WoodCFD

Clean and efficient wood stoves through improved batch combustion models and CFD modelling approaches

SINTEF NTNU

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Background

This handbook is prepared by SINTEF Energy Research and the Norwegian University of Science and Technology with the purpose to provide both partners in the WoodCFD project, relevant research projects and centres, policy makers and others with a simple and easy to read guide on clean and efficient wood stoves.

The information in this handbook is based on studies performed throughout a 4 year period in the competence building project entitled "WoodCFD – Clean and efficient wood stoves through improved batch combustion models and CFD modelling approaches".

WoodCFD is the successor of the competence building project StableWood (New solutions and technologies for heating of buildings with low heating demand: Stable heat release and distribution from batch combustion of wood, 2011-2014, **www.sintef.no/projectweb/stablewood**). It has run for four years (2015-2018) with a total budget of 18 million NOK, whereof 80% financed by the Research Council of Norway through the ENERGIX program and 20% financed by the industrial partners Jøtulgruppen, Dovre AS, Norsk Kleber AS and Morsø A/S.

The **overall objective** of WoodCFD has been development of clean and efficient wood stoves through improved batch combustion models and CFD modelling approaches through:

- Model development: improved transient wood log and gas release models, transient heat transfer and storage models, reduced kinetics models (NOx and soot), and transient models and approaches for heat distribution in the building; and verification of these
- Simulations: transient and stationary CFD simulations of wood stoves, and room and building integration simulations; and verification of these

The **sub-objectives** were:

- Develop improved sub models to be included in the CFD simulations
- Develop a numerical tool that is suitable to study concept improvements for wood stoves and to recommend new improved concepts with respect to high energy efficiency and low emissions based on simulation results
- Develop improved transient heat distribution models - giving reliable prediction of the effect of various heat transfer concepts in buildings and providing design guidelines for optimum wood stoves for tomorrows (energy efficient) buildings
- Education of highly skilled candidates within this area and training of industry partners
- Monitoring of activities and state-of-the-art within this area and dissemination of knowledge to the industry partners, and other interested parties when applicable

The anticipated results of the project were models and modelling approaches as a toolbox for wood stove development and building integration. Improved models and modelling approaches, in combination with targeted experiments, are keys in the development of future's downscaled clean burning and energy efficient wood stoves.

WoodCFD

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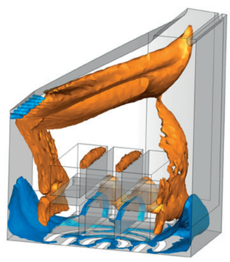


Introduction

Wood stove history in Norway

When the first iron stoves came to Norway in the 1500's, these iron stoves connected to chimneys led to a new era within fireplaces and cooking, and the building tradition was significantly influenced. The production of iron stoves in Norway started in the 1600's, around the mid-1600's the demand for stoves was considerable, and during the 1700's the cast iron stove became the main heating source. The production of stoves is a very important chapter in Norwegian ironwork industry, and later also for the iron foundries. Iron stove reliefs are and have been an important contribution to Norwegian sculpture and applied art. A short description of some major types of stoves from the very first iron stoves produced in Norway to today's stoves is given below.

The first stoves, **box stoves**, were just a simple iron box, with a separate smoke pipe/tube. The stove was either fired through a stove door, similar to today's stoves, or it was fired through the fireplace in the next room. The latter was commonly used until 1900.

Multiple hearth stoves came in the early 1700's for improved utilization of the wood and were very popular until around 1950. The stoves had a combustion chamber with one to four upper floors/ chambers with gradually reduced sizes. A few models are still produced today.

Cylinder stoves for firing wood, coke or coal were introduced after 1850 and were produced for nearly 90 years. These stoves had the combustion chamber in the lower part with a door for lighting the fire, while there was a door for filling of solid fuel higher up.

Wood burning **kitchen stoves** with oven were introduced around 1850. The versions without oven were gradually developed with several common features with the multiple hearth stoves of the time.

In the 1930's the more simple wood stoves that could be used for combined heating and cooking gained popularity. They looked quite similar to the really old stoves. Some models were quite long in order to have more than one cooking plate, other models had multiple hearths.

In the late 1980's development of new concepts were addressed in order to make the wood stoves more environmentally friendly, user-friendly and cost-efficient. As a result, new stricter regulations on emissions from wood stoves were introduced 1 July 1998. In order to fulfil these regulations, most stoves are based on staged air combustion where the wood logs are gasified in the primary combustion zone and additional air is injected in a secondary combustion zone for complete combustion.

Residential buildings of the future

The introduction of low energy and passive houses is accelerating. This sets new requirements to future heating systems.

The term low energy building, or low energy house, is any type of house that from design, technologies and building products uses less energy, from any source, than a traditional or average contemporary house. In Europe it generally refers to a house that typically use 30 to 20 kWh/m² per year for space heating, but it also depends on the location. Below this the term ultra-low energy building or passive house is often used.

The term passive house refers to an ultra-low energy building that requires little energy for space heating or cooling. Its efficiency is based on the application of a super-insulated building envelope. For example, the passive house standard for central Europe requires that the building fulfils the following requirements:

- The building must be designed to have an annual (space) heating demand as calculated with the Passivhaus Planning Package of not more than 15 kWh/m² per year in heating and 15 kWh/m² per year cooling energy OR to be designed with a peak heat load of 10 W/m². An annual heating demand of 15 kWh/m² corresponds to 1500, 3000 and 4500 kWh for 100, 200 and 300 m², respectively. A peak heat load of 10 W/m² corresponds to 1, 2 and 3 kW for 100, 200 and 300 m², respectively.
- Total primary energy consumption (primary energy for heating, hot water and electricity) must not be more than 120 kWh/m² per year. This corresponds to 12000, 24000 and 36000 kWh for 100, 200 and 300 m², respectively.
- The building must not leak more air than 0.6 times the house volume per hour ($n50 \leq 0.6$ / hour) at 50 Pa (N/m²) as tested by a blower door.

