THERMAL ENERGY ANALYSIS

Conduct a detailed thermal analysis of the home that you are currently in. You will estimate the energy required to maintain a comfortable indoor air temperature within your home for one full year.

Final Deliverables

(1) A detailed Thermal Circuit of your home, showing:

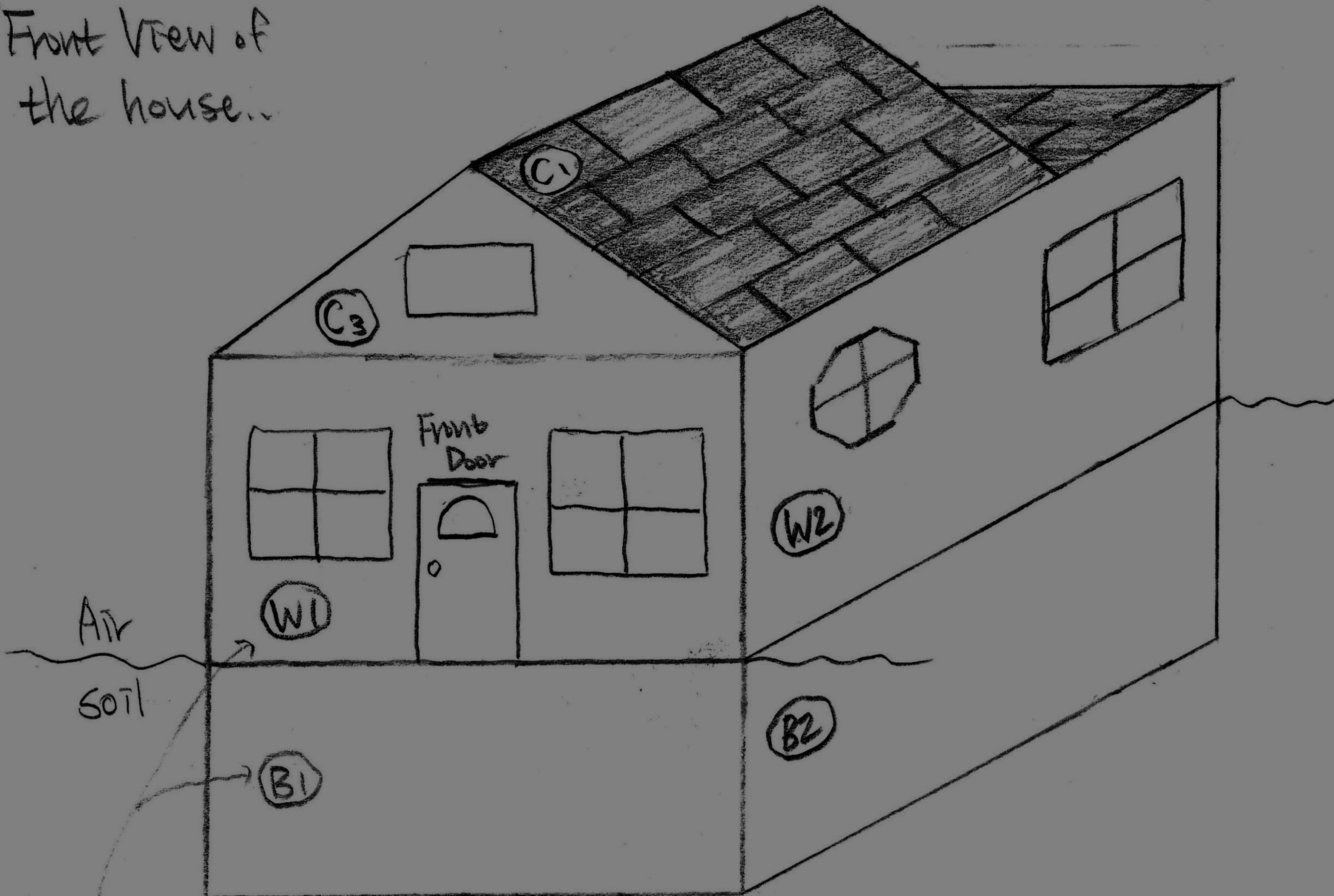
- All relevant resistances (conductive, convective, contact, etc.) laid out in a large clearly drawn circuit corresponding diagrams of the home's overall composite structure. Multiple versions of the whole circuit can, and should, be shown by simplifying the resistance network and using clearly explained equivalent circuits.
- Appropriate representations of all relevant features of the home including composite walls, floors, windows, attics, basements, etc.
- Appropriate representations of all relevant thermal processes and boundary conditions occurring in your home
- All resistive elements should be detailed as subcomponents in subsections including schematics showing geometry, material properties, and explicit calculations of HTC and all relevant assumptions and analysis used to do so.

(2) A Thermal Energy Analysis of your home showing the amount of energy required to maintain comfortable conditions inside your home for one full year. You will:

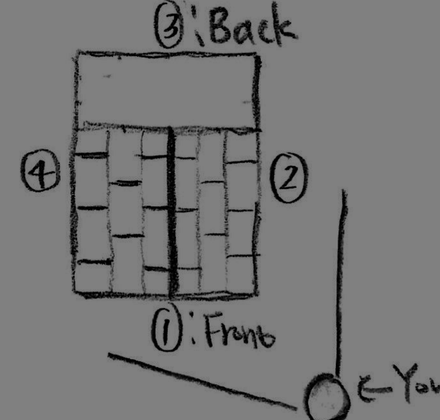
- Model the weather outside of your home using monthly averages from the city that you were born in. Include a subsection detailing the relevant weather conditions that you are using in your model. Plot them.
- Solve your thermal circuit to calculate the total thermal energy required to heat and cool your home so that you stay at a comfortable 70°F (21°C). Calculate and plot monthly values showing both heating and cooling loads.

June Kwon

Front View of the house..

