Computer Model of a Domestic Wood Burning Heater

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Abstract

Between April 2003 and April 2004 a project, funded by Technology New Zealand, was undertaken to develop a computer model of a wood burning heater for use at Applied Research Services Ltd. Applied Research Services Ltd is a science and engineering research company that specialises in the testing of wood burning heaters. The computer model will be owned by Applied Research Services Ltd and will be used to improve the design of their customers' heaters so that they may pass the particulate emissions and efficiency standards of AS/NZS 4013:1999.

The computer model used the software program, Engineering Equation Solver as a platform to solve the model equations. EES was particularly easy to use and more emphasis was able to be placed on the actual modelling. The final model included over eight hundred variables and equations. It included radiant, convective and conductive heat flows, over thirty heat balances, Arrhenious based rate expressions and many empirical equations derived from experiments and data acquired at Applied Research Services Ltd.

At the beginning of this project the objective was for the model to match the test results to within 10%. This has been met for the tests on the high airflow setting where the model error is 4% for flue temperature, 8% for heater output and 16% for flue oxygen. Unfortunately on low airflow setting, the model does not reach this target with model errors of 18% for flue temperature, 25% for heat output and 13% for flue temperature. The excellent results for the high flow setting are partially attributed to the use of calibration factors. The calibration factors model the processes in wood combustion that could not be modelled by this project, due to lack of time and resources. Some of these factors are the proportion of air that flows onto the charcoal ember bed or logs, radiation shape factor changes due to firebox geometry, convection heat transfer coefficients changing with turbulence. The calibration of the model only has to be completed once for each heater. The reason why the model does not work as well on low airflow setting is that with less airflow the proportion of air to the charcoal bed opposed to the logs would decrease, therefore decreasing the burn-rate.

This model can be used to determine the changes to a heater's performance from changes to air inlet areas, insulation type and thickness, wetback size, baffle size, primary vs secondary air, air bypass ratio and door size. The model provides all the results that are obtained from an emissions test plus extra information such as the amount of excess air, smoke conversion in each combustion zone, flame temperatures and distribution of heat output. The smoke conversions for each combustion zone are particularly helpful in diagnosing where problems with the combustion occur. The reasons for incomplete combustion, lack of temperature or oxygen, can be found and fixed by increasing either insulation or air areas.

The model can be used by Applied Research Services Ltd to improve heater designs. For the short term this will involve the author working as a part-time consultant. The project could be built on by another student by using CFD modelling for the sections of the wood burning process not modelled by this model and adding a graphical user interface to make the model easier to use.

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Nomenclature

Variables

A	Surface area	[m^2]
be	Burn energy release rate	[kW]
br	Burn-rate	[kg/s]
D	Diameter	[m]
DP	Pressure drop	[Pa]
DT	Temperature difference	[°C]
e	Reaction extent or emissivity	[kmol],[-]
E	Energy of reaction (Arrhenious term	[kJ]
F	Mass flow-rate	[kg/s]
FV	Volumetric flow-rate	[m^3/s]
h	Heat transfer coefficient	[kW/ m^2 C]
k	Rate constants	Many different units
m	Mass	[kg]
MM	Molar mass	[kg/mol]
Q	Heat content	[kJ]
qr	Heat flow-rate	[kW]
sf	Radiation shape factor	[-]
T	Temperature	[°C]
V	Volume	[m^3]
XA	Cross-sectional area	[m^2]
x	Fractions, concentrations or distance	[-,-,m]
y	Stoichiometric factors	[-]
z	Stoichiometric factors	[-]

Heater Sections

b	Baffle
ba	Baffle air (Firebox air above baffle)
c	Charcoal (Charcoal bed at the base of the firebox, assumed to cover entire floor)
d	Door
f	Flame
fb	Firebrick
fl	Floor
flhs	Floor heat shield
flue1	Lower half of the air inside the flue, below 2m
flue	Upper half of the air inside the flue, below 2m
flue2	From 2m to the top of the flue, 4.7m high
fluew	Wall surrounding flue air
flue1w	Wall surrounding flue1 air
Flue2 wall	Wall surrounding flue2 air
fw	Front wall
hs	Heat shield
hsa	Air between heater walls and heat shield
i	Inside (Closest to the logs)
l	Log
lw	Lower wall (Wall behind firebricks)
o	Outside (Furthest from the logs)
pa	Primary air (Lower half of the firebox air)
r	Calorimeter room air
rw	Calorimeter room walls
sa	Secondary air (Upper half of the firebox air)
sh	Shell of heater
sha	Air between heat shield and heater shell
st	Stand
tw	Top wall
uw	Upper wall (Wall above firebricks)

The variables can then be combined with the heater sections. For example:

The heat flow from the logs to the door is	qrldi
The cross sectional area of the flue is	XAflue