Old buildings require wood stoves with high heat release, while modern buildings require wood stoves with low heat release (Kjetil Strand)

Norway has defined its own passive house standard (NS3700) with specific performance requirements for the building envelope and ventilation system. Even though the Norwegian and German passive house definitions are different, it leads to similar technical solutions.

Challenges using wood stoves

In low energy and passive houses, user thermal comfort is becoming increasingly important. Due to the low heat demands of these houses, it is increasingly important to achieve a heat release profile without an excessive peak effect, in combustion units down to 2 kW nominal effect. The wood stoves should also operate on long combustion cycles (> 45 min) to get good efficiency and limited emission of pollutants. Integration of wood stoves in passive houses also faces challenges connected to indoor air quality. The airtight building envelopes equipped with balanced mechanical ventilation require independent air circuits for combustion air and flue gas removal.

Emissions and efficiencies

Standardization progress & new requirements

Future standards and regulations setting emission measurement methods are aiming at significantly stricter emission limits for point source heating applications like wood stoves. The most important among these are the Ecodesign Directive. Ecodesign requirements have been set for energy efficiency and for emissions of particulate matter (PM), organic gaseous compounds (OGC), CO and nitrogen oxides (NOx). The requirements will be operative from 1 January 2022. The new requirements for seasonal space heating energy efficiency for typical solid fuel wood stoves shall be no less than 65 %. The seasonal space heating energy efficiency shall be calculated as the seasonal space heating energy efficiency in active mode (based on the net calorific value of the fuel at nominal heat output) corrected by contributions accounting for heat output control, auxiliary electricity consumption and permanent pilot flame energy consumption.

When it comes to emissions of PM from closed fronted solid fuel local space heaters, these shall not exceed 40 mg/Nm^3 at 13% O_2 when measured with a heated filter (first method/current European method) at nominal load as well as at part load if appropriate. When measured by a second method (Norwegian method), i.e. over the full burn cycle using natural draft and a full flow dilution tunnel with particle sampling filter at ambient temperature, the requirements are 5 g/kg (dry matter). For OGC, CO and NOx the requirements are 120 mgC/Nm^3, 1500 mg/Nm^3 and 200 mg/Nm^3 expressed as NO_2, all values taken at 13% O_2. Additional requirements for product information/technical documentation have also been formulated.

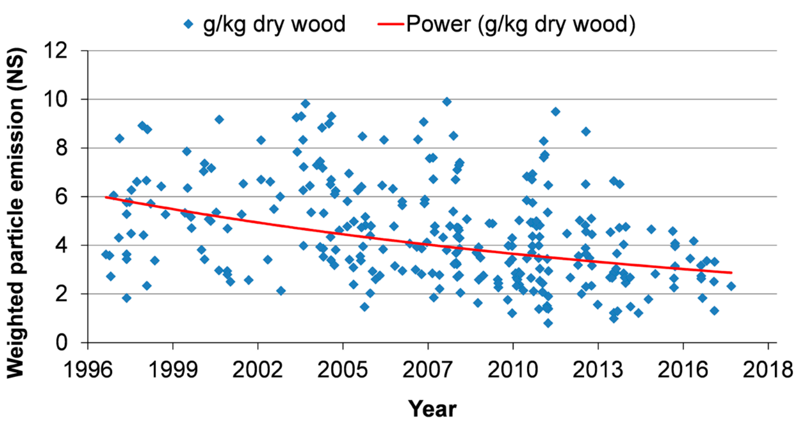
The increased stringency of the Ecodesign Directive as well as other European standards or standardisation initiatives will at some point have to be reflected in the Norwegian standard. It is therefore expected that the Norwegian standard, NS3059, which have had the same emission limits since 1998, will have to tighten up its current weighted emission limit of 10 g/kg, possibly down to 2-5 g/kg. The maximum allowed emission of 20 g/kg will also probably have to be reduced with at least 50% or more, down to 5-10 g/kg. Emission limits for OGC and CO will also probably be included as provided by the new Ecodesign requirements.

Stoves approved for the Norwegian market, 1998-2017

The figure below, illustrating the evolution of particle emissions from wood stoves approved for the Norwegian market, shows what has been achieved over the years, thanks to the close research/industry collaboration, in terms of wood stove emissions due to incomplete combustion in general. During the last 20 years, continuous improvements have resulted in wood stoves with much reduced particle emission levels, approaching 80-90% particle emission reduction compared to the current 10 g/kg dry fuel emission limit in NS3059. Due to increased stringency for both emissions and heat demand, new wood stoves must be developed that are able to operate at a significantly lower heating effect, with a much more constant heat release. Emissions must be reduced and stoves must be able to operate with a separate air intake and flue gas evacuation system with no risks of indoor smoke leakage.

Efficiency

The most important factors which affect the efficiency of a stove are the excess air ratio, the flue gas temperature and chemical losses due to incomplete combustion. Thermal efficiency will increase with decreasing chimney inlet temperature and excess air ratio. This means that at part load operation, i.e. below nominal effect and assuming an optimum amount of air, the efficiency will increase.There seems to be a common misunderstanding regarding part load operation where it is believed that such conditions always leads to lower efficiencies. One example of this can be found in the Nordic Ecodesign 2014 guidelines where it stated that “low air intake can lead to poor combustion, high emissions and poor efficiency”. That part load operation leads to higher particle emissions as compared to nominal operation has been known for decades. However, the negative effect on the efficiency, due to the chemical losses from poor combustion, is significantly smaller than the positive effect of lower part load flue gas temperatures for approved stoves; hence, an efficiency increase will occur for most wood stove configurations currently available on the market.