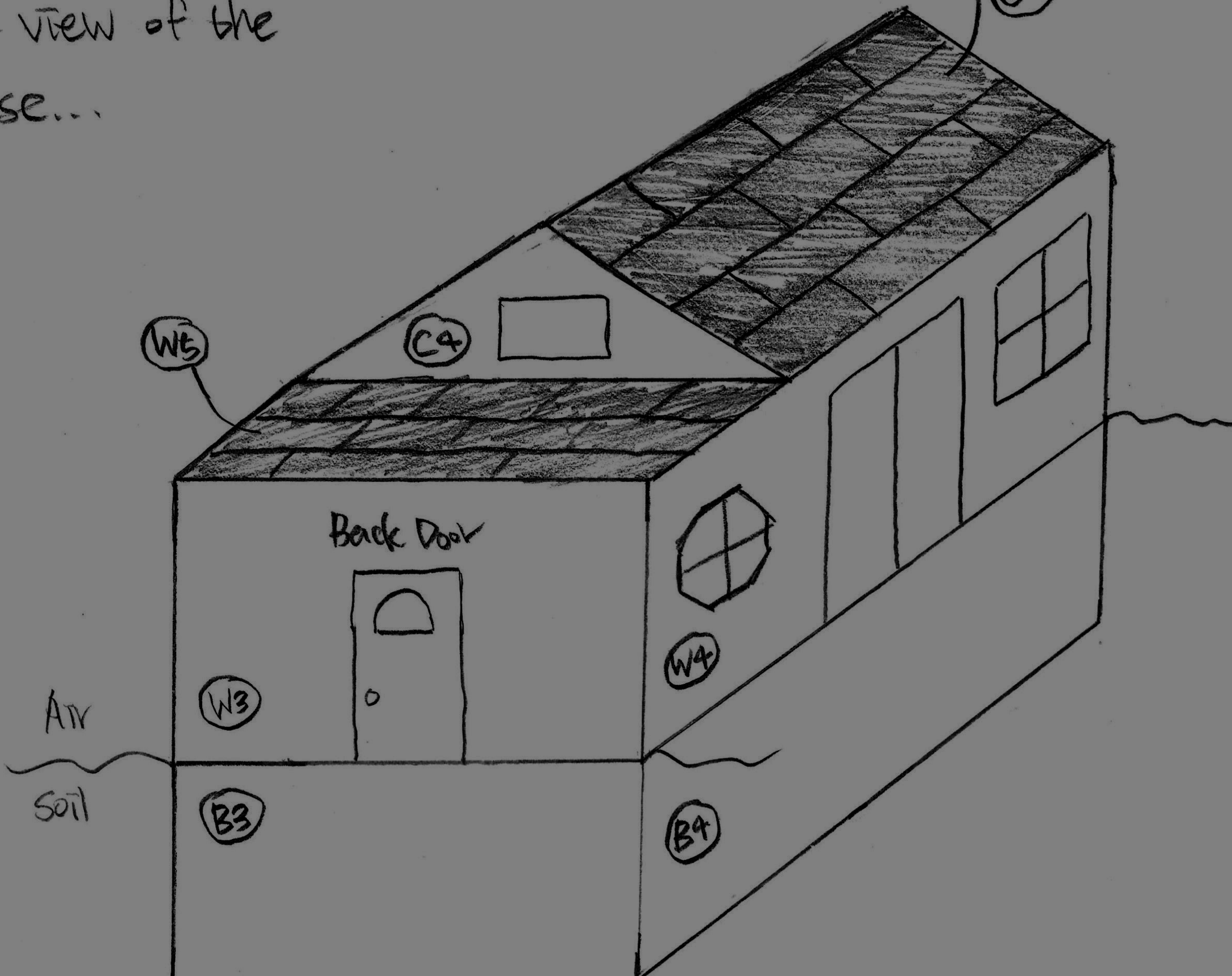


You are looking from...

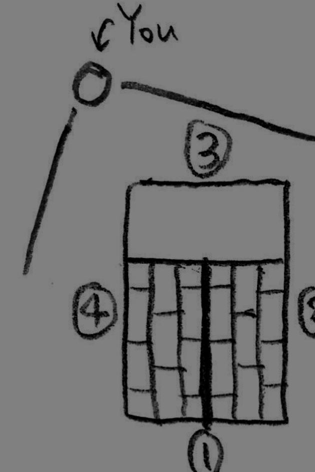


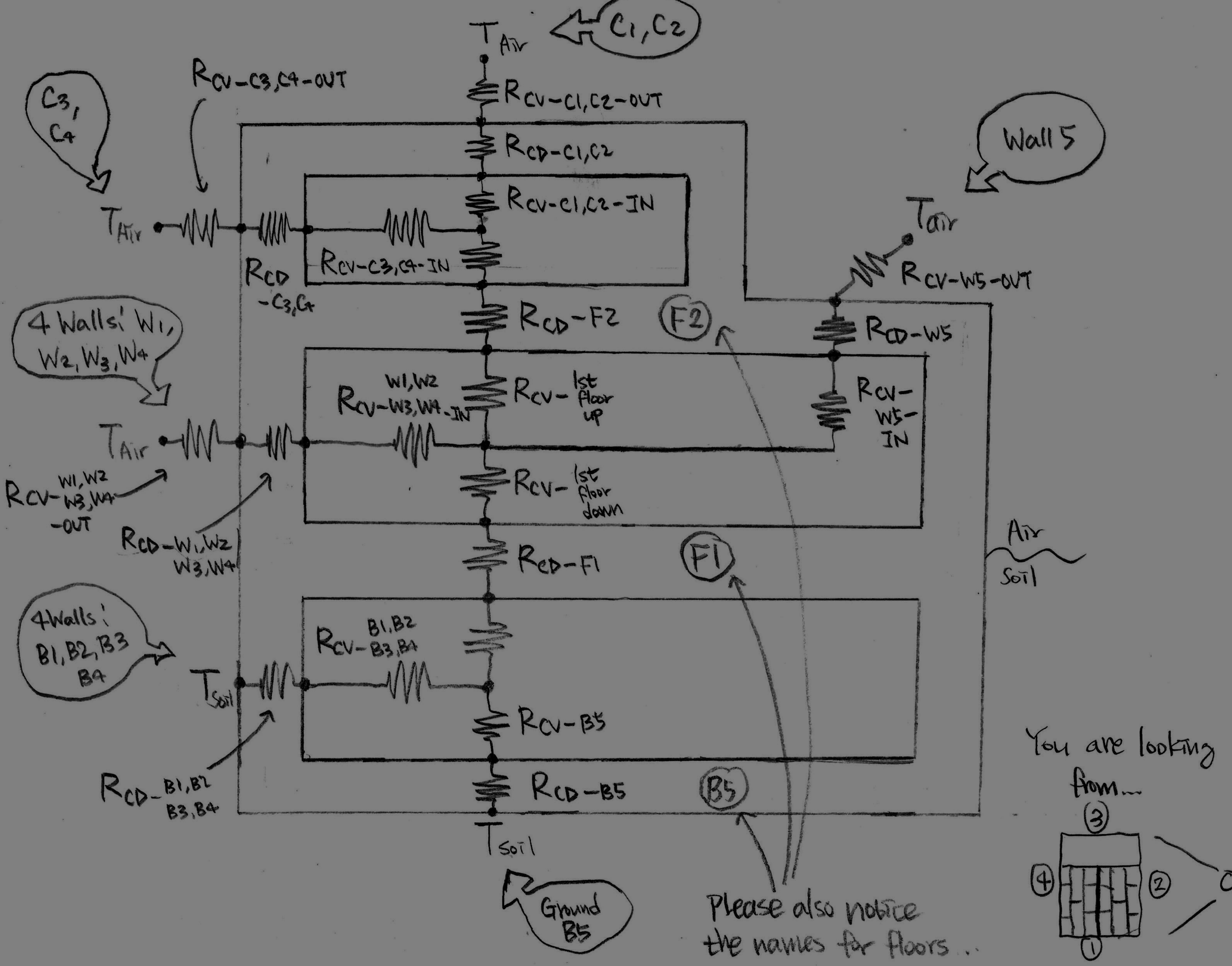
Please notice the wall names.. they will show up very frequently

Back view of the house...

