

Turn the gas off

Zero-energy achievement based on free floating internal conditions between health-related limits

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ABSTRACT: *The current trend in low energy building design is to reduce heating needs at ambitious levels – e.g. the Passive House concept - and to compensate residual consumptions with renewable. This leads to so called net-zero-energy buildings. This paper explores another possible definition of zero energy: a building that, without mechanical heat supply, maintains winter internal conditions between health related limits. Thanks to dynamic simulations, it is shown that an apartment designed according to passive architecture best practices is matching this definition. The paper concludes on a proposition of shared responsibility between the designers and the inhabitant: the passive achievement of healthy indoor conditions is the designer's responsibility, while the achievement of more comfortable indoor conditions falls to the inhabitant's share.*

Keywords: Zero energy, Passive House, free float, health, comfort

1. INTRODUCTION

1.1. Energy design tendencies

The net-zero-energy buildings (NZEB) concept is now strongly promoted : the European Parliament recently approved a recast of the Energy Performance of Buildings Directive proposing that all new buildings in the EU be at least 'net-zero energy' by 2019 [1].

Hernandez and Kenny give an interesting overview of the NZEB concept [2]. According to them, "*the most common approach to ZEB is to use the electricity grid both as a source and a sink of electricity (...). The term 'net' is used in grid connected buildings to define the energy balance between energy used and energy sold, the term 'net-zero energy' being applied when the balance is zero*". They show that the actual definition of NZEB is not satisfactory, especially because it is not based on a life cycle approach.

Another criticism of NZEB concepts is that they are not very useful at the design stage. Only two attitudes are possible at this stage. The first one is to determine the energy supply capacity of the site and to design the building in order to be lower or equal to this value. If the supply capacity is high, there is no guarantee that the building will be energy efficient. Such an attitude does not follow the Trias Energica [3]. The second attitude is to design the building as energy efficient as possible, and then to care about renewable energy supply sources in order to overwhelm the residual energy consumption. This attitude corresponds more to concepts such as "Passive House" [4] supplemented with renewable than to the NZEB concept.

1.2. Objective

From this introduction we formulate the following question: are there other ways to design net-zero energy buildings than through the idea of grid connected buildings? Obviously, there is one

solution, which is designing a building that actually does not use energy to maintain healthy indoor climate conditions. Next to a carbon footprint limited to embodied energy, such a building would ideally tackle fuel poverty. It would answer to environmental, social and economical aspects of sustainable development.

The aim of this paper is to check whether a dwelling designed according to Passive House principles may fulfill this definition.

Since internal gains are a major factor in a passive house energy balance, the evaluation has to be conducted for occupied dwellings. But it cannot be asked to inhabitants to live a winter season without heating. So the evaluation is done through dynamic simulations.

2. METHODOLOGY

In order to complete this exercise, we describe the studied dwelling (section 2.1) and define simulation parameters (section 2.2). We also discuss indoor climate conditions. At first, we consider commonly accepted comfort zones (section 2.3). Then, following the idea that before being comfortable, a dwelling should be healthy, healthy conditions are proposed based on existing literacy (section 2.4).

2.1. Example dwelling

The 119m² apartment investigated is shown in figure 1. An 11 zones model is created in trnsys17. Technical data's are summarized in table 1. Two performance levels are investigated. The first one allows the apartment to fulfill Belgian criteria of the "Passive house" standard (heating demand <15kWh/m²an and n50 infiltration rate <0.6). The second one proposes further improvements.

Internal gains are integrated in order to represent a 4 person family with typical working schedules. Metabolic gains represent 1.8MWh/y, equivalent to a

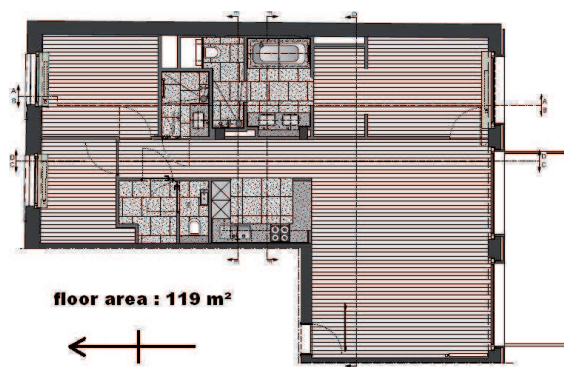


Figure 1: Studied apartment plan: 2 north rooms, 1 south room, south living room and internal technical spaces