Evolution of particle emissions from wood stoves approved for the Norwegian market

[Øyvind Skreiberg, Morten Seljeskog (2018). Performance history and further improvement potential for wood stoves. Chemical Engineering Transactions 65:199-204.]

High efficiency stoves give colder flue gas

(Kjetil Strand)

The aim and content of the WoodCFD project

Why bioenergy

Several national strategies points out the importance of bioenergy in the future energy supply for Norway. The most important one has been the ”Strategy for increased expansion of bioenergy (2008)” which states that Norway shall double the bioenergy production from 14 TWh (2008) to 28 TWh in 2020. Today we know that this doubling will not be possible to achieve, and that more efforts and time are needed to fulfil this target, including in the wood stove area.

Why wood stoves

Wood log combustion has long traditions in Norway, constituting above 40% of the use of biomass for energy purposes. The national strategy mentioned, states that the major single contributor of new bioenergy production shall come from bioenergy use in small-scale heating appliances for space heating, meaning in practice the use of wood log combustion in wood stoves and fireplaces. Using wood logs is also important as a part of security of supply in Norway where we today rely to a very large extent on the electricity grid to be able to deliver the needed heating for our houses.

Why WoodCFD

In order to reach these ambitious targets, new solutions and technologies that enable a more widespread and extensive use of wood log combustion are clearly necessary. The heat released during combustion of one batch of wood varies significantly, and measures to flatten the heat release from wood stoves are required. New houses as well as retrofit/upgrading of old houses have increasingly focused on improved insulation due to new regulations like the Norwegian passive house standard (NS3700), the TEK17 regulation and nearly-zero energy buildings in 2020. And hence, the heat release effect needed is reduced. This calls for new solutions and technologies that provide a stable heat release and distribution from wood log combustion at a heat release effect down to as low as 1 kW. These issues were addressed in the StableWood project through focus on:

- Improved heat production concepts through improved combustion control (by increased understanding of the batch combustion process)
- New or improved heat storage concepts by optimum material location and choice, including phase transition and change options, and through room integration
- New or improved heat distribution concepts through optimum passive and active methods and through building integration

An optimum combination of these will give increased heat comfort and a more stable heat release at a lower heating effect, enabling the implementation in low energy and passive houses as well as extending the wood log heating season. This would be an important contribution to the national target; doubling of the bioenergy use in 2020.

However, to arrive at those goals, the WoodCFD project followed up, focussing on model development and using computational tools to study concept improvements for wood stoves and to recommend new improved concepts with respect to high energy efficiency, low emissions and optimum building integration based on simulation results.

Wood log combustion
– So easy, but yet so challenging

Project achievements

Sub-project 1: Fundamental modelling & model development

Heat from wood combustion in domestic wood stoves is a main contributor to the bioenergy in Norway. However, wood combustion in such small-scale combustion appliances can cause significant emissions, e.g. fine particulate matter. Therefore, optimization of old technologies and the development of new designs are required in order to manufacture wood stoves with reduced emission levels, higher efficiency and greater ease of use. To perform the required improvements, the combustion process inside the wood stove must be well understood. Common CFD platforms, e.g. Ansys Fluent, have well-established models for the gas phase, but lack detailed solid phase models. At SINTEF/NTNU a solid phase model has in WoodCFD been developed as a standalone code. This code should now be dynamically connected with the gas phase model. Since processes in the gas and solid phases influence each another, a dynamic coupling of the two models is required to obtain an accurate simulation tool. Fundamental studies on wood combustion can still be done by means of the standalone code. The wood combustion process includes drying, devolatilization and char conversion of the solid fuel (see figure below). Since all three stages are interrelated, the detailed modeling of all conversion stages with respect to a distinct location inside the wood log had to be done to derive an accurate solid phase combustion model.

A review of numerical models for thermochemical degradation of thermally thick woody biomass has been written [1]. This has been used as a starting point for detailed studies on drying [2], decomposition and combustion [3], numerical issues related to wood log conversion [4] and the effect of higher dimensional simulations [5]. This work has been carried out in WoodCFD, and in all these publications the WoodCFD PhD candidate, Inge Haberle, has been the first author. She successfully defended her PhD thesis in November this year.

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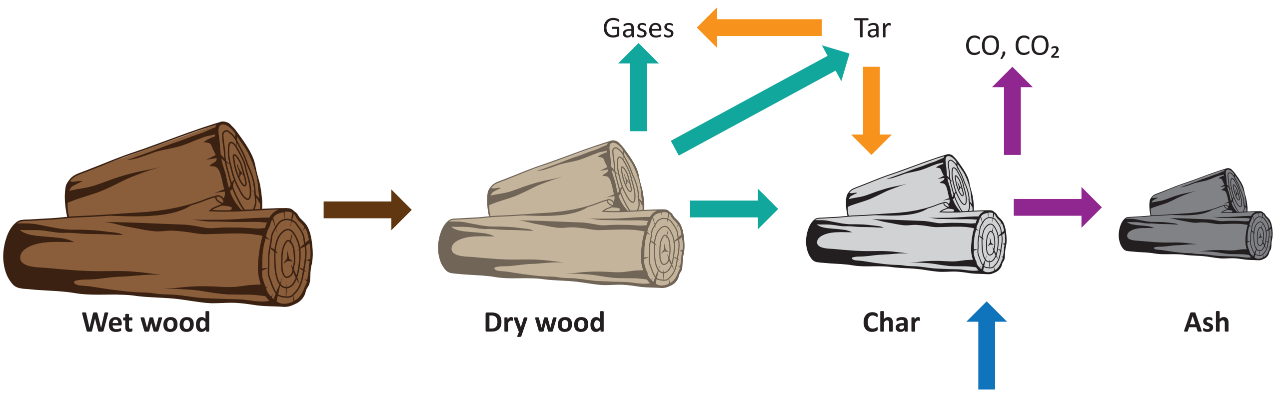