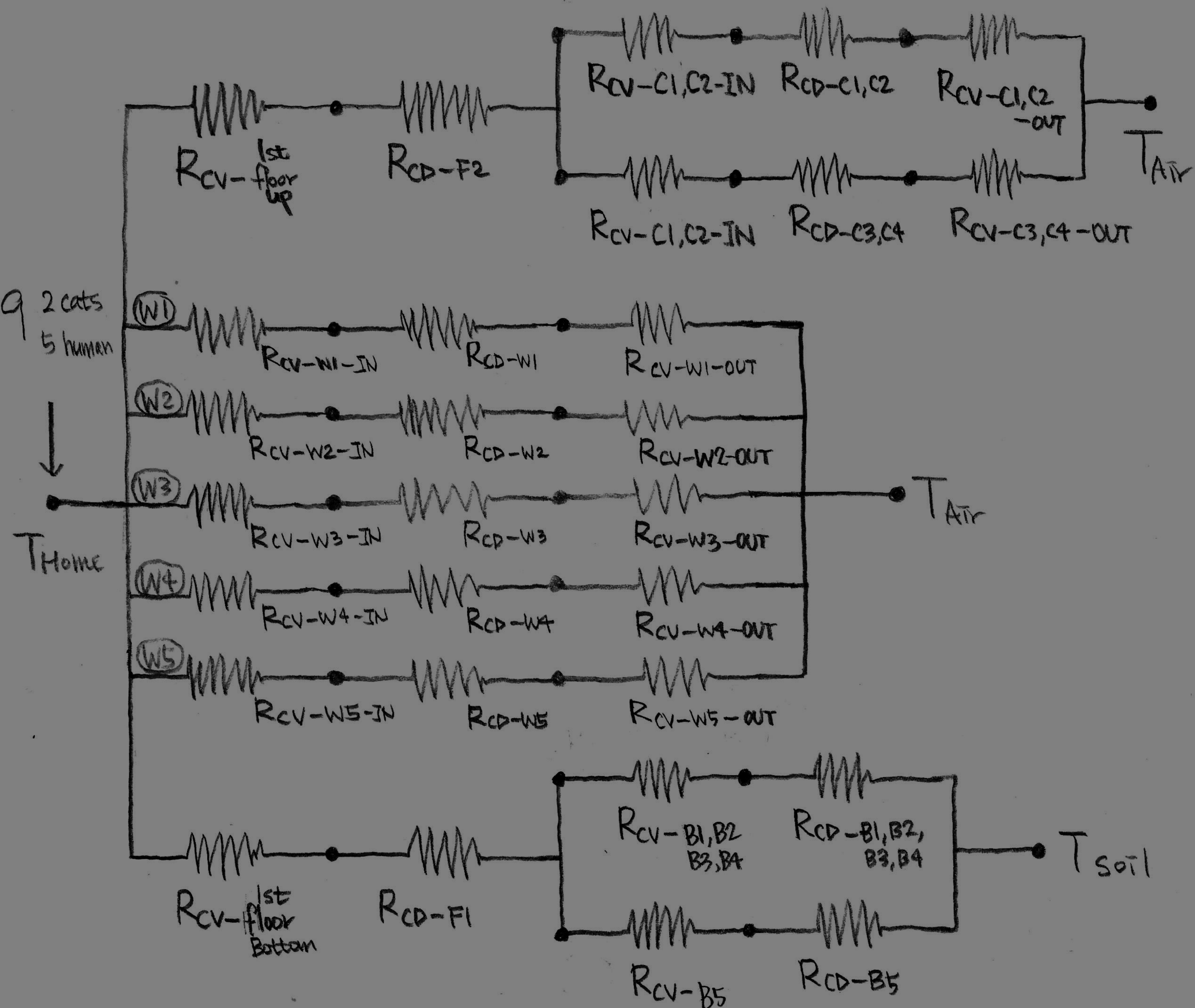


You are looking from...




C1, C2
T Air
RCV-C1,C2-OUT
RCD-C1,C2
RCV-C1,C2-IN
C3, C4
RCV-C3,C4-OUT
T Air
RCV-C3,C4-IN
RCD -C3,C4
Wall 5
T air
RCV-W5-OUT
RCD-W5
RCV-W5-IN
RCD-F2
F2
4 Walls: W1, W2, W3, W4
RCV-W1,W2 W3,W4-IN
RCV-1st floor up
T Air
RCV-W1,W2 W3,W4 -OUT
RCD-W1,W2 W3,W4
RCV-1st floor down
RCD-F1
F1
Air
Soil
4 Walls: B1, B2, B3 B4
RCV-B1,B2 B3,B4
T Soil
RCV-B5
RCD-B1,B2 B3,B4
RCD-B5
B5
T soil
Ground B5
Please also notice the names for floors...
You are looking from...
3
4
2
1

Then, my thermal circuit is...



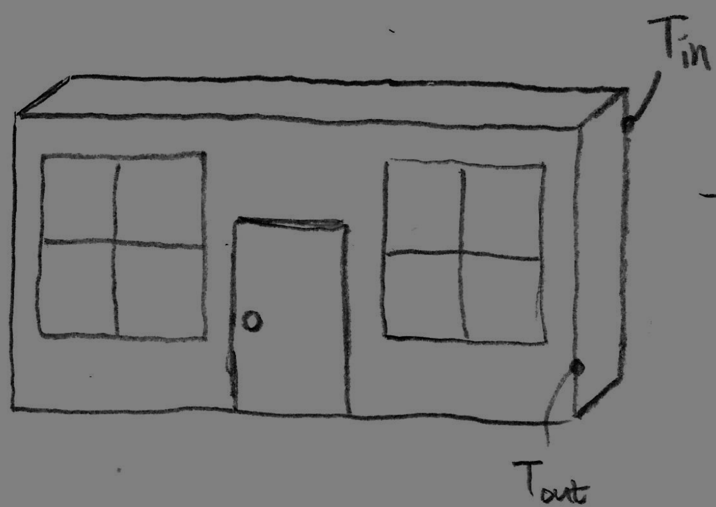
CV means.. "Convection"

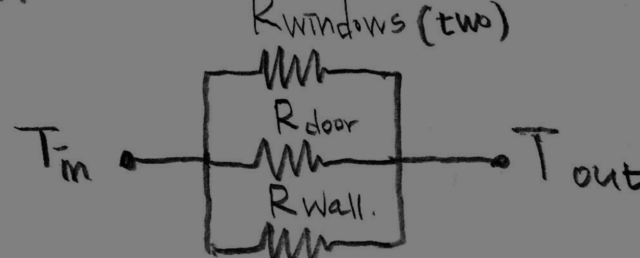
CD means "conduction"

(*For ex

Rcv-W4-IN: "Convective thermal resistance inside the home on wall 4")

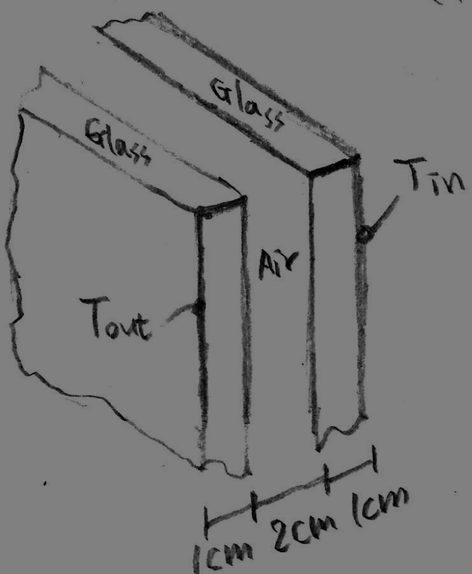
W1 Analysis





ok, let's examine one by one

$R_{windows}$) (My house's windows are double-pane glass.



