Another paper [11] aims to set a new understanding for building compactness assessment which can contribute to originate building morphologies in terms of comfort and thermal performance. On the basis of the cost optimal level methodology, some authors [12] have announced that the choice of the best energy efficiency measures underlined the importance of the building typology. Another research work led by Kadraoui et al [13] confirmed that the building envelope is the main source of heat loss. The integration of passive architectural concepts (such as compactness) is required to improve the building's energy performance.

In the field study of thermal buildings, a change in the size, particularly the concept height, without variation of the ceiling and floor surfaces, systematically causes a change in compactness index. This article wants to emphasize the effect of the building compactness by addressing such issues as the height of buildings and the different contact modes with the external environment. The assessment criteria will be based on a well-defined lifestyle and occupancy scenario, the indoor comfort temperature and the required energy consumption expressed in Kwh/year/m^2. It should be noted that the few existing works in these severe conditions (Saharan climate) do not deal properly with the problem. In addition, the uniqueness and asset of this contribution consist in applying a specific method to label any building and estimate energy needs. The combination of different approaches provided a new performing model.

2. GHARDAÏA CLIMATE AND CASE STUDIES

Ghardaïa (latitude 32.48° N, longitude 3.80° E) has a hot, dry and desert climate, the region is noticeable by large temperature differences with a clarity index of 0.8. It has a very important rate of insolation (75% on average) and the mean annual of global solar radiation measured on horizontal plane exceeds 20 (MJ/m^2). The sunshine duration is more than 3000 hours per year, which promotes the use of solar energy in various fields [14]. The lowest sunshine duration is registered in December with 234.5 hours; the highest values were recorded during July with 337.3 hours. The average sunshine duration between 2000 and 2009 was 3391.20 hours per year i.e. approximately 9 hours per day. The annual average temperature is about 22.61°C. Minimum temperatures of the coldest month are observed during the month of January with 5.5°C, while maximum temperatures of the warmest month are observed during the month of July with 41.7°C [15]. The relative humidity is very low; it is of the order of 21.60% in July, reaching a maximum of 55.80 % in January and an annual average of 38.33% [16].

The proposed study is focused on a residential building subjected to the Ghardaïa climate. This building has a living space of 92 m^2 (72.62% of the total area), the height of the walls is 3 m. Detailed overviews of the descriptive plan of this building are given in Figure 1. The different configurations of the roofs, ground and opaque walls are illustrated in Figure 2.

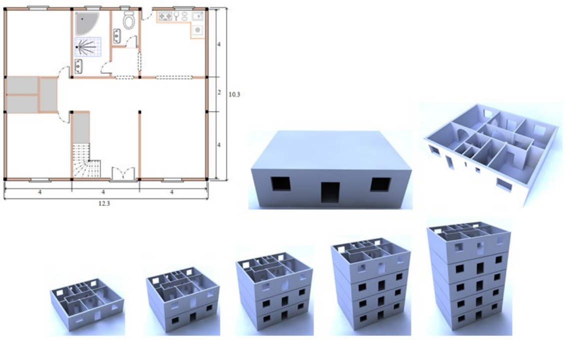
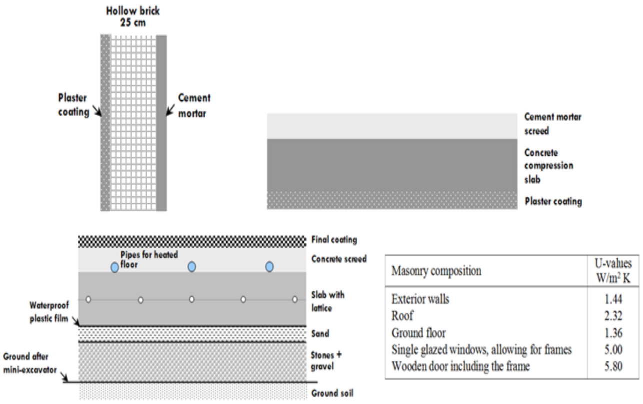


