The influence of occupation modes on building heating loads: the case of a detached house located in a suburban area

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ABSTRACT: Occupants' behaviour is known to have a great influence on energetic demand, management and consumptions of a building. However, parameters related to inhabitants' lifestyle are often neglected in energetic studies and researches that often focus on insulation, ventilation or climate. In this context, the aim of the paper is to investigate the influence of three parameters related to human behaviour (the family size and the modes of occupations, the management of the heating system and the management of the heated area) on the housing heating loads of a standard dwelling. The case study chosen for this analysis is a detached house located in a suburban area. Five levels of insulation are tested (no insulation, an intermediate level corresponding to 3 cm of insulation, the current standard for new buildings in the Walloon region of Belgium, the low energy standard and the passive house standard) in order to highlight the impact and the interactions between occupation modes and insulation levels. The relevance of the adaptation of the living area of the house according to the evolution of the family size is finally discussed.

Keywords: thermal simulation, energy consumptions, human behaviour, comfort, building performances

1. INTRODUCTION

The use of mathematical models and simulation tools is often presented as the most credible approach to model the comportment of a building and predict the heating consumptions, in a global vision of sustainability. This approach allows to take into account a large number of parameters which are known to act upon energetic behaviour, management and consumptions of a building and to carry out parametric variations in order to test the impact of different strategies. If the level of insulation, the ventilation or the climate are often discussed in the literature, especially as far as retrofit is concerned, the influence of the composition of the household, its evolution through the whole life cycle of a dwelling or the behaviour of the occupants, which evolve over time while the house remains a fixed and unchanged size, are more rarely debated. However, these parameters have a huge impact on the energetic invoice of a household. Building operations and maintenance, occupant's activities and indoor environmental quality, all related to human behaviour, are indeed known to have an influence as great as or even greater than climate, building envelop and energy systems [1].

In the actual context of growing interests in sustainable development and increasing energy prices, more and more households pay attention to their energetic consumptions, especially as far as heating consumptions are concerned [2] while a large part of the population, and namely elderly owners, stay reluctant to undertake heavy renovation works. The age of the occupants seems namely to have a huge impact on heating loads, and particularly on the occupancy rate and the comfort temperature [3]. Moreover, researches have shown that in general, technical improvements were preferred over behavioural measures and especially shift in consumption. Further, home energy-saving measures seemed to be more acceptable than transport energy-saving measures [4]. The behaviour and preferences of inhabitants and the solutions adopted by the households to reduce their consumptions can thus vary in a wide proportion and cannot be apprehended by one only standard type of household in simulations, as it is generally the case.

In this context, the paper aims at comparing the variations of three parameters related to human behaviours and occupation modes: the family size and the modes of occupations, the management of the heating system (thermostat) and the management of the heated area (the inhabitants occupy the ground floor and the first floor or just the ground floor). These three parameters are then used and combined in order to determine the evolution of the occupancy of the house during its life cycle.

The chosen case study for this analysis is a detached house located in a suburban area because this type of house represents a large part of the building stock and of the total energy consumptions related to housing in the Walloon region of Belgium, where urban sprawl is particularly familiar [5, 6].

The methodology, simulation tools and main assumptions used in this research are summarized in section 2. Then, the impact of the three studied parameters on the evolution of heating loads and internal conditions are presented and finally discussed for five significant levels of insulation.

2. METHODOLOGY AND ASSUMPTIONS

2.1. The TAS thermal simulation software

TAS is a software package for the thermal analysis of buildings. It includes a 3D modeller, a thermal/energy analysis module, a systems/controls simulator and a 2D CFD package. CAD links are also provided into the 3D modeller as well as report generation facilities. It is a complete solution for the thermal simulation of a building, and a powerful design tool in the optimisation of a building's environmental, energy and comfort performance. [7]

2.2. The climate

The climate of the northern part of Europe is a temperate climate. The Brussels' meteorological data are used. Data comprise the hourly data of temperature, humidity, global solar radiation, diffuse solar radiation, cloud cover, dry bulb temperature, wind speed and wind direction. In the analysis of the heating consumptions, a whole typical year is used [8]. The maximum and minimum temperatures, for the considered year are 34.9 ℃ and -9,1℃.