The wood log conversion process

[4] Inge Haberle, Nils Erland L. Haugen, Øyvind Skreiberg (2018). Simulating thermal wood particle conversion: Ash-layer modeling and parametric studies. Energy & Fuels 32:10668-10682.
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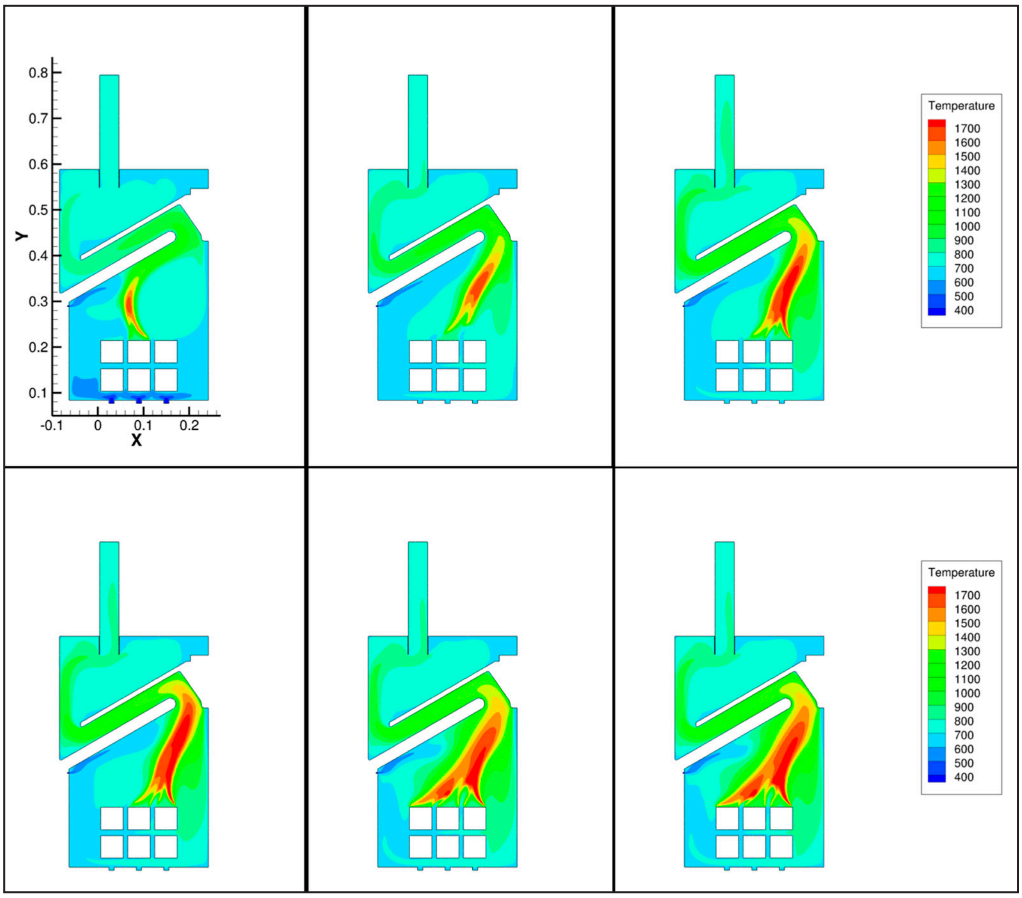
Sub-project 2: Wood stove CFD simulations and verification

Computational fluid dynamics (CFD) simulations have the potential to incorporate all necessary physical and chemical processes going on in a wood stove during combustion of a batch of wood logs. In a CFD model the sub-models for the fuel can be combined with modelling of the gas phase combustion process involving the volatiles released from the fuel and their mixing with combustion air. In order to have reliable results, modelling of chemical kinetics and turbulence and their interaction, radiative heat transfer as well as defining appropriate boundary conditions are essential. The chemical kinetics needs to be detailed enough to realistically represent the real combustion process. Especially if the goal is also to reduce NOx emissions, quite comprehensive detailed chemical kinetics is needed.

In WoodCFD the initial work on stationary CFD modelling of wood stoves carried out in StableWood, was taken further into a more comprehensive modelling approach, both for stationary as well as transient conditions. Initially both stationary and transient base cases were developed, for a specific stove geometry and including all models needed to carry out CFD simulations. Using these base cases as a starting point, extensive CFD simulations can be carried out, investigating in detail the influence of fuel properties and operating conditions for a specific stove (geometry, materials) on the energetic and environmental stove performance.



Temperature (K) at different time during the wood combustion cycle [1]

The developed base cases were applied in selected studies, firstly in transient simulations [1] where a fuel gas release model provided the link between the wood log batch and the gas phase computational domain. The individual wood logs were ignited one after the other. The ignition air was closed after 6 minutes where after only windows flushing air and secondary air was supplied. The figure on the previous page shows transient simulations for the first 30 minutes of the wood combustion cycle.