Figure 1. Descriptive plane, 2D and 3D Building modelling: Ground floor building and construction of single-to-four storey building

3. ENERGY-BALANCE MODEL



Masonry composition	U-values W/m^2 K
Exterior walls	1.44
Roof	2.32
Ground floor	1.36
Single glazed windows, allowing for frames	5.00
Wooden door including the frame	5.80

Figure 2. Masonry composition and building material proprieties

The energy balance has to deal with the physical parameters, thermal properties, building design, climatic conditions…etc.

In the heating season and during inter-seasons, consumption and heating energy needs for buildings are given by the following formula [17-18]:

$$Q_{Needs} = \left| Q_{Envelop} - \left(Q_{Occup} + Q_{Elc}\right) \pm Q_{Solar} \right| + Q_{DHW} + Q_{tot\_elec\_a\,ppl} \qquad (1)$$

In the cooling season, equation 2 has to be used [17-18]:

$$Q_{Needs} = Q_{Envelop} + \left(Q_{Occup} + Q_{Elc}\right) + Q_{DHW} + Q_{tot\_elecppl} + Q_{Solar} \qquad (2)$$

3.1 Energetic needs due to the building thermal envelope

Heating or/and cooling needs due to the building thermal envelope are defined by equation 3 [17-18]:

$$Q_{Envelop} = 24\ DP_{envelop}\ Dj \qquad (3)$$

Detailed calculations are provided in reference [19-20].

$DP_{envelop}$: envelope and ventilation heat losses (W/K).

Dj: numbers of degree-days.

3.2 Domestic hot water "DHW" Requirements

To compute the DHW needs, the calculation should be based on the equation below. In any event, it is considered that the required volume of the hot water is 50 litters of hot water at 50 °C per day per person. Energy needs for the DHW production is given by the following equation [17-18]:

$$Q_{DHW} = 1.1628\, V_{DHW}\, Nb_{occup} \left(T_{DHW} - T_{CW}\right) \tag{4}$$

Q_{DHW}: energy needs required to produce DHW for one day, in Wh

V_{DHW}: required volume of the hot water (litters)

Nb_{occp}: number of persons occupying the building

T_{DHW}: temperature of the hot water at the filling point (°C).

T_{CW}: average monthly temperature of the cold water entering the storage tank or the DHW production coil (instant production).

3.3 Internal heat gains

The human being diffuses radiations in sensible (by the body at 37°C) and latent (by the production of water vapor via respiration and perspiration) heat form. Different values are given in the literature [17-18], the heat diffusion (W) from the occupants' activities are given by Table 1. The general equation that gives the values of internal gains is given by the following expression:

$$Q_{Occup} = Cp\, Nb_{occup}\, D_{pres/day}\, Nb_{heated\_days} \tag{5}$$

Cp: the amount of heat given off by occupant (W/occupant).

$D_{pres/day}$: the period of presence during the day (h/day).

Nb_{heated_days}: Number of heated days (days/year).

The total amount of heat released by both equipment and lighting is determined according to the use and ignition mode of these electrical appliances. In this context, average values (default values) were adopted to define the internal loads in a building (Table 2).

Table 1. Cp & radiated heat per person [17-18]

Examples of activities	Heat diffusion per person (sensible and latent)
Static sitting activities (read and write)	120W
Simple works that can be done either sitting or standing, laboratory work, typewriter...	150W
Light physical activities	190
Medium to difficult bodily activities	More than 200W

Table 2. Cp & radiated heat per person [17-18]

	Duration (hours) and operating power modes (Watts)				Energy (Wh)
	Mode 1	Number of hours	Mode 2	Number of hours	
LCD TV + Integrated demo	20	19	78	5	1540
Refrigerator		Total par jour			552
Lighting	75	21.75			1631.3
Flat screen computer	32	2	186	4	808
Other					1200
Total par jour					5731.3

3.4 Internal heat gains

Three input data must be taken into account according 1200 to Table 3.