2.3. The studied building

The studied building is a detached house with a south-east oriented facade. It is a two-storeyed house, located in a suburban area. Figure 1 shows the plans of the 2 floors of the building. The ground floor is composed of a living room, a kitchen, an office, a hall and a cloakroom. The first floor comprises 4 attic bedrooms and an attic bathroom. The windows are located on the 2 gables. One bedroom has a roof window. The house also includes a cellar and an attic. The house has a surface area of 182 m².

2.4. The thermal characteristics

The analysis presented in this paper take into account 5 levels of insulation of the house: a level without insulation (NI) neither in the walls nor in the roof and the slab [9, 10], a level with 3 cm of insulation in the walls, roof and slab (3cm) [9, 10], the current standard (CS) for new buildings in Belgium [9, 10, 11, 12], a low energy level (LE) [9, 10, 13] and the passive house standard (PHS) [9, 10, 12, 14]. The main thermal characteristics of walls and windows are summarized in the Table 1.

Double-glazed windows are used in the four first cases and replaced by triple-glazed windows in the passive house. The natural ventilation (NV) corresponds to the opening of the windows from 5 pm till 6 pm (30 % of the surface of the window opened). The mixed-mode ventilation (with mechanical exhaust (ME)) and the mechanical ventilation (MV) work when the house is occupied. The ventilation has three speeds. The third and the most substantial one corresponds to the requirements of the Belgian ventilation standard [9]. The first speed, the most applied in practice, is worth 1/3 of the third one and is used in our simulations.

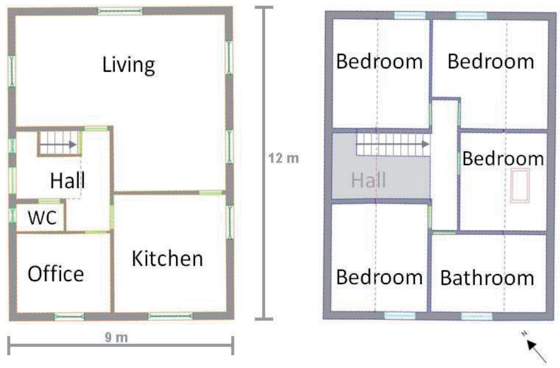

Figure 1: Plans of the ground floor and the attic floor of the studied house

2.5. The internal gains

The more the building is efficient, the more internal conditions have an influence on the heating consumptions of the building. The modelling of internal gains must be representative of the reality. Thanks to the multizone modelling adopted in the analysis, internal gains can be adjusted in each room, according to the moment of the day and the occupation mode.

The following heat emissions are used in the simulations [9, 13] :

- Occupation: 80W per person (the number of person varies from 0 to 5 according to the occupation mode)
- Fridge and deep freeze: 0.85 kWh/day
- Washing-up: 0.3*1.1 kWh/use
  (65 uses/(year.person))
- Appliances: 50kWh/(year.person)
- Television : 150W (1, 2 or 3hours/day)
- Computer: 70W (0, 1, 2 or 10hours/day)
- Cooking: 912W (0.5, 1 or 1.5hours/day)
- Lighting: 6W/m²
- Shower: 1486W/shower (0, 24 or 48 minutes/day)

Table 1: Main thermal properties of the 5 studied levels of insulation.

Levels of insulation	Roof (W/m²K)	External walls (W/m²K)	Ground floor (W/m²K)	Windows (W/m²K)	Airtightness (vol/h)	Ventilation	Annual heating requirement (exigency)
NI	3.586	1.757	1.874	1.22	0.6	NV	-
3cm	0.972	0.758	0.880	1.22	0.6	NV	-
CS	0.3	0.4	0.4	1.22	0.39 ($7.8h^{-1}$ under 50Pa)	NV	-
LE	0.265	0.326	0.395	1.22	0.1 ($2h^{-1}$ under 50Pa)	ME	≤ 60 kWh/(m² a)
PHS	0.129	0.147	0.199	0.774	0.03 ($0.6h^{-1}$ under 50Pa)	MV with heat recovery	≤ 15 kWh/(m² a)

Total internal gains used in each thermal simulation depend on the chosen occupation mode and thus on combinations of the treated parameters. The reference value comes from a monitoring and is worth 2.57 W/m² [15].

