A DESIGN TOOL FOR WOOD FIRED STORAGE APPLIANCES

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ABSTRACT

Tile coated wood fired appliances are designed to store heat from the intermittently burning fire in their massive structure and release it slowly to the room. The design of these systems should assure thermal comfort during the whole process and involves dynamic simulation. A customized design tool for these systems was developed. A model of the appliance was created and implemented in existing building simulation software. It was validated and tuned against laboratory measurements. It can be used in the context of a multi zone building including aspects like inter zone air flows. Data input is done remotely by a web based user interface. An input file is automatically generated and the simulation run launched on a server. The results include plots of the thermal comfort parameters in the different rooms. For a few real cases the results were compared to field monitoring data.

The tool is restricted to Swiss conditions. An international extension in the frame of a European project is planned.

INTRODUCTION

The Systems

Houses with a low heating energy demand favor the use of renewable energy sources. One possible approach is to cover this demand by wood fired appliances. These appliances are designed to store the heat from the intermittently burning fire in their massive structure made from fire brick or similar materials, and release it slowly to the room. Depending on the floor plan of the house, a room or a group of rooms can be heated by one appliance. With an addition of secondary heat release/storage elements served by flue gas ducts, so called "satellites", also more complicated house plans can be fully heated by such systems.

The design of these systems is a challenging task due to the different dynamic effects which are involved in a combined way. Assurance of thermal comfort during the whole process becomes crucial in the case where there is no additional heating system.

Figure 1: Example of an appliance

Goal

The goal of the project was to develop a customized design tool for this type of systems.

In order to enable the designer to prove sufficient comfort throughout the heating process, dynamic simulation had to be involved. The following steps had to be addressed in the project:

- Creation of a model of the appliance.

- Validation of the model against laboratory measurements and tuning.

- Implementation in the existing building simulation software IDA-ICE, to be used in the context of a multi zone building.

- Assure consideration of aspects like inter zone air flows. This involved the creation of a horizontal opening model.

- Validation of whole building/appliance model against field monitoring data.

- Development of a user interface for the design tool.

APPLIANCE MODEL

Model Description

The model of the appliance was developed by using the modeling feature of the IDA-ICE program, NMF (Neutral Model Format). The model represents all the processes shown in figure 2: convective and radiative heat exchange from heat source to inner surfaces, storage in fire brick parts, heat release through massive surfaces and through fire door, flue gas transport etc.
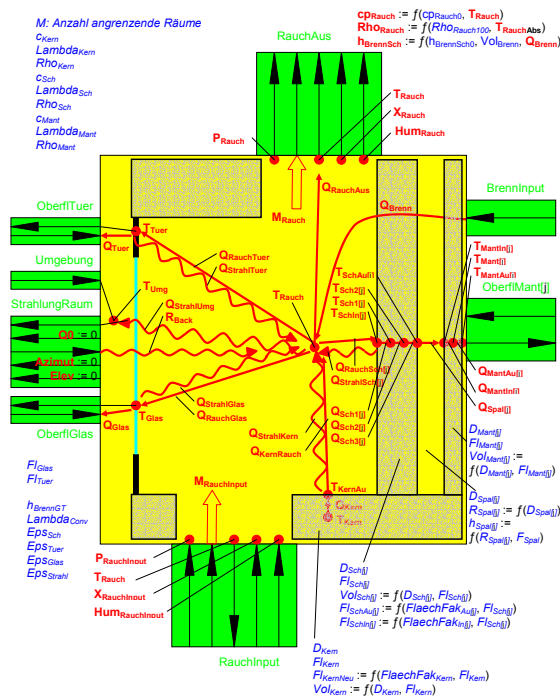

Figure 2: Graphic representation of the burning chamber model

Validation

The model was validated against data from laboratory experiments. The appliance used for the experiment consisted of two different parts: the burning chamber and a separate satellite.

Model development and validation was an iterative process. Several sets of experimental data with increasing complexity allowed refining the model step by step. Simplifications included replacement of the wood fire by a gas burner and omitting the tile shell.

For the more realistic cases where wood was really burned, this burn down process, which in reality is a complex dynamic process, had to be modeled in a

simplified way. The assumption for the time dependency of the heat release is shown in figure 4.

