User habits – impact on energy consumption in Passive Houses

H. Mahlknecht, D. Exner Eurac research, T. Mennicken Fachhochschule Rosenheim, E. Thaler Hochschule Luzern, T. Schrag Standortagentur Tirol, L. Degiorgis Regione Piemonte, M. Braun Energieinstitut Vorarlberg

Introduction

It is a fact that not all energy efficient buildings achieve the potential performances pursued during the design phases. There is a demand to investigate sources of problems of energy efficient buildings and provide recommendations for improvements.

To be able to give an answer to the question about possible deviations between the actual and designed performances of passive houses and relative causes, a monitoring campaign of passive houses in six alpine space regions (see fig. 1) was carried out within the ETC Alpine Space project "ENERBUILD"[1]. Topics of the analysis were: the actual building energy performance and comfort conditions, focusing the attention on external and internal climate and performances of the ventilation system. After excluding the fact that deviations could also derive from wrong design and execution of construction details (e.g. by determining thermal bridges), it was a central aim of the work to identify the impact of user behaviour on the energy consumption.

The monitoring was carried in six regions (Upper Bavaria, Central Switzerland, Vorarlberg, Tyrol, South Tyrol and Piemonte) based on a two stages approach: during the first-level-study 32 passive houses were analysed and documented in terms of building construction features, energy bills and energy calculations in order to identify the main building performance key figures. Questionnaires to the inhabitants helped to understand their general satisfaction and use of the building (user behaviour). In a second step, within these 32 Houses, 18 buildings (both one-family and multi-family houses) were chosen and analysed by long term monitoring collecting data on the thermal and electric energy consumption as well as on indoor comfort.

Survey on user satisfaction

50 inhabitants of the 32 documented passive houses of the first-level-study participated in the user survey. Aim of this inquiry was on one hand to get knowledge on the user satisfaction regarding the living comfort in passive houses in general and especially

[1] http://www.enerbuild.eu/

regarding the satisfaction about the ventilation system (the questions were taken from the study “Vergleichende Auswertung schweizerischer Passivhäuser” from the “Bundesamt für Energie” [Frei 2004]). Both aspects, together with questions on occupancy times and set-point temperatures of the heating and cooling system, should help to interpret the monitoring data, while questions about e. g. frequency and duration of ventilation through window opening gave information on the user behaviour.

The users survey showed positive results: a great majority of the inhabitants was satisfied with the living comfort, the overall impression of room comfort and the life quality in general. Also the costs and benefits ratio was evaluated positively. Expectation the inhabitants had towards the building could be considered as fulfilled for most of them. A big part of inhabitants felt fine with the indoor comfort both during summer and winter.

However a lower percentage of the inhabitants was satisfied with the following issues:

- Mean indoor temperature in summer: nearly 50% said that indoor room temperatures were slightly too high, ca. 6% even said it was too hot
- Mean indoor air humidity in winter: over 30% said the mean air was slightly too dry
- Ventilation system: about 17% were not satisfied with the ventilation system in general; ca. 8% felt disturbed by the noise of the ventilation during the day, while even nearly 30% during the night
- Provided information: 25% felt not well informed about the passive house concept, 10% about the instruction for use, 4% about the handling of the ventilation system

Long term monitoring of Passive Houses – Interpretation of statistical results

In the 6 involved Alpine Space pilot regions a total of 18 buildings with 147 apartments were chosen to be monitored.

Over the monitoring period five of six partner regions collected real data of the external climate from a dedicated weather station installed on the roof of the monitored passive house or if this was not feasible from a nearby weather station. The comparison of real weather data with reference climate from PHPP (meteonorm 6.1) showed deviations of heating degree days from 4 to 41%.

In all passive houses indoor climate was monitored, in most cases in two different zones – in the living room and in one bedroom. The comparison with the reference temperature of 20°C (used in the official standards or in regional energy calculation methods as well as in PHPP) showed that the measured internal temperatures were in nearly all passive houses – as expected – approximately 1 to 4 Kelvin higher (21° to 24°C).