$P_{elec\ 5731.3appl}$: the power of electrical appliances (W).

Nb_{hours}: the number of hours when the device is in an operational state during the day.

Nb_{days}: the number of days when the device is in an operational state during the year. Calculation, in kilowatt-hours, shall be as follows:

$$Q_{tot\_elec\_a\ ppl} = Nb_{hours}\ \ Nb_{days} \frac{P_{elec\_appl}}{1000} \tag{6}$$

Table 3. Average energy consumption per day for electrical appliances [17-18]

Type of equipment		Power (W)		Duration of the use per day (h & min)	Average daily consumption (Wh)
		Power (W)	Power (W)		
LCD TV with integrated demo	In service	90 to 250	140	5h	1514.0
	Standby mode	3	/	19h	
Refrigerator 250 liters capa city		150 to 200	/	Continuously	551.0
Lighting: 12 low-cost lamps	2: sitting room	14	/	6h	304.5
	1: Room 1			3h	
	1: Room 2			4h	
	1: Hall			1h	
	1: Kitchen			3h	
	1: WC			45mn	
	1: SDB			2h	
	1: corridor			1h	
	2: above the 2 doors			45mn	
	1: Terrace			15mn	
F1at screen computer	In service	70 to 80	75	4h	306.0
	Standby mode	3	/	2h	
GSM charger		5	/	3h	15.06
Iron		750 to 1100	925	7min	107.9
Vacuum cleaner		650 to 800	720	12 min	144.00
Radio alarm		3 to 6	4.5	Continuously	108.00
Electric razor		8 to 12	10	6min	1
Hair dryer		300 to 600	450	5 min	37.50
Washing machine		2500 to 3000	2800	30mn	1400
Total time per day (Wh)					4488.9/Day

3.5 Passive solar gains

The solar gains depend on the incident solar radiation, the orientation of the receiving surfaces and some characteristics such as: shading, transmission and absorption coefficients. This energy gain will be calculated according to the following equation [17, 19]:

$$Q_{Solar} = \sum_{j} I_{Sj} \sum_{n} \left(A \; F_{Shad} \; F_{Red} \; g \right)_{nj} \tag{7}$$

The first sum is made on all orientations j; the second is applicable on all surfaces n in different orientations "j"
I_S: solar irradiation per area unit (Wh/m^2)
F_{Red}: reduction factor for window frames, equal to the ratio of the transparent surface of the window to its total area; its value is set at 0.8
F_{Shad}: shading factor; its value is set at 0.7
g: solar factor of the bay window; its value is set at 0.8 for single-glazed windows.

4. COMPACTNESS AND BUILDING HEIGHT CONCEPT, COMPARATIVE ANALYSIS OF ENERGY CONSUMPTION

Before proceeding with the comparative study, it is preferable to draw up a summary table (4) giving the common energy parameters of all the cases to be studied. The attention paid to the average outside air temperature of the month in question, comfort temperature which was set between 21 and 26 °C, monthly temperature of the cold water, passive solar gain, monthly values of internal gains, energetic hot water needs of a single-family home and the equivalent electricity consumption for one family home. The other selected input parameters are as follows: T_{DHW} = 50 °C, Cp = 150 W, Nb_{occp} = 5, $D_{pres/day}$ = 15 h, the glass surface amount to about 95% of the window area, F_{Shad} = 0.7 for south orientation, F_{Red} = 0.8 and g = 0.8.