$$R_{glass} = \frac{L}{KA} = \frac{0.01}{(0.8)(0.012)} = 0.5208\ \text{K/W}$$

$$R_{air} = \frac{R''_{Tc}}{A} = \frac{0.4167}{(0.012)} = 17.36\ \text{K/W}$$

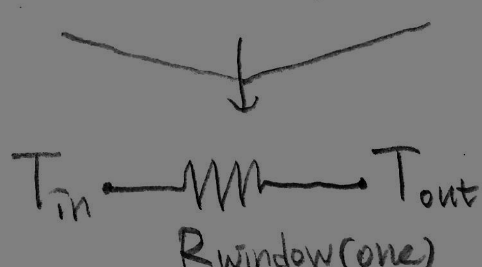
$$R_{glass} = \frac{L}{KA} = \frac{0.01}{(0.8)(0.012)} = 0.5208\ \text{K/W}$$

$A = 0.012\ m^2$

$k_{window} = 0.8\ W/mK$

$R''_{Tc} = 0.4167\ m^2K/W$

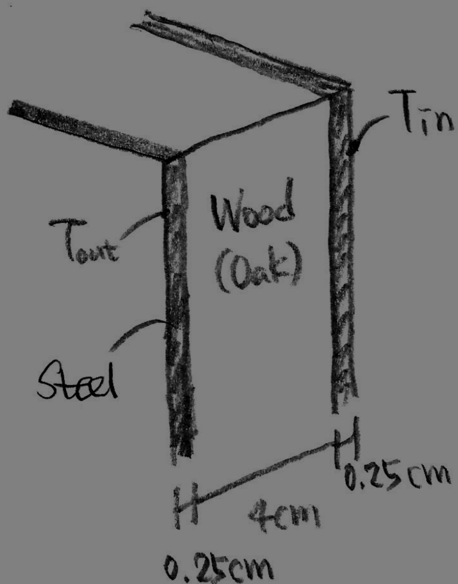
↑ contact resistance of air for 2cm

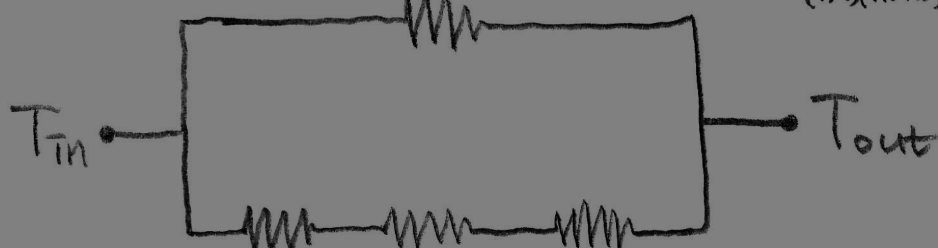


$$\underset{\text{(two)}}{R_{window}} = R_{glass} + R_{air} + R_{glass} = 36.8055\ \text{K/W}$$

R_{door})

$$R_{window(one)} = \frac{L}{kA} = \frac{0.04}{(0.8)(0.1413)} = 0.3538$$



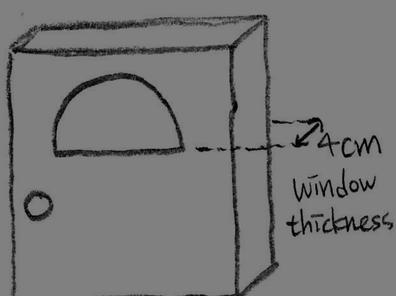


R_{ST} R_{oak} R_{ST}

$$R_{ST} = \frac{L}{kA} = \frac{0.0025}{(48.9)(1.6586)} = 3.0823\times10^{-5}\ K/W$$

$$R_{oak} = \frac{L}{kA} = \frac{0.04}{(0.19)(1.6586)} = 0.1269\ K/W$$

$$R_{ST} = \frac{L}{kA} = \frac{0.0025}{(48.9)(1.6586)} = 3.0823\times10^{-5}\ K/W$$



I also have a window (single pane)

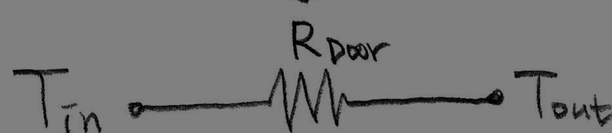
$A_{oak} = A_{ST} = 1.6586\ m^2$

$A_{window} = 0.1413\ m^2$

$k_{oak} = 0.19\ W/mK$

$k_{ST} = 48.9\ W/mK$

$k_{window} = 0.8\ W/mK$

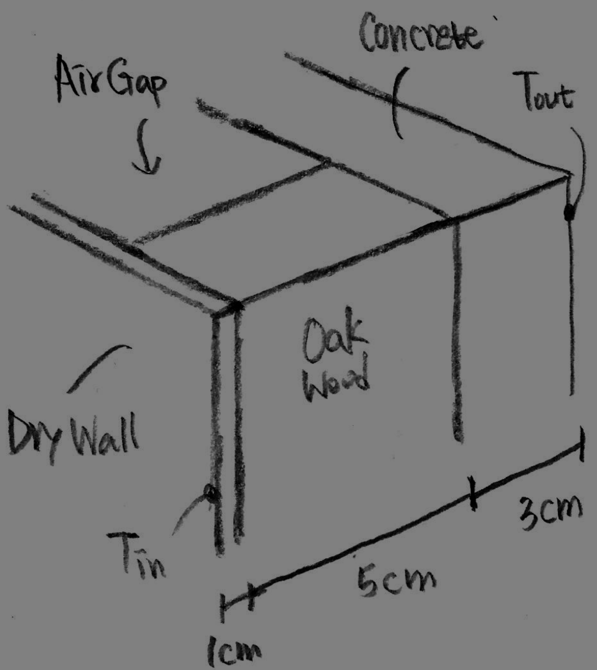


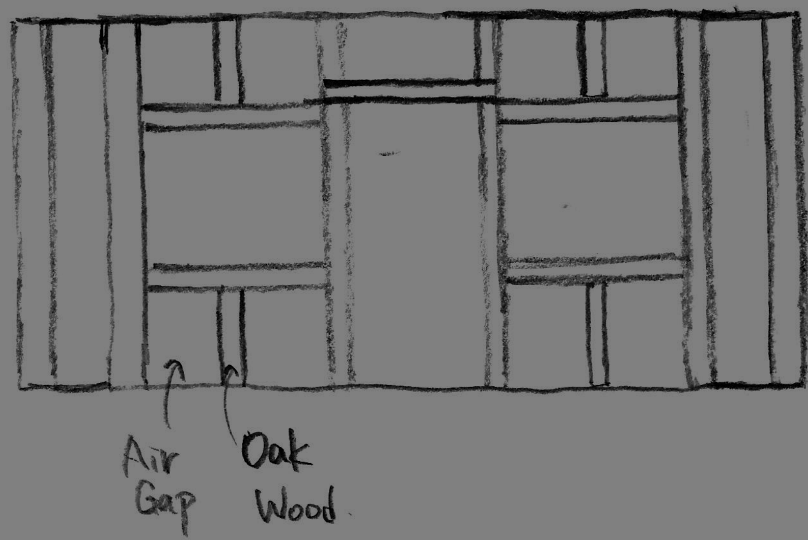
$$R_{door} = \left(\frac{1}{R_{ST}+R_{oak}+R_{ST}} + \frac{1}{R_{window(one)}}\right)^{-1}$$