The actual energy consumption for heating was determined, either measured directly with an energy meter, obtained from the quantity of consumed combustible or by manual meter reading, to compare the calculated demand (net energy in EU standard) and the measured consumption (delivered energy in EU standard). Although the two measurement variables are not directly comparable (net energy does not take plant efficiency and distribution losses into account), this approach was adapted to facilitate measurements.

For the evaluation of the data, energy consumptions were normalized to the external and the internal climate conditions in order to make them comparable with the design indoor and outdoor temperatures. In most of the cases the measured energy consumption for heating was higher than the calculated one in PHPP as well as the design value from regional software. However the consumption was in most of the cases pretty close to the calculated results, when the data was corrected in terms of internal temperature, outdoor climate data and when taking user behaviour into account. Through the monitoring of different flats in several multi-family houses it was possible to weight the influence of user behaviour by comparing the monitoring results: in fact, the energy consumptions differed a lot and they were highly connected to the user behaviour in terms of higher indoor temperatures and higher air exchange rates. In case of thermal energy consumption, it was excluded that differences arose because of different solar gains during the winter month or different orientations of the apartments. The graph below illustrates the case study “House Gartenpark” with annual energy consumption for heating and domestic hot water of six different flats (with the same size and orientation), divided by treated floor area (see fig. 1).This bring to the conclusion that higher energy consumptions result both from higher temperature levels in rooms, and from other “not conscious behaviours”, like opening the windows and consequently increasing the ventilation losses.

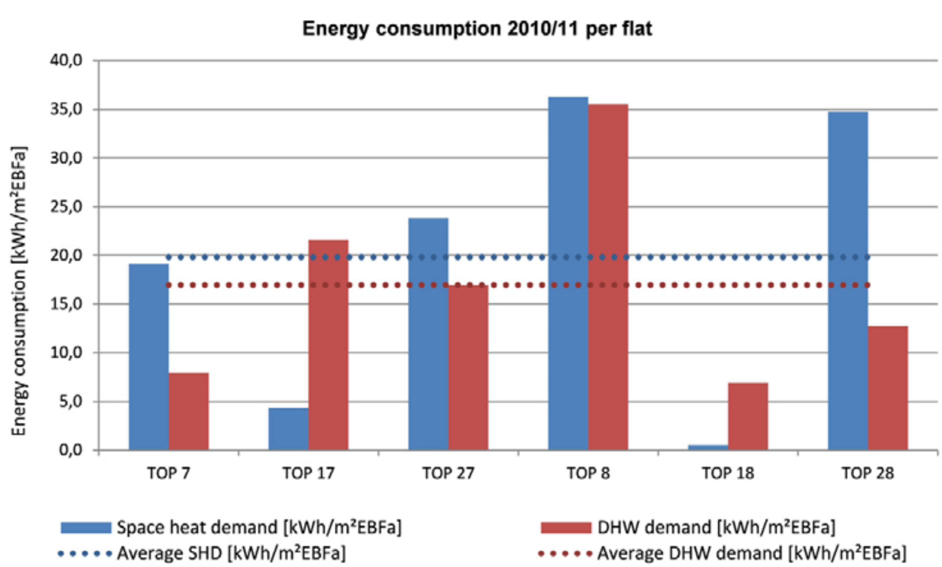

Fig. 1: Energy consumption for heating of 6 flats of House Gartenpark (region Vorarlberg)

In three of six regions also the ventilation and heat recovery systems were monitored. The data was evaluated in terms of temperature and air speed and its effect on comfort conditions. The effectiveness of air exchange was determined by analysing CO2 concentration levels. Data analysis showed in most of the cases an efficient air exchange, because high CO2 concentrations were avoided; relative humidity and volume flows were mostly in the range of comfort. In some rare cases in bedrooms the concentration increased to 1.600 ppm.