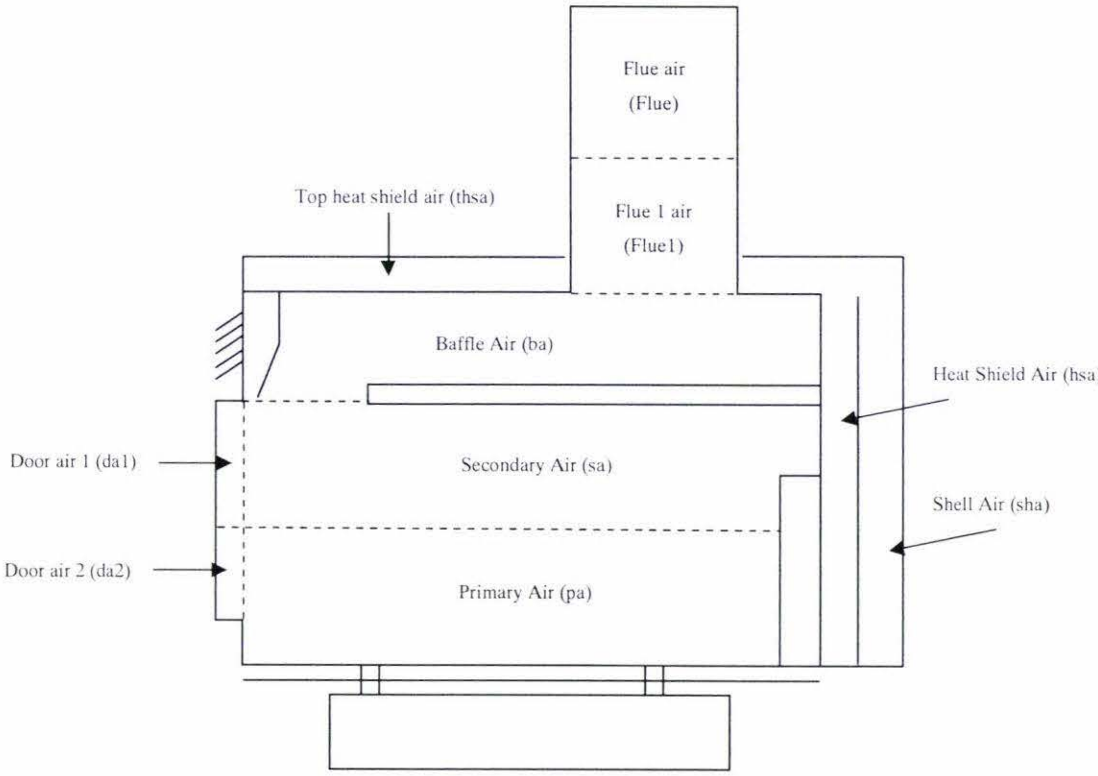

Figure 1: Air section naming convention for the final model

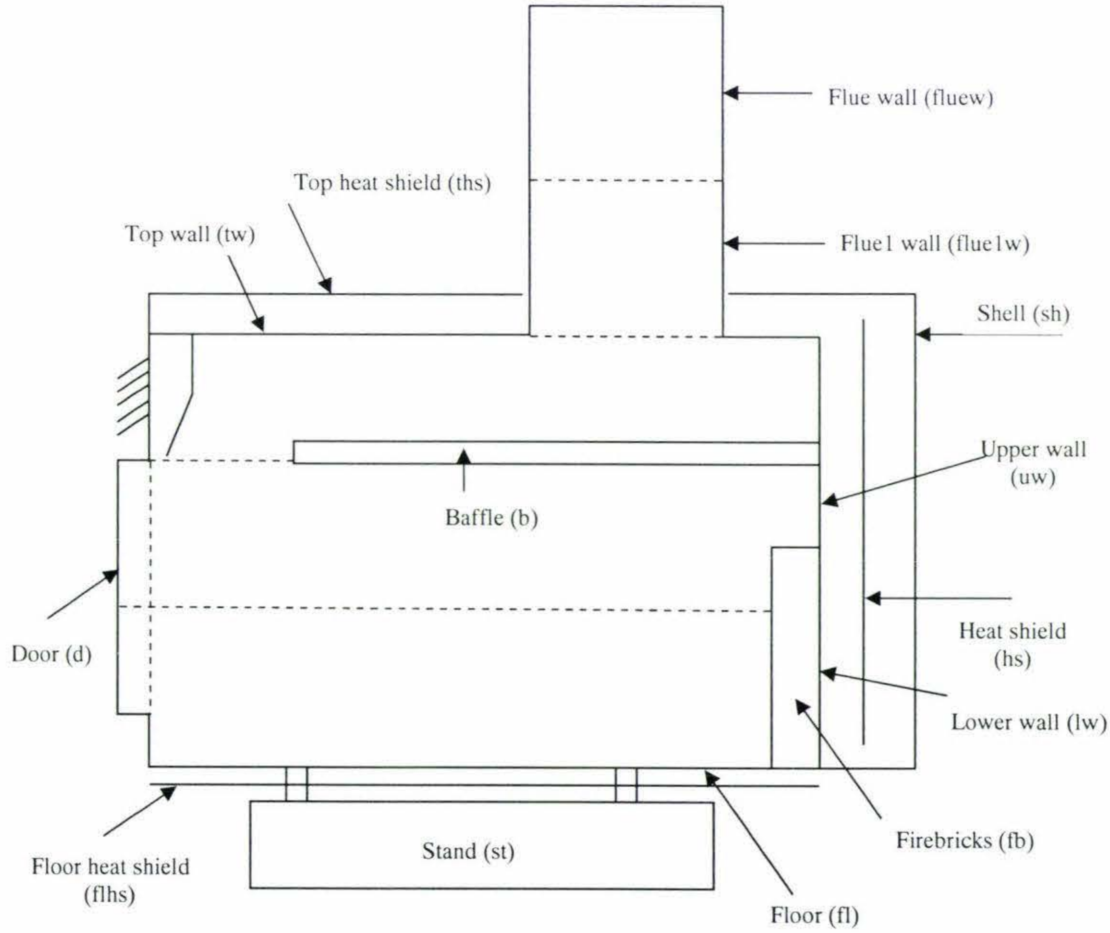

Figure 2: Heater solid sections naming convention for the final model