Comparison of heat load calculated through standard and building simulation models

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Key Innovations

- Comparison of calculated, measured and simulated heat load for about 1000 cases
- Simulations based on realistic winter conditions

Research Implications

The measured weather data used in our study shows clear correlations between dry bulb temperature, wind speed and solar radiation; e.g. when outdoor temperatures sink below -3°C, the wind speed drops but the solar radiation tends to increase. Commercially available weather data often contain uncorrelated wind speeds, however, which can lead to an overestimation of the infiltration losses and the resulting heat demand at (very) low temperatures.

Introduction

For a long time, the research and policy focus has been on reducing energy demand and increasing energy efficiency. However, with increasing renewable energy production, also the profile of this energy demand and the potential for demand side management needs to be assessed. Moreover, due to energy distribution restrictions, (simultaneous) peak powers need to be reduced or shifted. Regarding dwellings, for which heating still determines the bulk of the energy use in most of the EU, this means that reducing, or at least better characterizing the heat load becomes more important.

The current method for the calculation of the design heat load, the EN12831-1, is a static method, however, and tends to overestimate the heat load. Our research aims at reducing this gap between measurements, dynamic simulation results and calculations of the heat load and give insights on the physical processes behind.

Methods

This paper focusses on the comparison of the calculated design heat load, using the Belgian standard NBN EN 12831-1 ANB:2020 and the maximum simulated heat load for circa 1000 combinations of different dwelling types and heating installation parameters, using EnergyPlus simulation software version 9.4.0.

To assess the impact and simultaneity of all heat losses (and potential heat gains) correctly, also the air flows and thermal balance calculations are coupled. The air flow rates were defined on underlying simulations using CONTAM software, as explained by Pecceu (2021), including the complex interactions between uncontrolled air infiltration and the ventilation system. These simulated air flows are then used as an input of the thermal simulations, conducted using EnergyPlus software with scripted input parameters, as explained by Verbeke (2017).

The classic TRY weather file of Uccle, Belgium, could not be used for these simulations as this is an average weather profile, while we need to focus on the coldest periods to assess the heating load. Commercially available extreme weather files showed deficiencies as well, since their wind profiles didn't correspond with measured wind data during cold spells. Therefore, new weather files are constructed based on a selection of the most severe cold waves of the recent 10 years (2010-2020) at three Belgian weather stations.

The almost 1000 simulation cases consist of 3 dwelling typologies (terraced, semi-detached, detached), combined with the 3 different climate conditions, different orientation, insulation and airtightness level, ventilation flow rate and system (including variants with heat recovery and demand-controlled ventilation), thermal mass, solar gain parameters, number of occupants (and heat gain profiles) and temperature control strategies (based on either air or operative temperatures).

Finally, also 45 real in-situ cases that have been monitored continuously over multiple years are added to the study database.

Results

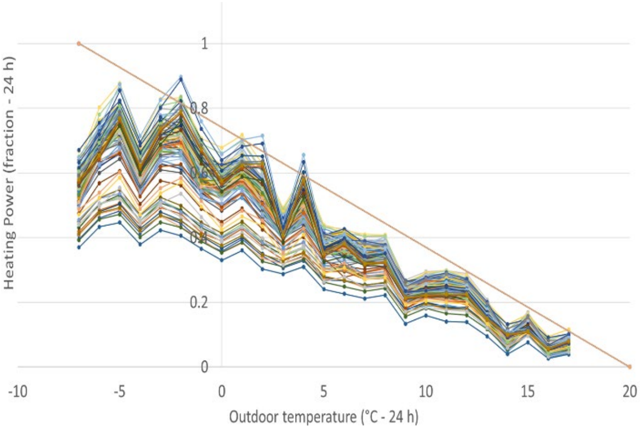

Figure 1: Comparison of calculated and simulated heat load (daily averaged kW/kW) for 99 cases

Figure 1 compares the heat load calculated using the EN12831-1 ANB:2020 (without reheat power) with the simulated heat loads at different outdoor temperatures. The fraction of calculated values versus simulated results is given for a selection of 99 cases (with continuous heating schedules). The simulations are run for a whole winter on a 5-minute time step, but the necessary heating power is in post-processing firstly daily averaged, and afterwards the maximum of those daily averaged powers is selected for each daily averaged outdoor temperature.