Figure 3: Experimental appliance in calorimetric chamber for measurements
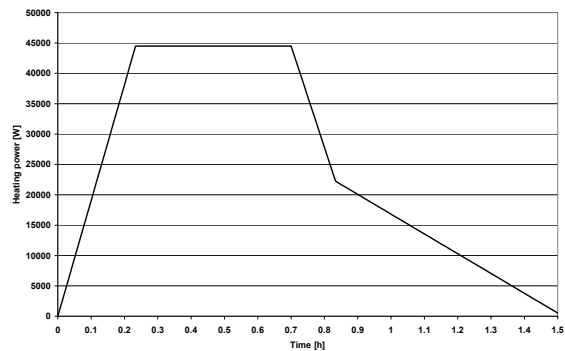

Figure 4: Simplified representation of the wood burning process

Figure 5 shows a good agreement between measured and simulated temperatures in the burning chamber.

HORIZONTAL OPENING MODEL

Model Description

A considerable part of the heat released by the appliances is distributed in the buildings by natural convection. It is obvious that in multi storey houses openings between the floors like open staircases have a strong influence on this.

Although the used simulation software has an inter zonal air flow model included, a proper model for large horizontal openings to represent the elements characterized above was missing.
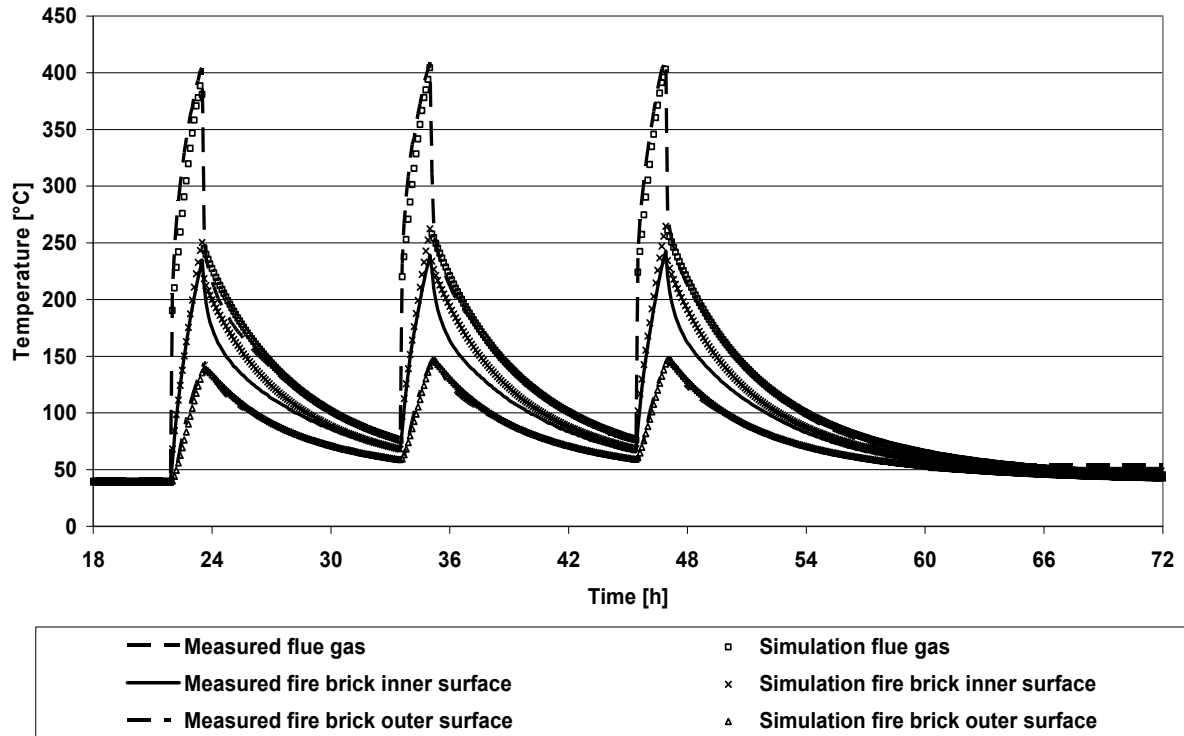
Figure 5: Comparison of simulated and measured temperatures for the stove

The model is based on the work of Blomqvist et al (2004). The air flow through a horizontal opening in a flat plate between two spaces with different temperatures is described by equation 1.

$$\dot{m} = f_{St} \cdot k \cdot A^n \cdot \left[g \cdot \left(\rho_2 - \rho_1 \right) \right]^m \qquad (1)$$

with

$\dot{m}$ air mass flow rate

f_{St} stair factor

k   proportional factor

A   opening area

n   exponent for area correction

g   gravitational acceleration

ρ_2 air density upper zone

ρ_1 air density lower zone

m   exponent for density difference

Validation

CFD simulations were used to evaluate this approach. Air flow rates through the opening resulting from a surface integral from the CFD simulation were compared to the result from equation 1.