Indoor comfort was monitored in terms of temperature of at least two zones, plus surface temperature and relative humidity of indoor air. To get information about the comfort in the passive houses the data were evaluated with different comfort models [EN ISO 7730 ; psychrometric chart with Ashrae comfort zones and adaptive model of comfort EN 15251: 2008]. Generally it can be said, that the temperatures as well as the humidity were in the acceptable „zone", with no meaningful surprises. The buildings could face even quite extreme weather conditions like very hot summer in 2010 and very cold winter periods in 2012. Most of the time the „building climate" was in the comfort zone (see fig. 2).

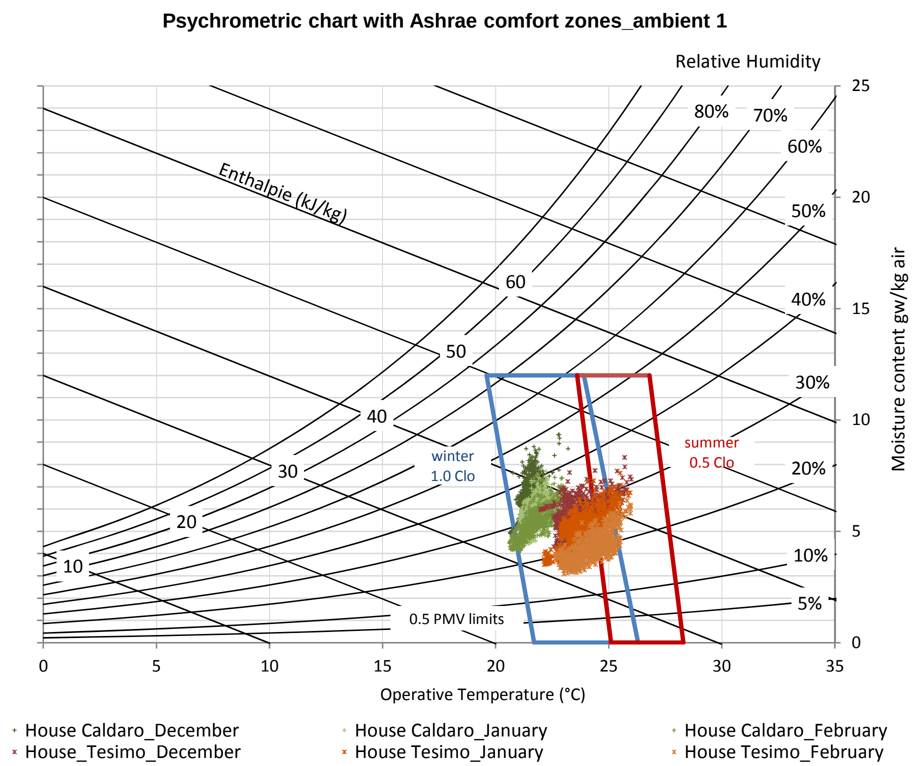

Figure 2: Evaluation of thermal comfort in wintertime for two different one-family houses from December 2011 to February 2012

Conclusions

Even if the negative votes in the questionnaire about user satisfaction were the minority, designers as well as SMEs are demanded to improve communication strategies of the passive house concept and to provide better information to passive house users.
In almost all cases of negative votes, the surveyed inhabitants were tenants and not owners. From the experience of the evaluators, this could be caused by the fact that

building owners are more involved in the project and construction phases. Every investment in the building is an owner decision. That's one reason why building owners are more informed on the building concept, on used technologies and building system. As a consequence, owners might be more aware of the effects the living in a passive house implicates, compared to tenants which are much less prepared to live in a passive house. Adequate informed users about functioning of passive houses and their performance will have positive effects on the users behavior and thus on the energy consumption and comfort. The challenge in the future is to address other types of inhabitants/users, by providing suitable information on passive houses and by improving them in a way that every inhabitant can be satisfied with the dwelling.
Secondly some negative votes lead to the conclusion, that building comfort regarding air humidity in winter and air temperature in summer remain still issues to improve.