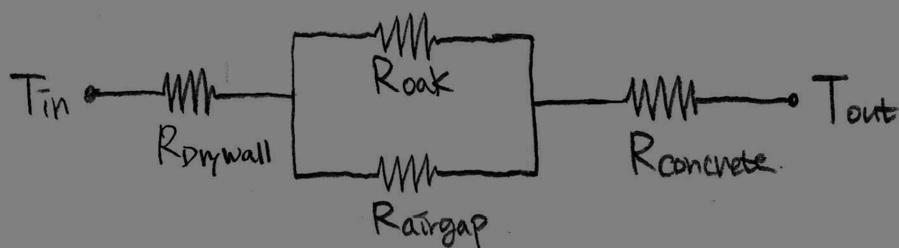
Plug in.. I have R_{door}

$$\langle\ R_{door} = 0.0934\ K/W\ \rangle$$

R_{wall})







$A_{Drywall} = 25m^2$

$A_{concrete} = 25m^2$

$A_{AirGap} = 21m^2$

$A_{oak} = 4m^2$

$K_{DryWall} = 1.1\ W/mk$

$K_{concrete} = 0.67\ W/mk$

$K_{AirGap} = 0.024\ W/mk$

$K_{oak} = 0.19\ W/mk$

$$R_{Drywall} = \frac{L}{KA} = \frac{(0.01)}{(1.1)(25)} = 3.6363\times10^{-4}\ K/W$$

$$R_{oak} = \frac{L}{KA} = \frac{(0.05)}{(0.19)(4)} = 0.06579\ K/W$$

$$R_{concrete} = \frac{L}{KA} = \frac{(0.03)}{(0.67)(25)} = 0.00179\ K/W$$

$$R_{Airgap} = \frac{L}{KA} = \frac{(0.05)}{(0.024)(21)} = 0.0992\ K/W$$

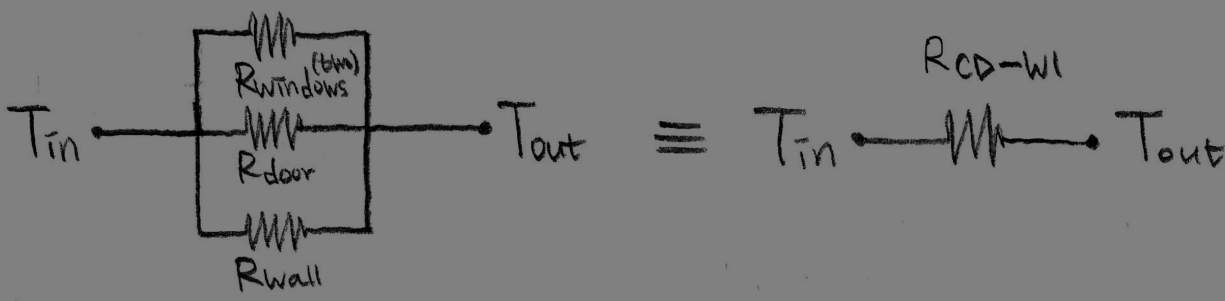
Thus,

$$R_{wall} = R_{Drywall} + \left(\frac{1}{R_{oak}} + \frac{1}{R_{airgap}}\right)^{-1} + R_{concrete}$$

Plug in

$$\langle\ R_{wall} = 0.04171\ K/W\ \rangle$$

Thus, R_{CD-WI} is...

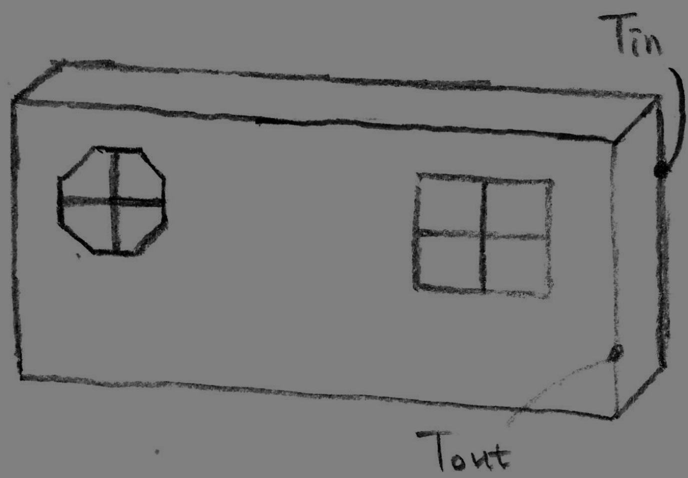


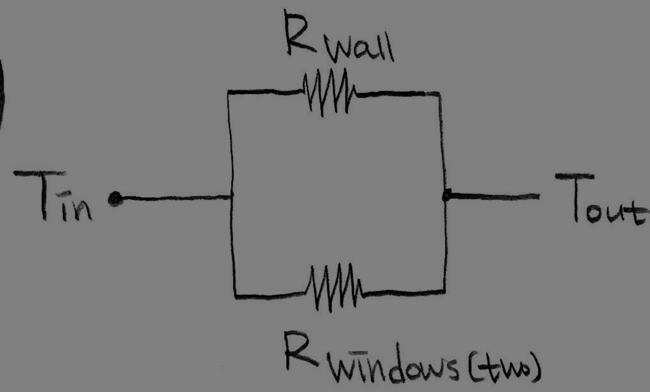
where

$$R_{CD-WI} = \left(\underset{\uparrow\, 36.8055\ K/W}{\frac{1}{R_{windows(two)}}} + \underset{\uparrow\, 0.0934\ K/W}{\frac{1}{R_{door}}} + \underset{\uparrow\, 0.04171\ K/W}{\frac{1}{R_{wall}}} \right)^{-1}$$

$$\left[R_{CD-WI} = 0.02881\ K/W \right]$$

W2 Analysis





$R_{windows(two)}$ (Double Pane, same as W1 analysis)

$$R_{windows(two)} = R_{glass} + R_{air} + R_{glass} = \frac{L}{kA} + \frac{R''_{TC}}{A} + \frac{L}{kA}$$

* Plug in

$L_{glass} = 0.01\,m$ $\qquad R''_{TC} = 0.4167\ m^2K/W$

$k_{window} = 0.8\ W/mK$ $\qquad A = 1.35\,m^2 + 0.3\,m^2 = 1.65\,m^2$

↑ square window ↑ Octagon window

$$= \frac{0.01}{(0.8)(1.65)} + \frac{0.4167}{1.65} + \frac{0.01}{(0.8)(1.65)}$$

Thus,

$$\langle R_{windows(two)} = 0.2677\ K/W \rangle$$

R_{wall}) for W2

$A_{Drywall} = 31\,m^2$

$A_{concrete} = 31\,m^2$

$A_{airgap} = 26\,m^2$

$A_{oak} = 5\,m^2$

Same wall property as W1 only <u>area</u> is different

$$R_{DryWall} = \frac{L}{KA} = \frac{0.01}{(1.1)(31)} = 2.9325\times10^{-4}\ K/W$$

$$R_{oak} = \frac{L}{KA} = \frac{0.05}{(0.19)(5)} = 0.05263\ K/W$$

$$R_{concrete} = \frac{L}{KA} = \frac{0.03}{(0.67)(31)} = 0.00144\ K/W$$

$$R_{Airgap} = \frac{L}{KA} = \frac{0.05}{(0.024)(26)} = 0.08012\ K/W$$

Thus,

$$R_{wall} = R_{Drywall} + \left(\frac{1}{R_{oak}} + \frac{1}{R_{airgap}}\right)^{-1} + R_{concrete}$$