The results were within 20 % of deviation when using the values shown in table 1.

Table 1: Values used in equation 1 for conformity

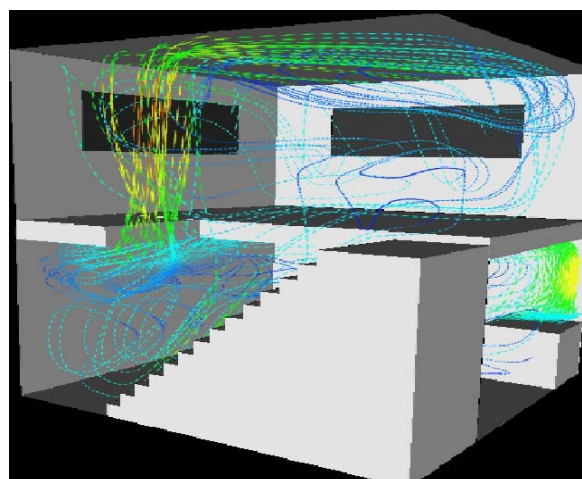| QANTITY	VALUE
f_{St}	1.3
k	0.5
n	0.5
m	0.5

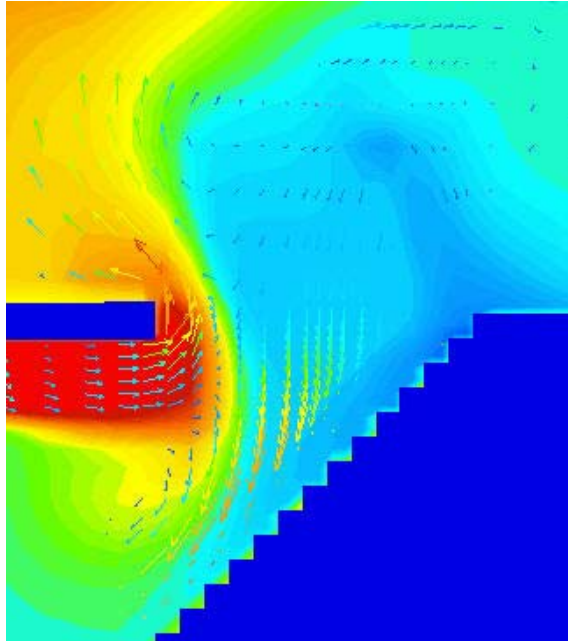*Figure 6: CFD calculation of horizontal opening with closed staircase*

Figure 7: Air flow distribution in horizontal opening with closed staircase
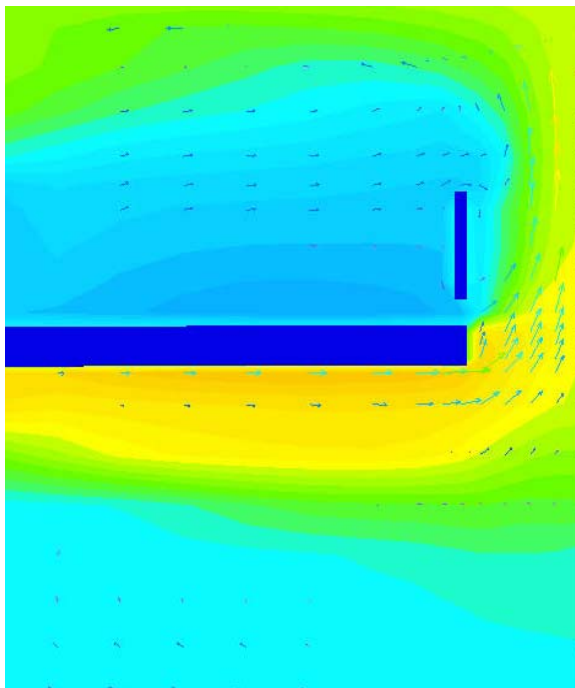

Figure 8: Air flow distribution on gallery with open balustrade

The following points were learned from the validation:

- The mass flow rate is increased by 30 % when a closed stair is put under the opening as shown in figures 6 and 7. The stair factor of 1.3 is valid for these cases. Thus, a closed stair increases the mass flow rate.