2.6. The parametric variations

The study presented in this paper aims at comparing the influence of three parameters related to human behaviour and occupation mode on the heating loads. The studied parameters and their variations are presented below.

The first parameter deals with the family size and the corresponding occupation mode. Two types of family composition are considered and allow to target and to characterize the four following occupation modes.

- Occupation mode 1 (OM1): an active couple works outside the house during the day while their three children go to school.
- Occupation mode 2 (OM2): a self-employed or unemployed couple works/stays at home during the day while their three children go to school.
- Occupation mode 3 (OM3): an active couple without children works/stays outside during the day. Five cases are discussed.
- Occupation mode 4 (OM4): a retired couple, not very active, spends a lot of time at home. Two cases are discussed.

The second parameter deals with the management of the heating system. This modelling is based on three types of management of the thermostat, that depend on the occupation mode. The three studied cases are :

- T1: 20 ℃ in the occupied rooms with a drop to 16 ℃ at night and during the day. The heating season begins the first of October and ends the first of May
- T2: 20 ℃ in the occupied rooms with a drop to 16 ℃ at night. The heating season begin the first of October and ends the first of May.
- T3: 21℃ in the occupied rooms, all over the year , during day and night.

The last parameter is the management of the heated area. The size of a family and its activities evolve over time while the house has a fixed and unchanged size but sometimes, people remove in a part of the house which became too big for them (after the departure of children for example, facing the difficulty of climbing stairs,...). In the simulations, the house is occupied either completely (ground floor and the first floor (GF)) or only partially (just the ground floor (G)). In this case, we consider that the office is transformed into a bedroom.

2.7. The studied cases

Several cases can be arised from the combination of the parameters presented in the previous section. The nine studied cases are summarized in Table 2 (OM is the occupation mode, T1, T2 and T3 are the temperature settings, a cross in the GF column means that both the ground floor and the first floor are occupied (totally or partially) while a cross in the G column means that only the ground floor is occupied).

Table 2: The 9 case studied in the simulations

	OM	GF	G	T1	T2	T3
Case 1.1	1	x		x		
Case 2.2	2	x			x	
Case 3.3	3	x		x		
Case 3.4	3	x			x	
Case 3.5	3		x		x	
Case 3.6	3	x				x
Case 3.7	3		x			x
Case 4.8	4	x				x
Case 4.9	4		x			x

3. RESULTS

The results are presented in 4 parts:

1. the analysis of the 2 cases representing a family with children (case 1.1 and case 2.2),
2. the analysis of the 5 cases representing an active couple without children (cases 3.3 to 3.7),
3. the analysis of the 2 cases representing a retired couple (case 4.8 and case 4.9) and
4. the analysis of the 3 extreme cases representing 3 of the 4 modes (the cases 1.1, 3.4 and 4.9).

Table 3 presents the heating loads of the 9 simulated cases for the 5 levels of insulation. In the first part of the table (part A), the total heating loads calculated for the house are divided by the total surface area of the house (182m²) in each case because if the occupied and heated area changes, the position of the insulation stays the same in each case. In the second part (part B), the total heating loads calculated are divided by the occupied and heated area (182m² if the house is totally occupied by a family (the cases 1.1 and 1.2), 138m² if the ground floor and the first floor are partially occupied by a couple (the cases 3.3, 3.4, 3.6 and 4.8) and 91m² if only the ground floor is occupied by a couple (the cases 3.5, 3.7 and 4.9)).

3.1. OM 1 and 2 : couple with 3 children

Table 3 shows that case 1.1 is more energy-efficient than case 2.2 for all the levels of insulation tested, excepted for the passive case. Proportionally, the biggest difference between these two cases is observed at this passive level: the difference in heating loads between cases 1.1. and 1.2 reaches 2.28 kWh/(m².year) (28.73%). For the other levels of insulation, the difference between the two cases is contained in a range between 0.75% and 8.28% (from 0.45 to 14.98 kWh/(m².year)). This table also reveals the importance of the level of insulation. The change from one level of insulation to another permits a huge reduction in heating loads. Moreover, for both considered cases, the greatest energy reductions are visible when the passive standard is reached. In general, the change from one level of insulation to the higher one is very interesting and has a greater impact than the benefit gained from occupation modes case 1.1 on case 2.2.

