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On the proper integration of wood stoves in passive houses under cold climates

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ABSTRACT

The space-heating (SH) of residential buildings using a wood stove is an attractive solution. The way to properly integrate stoves in passive houses (PH) is still in question: current nominal powers are generally oversized compared to the PH needs (i.e. overheating risk) and it is not well understood how one stove can contribute to the SH of the entire building during a heating season. This question has already been addressed for the temperate climate of Belgium in a previous paper. The present work investigates cold climates also using a larger range of stove parameters. This is done using detailed dynamic simulations (TRNSYS) on a typical Norwegian single-family house typology. Using a large sensitivity analysis, recommendations to prevent overheating are given with a distinction between pellet and log stoves. Results also show that the overheating risk is somehow comparable between cold climates. On the contrary, the ability of one stove to ensure alone the thermal comfort strongly depends on the local climate. For the milder climates, the stove can cover a significant part of the SH while, for colder climates, the stove should only be considered as a part of the total SH emission system.

1. Introduction

On the one hand, wood is a very important renewable energy source. Today, wood and its waste accounts for almost 50% of the EU-27 renewable energy production [1]. In some European countries with cold climate, the share of bioenergy is much higher than 50% and wood logs account for a considerable part of this [2,3]. In the future, renewables should cover 20% of the final energy consumption in Europe by 2020 and a large part by 2050 [4]. For example, the goal in Norway is to double the use of bioenergy from 2008 to 2020 [5], and wood logs used in stoves is expected to account for 50% of this increase. Hence, there is no doubt about the expected importance of bioenergy among the renewable energy sources, nor the importance of wood logs for renewable energy production. On the other hand, energy consumption of buildings in developed countries comprises 20–40% of total energy use [6] so that its reduction has become a major concern, as illustrated by the European Performance of Buildings Directive [7]. A common strategy is to reduce the space-heating (SH) needs by a better insulation of the building envelope. Among building concepts that have emerged, the passive house (PH) is based on a super-insulated building envelope [8]. Furthermore, the concept of *Zero Energy Building* (ZEB) has also been increasingly popular. In many research developments, the PH standard is often considered as a minimal performance requirement for ZEB envelopes.

The SH of passive houses using wood stoves is thus a strategic area. Furthermore, this solution can be cost effective [9] and state-of-the-art stove technologies present acceptable energy efficiency (e.g. 85%). This heating strategy has also positive aesthetic aspects as well as can provide thermal coziness. New airtight stoves equipped with an independent supply for the combustion air and flue gas removal are now developed so that it enables to maintain an acceptable indoor air quality (IAQ) in airtight building envelopes [10]. In fact, the integration of wood stoves in passive houses presents some challenges. These challenges have already been investigated for the Belgian context in previous communications from the authors [11,12]. Belgium is characterized by a temperate climate and a PH definition comparable to Germany. Besides, analysis using a similar methodology and conclusions can be found for the German context [10,8].

Firstly, there is a real overheating risk in the room where the stove is placed. Current wood stoves have a minimal nominal power, $P_{c,n}$,[1] of about 8 kW while the nominal power of the losses

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[1] Different definitions of the *nominal* power exist. By convention, it is here taken as the maximal power of the stove.

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Nomenclature

A_{fl}	heated area [m^2]
C_d	discharge coefficient of a large opening
CTMY	coldest hours of the heating season based on a TMY
HDD_{18}	heating degree-days based on a Θ of 18 °C
I_{th}	stove thermal mass [kJ/K]
$I_{tot,rad}$	mean total radiation on a horizontal surface [W/m^2]
P_c	combustion power of the stove [W]
$P_{c,min}$	minimal combustion power of the stove [W]
$P_{c,n}$	nominal combustion power of the stove [W]
P_d	net power delivered to the stove envelope [W]
$P_{d,n}$	nominal net power delivered to the stove envelope [W]
P_e	power emitted by the stove into the room [W]
$P_{SH,n}$	net space-heating power in SDC [W/m^2]
Q_d	batch load (i.e. energy to the stove envelope per batch) [kWh/batch]
Q_{max}	maximal allowed value for the annual net SH needs [kWh/m^2 year]
SDC	Standard Design Conditions with $\Theta_{SH,dim}$ and no gains
τ	combustion cycle length [min]
τ_{min}	minimal imposed cycle length [min]
t_c	power fraction emitted by the stove in form of convection
$T_{op,5\%}$	5% percentile T_{op} during the heating season [°C]
$T_{op,95\%}$	95% percentile T_{op} during the heating season [°C]
$T_{op,max}$	maximal T_{op} during the heating season [°C]
$T_{op,min}$	minimal T_{op} during the heating season [°C]
T_{op}	operative temperature [°C]
T_s	sensible air temperature [°C]
T_{set}	set-point air temperature for the space-heating [°C]
TMY	Typical Meteorological Year
Θ	outdoor air temperature [°C]
Θ_{ym}	annual mean outdoor temperature [°C]
$\Theta_{SH,dim}$	design outdoor temperature [°C]
WTMY	warmest hours of the heating season based on a TMY