- A stair with an open air gap between the steps, however, decreases the mass flow rate due to

enhanced turbulence. Equation 1 is not valid for this case.

- For galleries, equation 1 is only valid when there is an air gap in the balustrade as shown in figure 8.

- The room height has little influence on the flow rate.

The model has restrictions in application:

- The temperature in the lower zone must be higher than in the upper zone.

- The geometry of the opening is not taken into account. It must be near quadratic. Narrow gaps or cracks are not adequately represented.

- The size of the openings was between 4 and 8 m^2. Larger openings may be well represented, but this is not proven.

- Heat sources placed directly under the opening largely increase the flow rate. This is not represented.

IMPLEMENTATION AND VALIDATION OF COMBINED BUILDING/APPLIANCE MODEL

Model Description

The two models for the stove and the horizontal opening described above were implemented in the simulation program IDA ICE, where it is possible to connect these to the existing building component models.

Validation

In two houses equipped with appliances as examined here, field monitoring data were taken. This allowed evaluating the behavior of the whole building / appliance model in real operation mode. One of the houses had a simple stove a mechanical ventilation system. Figure 9 shows the floor plan and section of the other house, which is equipped with a stove on the ground floor and a satellite in the upper floor.

Figure 10 shows the comparison of measured and simulated air temperatures in one of the bedrooms on the upper floor. There are times with very good agreement and times with larger deviations. The reasons for this are some idealizations which had to be made for the simulations, especially for the wood burning process, which could not be modeled exactly as in reality.

It has to be stated that the distribution of the heat in the house is an important issue with these systems. In the object shown here this is supported by the family life with open doors and movements. In the other case the mechanical system helps a lot in this respect.
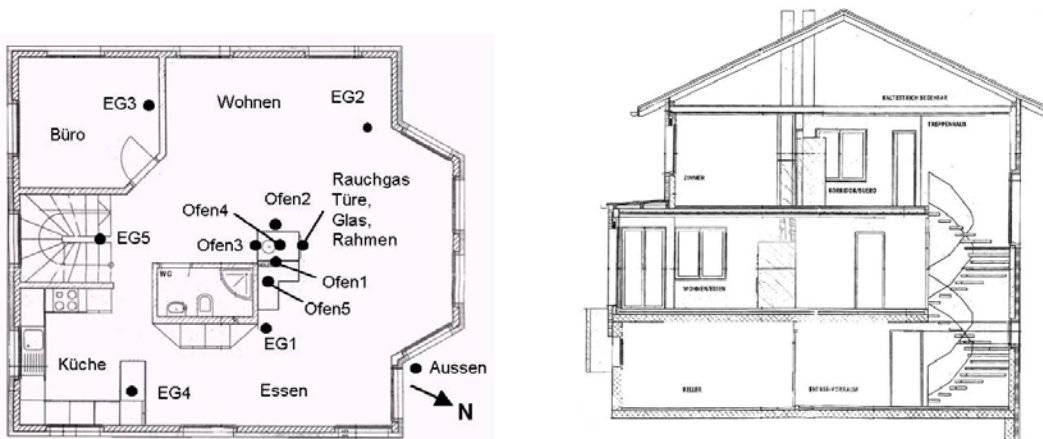
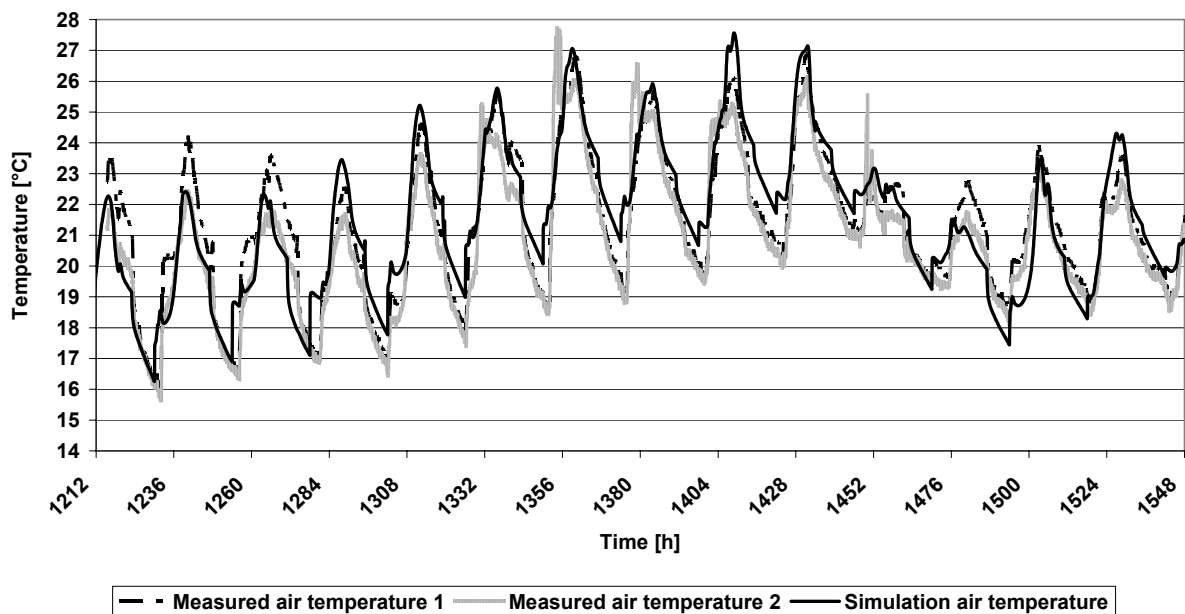*Figure 9: Ground floor plan and section of example house with stove and satellite. The dots represent sensor placements*