Table 1: Technical characteristics of the Passive apartment

	Case 1	Case 2
Construction type	Massive concrete building with outside insulation	
External wall	0.183 W/m²K	0.10W/m²K
Glazing	0.7 W/m²K+ spacer g=0.5	0.52 W/m²K g=0.59
Frame	0.87W/m²K	0.87W/m²K
Hygienic ventilation	Mechanical inlet and exhaust	Mechanical inlet and exhaust
Flow rate	144kg/h 0.43 ach	144kg/h 0.43 ach
Heat exchanger	Flat plate Constant 76% efficiency	Hygroscopic Constant 80% efficiency
External wall air tightness Q_{50}	4.3 m³/hm²	2m³/hm²

constant gain of 1.7W/m² (gross floor area). Daily occupation profiles are shown in figure 2. Electrical consumptions relative to lighting and other uses represent 1.8MWh/y. This value is lower than the 2.5MWh/y value representative of a Walls family of 4 people without electrical cooking facilities [5]. The cumulated value of internal gains is 3.55MWh/y, equivalent to a constant gain of 3.4W/m² (relative to gross floor area). This is higher than the typical 2.1 W/m² (net floor area) proposed in the Passive House certification assessment tool [6] but nevertheless seems representative of actual conditions in an apartment.

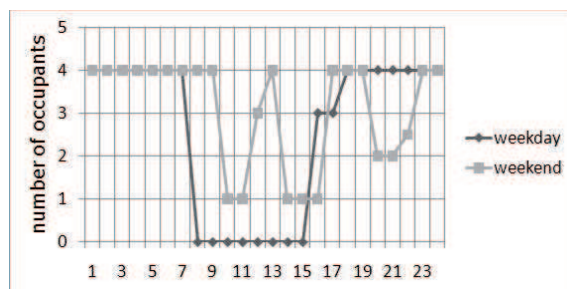


Figure 2: Daily occupation profiles

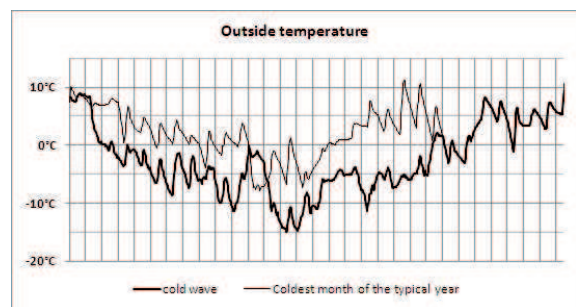


Figure 3: Temperature profile for the reference year and the cold wave

Table 2: Meteorological monthly values

	Coldest month of the typical year	Cold wave
Mean temperature °C	2.5	-2.4
Min. Temperature °C	11.3	11.1
Max. Temperature °C	-7.9	-14.9
Global horizontal radiation kJ/m²/month	72306	76223

Humidity production is considered. A 65gr/h/person production is assumed. Cumulated with vapor production in the bathrooms and the kitchen, an average humidity production of 6.3l/day (0.053 l/day/m²) is obtained. Trnsys17 capacitance humidity model is used with a humidity capacitance ratio of 4 in every zone.

2.2. Simulation parameters

Simulations are conducted for both an extreme winter month ("cold wave") and a typical Belgian winter (Meteonorm file for Uccle). Figure 3 shows external temperature profiles. Table 1 summarizes meteorological values for the cold wave and the coldest month of the typical year. The simulation is conducted with a 0.5h time step and a 6 month initialization period.

2.3. Definition of comfort zones

Criticisms are expressed against too simple definitions of thermal comfort. Especially, the variability of comfort feeling with the subject behavior and their adaptation to the climatic conditions has been discussed [7]. So called adaptative approaches based on field surveys have been developed to define thermal comfort guidelines including both physical parameters and behavioral and psychological parameters [8, 9, 10, 11].

Nevertheless, traditional comfort zone definitions explicitly consider ambient humidity, while adaptative methods use functions of the external and indoor operative temperature only. Since the humidity ratio is a key parameter regarding health, as exposed in section 2.4, we choose in this study to consider traditional comfort indexes.

Two comfort zones are drawn in the psychometric chart (Figure 4). The first one is the ASHRAE Standard 55-2004 acceptable range of temperature based on a PMV evaluation [12]. The

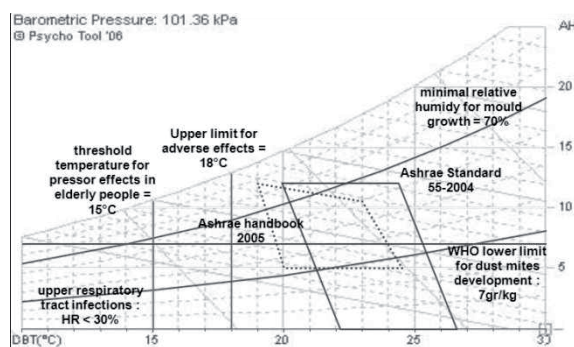


Figure 4: Health and comfort limits.

second one comes from ASHRAE handbook 2005 [13]. This last one includes a minimal humidity limit.