3.2. OM3 : active couple without children

If heating loads are divided by the heated area (Part B of Table 3), 4 of the 5 cases relating to the

Table 3: The heating loads of the 9 studied cases (in kWh/m²). The first part of the table (A) presents the total heating loads divided by the total surface area of the house (182m²). The second part (B) presents the heating loads divided by the occupied area (182m², 138m² or 91m² according to the corresp onding occupation mode).

	Case 1.1	Case 2.2	Case 3.3	Case 3.4	Case 3.5	Case 3.6	Case 3.7	Case 4.8	Case 4.9
A.) kWh/m² (Heating loads are divided by the total surface area of the house (182m²))									
NI	180.13	195.11	154.78	170.70	132.19	231.00	178.71	214.71	175.43
3 cm	96.46	101.30	92.94	101.35	88.25	132.15	115.16	122.76	111.96
CS	59.53	59.08	60.50	64.92	59.69	80.75	74.54	74.88	71.62
LE	28.46	31.03	30.18	36.19	31.99	44.82	39.74	40.69	36.99
PHS	7.25	5.16	11.88	13.28	12.76	15.93	15.39	13.54	13.15
B.) kWh/m² (Heating loads are divided by the occupied area (182, 138 or 91m²))									
m²	182	182	138	138	91	138	91	138	91
NI	180.13	195.11	205.40	226.53	265.46	306.55	358.88	310.73	352.28
3 cm	96.46	101.30	123.34	134.50	177.22	175.37	231.25	177.67	224.83
CS	59.53	59.08	80.29	86.15	119.87	107.16	149.68	108.37	143.82
LE	28.46	31.03	40.05	48.02	64.24	59.48	79.79	58.89	74.29
PHS	7.25	5.16	15.76	17.62	25.61	21.14	30.91	19.59	26.41

third occupation mode do not meet the passive house standard. If the heating loads for cases 3.3 to 3.7 are divided by the total surface area of the house, the passive standard is respected. The values of cases 3.6 and 3.7 are indeed nearly beyond the bounds, especially since these cases are considered only with a “speed 1” ventilation rate.

The low energy standard is not reached for case 3.5 and 3.7 (Table 3B) if the occupied area is considered but is reached when the total surface is used (Table 3A).

The heating demands vary a lot according to the occupation mode (Table 3A). The two extreme cases are case 3.5 and case 3.6, The differences between these two cases vary from 98.81 kWh/(m^2.year) for the non insulation case (42.77%) to 3.17 kWh/(m^2.year) for the passive house standard (19.93%). The average of the differences is worth 30.10%. In general, the more the building is insulated, the more the difference between the cases decreases. The impact of behaviour becomes thus less huge and less marked. These two cases develop opposite behaviours. According to Table 3B, the two extreme cases are cases 3.3 and 3.7. The differences between heating loads are contained in a range between 153.18 kWh/(m^2.year) for the non insulated case and 15.15 kWh/(m^2.year) for the passive house standard. The average of the differences is worth 46.89%, which means that a couple, living in a house with 3cm of insulation, with a behaviour similar to case 3.7, can consume as much as a couple living in a non-insulated house with a more responsive and better managed behaviour. In general, if the building has a good insulation, the impact of the behaviour, compared with heated squared meters, can be proportionately as high as the impact of changing from a level of insulation to a better one.

This result highlights the very low equilibrium between comfort and good energy management. If people have very different schedules, it is quite interesting to be able to switch on by remote control the heating and the ventilation which allows to trigger the revival of the heating system. Lowering the day temperature from 20 °C to 16 °C can make a saving of about 10%, by comparing cases 3.3 and 3.4.

A very good insulation will reduce the consequences of the carelessness of people or of their no energy-efficient behaviour. But the reduction of consumptions remains and is thus easily improvable!

