Analysing energy use in residential neighbourhoods: a comprehensive approach on complementary case-studies

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1. Introduction: framework, aim and approach

The most commonly used tool for the evaluation of the energy performance of dwellings, the governmental EPBD-calculation tool, assumes an 'average' user behaviour as well as 'average' comfort criteria. However, field studies have demonstrated the large dependency of both energy use and indoor comfort on the varying user profiles [1]. Furthermore, shifts in user behaviour have also been indicated depending on the buildings' characteristics [1,2]. Within this context, several case-studies are analysed through a comprehensive approach. The cases are selected to be illustrative of the heterogeneity within the Belgian housing sector. The aim is to gain further insight and knowledge about the variation in user behaviour (e.g. use of windows, ventilation and heating devices), comfort experience and resulting energy use, specifically during the heating season in Belgian single family houses. The challenge resides in pursuing this investigation through pragmatic though comprehensive in-situ data-gathering campaigns. Information on the buildings' thermal and energy performance as well as on the users' behaviour and experience are gathered through in-situ measurements as well as through a thorough survey of the different inhabitants. The findings are further implemented in an improved yet pragmatic calculation tool, aiming at better correlations between calculated and measured energy use. This paper presents results from three case-study neighbourhoods and illustrates the general approach of this research project. It demonstrates how measurements and surveys efficiently complement each other. Nevertheless, huge difficulties remain when analysing the collected data and extrapolating the findings to evaluate the resulting building performance in real life.

2. Case-study & direct findings

2.1. The dwellings

Three neighbourhoods of single-family houses are analysed. Each of the three neighbourhoods separately are composed of (nearly) identical houses. This allows to better differentiate the variations due to the users' behaviour from those due to the buildings' characteristics. The houses of the first two neighbourhoods ('cs1': 36 houses [3] & 'cs2': 16 houses) date from the '50ties and '60ties, are barely insulated, have no mechanical ventilation systems and are mainly heated through a single gas furnace in the living room. The third sample ('cs3': 27 houses) is a recent neighbourhood (~2006), representative of the current Belgian building standard. The houses have standard insulation levels, central exhaust ventilation systems and central heating. A clear performance gap is assumed between the old, barely renovated houses and the more recent, 'standard-built' houses. This theoretical gap is further investigated through measurements on the building level (air-tightness and heat-flux measurements, IR-thermography). Within each neighbourhood, the accumulation of small variations between the individual houses does create some spread within the estimated energy use according to the EPBD-method. However, it doesn't even remotely explain the seemingly random spread in measured energy use within one sample (see Fig. 2b).

2.2. <u>The inhabitants</u>

The differences between the neighbourhoods don't only reside in their different building characteristics, but also in their different population sets. Extensive surveys of the inhabitants (79 households, 229 people) took place to collect data on the users, their habits and their interaction with the building as well as on their motivations, understanding and appreciation of the building and the resulting performance (energy use and comfort). The surveys are submitted directly after the measurement periods, not to influence the inhabitants' behaviour during measurements yet to gather answers that would correspond as close as possible to the measured conditions. This way, measurements (temperature, relative humidity and CO_2-levels) and surveys can be compared and their complementarity can be exploited.

The first two neighbourhoods are rented social houses, built and owned by two social housing companies. The third neighbourhood was also built by a single construction firm, but many houses are inhabited by their respective, private owners. This third neighbourhood mainly houses young families, while the first two sets of households are more heterogeneous, with more elder (Fig. 1a) and unoccupied people. Those different *household configurations* strongly affect the daily occupation profiles of the houses. During weekdays, in the living room, much higher probability of *presence* occurs in cs1 and cs2 in comparison to the very low occupancy in cs3 (Fig. 1b). During the weekend however, the occupancy of the living rooms reach similar, high levels in all neighbourhoods. The daily *heating* profiles, in turn, appear strongly correlated with these presence profiles of the individual rooms. Both for the older and the recent dwellings, the surveys also showed the recurrent asynchrony, in time and space, between the opening of *windows* on the one hand and both the presence in and the heating of the rooms on the other hand. Windows in the strongly conditioned living rooms appear to be opened only very rarely, while bedroom windows are often opened during the day, especially in the morning, just before leaving the room. However, the use of the bathroom windows does diverge significantly between the old and recent neighbourhoods. The much lower opening frequency of bathroom windows in the new houses might be indirectly linked to the efficient exhaust ventilation system and the insulation level. In the bathroom of the older houses, high humidity levels are measured and condensation spots appear on the non-insulated walls. Their inhabitants also do complain about this and try to lower the humidity levels by opening the windows. This in turn, will influence both the heating demand and the comfort levels.