While working with further developing the CFD simulation approach, a discovery was made that has never been modelled before, i.e. wood log combustion hysteresis [2]. In short, the flow conditions in a wood stove can significantly fluctuate and a small disturbance can change the velocity field rapidly and completely. Steady state simulations performed for the selected wood stove geometry showed that there exist two solutions for the case studied. It was possible to switch from solution one to solution two by patching a disturbance into the first solution and using this one as the initial field. The same phenomenon was demonstrated through transient simulations. When starting with a distinct flame close to the purge air outlet and practically no flame close to the woodpile, reducing the mass flow rate of fuel gas released from the woodpile gradually, at some point caused a rapid change in the velocity field. This allowed the purge air to flow down along the stove glass window and thereafter turning towards and reaching the woodpile in significant amounts. This resulted in ignition of the fuel gas close to the woodpile and no flame close to the purge air outlet. Increasing the mass flow rate gradually back to the initial conditions did not change the characteristics of the velocity field back to the initial velocity field. The fact that the state of the combustion depends on its history, means that this is a hysteresis. The rapid change in velocity and temperature field was also observed for the same stove in the laboratory.

Additionally, a work was carried out on transient CFD simulations of wood stoves with varying heat storage capacity [3]. Transient CFD simulations of a full wood log combustion cycle were performed to study the transient behaviour in cast iron and soapstone wood stoves. The effect of the wood stove material and its thermal inertia and conductivity on the combustion process and the transient heat release to the surroundings was studied. In addition, transient variation in gas compositions, and gas and wall temperatures as well as heat release to the surroundings during the combustion cycle, was also studied. The simulations clearly show the effect of stove type on the transient heat release, as well as on the inner wall temperatures and the amount of heat transferred into the walls.

Including the stove walls in the computational domain provides a coupled heat transfer interaction between a single wall and the gas phase and radiating surfaces. Hence, the transient heat transfer into the stove wall can be derived. This is bringing the earlier work [4] on options to flatten out the heat production profile in wood stoves one step further.

Even though important scientific progress was achieved in WoodCFD on this topic, further work is still needed to arrive at an optimum CFD simulation tool for wood stoves. Then the direct coupling of the thermal degradation of the wood log batch with the gas phase computational domain is needed.

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[1] Mette Bugge, Nils E. L. Haugen, Øyvind Skreiberg (2017). Transient CFD simulations of wood log combustion in a wood stove. 25th European Biomass Conference & Exhibition (EUBCE), 12-15 June 2017, Stockholm, Sweden.

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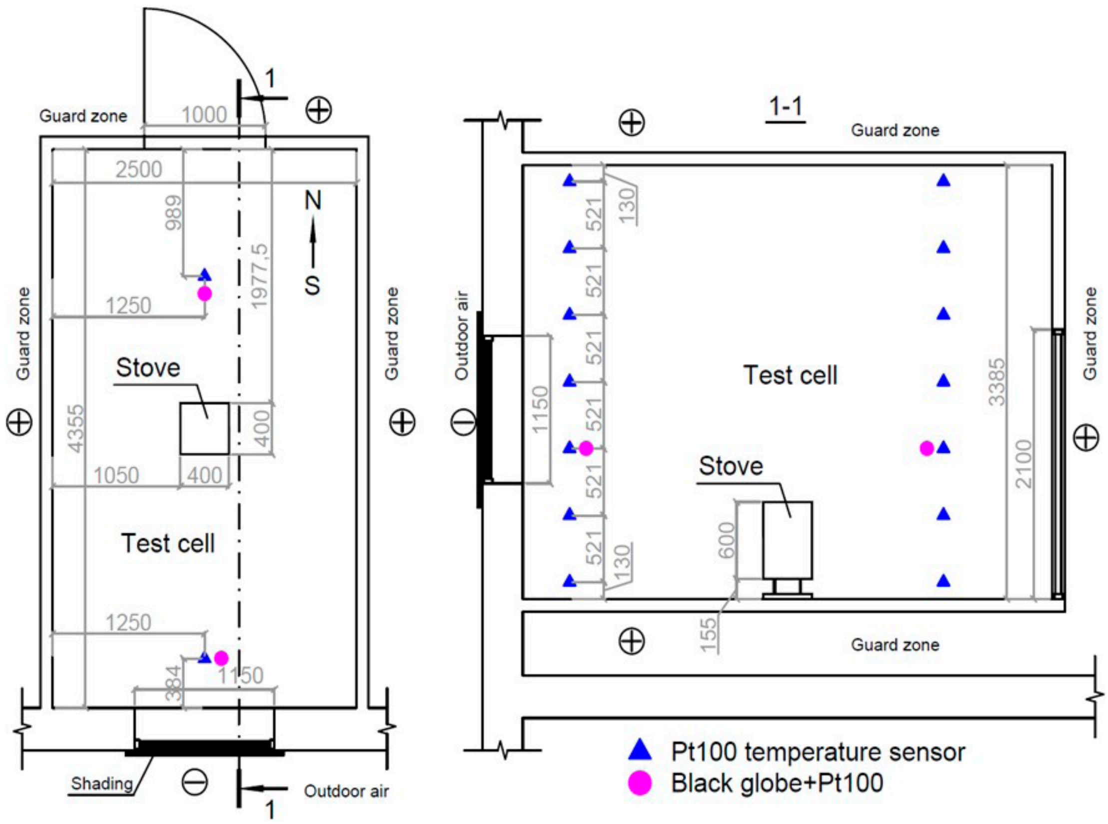
Sub-project 3: Heat distribution modelling in the building/room