Table 4. Monthly values of the common energy parameters of all the cases to be studied

	T_{out}	T_{conf}	T_{cw}	Q_{solar}	**Internal heat gains (kWh)**		Q_{bHw} (kWh)	Q_{Elec} (kWh)
					Q_{occup}	Q_{Elc}		
January	10.1000	21.0000	7.0000	394.5667	348.7500	177.6703	387.5031	139.1559
February	12.3000	21.0000	9.0000	338.8108	315.0000	160.4764	333.7236	125.6892
March	15.3000	21.0000	11.5000	323.4353	348.7500	177.6703	346.9504	139.1559
April	20.0000	21.0000	13.0000	0	337.5000	171.9390	322.6770	134.6670
May	24.5000	24.5000	16.0000	0	348.7500	177.6703	306.3978	139.1559
June	29.7000	26.0000	19.0000	0	337.5000	171.9390	270.3510	134.6670
July	33.4000	26.0000	21.0000	0	348.7500	177.6703	261.3393	139.1559
August	32.7000	26.0000	20.0000	0	348.7500	177.6703	270.3510	139.1559
September	27.8000	26.0000	17.5000	0	337.5000	177.9390	283.4325	134.6670
October	20.7000	21.0000	15.0000	0	348.7500	177.6703	315.4095	139.1559
November	14.4000	21.0000	11.0000	354.1864	337.5000	171.9390	340.1190	134.6670
December	10.7000	21.0000	8.0000	348.3617	348.7500	177.6703	378.4914	139.1559
							$3.8167\ 10^3$	$1.6384\ 10^3$

4.1 Without thermal insulation

Table 5. Monthly and annual energy needs to maintain comfort between 21 and 26 °C

n	**1**	**R+1** **2**	**R+2** **3**	**R+3** **4**	**R+4** **5**	**R+5** **6**	**R+6** **7**	**R+7** **8**	**R+8** **9**	**R+9** **10**	**R+10** **11**	**R+11** **12**	**R+12** **13**
S/V	0.6901	0.5234	0.4679	0.4401	0.4234	0.4123	0.4044	0.3984	0.3938	0.3901	0.3871	0.3846	0.3824
Jan	7404	10277	13150	16022	18895	21767	24640	27512	30385	33258	36130	39003	41875
Feb	5258	7250	9242	11234	13226	15218	17210	19202	21193	23185	25177	27169	29161
Mar	3694	5025	6355	7685	9015	10346	11676	13006	14337	15667	16997	18327	19658
Apr	632	964	1646	2327	3008	3690	4371	5052	5734	6415	7097	7778	8459
May	972	1944	2916	3888	4860	5832	6804	7776	8748	9720	10692	11664	12636
Jun	3473	5449	7424	9399	11374	13349	15324	17299	19274	21250	23225	25200	27175
Jul	6285	9417	12549	15682	18814	21946	25078	28211	31343	34475	37607	40740	43872
Aug	5774	8705	11635	14566	17496	20426	23357	26287	29218	32148	35078	38009	40939
Sep	2165	3607	5049	6491	7933	9375	10816	12258	13700	15142	16584	18026	19468
Oct	769	1662	2554	3447	4340	5232	6125	7018	7910	8803	9695	10588	11481
Nov	4163	5676	7188	8700	10212	11724	13236	14749	16261	17773	19285	20797	22309
Dec	7009	9736	12463	1.519	17917	20644	23371	26098	28825	31552	34279	37006	39733
Tot (kWh/year)	47600	69711	92170	114630	137090	159550	182010	204470	226930	249390	271850	294310	316770
Tot/S (kWh/m^2/year)	375.72	275.12	|242.51	226.2	216.42	209.89	205.23	201.74	199.02	196.85	195.07	193.59	192.33

n: the number of family houses in the entire building. S: The outer surface of the walls (m^2). V: total volume of the entire building (m^3). S/V: the compactness index

The approach is based on an in-depth study of the difference between several identical family houses. This similarity concerns the entire characteristics: thermo-physical properties of the building envelope, structural element dimensions, occupant lifestyles and their desired comfort temperatures. The only difference is in its implantation in the building. The results that will be provided will therefore be expressed in kWh/m^2/an. These unit values represent the average annual energy requirements even for a family home located in the same building. It is reminded that each house of the same building is characterized by the same properties previously announced. The calculation program designed for this purpose gives us the opportunity to calculate the energy needs of a house exposed at all levels. It is also feasible to study buildings containing several floors and family houses. Table 5 provides results for calculating monthly and annual energy requirements of the different cases. In this regard, a comparison can be made between a single-family home at all levels and a multi-family building, including the number of floors in question.