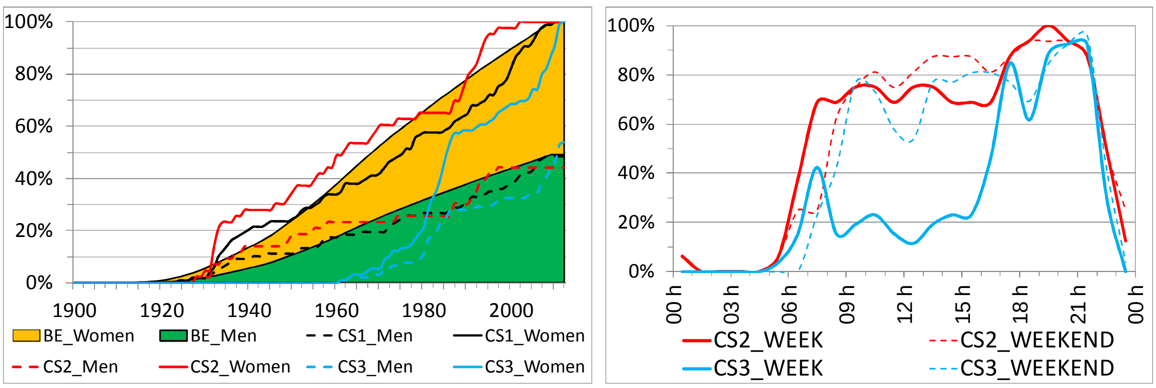

FIG. 1: (a) year of birth, cs1/cs2/cs3 vs. Belgian population; (b) living room : daily probability of presence

While some general trends and conclusions can be derived when comparing the data at the neighbourhood level, the variation within a single neighbourhood shouldn't be underestimated. This can be seen both from the surveys as well as from the indoor in-situ measurements. By way of example, Fig. 2a shows the huge variation in daily heating hours and set-point temperatures in the living rooms during weekdays in cs1 and cs3. Different heating profiles can be mainly attributed to varying user profiles (e.g. lower occupancy time in cs3 during weekdays). Illustratively, for cs3, dotted bars indicate the higher daily heating hours observed during the weekend. Additionally, the surveys also indicate the importance of the building characteristics affecting the perceived thermal comfort and thus the use of the heating system and its set-point. This was foremost noted in the old houses where inhabitants complained about different types of local discomfort such as draught, low floor temperature and radiation asymmetry, which can be partially compensated by higher heating set-point temperatures.

3. Improved heating demand calculation

Ultimately, one goal of increasing knowledge on user behaviour and energy use, is to improve the accuracy of calculated predictions of heating demands. Therefore, the findings from both measurements and surveys are further implemented in a fast and pragmatic energy calculation model. The multi-zone model is based on the quasi-steady state monthly model formulated in ISO 13790 [4], including some corrections and extensions to take better into account intermittent and personalised user profiles in adjacent zones. Better correlations between calculated and measured heating demand are obtained, yet considerable discrepancies remain even though measurement and survey data are used to refine and personalise the inputs (Fig. 2b). Many causes of uncertainty can be identified, ranging from measurement uncertainties and inaccuracy of surveys to errors and simplification of analyses and models etc. However it remains very difficult not only to tackle these issues but also to quantitatively ascribe fractions of these remaining discrepancies to their individual causes.

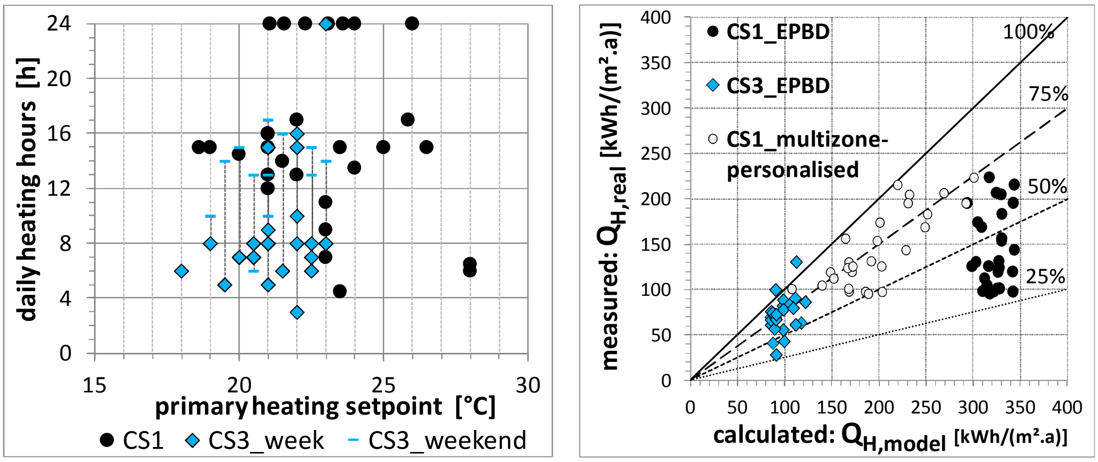

FIG. 2: (a) heating setpoint & daily heating hours (living rooms); (b) measured vs. calculated gross heating demand [kWh/(m².a)]

4. Conclusions

The presented results are merely illustrative of both the complexity as well as the value and extent of such case-study analyses. While the collected data and derivable knowledge from these case-studies are much more extensive than presented here, this paper already proves the valuable complementarity between data from surveys and measured data, on the building, the users and their interaction. A comprehensive approach is needed to thoroughly investigate real energy use in dwellings and possible savings. Making statistically solid, detailed statements would require many more and larger, yet still comprehensive and thus very extensive datasets. Yet the two aims of this research project are mainly (1) to identify and investigate the existing variations, discrepancies and their causes as well as (2) to investigate the main and minimally required tools and approaches (measurements, questions, calculation models) for analyses and estimations of real performances. To keep up with the quickly evolving building practice, the same comprehensive approach will be applied on additional neighbourhoods over the coming two years, this time looking at low-energy and passive houses.

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