Thus

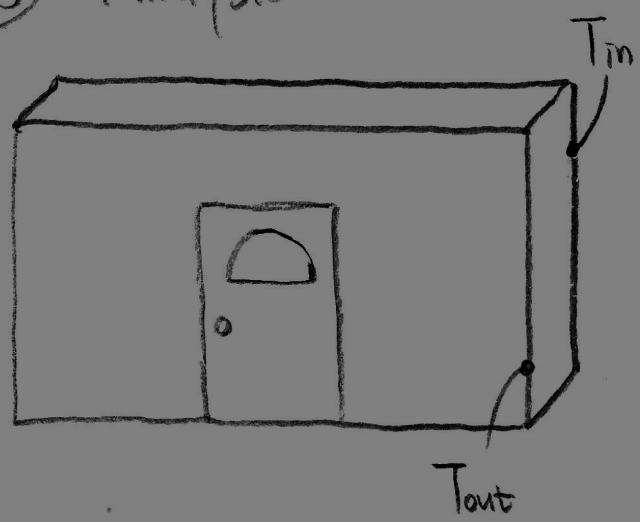
$$\langle R_{wall} = 0.03350\ K/W \rangle$$

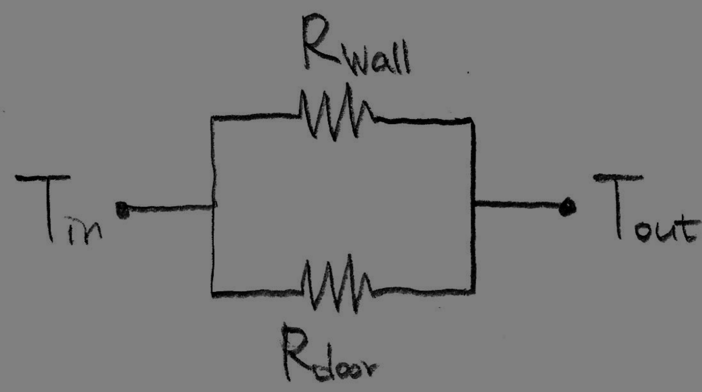
Therefore, R_{CD-W2} is...

$$R_{CD-W2} = \left(\frac{1}{\underbrace{R_{windows(two)}}_{0.2677\ K/W}} + \frac{1}{\underbrace{R_{wall}}_{0.03350\ K/W}}\right)^{-1}$$

$$\left[\ R_{CD-W2} = 0.02977\ K/W\ \right]$$

W3 Analysis





R_{door})

R_{door} = same as R_{door} from W1 $= 0.0934\ K/W$

R_{wall})

same wall property as W1, only area is different

$A_{Drywall} = 22\ m^2$, $A_{concrete} = 22\ m^2$, $A_{airgap} = 18\ m^2$, $A_{oak} = 4\ m^2$

$$R_{DryWall} = \frac{L}{KA} = \frac{0.01}{(1.1)(22)} = 4.1322\times10^{-4}\ K/W$$

$$R_{oak} = \frac{L}{KA} = \frac{0.05}{(0.19)(4)} = 0.06578\ K/W$$

$$R_{concrete} = \frac{L}{KA} = \frac{0.03}{(0.67)(22)} = 0.00203\ K/W$$

$$R_{Airgap} = \frac{L}{KA} = \frac{0.05}{(0.024)(18)} = 0.11574\ K/W$$

Thus,

$$R_{wall} = R_{Drywall} + \left(\frac{1}{R_{oak}} + \frac{1}{R_{airgap}} \right)^{-1} + R_{concrete}$$

Thus

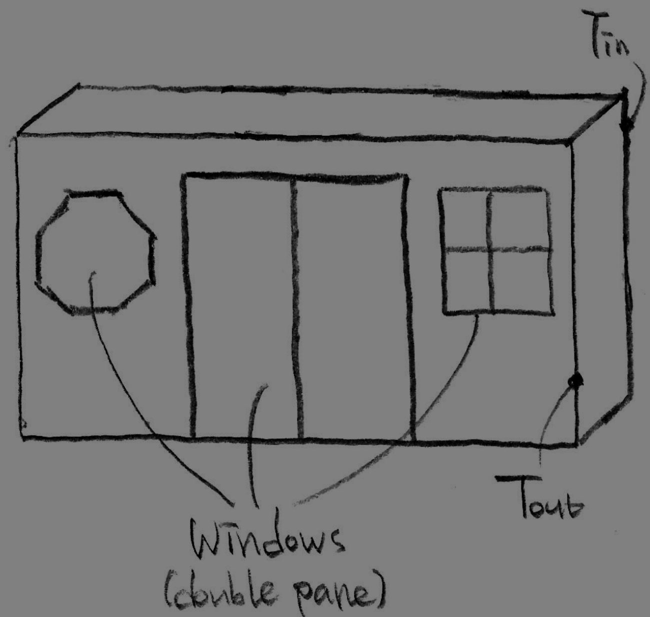
$$\langle R_{wall} = 0.04439 \ K/W \rangle$$

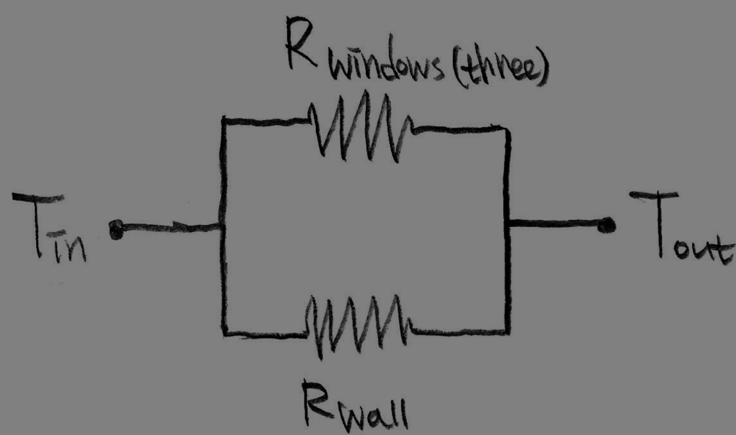
Therefore, R_{CD-W3} is

$$R_{CD-W3} = \left(\frac{1}{\underset{\uparrow 0.0934 \ K/W}{R_{door}}} + \frac{1}{\underset{\uparrow 0.04439 \ K/W}{R_{wall}}} \right)^{-1}$$

$$\left[R_{CD-W3} = 0.0301 \ K/W \right]$$

W4 Analysis





$$R_{windows\,(three)} = R_{glass} + R_{air} + R_{glass} = \frac{L}{KA} + \frac{R''_{TC}}{A} + \frac{L}{KA}$$

* plug in

$L_{glass} = 0.01\,m$ $\qquad R''_{TC} = 0.4167\ m^2K/W$

$K_{window} = 0.8\ W/mK$ $\qquad A = 0.9375\,m^2 + 0.3\,m^2 + 2.1\,m^2$

↑ square window ↑ Octogon window ↑ Balcony window

$= 3.3375\,m^2$

$$= \frac{0.01}{(0.8)(3.3375)} + \frac{0.4167}{3.3375} + \frac{0.01}{(0.8)(3.3375)}$$