Figure 10: Comparison of simulated and measured air temperatures in an upper floor bedroom

DESIGN TOOL

Goal

The final step of the project was to develop a customized design tool for the dimensioning of these appliances. It enables the designer to do several steps:

- Perform a heating load calculation of the house

- Do the design of the stove and possibly of satellites

- Allocate the heat release surfaces to the different rooms

- Perform a dynamic calculation of the whole setup under winter design conditions to assure comfort conditions in all rooms at the appropriate time.

Description

The design tool is strongly linked to the general web based design tool IDEA^{XP} described in Zweifel et al (2005).

The user interface is web based; no local installation is needed for most of the tasks, with one exception mentioned below.

The heating load calculation is performed according to the relevant standard. The result, the total heating load of the building and the distribution to the rooms, is the base for the design of the appliance.
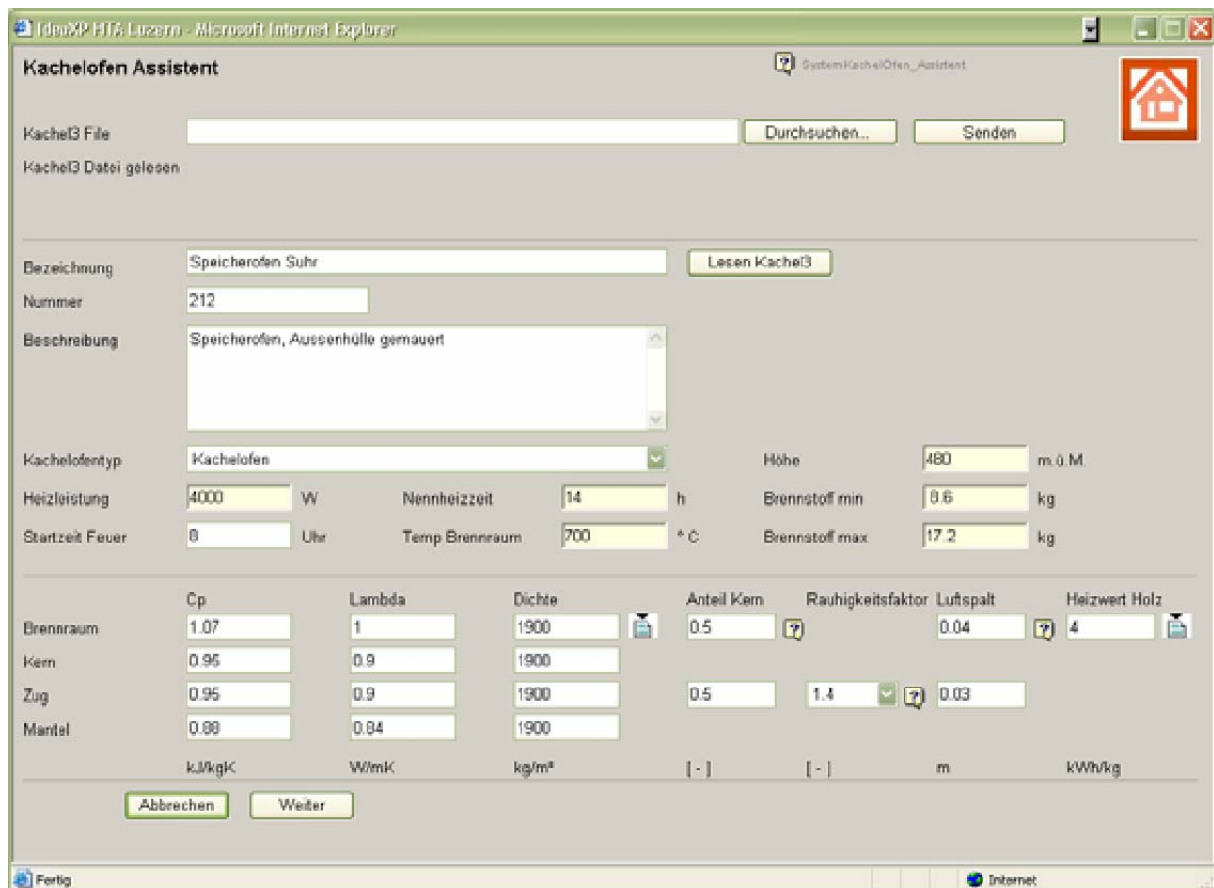
Figure 11: Wood stove assistant window