in passive houses during design conditions is much lower (roughly 3 kW for Oslo): current stoves are thus much oversized compared to the instantaneous envelope needs. Furthermore, wood stoves are characterized with rather long combustion cycles, typically more than 45 min for a log stove [13], while a pellet stove typically has a 30 min start-up period [14]. These long cycles should be promoted in order to get the best energy efficiency and to reduce the emission of pollutants that are dominant during the start and stop phases. In addition, the power modulation of the state-of-the-art stoves is limited: the minimal combustion power ($P_{c,min}$) with a pellet stove is typically 30% of $P_{c,n}$ and 50% for log stoves. As a result, there is thus a strong overheating risk to operate an oversized wood stove on a long production cycle in a passive house. This phenomenon was observed experimentally in field measurements [15,16] within Danish low-energy houses. Let us mention that the expression *on–off* stove refers to a stove that can only operate at nominal load $P_{c,n}$. It therefore can be applied consistently to pellet stoves. On the contrary, the combustion power of wood logs in a batch is by nature unsteady so that the expression *on–off* stove may be misleading. In this case, we rather refer to a log stove *without power modulation*: the time-averaged combustion power of one batch is then equal to $P_{c,n}$.

Investigations for the Belgian context [12] were performed for wood stoves without large heat storage. It was shown that the integration of a 8 kW pellet stove does not generate severe overheating if the stove has a 30% power modulation. If the pellet stove cannot modulate (i.e. an on–off stove), the integration is still possible but some architectonic measures should be taken to limit the overheating (i.e. high building thermal mass and opening of the doors inside the building). As regards log stoves, their combustion cycles are usually longer so that a 50% power modulation is a necessary but not sufficient condition to prevent overheating. It should be complemented with some additional architectonic measures to prevent the overheating (as for the on–off pellet stove). From these investigations, general recommendations were that stove manufacturers should develop solutions with a $P_{c,n} < 8$ kW, a large power modulation ($P_{c,min} < 0.5P_{c,n}$) and/or a large thermal mass ($I_{th} \gg 150$ kJ/K).

Secondly, the wood stove could mainly cover the SH needs if the heat delivered by the stove can diffuse efficiently inside the entire building envelope. Somehow, it is in line with the original philosophy of the passive house [8] where the SH distribution system should be simplified as much as possible, a wood stove being a potential basis for this simplification. Investigations in the Belgian context have shown that one stove cannot alone ensure the thermal comfort in standard design conditions (SDC), i.e. during a cold wave. However, the stove may cover a significant part of the heating load during a Typical Meteorological Year (TMY) if the building occupants can accept a lower operative temperature (T_{op}) in bedrooms and often leave the internal doors of the building open.

In fact, the implementation of a so-called *hydro-stove* equipped with a hot-water heat exchanger is already a solution to the heat distribution and to prevent the overheating problem: a large part of the power released by the combustion is indeed recovered and can be fed into a hydronic system equipped with radiators (see e.g. [17,18]). Nevertheless, the present work aims at investigating the limits of the integration of stoves using the standard approach where all the heat is directly released into the room. Furthermore, only stoves corresponding to state-of-the-art products already available on the market are investigated. It is still assumed that the stove envelope has no large dedicated heat storage (i.e. $I_{th} \leq 150$ kJ/K).

The first objective of the present article is to extend results to cold climates. Basically developed for temperate climates as Germany, the PH concept has then been exported to Nordic countries as Denmark, Norway, Sweden as well as to cold climates like Canada and Estonia. Sometimes, the PH standard has been adapted to local conditions, such as the climate (e.g. Norway [19] and Sweden [20]). The integration of wood stoves should therefore be assessed in the specific context of cold climates. Preliminary results for Norway were communicated in a conference [21]. The second objective of the article is to investigate a larger range of stove properties, such as the $P_{c,n}$ and the power modulation. A large parametric study is done on both the stove and building properties so that conclusions are general and representative for many countries. Even though a total of ~4000 simulations has been performed, the number of investigated test cases had nonetheless to be restricted. This research effort aims at developing a conceptual and theoretical background for the stove integration inside super-insulated building envelopes. This is done using detailed dynamic simulations in order to investigate the whole-year thermal comfort at an acceptable computational cost. This framework can subsequently serve as a basis for field measurements or more detailed simulations (e.g. Computational Fluid Dynamics, CFD).

2. Methodology

The thermal comfort is investigated using detailed dynamic simulations (here using TNRSYS [22]) on a detached single-family house. For the sake of consistency, the simulation methodology is kept equivalent to the investigations for the Belgian context.