3.3. OM4: retired couple not very active

The occupation mode related to retired couple that is not very active and stays at home during the day is less energy-efficient because the house is more often occupied which means more heat, more light, more cooking times. Moreover, thermal comfort is the basis of the notion of comfort for elderly households. This occupation mode requires a great need for heat and that is not negotiable. Note that heating loads predicted by these simulations are low compared to real consumptions generated by some elderly households' behaviours, for example maintaining indoor air temperature at 26℃ all over the year during day and night.

Occupying just a part of the house (here the ground floor), is energetically more interesting. According to Table 3A, if the house is not insulated, the difference between cases 4.8 (the ground floor and the first floor are partially occupied) and 4.9 (the ground floor, only, is occupied) is worth 39.28 kWh/(m^2.year) (18.29%) but this difference is only worth 0.38 kWh/(m^2.year) (2%) in the passive house. According to Table 3B, the average of the differences between these 2 cases is about 21% (contained in a range between 6.83 and 47.16 kWh/(m^2.year)). But these 2 cases do not concern the same surface area and thus the most consumers in terms of kWh/(m².year), the case 4.8, gives the impression to consume less than the case 4.9. It might be interesting to bring in a density factor. Once again, the impact of the occupation mode in terms of kWh/m².year decreases if the insulation of the house is better.

3.4. Comparison between 3 representative occupation modes: synthesis

This section aims at comparing the heating loads results related to 3 extreme occupation modes. The 3 selected cases are case 1.1. (an active couple working outside the house during the day with three children going to school), case 3.4 (an active couple without children working outside the house during the day), and case 4.9 (a retired couple not very active, staying at home with a higher comfort temperature).

The more the building is insulated, the more the occupation mode is marked. The comparison between case 1.1 and case 3.4 (Table 3A) highlights that the difference between heating loads is contained in a range between 5.24% (9.44 kWh/(m^2.year)) for a non-insulated house and 45.42% (6.03 kWh/(m^2.year)) for the passive house standard. The difference in heating loads between the two modes related to a couple without children (cases 3.4 and 4.9) are relatively low. The average of the differences is indeed worth 5.74%. Figure 2 shows that if the building is not insulated, the occupation mode related to the family with three children is the higher consumer of energy. But this occupation mode with children becomes more efficient than the two others modes if the house is insulated. That also reveals the importance of internal gains.

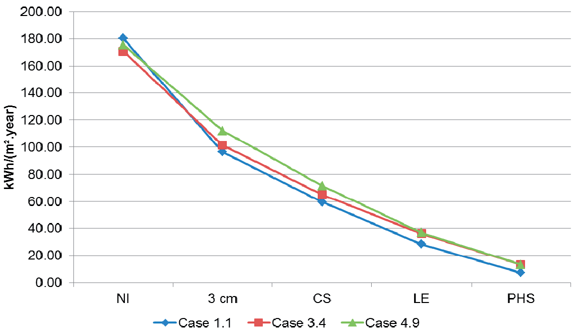

Figure 2: Heating loads (kWh/(m².year)) based on the 5 levels of insulation tested for cases 1.1, 3.4 and 4.9 (In this figure, heating loads are divided by the total surface area of the house (182m²)).

If we consider now the second part of Table 3 (where heating loads are divided by the occupied area), the differences between the three studied cases are more important. The average of the differences between case 1.1 and case 3.4 (range from 10.38 to 46.39 kWh/(m^2.year)) and between case 3.4 and case 4.9 (range from 8.79 to 125.76 kWh/(m^2.year)) are worth 36%. Case 1.1 remains the most interesting one for any level of insulation thanks to the largest heated area, to the numerous internal gains and to the better management of the heating system.

The differences between the cases increase with the level of insulation even if the difference of heating load between cases 3.4 and 4.9 and case 1.1 is more marked if heating loads are divided by the occupied area, as it can be seen on Figure 3.