For the detailed design of the stove and the satellites, the specialists are customized to a special Austrian design tool described in Baumgartner et al (1997). It was decided to leave this tool as a stand alone solution. An import interface was created to import the results of this tool.

A special assistant added to IDEA^{XP} (figure 11) allows allocating the right file, to import the data and to edit the data afterwards.
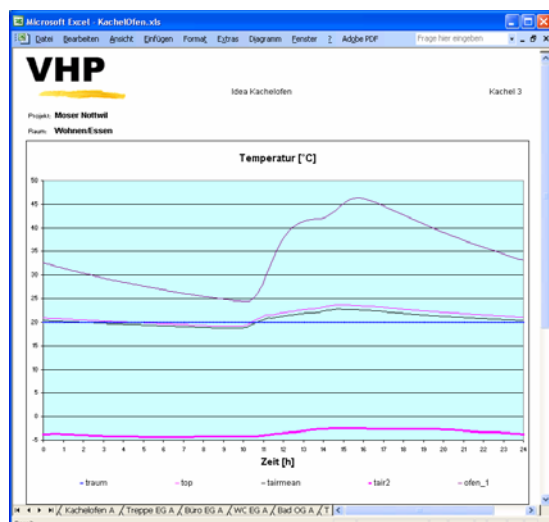

Figure 12: Comfort calculation result

When imported, the data are shown in the tree structure of the program, and several input windows enable the user to allocate heat release surfaces to rooms and flue gas ducts to the surfaces etc.

When the whole input process is completed, the comfort calculation can be launched, with this action, an input file for the IDA ICE program is automatically generated, and then the simulation run is launched. The results include temperature profiles during a winter design period for all rooms (figure 12) and allow a comfort evaluation according to the known theories of thermal comfort.

OPERATIONAL EXPERIENCE

The tool covers all the requirements of the wood stove designers to do a complete design of their systems and evaluate its behavior.

Due to the fact, that a detailed multi zone building model is needed and that there are many different effects with partly high calculation intensity involved, the calculation time was initially pretty long. In collaboration with the program supplier team, the models could be cleaned up and speed was

enhanced by a factor. In the meantime calculation time is reduced to less than 30 min.

CONCLUSIONS

The simulation shows that the massive structure of the appliance strongly influences the characteristic of the heat release curve. The appropriate heat output over time is crucial for the room comfort. It is important to avoid an overshooting of the room temperatures by peak heat outputs. An optimum design of the appliance gives the biomass branch the possibility to guaranty quality standards to their customers, which helps disseminating wood heat appliances due to a good reputation and feasible costs. This is very important for the manufacturers to be competitive on the market.

With the developed design tool the stove designer is in the position to do the layout of an appliance according to the energy requirement.

OUTLOOK

The design tool is restricted to Swiss or at least meddle European conditions. It is available in German language.

It is planned to further develop the tool in the frame of a European project, in order to extend its usability to a wider range of countries.

ACKNOWLEDGMENTS

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