Thus,

$$\langle R_{windows\,(three)} = 0.13234\ K/W \rangle$$

R_{wall})

same wall property as W1 only area is different

$$A_{Drywall} = 28\,m^2,\ A_{concrete} = 28\,m^2,\ A_{airgap} = 24\,m^2,\ A_{oak} = 4\,m^2$$

$$R_{Drywall} = \frac{L}{KA} = \frac{0.01}{(1.1)(28)} = 3.2467\times10^{-4}\ K/W$$

$$R_{oak} = \frac{L}{KA} = \frac{0.05}{(0.19)(4)} = 0.06579\ K/W$$

$$R_{concrete} = \frac{L}{KA} = \frac{0.03}{(0.67)(28)} = 0.0016\ K/W$$

$$R_{airgap} = \frac{L}{KA} = \frac{(0.05)}{(0.024)(24)} = 0.0868\ K/W$$

Thus,

$$R_{wall} = R_{Drywall} + \left(\frac{1}{R_{oak}} + \frac{1}{R_{airgap}}\right)^{-1} + R_{concrete}$$

Thus,

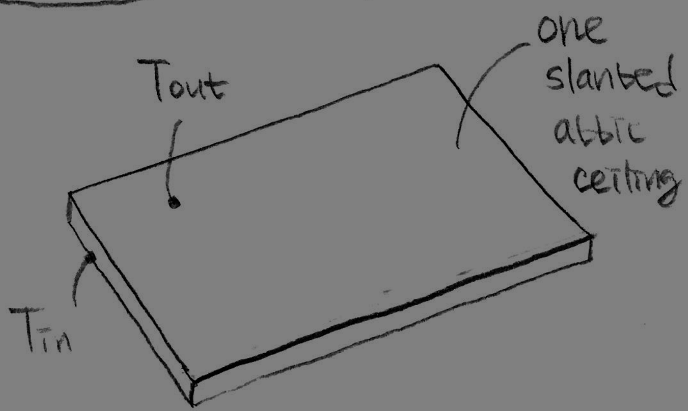
$$\langle R_{wall} = 0.03934\ K/W \rangle$$

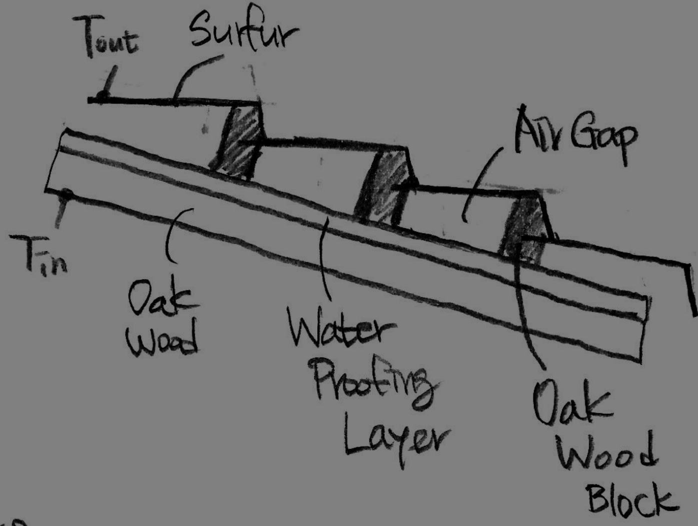
Therefore, R_{CD-W4} is

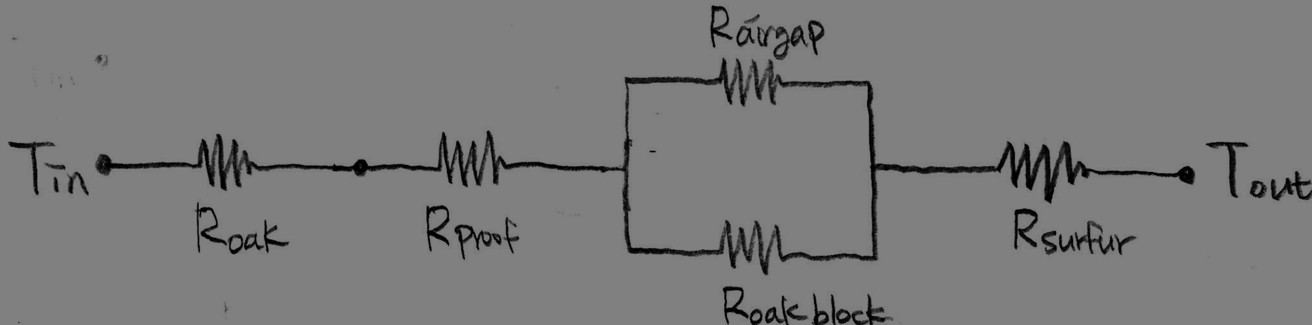
$$R_{CD-W4} = \left(\frac{1}{\underset{\uparrow\,0.13234}{R_{\substack{windows\\(three)}}}} + \frac{1}{\underset{\uparrow\,0.03934}{R_{wall}}}\right)^{-1}$$

$$\left[\ R_{CD-W4} = 0.03033\ K/W\ \right]$$

C_1, C_2 Analysis







oak: $L = 3\,cm$, $k = 0.19\ W/mK$, $A = 23\ m^2$

Water Proofing Layer: $L = 1\,cm$, $k = 0.3\ W/mK$, $A = 23\,m^2$

Airgap: $L = 3\,cm$ (Average), $k = 0.024\ W/mK$, $A = 11\ m^2$

Oak block: $L = 4\,cm$, $k = 0.19\ W/mK$, $A = 12\ m^2$

Surfur: $L = 1.5\,cm$, $k = 0.24\ W/mK$, $A = 23\ m^2$

$$R_{oak} = \frac{L}{KA} = \frac{0.03}{(0.19)(23)} = 0.00686\ K/W$$

$$R_{proof} = \frac{L}{KA} = \frac{0.01}{(0.3)(23)} = 0.00145\ K/W$$

$$R_{airgap} = \frac{L}{KA} = \frac{0.03}{(0.024)(11)} = 0.1136\ K/W$$

$$R_{surfur} = \frac{L}{KA} = \frac{0.015}{(0.24)(23)} = 0.00272\ K/W$$

$$R_{oak\ block} = \frac{L}{KA} = \frac{0.04}{(0.19)(12)}$$

$$= 0.01754\ K/W$$

Thus, combining all. $T_{in} \xrightarrow[R_{CD-C1}]{} T_{out}$

$$R_{CD-C1} = R_{CD-C2} = \overset{0.00686}{R_{oak}} + \overset{0.00145}{R_{proof}} + \overset{0.00272}{R_{surfur}} + \left(\frac{1}{\underset{0.1136}{R_{airgap}}} + \frac{1}{\underset{0.01754}{R_{oakblock}}} \right)^{-1}$$

$$\boxed{R_{CD-C1} = R_{CD-C2} = 0.02623 \ K/W}$$

W5 Ananlysis

W5 is a roof just like C1 and C2
with same structure inside.
only area is different.

