APPENDIX A

EQUATIONS FOR ENERGY ANALYSIS

Symbols and Constants

A = Wall area (m^2)

HV = Heating value of rubber wood = 13,600 [14] (kJ/kg)

L = Height of door (m)

Q_{in} = Input energy to the smoking room (kJ)

Q_{lc} = Energy loss due to conduction through walls (kJ)

Q_{le} = Exhaust loss (kJ)

Q_{sr}, Q_{sc} = Heat stored in rubber and room structure, respectively. (kJ)

Q_{vr} = Latent heat of water (kJ)

T_i, T_o, T_α = Inside, outside wall surfaces and surrounding temperatures, respectively (K)

a = Ash content of rubber wood = 0.041 [13]

C_{pH_2O}, C_{pv}, C_{pa} = Specific heat of water, water vapor and air, respectively.

C_{pr} = Specific heat of rubber = 1.84 kJ/kg K [15]

C_{ps} = Specific heat of room structure materials

$h_{fg\ 65^\circ C}$ = Latent heat of water at 65°C

k = Thermal conductivity (W/mK)

m_a = Mass of dry air (kg)

m_r = Mass of smoked rubber (kg)

m_s = Mass of room structure (kg)

m_w = Mass of firewood (kg)

m_{wr} = Mass of water removed from rubber (kg)

t = Time (sec)

x = Wall thickness (m)

ϕ = Wood moisture content = 0.422 wet basis [12]

υ = Kinematic viscosity (m^2/s)

ω_i, ω_e, = Humidity ratios of inlet air and exhaust, respectively.

Table A1 : Thermal properties of room structure [15,16]

Structure material	k (W/m K)	C_p (kJ/kg K)	Estimated mass (kg)	Thickness (m)
Brick (left wall)	1.13	0.922	10351	0.075
Brick (right wall)	1.13	0.922	10351	0.075
Brick (back wall)	1.13	0.922	2911	0.075
Gypsum board (ceiling)	-	1.084	562	0.004
Steel (door)	-	0.522	500	0.0012
Concrete (floor)	-	0.653	33221	0.200

Maximum temperatures used in heat storage calculation were obtained from the maximum of the averages of 10 consecutive measurements advancing through the whole range of data. That is, started with the averaging the temperatures of records 1-10, 2-11, 3-12... then used the maximum value of these averages for the calculation.

Input Energy

Calculated from fuelwood heating value

$$Q_{in} = HV.\ m_w\ (1-\Phi) \qquad (1)$$

Energy Losses

1. Conduction through walls

$$Q_{lc} = \Sigma\ (kA\ \frac{\Delta T}{\Delta x},\ \Delta t) \qquad (2)$$

2. Radiation and Convection of Steel Door [16]

Door is made of thin steel sheets which is more accurate if energy loss is calculated with respect to radiation and convection.

Radiation $$Q = \Sigma\,(\varepsilon\,\sigma A\,(T_o^4 - T_\alpha^4)\,.\,\Delta t) \qquad (3)$$

where $\varepsilon = 0.80$

$\sigma = 5.67\text{x}10^{-8}\ (W/m^2\ K^4)$

Free convection $$Q = \Sigma\,(h\,A\,(T_o - T_\alpha)\,.\Delta t) \qquad (4)$$

where $h = 0.95\,(\Delta T)^{1/3}$ for $Gr_L\,Pr > 10^9$

$$\text{and } Gr_L\,Pr = \frac{g\,\beta\,(T_o - T_\alpha)}{\upsilon^2}\,L\,.\,Pr$$

where $g = 9.81\ m/s^2$

$\beta = 1/T_\alpha$

$\upsilon = 20.76\text{x}10^{-6}\ m^2/s$ at 350 K

$Pr = 0.697$ at 350 K

3. Exhaust Loss (with reference to surroundings)

$$Q_{le} = m_{Tg}\,C_{pa}\,\Delta T + m_{Tv}\,C_{pv}\,\Delta T$$

where m_{Tg} = Total exhausted gas (kg)

$= m_a + (1-a)(1-\Phi)\,m_w$

m_{Tv} = Total exhausted vapor (kg)

$= [m_a + (1-a)(1-\Phi)\,m_w]\,\omega_e$

Thus $$Q_{le} = \{[m_a + (1-a)(1-\Phi)m_w]\Delta T\}\{C_{pa} + \omega_e\,C_{pv}\} \qquad (5)$$

4. Latent Heat That Vaporizes Water in Rubber

$$Q_{vr} = m_{wr}\,h_{fg\ 65^\circ C}$$

where $m_{wr} = m_{Tv} - \Phi\,m_w - \omega_i\,m_a$

$= [m_a + (1-a)(1-\Phi)\,m_w]\,\omega_e - \Phi\,m_w - \omega_i\,m_a$

Thus $$Q_{vr} = \{[m_a + (1-a)(1-\Phi)\,m_w]\,\omega_e - \Phi\,m_w' - \omega_i\,m_a\}\,h_{fg\ 65^\circ C} \qquad (6)$$

5. Heat Stored in Rubber

$$Q_{sr} = m_r C_{pr} \Delta T + m_{wr} C_{pH_2O} \Delta T \quad (7)$$

6. Heat Stored in Room Structure

$$Q_{ss} = \Sigma (m_s C_{ps} \Delta T) \quad (8)$$