The averaging of the simulation results is necessary as the standard also works with daily averaged values. E.g. the design temperature of -7°C for Uccle is defined as the daily averaged outdoor temperature that is only subceeded 20 days during the last 20 years. Finally, the standard only demands a calculation at this -7°C, but if it would be calculated also for other average outdoor temperatures, the straight red line on Figure 1 can be formed.

If we now compare that (theoretically calculated) straight line with the simulation results, the heat load profiles show a different form; the absolute maximum values of the simulated heating powers are not reached at the minimal daily temperature of -7°C, but rather at -5°C or -3°C depending on the case. Conduction losses reach their peak at the coldest outdoor temperature, but due to the aforementioned climatic correlations, solar gains seem to rise with dropping temperatures under 0°C and also infiltration losses tend to reach their maximum at higher temperatures as the wind speed is the highest around 10°C, and the wind drops below -3°C. These effects create rather a heat power plateau than a straight heating curve.

Also the measured heating powers show this plateau; Figure 2 compares the power fraction (daily averaged heating power divided by the maximum power of the whole measurement period) of three in-situ measured cases in relation to the daily averaged temperature.

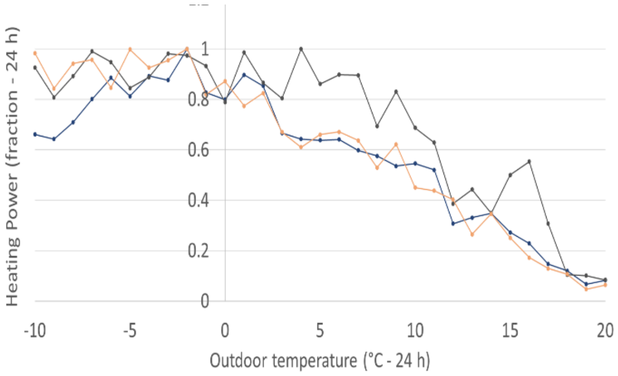

Figure 2: The measured heating power fraction (daily averaged power divided by the all-time maximum) i.r.t. the corresponding daily average outdoor temperature

Some of the measurements reach their maximum heat power already at +4°C outside while others rather at -3°C. The plateau is thus even more outspoken for the measured power profiles compared with the simulation results, which can be caused by control interventions (eg. demand-controlled ventilation) or other occupant behaviour that limits heat losses (eg window and door closing) during cold spells.

Conclusions

Both measurements and simulations show an overdimensioning factor that ranges from rather small and acceptable (10 %, a minimum safety margin that could be justified for sizing purposes) to very significant (> 100 %), which is probably not acceptable from economic and efficiency related perspective.

A detailed parameter analysis will be performed on the newly created dataset with simulation results so that the physical phenomena behind this oversizing can be found and the standard could be improved.

What we already can conclude from the simulation results is that between -3°C and 15°C the required heating power follows the trend of the linear heating curve that can be theoretically calculated. However, below -3°C, while approaching the design temperature, the simulated retrieved power appears to flatten out; thereby increasing the discrepancy with the calculations according to the procedures in the standard.

Several explanations may be at the origin of this effect. Firstly, during the period of 2010-2020 no days are observed in Belgium with at the same time the lowest temperatures, maximum wind speed and minimum solar gains, while the standard implicitly assumes simultaneous occurrence of these parameters.

Looking at our measurement data from Figure 2, this ‘plateau effect’ is even more visible, probably amplified by occupant behaviour and automatic control interventions. Further research will be necessary to further pinpoint these phenomena.

Acknowledgments

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