In order to perform a consistent comparative study, the method would refer to the various buildings shown in figure 1, going up to the twelfth floor.

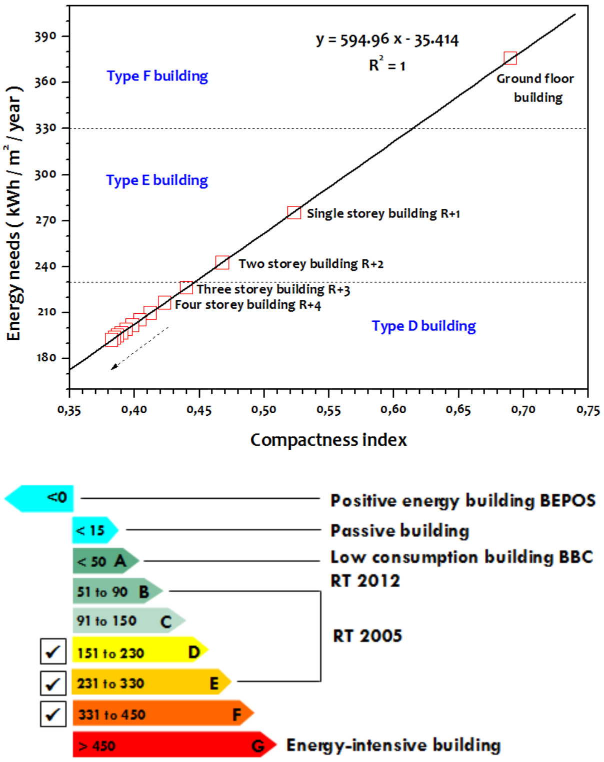


Figure 3. Energy needs according to the number of floors and building labeling scheme (kWh/m^2/year)

Energy needs vary linearly in accordance with compactness index; the corresponding equation is shown in the figure. The difference between the total energy loads is sometimes radical; these buildings will join the constructions that have an energy label of type F, E or D. This indicates that in this case, it is necessary to favor large buildings to rationalize energy consumption. In addition, the obtained results indicate that the convergence of values (by increasing the number of floors, i.e. by improving the building compactness and reducing the compactness index) towards smaller values was very fast at first, but beyond a certain level, this convergence will not become interesting. To be more precise, it was necessary to trace the variation in energy savings according to the number of floors (figure 4).

In comparison with the values in the above figure, it has been found that an energy saving of exactly 26.77% can be achieved just by varying a single house to one-storey building. By crossing the fourth-storey building, i.e. for a construction with five family houses (n = 5), it will have more substantial savings that exceed 40% but with a clear stability of the values. This variation is translated by a polynomial regression model of order 6.

4.2 With thermal insulation

In this section, the same research work is conducted with an external integration of a thermal insulation covering the whole envelope surface (thermal conductivity λ= 0.04 W/m K, and a thickness of 10 cm). Table 6 summarizes the calculation results regarding the monthly and annual energy needs in different cases. Accordingly, the comparative study between the different buildings (up to the eleven storey building) is shown in figures 5 and 6.