For a long time, building science has developed theories and methods to evaluate the indoor thermal environment of buildings and the resulting thermal comfort for occupants. Nowadays, these methods are commonly used in the building industry and typically resort to building performance simulation (BPS). Nevertheless, the space-heating using a wood stove challenges these theories and evaluation methods. Wood stoves are point heat sources. They are relatively powerful compared to other heat emission systems (such as radiators). In addition, their heat emission to the room is transient and the operation of the stove is strongly related to users. Firstly, this transient and powerful heat source challenges the standard thermal comfort theories (such as ISO 7730). Secondly, the heat source tends to create less homogeneous temperatures in the room where the stove is placed (i.e. wall and air temperatures). This is against the common assumption in commercial BPS tools that typically assume isothermal walls and air in the room. To solve this problem, one may think about Computational Fluid Dynamics (CFD) but this method is computationally expensive. In fact, the indoor temperatures resulting from wood stove heating are strongly related to the building thermal mass. To be correct, the problem should both compute the slow thermal dynamics of walls and the fast dynamics of airflows. This makes the use of CFD prohibitive to investigate thermal comfort during the entire space-heating season, or limits the use of CFD to short periods of physical time (i.e. a couple of hours).

Nonetheless, it would be beneficial to be able to accurately predict the indoor thermal environment of buildings heated by wood stoves. Firstly, this would support measures to ensure thermal comfort and user satisfaction. Secondly, it would increase the knowledge about the building integration of wood



Sketch of a laboratory room in Trondheim heated using an electric stove that mimics the heat emission of real wood stoves: the measured air and wall temperatures are compared to simulations

stoves. For given building geometrical and thermal properties, it would make possible to specify the characteristics of the wood stove that guarantee thermal comfort and sufficiently long cycles necessary for clean combustion. For instance, a stove that is oversized may lead to overheating or make the user operate the stove most often at part load, with small but not optimal batch loads or even close the air vents to stop the combustion. Thirdly, the energy use with wood stoves would be better understood and documented. In current building standards, the heat emission efficiency related to wood stoves is most often simplified and rely on limited scientific grounds. Finally, this would enable to make virtual testing of new stove technologies such as using advanced heat storages or radiation shields in the stove envelope.

In the past decade, NTNU and SINTEF in Norway have been strongly involved in this research area by the two successive national research projects StableWood and WoodCFD. The potential and limitation of standard BPS tools to predict the indoor thermal environment has been properly documented using field measurements [1]. The building integration of wood stoves in passive houses has been investigated for Belgium [2] and Norway [3]. Simplified power sizing methods for wood stoves as a function of the building thermal properties are under development. Finally, so-called “zonal models” have been successfully tested as a cheaper alternative to expensive CFD [4]. In the future, this knowledge will be further extended and validated, for instance, by better taking the user behavior into account.

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[1] Laurent Georges, Øyvind Skreiberg (2016). Simple Modelling Procedure for the Indoor Thermal Environment of Highly Insulated Buildings Heated by Wood Stoves. Journal of Building Performance Simulation 9(6):663-679.

[2] Laurent Georges, Øyvind Skreiberg, Vojislav Novakovic (2013). On the proper integration of wood stoves in passive houses: Investigation using detailed dynamic simulations. Energy and Buildings 59:203-213.

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Sub-project 4: Education and training

Education and training are an important part of a competence building project, involving both knowledge transfer to the industry and education of Master students and PhD and PostDoc candidates. In WoodCFD, the PhD candidate Inge Haberle from Austria contributed extensively to the work in sub-project 1, while the PostDoc candidate Martin Thalfeldt from Estonia similarly contributed to sub-project 3. Inge Haberle successfully defended her PhD thesis ”Numerical simulation of transient behavior of wood log decomposition and combustion” in November 2018, as well as gave a trial lecture on the topic ”100% renewable energy for heating and cooling of buildings not connected to district heating networks in Europe in 2050 – technology options and the potential role of wood stoves”. Both candidates are now back in their home country to continue their professional careers. Several Master students have also been connected to WoodCFD, contributing to different topics through a specialisation project or a Master thesis. In addition, a summer job student has been financed by WoodCFD, through the annual SINTEF summer job project. The combined contribution from the students has been invaluable for the project, making it possible to achieve more within the given budget. Finally, annual workshops targeting the WoodCFD industry partners were arranged, with the purpose of dissemination as well as discussions, benefitting all parties in the project.

Sub-project 5: Technology monitoring and dissemination

Technology monitoring and dissemination are default activities in a competence building project, and in addition to the default state-of-the-art scientific monitoring within the core areas of the project, also more general monitoring in a broader area is carried out, and is also disseminated where appropriate. Dissemination to the general public has been carried out through the WoodCFD website and through two newsletters per year, as well as through popular science publications. Dissemination to the scientific community has been carried out through scientific presentations at workshops, seminars and conferences, as well as publications in conference proceedings and in international scientific journals. The WoodCFD industry partners have continuously through the project period been kept informed about project progress and achievements. All in all, extensive dissemination of project results has been carried out, in line with the expectations from the Research Council of Norway for a competence building project.

Collaboration with other projects

During the four years of the WoodCFD project, several parallel projects have been running on connected topics, with direct mutual beneficial collaboration or only information exchange. FME CenBio (Bioenergy Innovation Centre) and PCM-Eff have been the two direct collaborating projects in WoodCFD. Especially PCM-Eff (**www.sintef.no/en/projects/pcm-eff/**), an internal SINTEF Energy Research competence building project on the use of phase change material (PCM) for different applications, including wood stoves, has contributed significantly to the WoodCFD output, through CFD simulations connected to use of PCM in wood stoves to flatten out the heat release profile to the room. Proper integration of PCM in wood stoves and the possibility to include the PCM in the computational domain in a CFD simulation is very interesting with respect to further development of a complete CFD toolbox for wood stoves.