Both comfort zones are originally defined regarding operative temperature. In order to express all our results in ambient air temperature we make the hypothesis that operative and ambient temperatures are equals. This implies that $T_{mrt} = T_{amb}$. Thanks to high insulation levels, highly compact design and mostly convective internal gains, we consider this hypothesis as reasonable in Passive Houses. We invite the reader to keep in mind that if $T_{mrt} < T_{amb}$, the comfort zone would slide to higher internal temperatures. So the used comfort zone may be seen as slightly colder than the actual feeling.

2.4. Definition of a health limits

The relation between indoor climatic conditions and health hazards is close and shortly presented in this section.

In winter, direct pathologies from low temperatures, such as hypothermia symptoms occurs, but on a much smaller occurrence that respiratory and circulatory affectations [14]. Nevertheless some authors argue that cold indoor temperatures are responsible for the "greater part" of the excess winter death [15].

Dr Collins gives evidence that there is greater increase in winter mortality from respiratory illness than from circulatory (coronary) and that respiratory health is more related to indoor temperature and cardiovascular to outdoor cold, although this conclusion needs to be examined further [16]. Meanwhile, if cold indoor temperature impacts the upper and lower respiratory system, there is no experimental evidence of a direct correlation between cold and a lowering of the body resistance [16]. Other factors have to be considered such as easier virus propagation due to higher promiscuity in winter and the combination of cold and dampness in houses.

In this section we identify a "healthy zone" on a psychrometric chart (figure 4). We focus on winter periods and consider minimal and maximal humidity levels and minimal temperature. The question of maximal temperatures in summer is not discussed in this paper. Even without considering summer periods, it remains a difficult exercise due to limited medical knowledge, especially when considering other parameter such as atmospheric pollution [17], particular sensibility, activities, living and hygienic habits [16]. Also, such a representation cannot take

into account transient situations, although resistance and sensibility to climatic variations should be considered. So the limits of the proposed "healthy zone" are to be seen as indicative only.

The proposed temperature and humidity limits are expressed as mean ambient conditions. It must be kept in mind that mean internal conditions are not representative of local conditions, such as those occurring on cold bridges. Nevertheless, we will assume such equivalence. This assumption is supported by the high insulation levels and the exhaustive resolution of cold bridges asked for by the Passive House concept. Both elements help bring about small differences between surface and ambient conditions.

The proposed limits are the following:

1/Maximal humidity: excessive dampness appears to be the most determinant parameter for fungal growth and house dust mites. Laboratory measurements have demonstrated that mould grows when wall surface RH is above 80% for a period of several weeks, although some moulds will grow at relative humidity as low as 70% [18]. It is usually accepted that a relative humidity of 70% is sufficient to sustain mould growth [16, 19].

About dust mites, maintaining a relative humidity lower than 50% thorough the year is recommended in homes [20]. This limit should be respected for mean daily RH, with maximal periods for 2 to 8 hours daily above 50% [21]. Also, it has been shown that almost no house dust mites are able to survive below 45% relative humidity at 20–22 °C but at higher humidity the number of mites increases rapidly [22]. The World Health Organization set a figure for absolute humidity of 7g/kg as the limiting factor for the growth of colonies of dust mites [23]. Below this level numbers of mites begin to fall, due to direct desiccation of the mites themselves plus the dehydration of the skin scales on which they feed. This last expression of maximal humidity is in good agreement with the 50%RH limit for temperatures between 18 and 21°C, but stricter for higher temperatures.

Considering that dust mites are hazardous only for allergic people while mould is hazardous to everyone, both maximal humidity limitations do not have to be regarded as equivalent. Only the mould related humidity limit will be considered further.

2/Minimal humidity: Too dry conditions cause the development of irritation symptoms in eyes and upper airways. Studies indicate that RH about 40% is better for the eyes and upper airways than levels below 30% [24]. It is also shown that the occurrence of upper respiratory tract infections increases when indoor relative humidity is below 30% [16].

3/Minimal temperature: Below 18°C the risk of adverse effects – respiratory infections, bronchitis, heart attacks, stroke – rises. The risk increases the more temperature falls. Below 10°C the risk of hypothermia becomes appreciable, especially for the elderly [15]. Other studies have shown that 15°C appears to be the threshold temperature for pressor effects in elderly people and therefore this would be a minimum level at which elderly people should live in their homes [25].