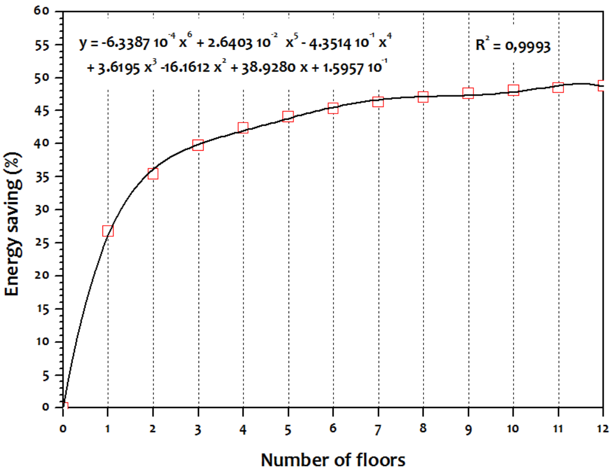


Figure 4. Annual energy savings according to the number of floors by referring to the single family house exposed to all levels

The obtained results generally raise the same remarks. The regression equation shows that the variation between energy needs and compactness index is also linear.

With the exception of the first case (only one family house exposed at all levels), the others can be integrated in the buildings that have an energy label of "type C". It was reconfirmed that it was essential to privilege large building constructions. Similarly, the convergence towards smaller values was at first very fast and beyond a certain level this convergence will not become interesting. On the basis of the calculated data, an energy gain of exactly 21.17% can be saved by varying a single house to one-storey building. This value seems less important compared to the first case but it is still interesting in terms of energy saving. On the three storey building, the reduction in energy use exceeds 35% but remains below 38.5%. This variation is translated by a precise regression polynomial model of order 6. Otherwise, it is possible to study the relationship between thermal insulation and compactness. This is the reason why we are led to trace the variation of the energy consumption reduction due to the thermal insulation as a function of the compactness index (Figure 7).

Table 6. Monthly and annual energy needs to maintain comfort between 21 and 26 °C, case of a building envelope insulated by 10 cm thick

n	1	R+l 2	R+2 3	R+3 4	R+4 5	R+5 6	R+6 7	R+7 8	R+8 9	R+9 10	R+10 11	R+11 12	R+12 13
S/V	0.6901	0.5234	0.4679|	0.4401	0.4234	0.4123	0.4044	0.3984	0.3938	0.3901	0.3871	0.3846	0.3824
Jan	2621.3|	3614.3	4607.2|	5600.2	6593	7586	8579	09572	10565	11558	12551	13544	14537
Feb	1812.1	2451.4	3090.6	3729.9	4369	5008	5648	06287	06926	07565	08205	08844	09483
Mar;	1197.2	|1548.7	1900.1	2251.6	2603	2954	3500	04120	04741	05362	05983	06603	07224
Apr	0706.2	1553.1	2400	3247	4094	4941	5788	06635	7482	08329	09175	10022	10869
May	0972	1943.9	2915.9	3887.9	4860	5832	6804	07776	8748	09720	10692	11664	12636
Jun	1905.7	3266.9	4628.2	5989.4	7351	8712	10073	11434	12796	14157	15518	16879	18241
Jul	3041.1	4900.9	6760.7	8620.4	10480	12340	14200	16060	17919	19779	21639	23499	25358
Aug	2838.3	4617.2	6396.1|	8175	9954	11733	13512	15291	17070	18849	20627	22406	24185
Sep	1402.6	2546.4	3690.1	4833.9	5978	7121	8265	9409	10553	11696	12840	13984	15128
Oct	0900.5	1844.4	2788.3	3732.2	4676	5620	6564	7508	8452	09396	10339	11283	12227
Nov	1364.5	1779.1	2193.6	2608.2	3023	3437	3852	4266	4681	05096	05510	05925	06339
Dec	2490.4	3442.1	4393.7	5345.4	6297	7249	8200	9152	10104	11055	12007	12958	13910
Tot(kWh/year)	21252	33508	45765	58021	70277	82534	94984	107510	120040	132560	145090	157610	170140
TotS(kWh/m^2/year)	167.75|	132.24	120.41	114.49	|110.94	108.58	107.1	106.07	105.27|	104.63	104.11	103.67	103.3

The advantage of the external thermal insulation is to increase significantly the overall thermal performance of the building, which promotes a significant reduction in heating and cooling costs and improves thermal comfort. It has also been found that this advantage gradually decreases by improving the building compactness (by adding additional floors). This aspect can be translated by the nonlinear curve indicated in the previous figure. Furthermore, at the beginning, the decrease is consistent, considering a two-storey building (energy saving of 55.35%) instead of a single family home (energy saving of 51.93 %), a difference of 3.42% can be seen. This gap will be quickly amortized; it becomes 0.47% from a four-story building to a five-storey building and 0.16% from an eleven-story building to a twelve-storey building.