Internationalisation

WoodCFD has been an international project, having one international industry partner and as well both an international PhD candidate and PostDoc candidate. Extensive dissemination of project results internationally has been carried out, as well as dissemination of international activities to the project partners. Especially interesting international activities have been those of IEA Task 32 - Biomass combustion and cofiring, RHC-ETIP (Renewable Heating and Cooling - Energy Technology and Innovation Platform) and EERA (European Energy Research Alliance) Bioenergy - Stationary Bioenergy. Norwegian participation in such international forums ensures information flow and influence. Finally, participation in international standardisation activity connected to wood stove approval testing is important, and this has been done through other parallel projects.

All in all, the combined research and development efforts on wood stoves ensures a strengthening of competence and research capacity, benefitting the wood stove industry and connected industries while ensuring a continuous focus on energetic and environmental performance.

Recommendations

Wood stoves for low-energy and passive houses needs to be downscaled (typically to 4 kW nominal effect and below) compared to today's typical wood stoves (of typically 8 kW nominal effect), without sacrificing environmental performance, but rather improving it. The WoodCFD project has generated a detailed knowledge base and established models and modelling approaches and tools to aid in the development of future's wood stoves for low-energy and passive houses. The negative effects of the unsteady and transient heat production profile in wood stoves can be reduced by improved operation, control and stove designs, including applying the proper materials and material configurations to ensure a flattened heat release profile to the room. Also, proper building integration will further improve the thermal comfort performance of wood stoves in low-energy and passive houses. The targeted and comprehensive work carried out in WoodCFD have resulted in the following key achievements:

- Putting together a model toolbox in sub-project 1, validated to the current extent possible, and applied up to 2D for the wood log model
- Establishing base cases and carrying out CFD simulations in sub-project 2, including transient 2D simulations
- Developing and validating the zonal model in sub-project 3, making it possible to carry out more accurate but still fast all-year simulations to ensure an optimum building integration of wood stoves, in various climate zones
- Extensive educational activity: Master students, PhD and PostDoc
- Extensive dissemination activity, at different levels and through various channels
- I.e. very much contributing to expanding the knowledge base within this research area

WoodCFD has been successful in progressing the knowledge and modelling tools significantly. However, more work is still needed to reach the final target, i.e. to be able to use CFD as a cost-effective design tool for wood stoves and to use a building integration tool as a cost-effective tool to ensure their proper building integration. This will secure the continued use of wood stoves as an important and comfortable heat source in future's residential building stock. To reach this final target, i.e. to arrive at clean and efficient wood stoves through effective CFD and building integration modelling approaches, further work is needed on:

a) Model development: through advanced yet effective wood log, wood stove and building integration models; and validation of these
b) Simulations: through transient and stationary CFD simulations of wood stoves, and room and building integration simulations

Specifically, there is a need to:
1. Refine, validate and integrate the wood log model with the stove model, and validate the overall model
2. Carry out CFD based optimisation with respect to combustion efficiency, thermal efficiency and heat storage, and simplify the scientific CFD tool for industrial use
3. Validate the advanced room model to capture the transient indoor thermal environment of buildings heated using stoves, to better understand the user behaviour and propose guidelines for the proper integration of wood stoves, especially in highly-insulated buildings equipped with balanced mechanical ventilation and heat recovery
4. Educate highly skilled candidates within this area and ensure knowledge transfer to the industry and other interested parties when applicable

In the end, wood stoves are not only a renewable space heating solution, but part of the Norwegian soul, and the flame picture and the crackling sound when the wood logs are burning are an important part of that, which cannot be provided by any other heating technology. To be able to enjoy this and the heat comfort that wood stoves provide also in the future, meeting the increasing demands from both consumers and authorities are necessary!

Knowledge is the key to the wood stove future

The four industry partners, their products and strategies

NORSK KLEBER 1893

Norsk Kleber builds upon centuries of experience in the development and production of genuine soapstone stoves and fireplaces. The company itself was founded in 1893, as a result of an industrialization in which several small independent handcrafters merged into one company. Our goal is to keep alive and further improve century old and thoroughly tested traditions in the use of soapstone, and to combine these with modern Scandinavian design. As such we combine tradition and innovation with an eye towards functionality, quality and good design. Our products are exported to a number of European countries.

The future of genuine soapstone furnaces

The industry is facing strict regulations from the authorities at the one hand and needs for low energy output from end customers at the other hand. Our products are naturally optimally suited to satisfy these demands, since we develop and produce soapstone furnaces without iron or steel inserts. In this manner, the soapstone captures maximal heat from the fire in the most effective way. Consequently, the heat will be dissipated by convection and infrared radiation from the soapstone long after the fire is extinguished. This heat is experienced in much the same way as the warmth from the early morning – or late evening sun. Our stoves deliver warmth, because of their rather moderate size, rather quickly, and continue to do so for a considerable time. In other words: with our genuine soapstone stoves you generate warmth quickly, but not more than you need!

Cooperation with leading research institutions

Norsk Kleber only produces stoves and fireplaces that fulfil the strictest regulations regarding safety, environment and clean combustion. We continuously seek to improve the efficiency and the emissions of our stoves in close cooperation with qualified research partners, both nationally and internationally, in order to be able to maintain our position as one of the leading manufacturers of wood burning stoves in the world. Our participation in the WoodCFD project is central to this aim.