On the external climate data it should be noted, that weather conditions can be very „local " within the Alpine Space. In terms of temperature, data can differ a lot from one location to another, because of topographical and geographical reasons. Therefore it is difficult to obtain consistent climate data for a larger area within a mountainous region. Standard weather datasets used by energy calculation programs are bases on statistical values or generated by the meteorological databases like meteonorm and do not take microclimatic influences into account. The measurements showed that deviations of calculated heating degree days and standard heating degree days in the range of 4 to 41% occurred. Especially when dynamical software with hourly data sets are used, reliable data sets becomes a prerequisite for obtaining corresponding simulation results.

Building regulation codes in Alpine Space Regions use 20°C as reference indoor temperature, which seems, according to the monitoring of indoor climate, too cold for the habits of most of the inhabitants. It could be easy, but not energy and cost effective thinking about an adaptation of this standard temperature in the future moving it to 22°C, which is much closer to reality. These measures would help to reduce troubles, as many people compare the calculated demands one-by-one with their real consumptions and are disappointed when getting higher figures than calculated. The second more challenging possibility, acting in favor of energy reduction, is to try to change the inhabitant's behavior. As the comfort requirements have increased very substantially during last decades, a counter trend is difficult to implement. However the trend of having low clothing level in winter in high heated rooms (23 - 24°) should be limited through information campaigns, which inform about the effect of higher indoor temperatures and related higher energy consumption.
Another remark has to be made on the influence of surface temperatures on indoor air temperature. The assumption that in case of higher surface temperatures, as it is the case in passive houses, the air temperature might be lower, for obtaining the same level of thermal comfort, stands in contrast to measured indoor air temperatures.

The fact, that energy consumption is highly depending on user behavior, leads to the assumption that a good introduction to the inhabitants about energy concepts and functioning of the building is necessary. Particularly important seems the right use of ventilation systems, what can be achieved by training and operator-friendly equipment technology. The effects of the user behavior on energy consumption and on energy costs should be clear for users. Providing information, training and support, could be one of the most efficient and cheapest measures for reducing energy consumptions of buildings in the near future.

Usually energy certification systems base their evaluation on the thermal energy demand for heating. Thermal energy demand for domestic hot water is not taken into account, although it covers a significantly portion of the thermal energy in energy efficient residential buildings. Of course domestic hot water demand is depending on the number of inhabitants and individual DHW requirements. On the other hand, thermal energy for heating is calculated per square meter and leads not immediately to per capita consumption, which is more significant when regarding absolute consumptions and energy costs. Nevertheless primary energy consumption should become a common minimum requirements, like thermal energy demand. But also building equipment’s efficiency and renewable energy share requirements should be included. This should lead to an increased use of solar thermal, photovoltaic, bio-mass systems and as well boost the development of novel electric energy saving strategies. In the future the reduction of the electric energy consumption will be the most important task to take care about.

To solve the problem of high CO_2 levels, measured in some rare cases, the ventilation system could be controlled by CO_2 sensors. The low CO_2 levels and good air quality, measured in most of the passive houses, is due to a elevate ventilation rate. High ventilation rates can rise to higher energy consumption, but also lead to low humidity rates in winter. The determination of the right ventilation rate or a development of systems with a more flexible ventilation rate, seems to be one of the main tasks of the technical development of passive houses.

List of references

[Frei 2004] Frei B., Reichmuth F., Huber H., Vergleichende Auswertung schweizerischer Passivhäuser, Bundesamt für Energie, Bern, 2004; p 87.
[ISO 7730: 2005] Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.
[EN 15251: 2007] Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. 2007.
[ASHRAE Standard 62: 1989] Ventilation For Acceptable Indoor Air Quality