To integrate this passive concept, it is compulsory to study the techno-economic aspect which must therefore have a particular interest in these similar situations. This is the reason why we will be interested in the return time on investment. The method consists firstly in estimating the total cost resulting from the isolation procedure by adding the total cost of the isolation procedure defined by the sum of the polystyrene price and the cost of all insulation works (3000 DZD/m^2), and the annual energy bill. The retained price of a polystyrene plate (5 cm thick layer and 2 m^2 of surface area) is fixed at 600 DZD.

The variation of the return time on investment, expressed by the number of months, is the ratio of the extra cost (the total cost of the isolation procedure – the initial bill without thermal insulation) multiplied by 12 and the annual financial gain which is defined by the difference between the initial bill (without thermal insulation) and the energy bill in the case of thermal insulation. Figure 8 focuses on the effectiveness of this passive aspect and their financial impact on the investment-return time.

The figure indicates that the investment-return time decreases slightly by transiting to a building with an upper floor. In this respect, it is worth noting that it took 4 years and 5 days to recover the expensed amount for a 10 cm layer of thermal insulation in the case of a single house. For a single storey building, it is possible to reduce this period to only 3 years, 10 months and 27 days. By changing a single-storey building to a two-storey building, the investment-return time will be decreased by 22 additional days. For higher floors, it will be possible to obtain greater savings but with a better stability. Generally, the investment-return time is between 49 months and 44 months.

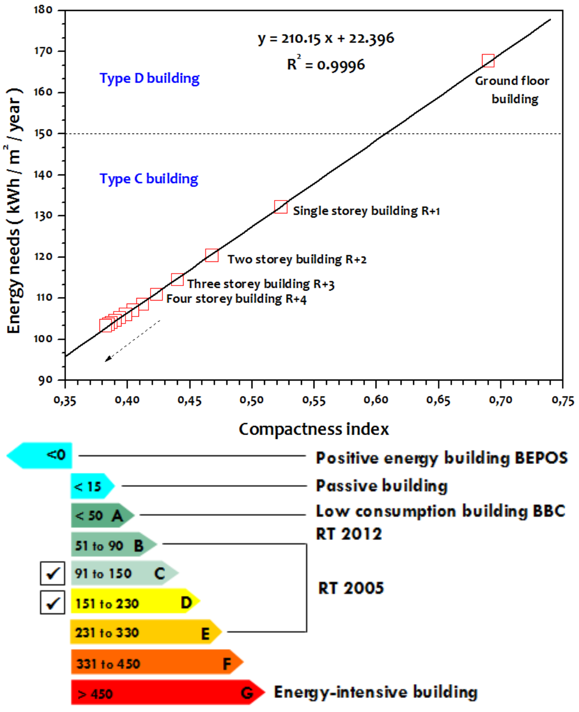


Figure 5. Energy needs according to the number of floors and building labeling scheme (kWh/m^2/year), case of a building envelope insulated by 10 cm thick