3. RESULTS

Results for cases 1 and 2 for the coldest month of the typical year are shown in figures 5 and 6. Figures 7 and 8 show results for the cold wave. In all those figures, each dot represents a daily mean value in one thermal zone. Figures only show thermal zones with long term standing, e.g. the living room and sleeping rooms.

Figure 5 indicates that the gap between internal conditions and health related limits is large during the coldest parts of a typical year in Brussels. It is of course worse for a more extreme period (Figure 7). Thanks to technical improvements (case 2) healthy conditions are achieved for typical periods (Figure 6), but not for extreme periods (figure 8).

In order to illustrate daily variations, figure 9 shows hourly values for the coldest week of the year for the living room in case 1 and 2. Daily variations appear to be horizontal ones, indicating temperature shifts of 2 to 3.5°C and absolute humidity stability. This stability indicates an adequate hygienic ventilation rate.

4. DISCUSSION

This section discusses interpretation and use of the results exposed in section 3.

4.1. Interpretation

Both case 1 and case 2 use existing technologies and correspond to best practices matching Passive House recommendations.

The hypothesis of a continuous occupation is

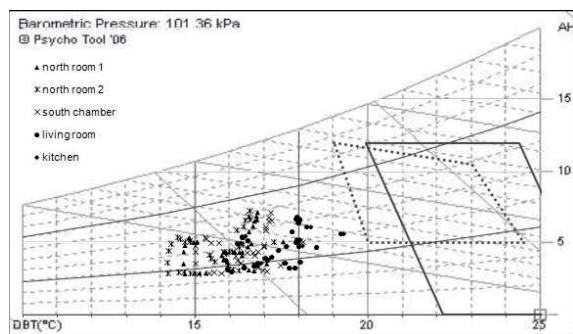


Figure 5: Internal conditions in the living and sleeping rooms of the "case 1" apartment for the coldest month of a typical year.

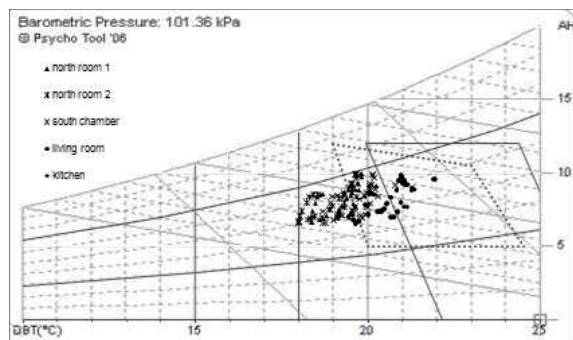


Figure 6: Internal conditions in the living and sleeping rooms of the "case 2" apartment for the coldest month of a typical year.

crucial. We assumed neither winter holidays nor even an evening totally unoccupied. Such reductions in internal gains would result in lower temperatures. It is well known that Passive House standards achievement is rather sensitive to internal gain variations. Those gains typically account for 1/3 of the heat demand [26]. In the case of apartments, thanks to very low conductive losses, this proportion is higher. For the coldest month of the typical year, it reaches 47% in case 1, while solar gains only account for 15%. Figure 10 shows, for the coldest week of the typical year, values of internal and solar gains and total heat demand and supply in order to maintain a 21°C ambient temperature, for case 1.

4.2. Use

Our results demonstrate that it is possible to achieve healthy conditions thanks to passive heating measures only, for an occupied apartment and

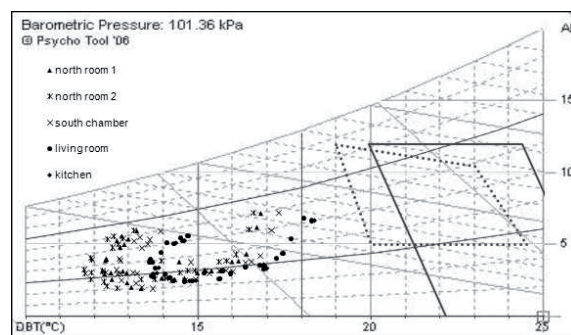


Figure 7: Internal conditions in the living and sleeping rooms of the "case 1" apartment for a cold wave.

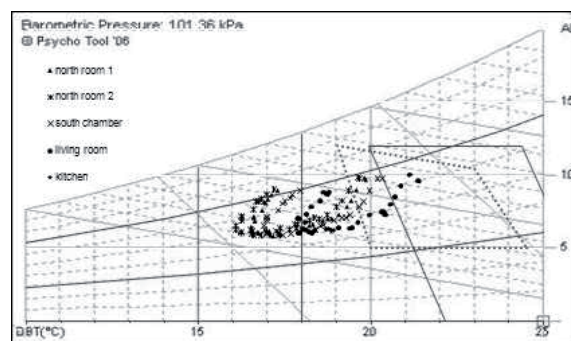


Figure 8: Internal conditions in the living and sleeping rooms of the "case 2" apartment for a cold wave.