By appointment to The Royal Danish Court
morsø

The history of Morsø dates all the way back to 1853, and the company early became one of the leading iron foundries in Denmark. For generations, Morsø has supplied high quality wood-burning stoves made of cast iron. In 1915 the company was bestowed the prestigious title of Purveyor to the Royal Danish Court. The subsidiary company – Morsø UK was established in 2004 in Rugby, the United Kingdom.

Today Morsø UK and the Danish mother company employ 90 people. In addition to the main markets in Denmark and the United Kingdom, Morsø exports to 32 different countries worldwide.

Main products

Over the years, Morsø has developed a broad range of products, which comprises both classical and modern stoves of cast iron or steel. Furthermore, Morsø distributes a diverse range of accessories, including fire tools and hearth plates.

In 2011 Morsø increased its product range and included a new outdoor concept, which consists of outdoor ovens, grills and cast iron cookware bringing comfort into the garden.

Morsø has always led the way in both new designs and new ways of combining form and function with environmental awareness. The wood-burning stoves developed meet some of the strictest environmental standards in the world. In particular, they meet the Norwegian Standard, which sets out stringent requirements on minimising particle emissions. Most Morsø wood burning stoves are certified by the Nordic Swan Eco-label. This does not only prove the stove's minimal impact on the environment when operating, it also highlights the minimal environmental impact caused by the actual production and packaging.

Future development

Morsø has always been at the forefront when it comes to environmentally friendly combustion, especially in the field of low emissions. Morsø constantly seek to improve its knowledge in order to develop high quality wood burning stoves with the best possible combustion systems providing use-value to the consumer.

For Morsø the WoodCFD project has been inspiring and proved constructive, particularly due to the composition of its member including both researchers and professionals from recognized companies. The WoodCFD project has taken concrete steps in order to meet the most stringent requirements of future wood log combustion.

Dovre is the world's oldest manufacturer of fireplaces, established in Ulefoss, Norway, in 1933. Dovrepeisen obtained 50 years world wide patent for the unique convection heating system which gave a completely different and significantly improved distribution of the heat. The principle is still used by several manufacturers all over the world. Dovrepeisen was a success both in Norway and in Europe.

In 1981 the capacity at Ulefoss became too small and the production was moved to Weelde in Belgium, and Dovre has developed into a large and modern manufacturing company with one of Europe's largest foundries. Products made by Dovre are sold all over Europe, in the Far-East and Asia. In 1991, Dovre introduced a new generation of stoves - the clean burning system. This double combustion system ensured a substantial increase in the energy efficiency and a reduction in wood consumption of almost 40% could be achieved, compared to the old stoves.

Development of new products

Dovre is continuously working on product development, in order to be in the forefront regarding further development of existing and new internal combustion systems as well as new solutions for heat storage and heat distribution, which have been research topics in the WoodCFD project. The fact that we have been a leading supplier and a driving force of combustion technology since 1933 both inspires and commits our work.

Dovre's vision is to be a leading supplier of new technology. The goal is that the new technology is in the forefront of environmental requirements given by national and international authorities, ensuring that we are a driving force in the development of combustion systems. We are also a prime mover (pushing) for more stringent environmental requirements in general.

Todays and future houses need less energy than before. In order for Dovre being a fireplace and wood stove supplier to these houses, development of fireplaces and wood stoves that provide less effect directly to the rooms, as well as store any excess heat that can be utilized later, are needed.

The collaboration with SINTEF Energy Research and the support from the Research Council of Norway has contributed to a more cost efficient and less labour intensive development of new combustion systems. We are proud of the results we have achieved together, the collaboration has given motivation, inspiration and new knowledge in our development of new combustion systems.

JØTUL®

Jøtul has a more than 160-year-long history. In 1853 Oluf Onsum founded Kværner Jernstøberi at Loelva east of Kristiania, now Oslo. Kværner started as a manufacturer of cast-iron goods, where cast-iron stoves were one of the most important products. In the years leading up to 1900, the company established one of the largest stove foundries in Norway. In 1916 the stove production was sectioned out from Kværner Brug. The company received its present name, Jøtul, in 1935.

A new era, with international focus, started in 1977 when the company was sold to Norcem. In the 1980s, additional steps were taken to expand globally through a number of acquisitions of foundries and import companies in the US and Europe. Today Jøtul has the world's largest distribution network for stoves and fireplaces, 43 countries, and is one of the highest sought after brands in the stove and fireplace industry.

The Jøtul Group today

Jøtul develop, manufacture, market and sell our products under brand names Jøtul, Scan, Atra, Warm and Ild. Our products are based on Nordic heritage and expertise focusing on environmentally conscious processes during production and daily use. Jøtul Group has approximately 640 employees and an annual turnover of approximately 838 MNOK. The production takes mainly place in Fredrikstad, Odense and Portland.

New challenges

In the last years there has been an increasing demand for stoves with low output due to better insulated buildings with very low air leakage and low heating needs. The focus on particle emissions is also increased, and there have generally been higher demands for stoves with high efficiency and low emissions.

New combustion technology and new ways to store and distribute the heat are required in order to meet these new challenges. Our involvement in the WoodCFD project was a result of these needs. The WoodCFD project has brought us closer to a realistic computer simulation of the batch combustion process, which will be a very effective tool for optimizing the stoves. The project has also given very important knowledge on heat storage and distribution in modern buildings. New stoves in development already take advantage of some of the knowledge acquired in the WoodCFD project.

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SINTEF

NTNU

WoodCFD

Industry partners:
Jøtulgruppen, Dovre AS, Norsk Kleber AS, Morsø A/S

Research partners:
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WoodCFD

Clean and efficient wood stoves through improved batch combustion models and CFD modelling approaches