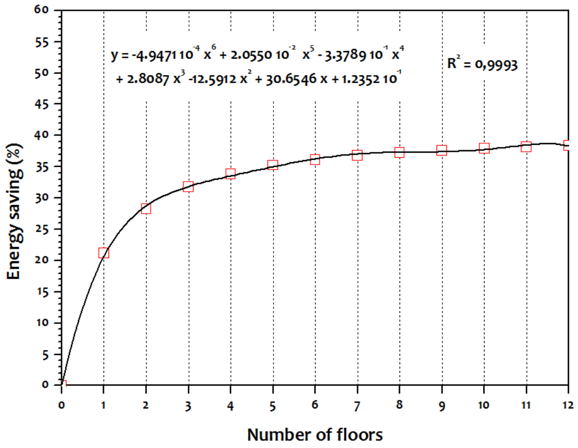


Figure 6. Annual energy savings according to the number of floors by referring to the single family house exposed to all levels, case of a building envelope insulated by 10 cm thick

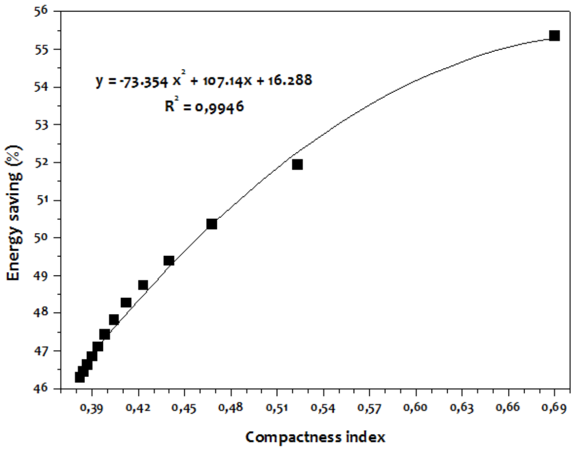


Figure 7. Decrease in energy needs due to thermal insulation (10 cm) as a function of the building compactness index

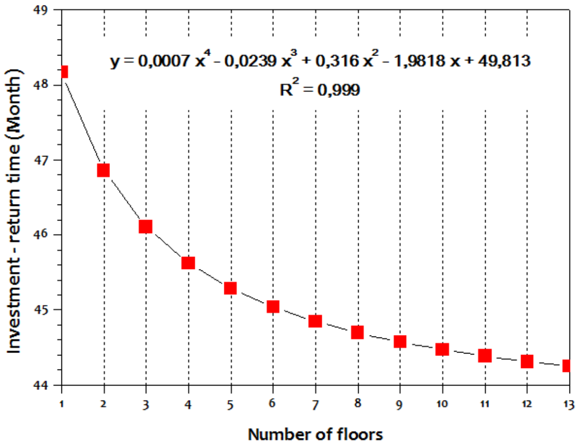


Figure 8. Variation of the return time on investment according to the cost of the number of floors

5. FINDING CONCLUSIONS

The main objective of this accomplished research work is to examine the impact of the building height concept on energy needs. It takes into account the variation of the depreciative surfaces in contact with the external environments. According to the results, and under several conditions, compactness can contribute to the improvement of thermal comfort and to the minimization of the energy requirements. The contact mode and the height of the building influence the building energy demand.

The compactness index defined as the ratio between the envelope surface and the inner volume of the building. The running of reliable prediction models and their relative simplicity allow them to be used as a tool for estimating the different physical quantities (energy needs, energy savings and investment-return time). Optimal compactness results in minimal thermal losses, that are why, to compensate the increased energy needs due to the lower compactness of the building, one can, increase the insulation level of the building envelope.

The absence of insulation would result in an energy saving of exactly 26.77%, by raising a single house to one-storey building. It will be more substantial savings (more than 40%) by exceeding the fourth floor. In the case of an insulating layer of 10 cm, an energy gain of 21.17% can be saved by varying a single house to one-storey building. The reduction in energy needs exceeds 35% but remains below 38.5% for buildings which are over three storeys high.

Generally, the investment-return time is between 49 months and 44 months, and it is inversely proportional to the number of storeys in the dwelling.

Optimal compactness serves to minimize the energy needs of the buildings, which will systematically reduce the required level of thermal insulation. It is therefore necessary to favor large buildings to rationalize energy consumption.

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