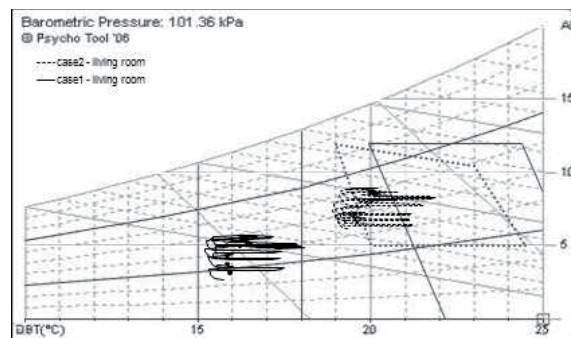


Figure 9: Hourly internal conditions in the living room in cases 1 and 2 for the coldest week of a typical year. Daily mean values are also indicated.

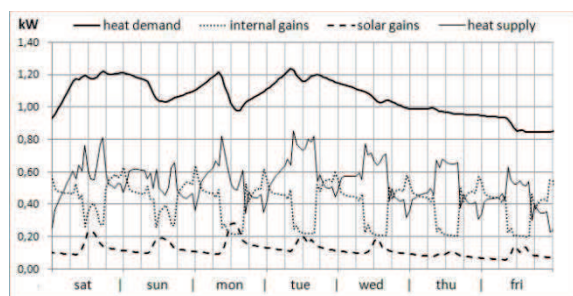


Figure 10: Case 1 gains compared with total heat demand and heat supply for the coldest week of a typical year.

for typical meteorological condition. Although, it does not allow to design housing unequipped with heating power. Because the proposed healthy limits are less strict than comfort limits. And because heating power is needed to reach comfortable or healthy indoor conditions, after inoccupation periods or during extremely cold periods.

We consider that our results are above all of conceptual use. In northern Europe, heating supply as until now be seen as inevitable. Recently, heating consumptions in buildings were seen as normal but to be reduced in order to face climate change. But full disappearance of this consumption was not hoped for, and an attitude based on their compensation was developed (i.e. "NZEB" concepts). In this context, both heating consumption reduction and renewable energy supply are seen as part of the design team responsibility.

Thanks to our results, another vision may rise, based on the sustainability principle of shared responsibility [27]. This principle urges both designers and inhabitants to act at their own level. This paper suggests that the responsibilities of architects and designers may be: 1/ to design the building in order to achieve healthy conditions without heating and 2/ to design a heating system allowing the inhabitant to use it in an adequate efficient way. When living in such a dwelling, the inhabitant responsibilities would be: 1/ to choose living conditions that, although matching his own particular comfort feeling, are as close as possible as the without heating supplied healthy conditions and 2/ to use the heating system in order to create these comfort conditions with the least energy.

This idea that the inhabitant has to share responsibility in the buildings environmental performance is consistent with the 2009 Plea manifesto [28].

5. CONCLUSION

This paper presents two developments.

Healthy temperature and humidity limits are exposed based on a literature survey. Those limits are compared with ASHRAE comfort zones.

Dynamical simulation results are presented for a free float running Passive house apartment. It indicates that healthy conditions can be maintained without mechanical heating supply for a typical winter in Belgium, as long as the apartment is inhabited.

Based on these results, we propose a conceptual development about the necessity to achieve energy

efficient dwelling. It is to share the responsibility between the designer and the inhabitant. Each one's responsibility is exposed. The designers' responsibility is about healthy conditions and the quality of heating systems, while inhabitant's responsibility is about comfort conditions and the proper use of heating systems.

6. FUTURE WORKS

The survey of medical references should be pursued in order to determine maximal temperature limits. Since comfort limits in summer have been shown to be transient, it may be suspected that health limits will be too. An alternative graphical or numerical expression of health limits that is best suited for transient criterions should then be developed.

The ability of Passive House apartments to fulfill these criterions without mechanical cooling should be demonstrated. But since such dwellings have been shown to be comfortable if properly designed [27, 28], this demonstration should be implicit. Other buildings types such as row houses or commercial buildings have to be studied.

Finally, this article indicates that the proposed definition of the designers' responsibility correspond to slightly improved best practices in passive building design. Further development could determine practical and methodological recommendations in order to adapt Passive House recommendations to this new objective.

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