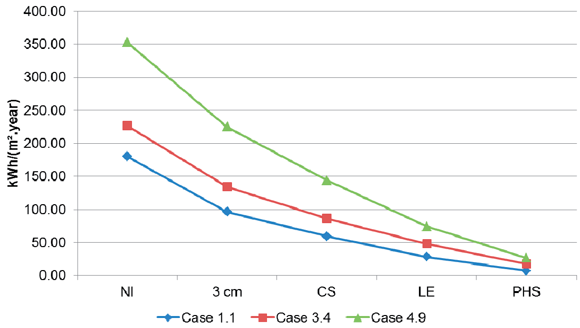

Figure 3: Heating loads (kWh/(m².year)) based on the 5 levels of insulation tested for cases 1.1, 3.4 and 4.9 (In this figure, heating loads are divided by the occupied area).

4. DISCUSSION

This section aims at discussing the impact of these occupation modes during the life cycle of the house. Indeed, several occupation modes can follow one another during the life of a house. To assess their impact on the life expectancy of the studied house, 4 assumptions of occupation are established for a period of time of 100 years and summarized in Table 4. For example, in A1, the house is occupied during 45 years by a family with 3 children (case 1.1) then by an active couple without children (case 3.4) during 30 years and finally by a retired couple (case 4.9) during 25 years.

Table 4 : Years of occupation of each occupation mode, for a life cycle of 100 years : 4 assumptions

	A1	A2	A3	A4
Case 1.1	45	25	60	25
Case 3.4	30	50	25	55
Case 4.9	25	25	15	20
Total	100	100	100	100

Average heating loads calculated for the four scenarii of occupation presented in Table 4, and divided by the heated area, are summarized in Table 5. In two cases (A2 and A4), the requirements of the passive house standard are not met. The more the building is insulated, the more the difference of heating in % increases between the two cases. In the passive house standard, this difference reaches 26.18% (4.51 kWh/(m^2.year)) between A2 and A3, that are the 2 extreme cases.

If the size of family evolves over time, the size of the house and its occupation modes should also be adapted. This strategy would allow to reduce the heating consumptions during the whole life cycle of the building. The aim is to maximize the occupation of the house. But that can lead to significant works of adaptation (extra kitchen, independent entrances, etc.). The insulation and possibilities of thermal improvement of the building must also be taken into account in order to choose the best option.

Table 5 : Average heating loads (in kWh/(m².year)) of a house on his life (100 years) based on the assumptions of occupation modes presented in Table 4.

	A1	A2	A3	A4
NI	237.09	246.37	217.55	240.08
3 cm	139.96	147.57	125.22	143.05
CS	88.59	93.91	78.83	91.03
LE	45.78	49.70	40.22	48.38
PHS	15.15	17.23	12.72	16.79

5. CONCLUSION

Nine types of occupancy of a standard detached house located in a Belgian suburban area have been determined by combining several representative types of households, occupation modes and thermal preferences (management of the thermostat). Thanks to multi-zone thermal simulations performed with a dynamic thermal simulation software (TAS), heating loads have been calculated for these nine case studies and for four combinations of the most representative ones during the life cycle of the building (100 years).

These analyses have highlighted the importance of internal gains related to the different modes of occupation, their influence on heating loads for the studied levels of insulation and the significance to take into account several types of households and occupation modes in thermal studies.

These analyses have particularly highlighted that the more the building is insulated, the more the lifestyle, namely through internal gains, influence proportionally the heating loads even if, in terms of kWh, this impact decreases. These results emphasize that the number of inhabitants and their presence in the house can reduce the heating loads. However, insulation is paramount and increasing the insulation of the house always gives better results than just adapting the occupation mode.

For the studied building, the model that presents the lower heating loads is the active couple working outside with three children, because, in this case, the number of inhabitants is quite adapted to the size of the house. The balance between optimal comfort and good management of the energy is very low and particularly if people have varied schedules. It is thus quite interesting to be able to switch on by remote control the heating and ventilation systems which allows to trigger the revival of the heating.

Last but not least, a more responsible behaviour can easily improve the energy balance of a house. Buildings thermal improvements are also very efficient but take more time and money to be realized. To heighten public awareness of the impact of their lifestyle is thus crucial and can quickly lead to significant reductions in the total energy consumptions of a family.

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