oak: Area = $18 m^2$

Water Proofing Layer: Area = $18 m^2$

Airgap: Area = $9 m^2$

Oak Block: Area = $9 m^2$

Surfur: Area = $18 m^2$

$$R_{oak} = \frac{L}{KA} = \frac{0.03}{(0.19)(18)} = 0.00877 \ K/W$$

$$R_{proof} = \frac{L}{KA} = \frac{0.01}{(0.3)(18)} = 0.00185 \ K/W$$

$$R_{airgap} = \frac{L}{KA} = \frac{0.03}{(0.024)(9)} = 0.1389 \ K/W$$

$$R_{surfur} = \frac{L}{KA} = \frac{0.015}{(0.24)(18)} = 0.00347 \ K/W$$

$$R_{oakblock} = \frac{L}{KA} = \frac{0.04}{(0.19)(9)} = 0.0234 \ K/W$$

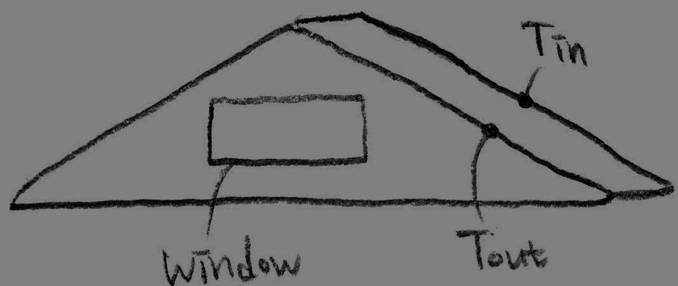
Thus

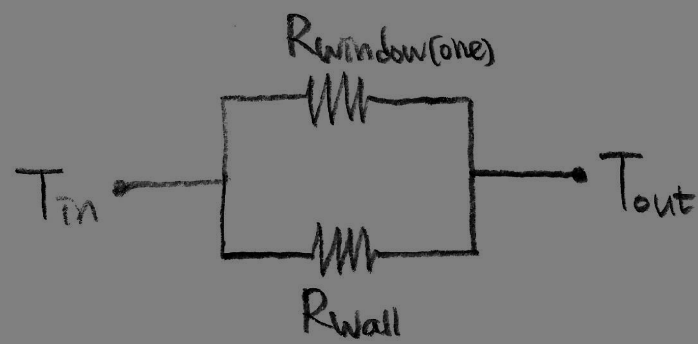
$$R_{CD-W5} = \overset{0.00877}{R_{oak}} + \overset{0.00185}{R_{proof}} + \overset{0.00347}{R_{surfur}}$$

$$+ \left(\frac{1}{\underset{0.1389}{R_{airgap}}} + \frac{1}{\underset{0.0234}{R_{oakblock}}} \right)^{-1}$$

$$\left[R_{CD-W5} = 0.03412 \ K/W \right]$$

C3, C4 Analysis





$$R_{window(one)} = R_{glass} + R_{air} + R_{glass} = \frac{L}{KA} + \frac{R''_{TC}}{A} + \frac{L}{KA}$$

(Double pane)

* Plug in

$L_{glass} = 0.01\,m$ $\quad R''_{TC} = 0.4167\ m^2K/W$

$K_{window} = 0.8\ W/mK$ $\quad A = 0.375\ m^2$

$$= \frac{0.01}{(0.8)(0.375)} + \frac{0.4167}{0.375} + \frac{0.01}{(0.8)(0.375)}$$

Thus,

$$\langle R_{window(one)} = 1.1779\ K/W \rangle$$

R_{wall})

same wall property as W1. only area is different.

$A_{DryWall} = 15\ m^2$ $\quad A_{Airgap} = 11\ m^2$

$A_{concrete} = 15\ m^2$ $\quad A_{oak} = 4\ m^2$

$$R_{Drywall} = \frac{L}{KA} = \frac{0.01}{(1.1)(15)} = 6.0606\times10^{-4}\ K/W$$

$$R_{oak} = \frac{L}{KA} = \frac{0.05}{(0.19)(4)} = 0.0658\ K/W$$

$$R_{concrete} = \frac{L}{KA} = \frac{0.03}{(0.67)(15)} = 0.00298\ K/W$$

$$R_{airgap} = \frac{L}{KA} = \frac{0.05}{(0.024)(11)} = 0.18939\ K/W$$

Thus,

$$R_{wall} = R_{Drywall} + \left(\frac{1}{R_{oak}} + \frac{1}{R_{airgap}}\right)^{-1} + R_{concrete}$$

Thus,

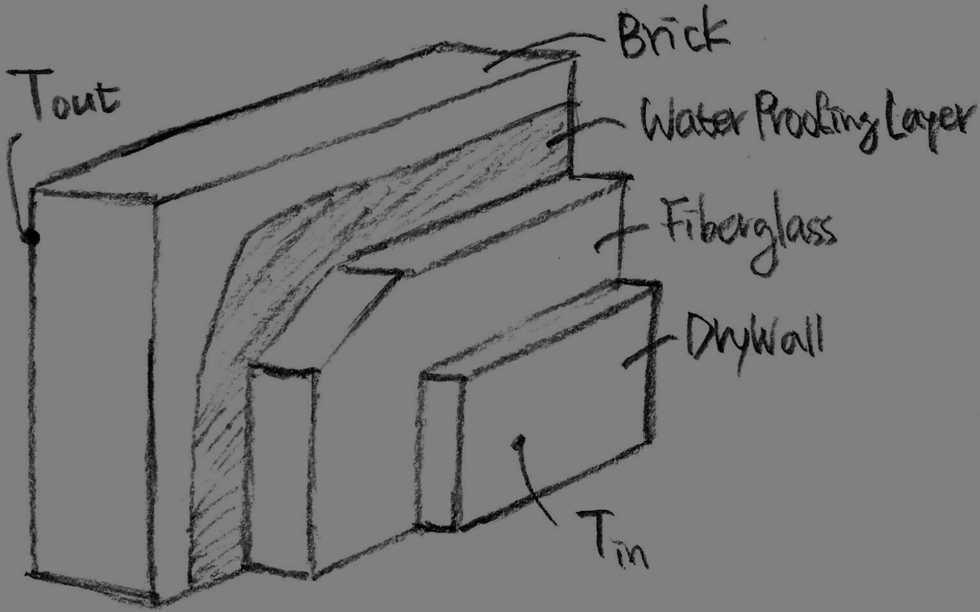
$$\langle R_{wall} = 0.05242\ K/W \rangle$$

Therefore, R_{CD-C3}, R_{CD-C4} are...

$$R_{CD-C3} = R_{CD-C4} = \left(\frac{1}{\underbrace{R_{windows\,(one)}}_{1.1779}} + \frac{1}{\underbrace{R_{wall}}_{0.05242}}\right)^{-1}$$

$$\left[R_{CD-C3} = R_{CD-C4} = 0.05018\ K/W \right]$$

B1, B2, B3, B4 Analysis



DryWall: $L = 1\,cm$, $K = 1.1\,W/mK$, $A = 21.5\,m^2$ (one wall: Average of 4 walls)

Fiber Glass: $L = 4\,cm$, $K = 0.058\,W/mK$, $A = 21.5\,m^2$

Water Proofing Layer: $L = 1\,cm$, $K = 0.3\,W/mK$, $A = 21.5\,m^2$

Brick: $L = 4\,cm$; $K = 1.3\,W/mK$, $A = 21.5\,m^2$

$$R_{Dry} = \frac{L}{KA} = \frac{0.01}{(1.1)(21.5)} = 4.228 \times 10^{-4}\,K/W$$

$$R_{Fiber} = \frac{L}{KA} = \frac{0.04}{(0.058)(21.5)} = 0.0321\,K/W$$

$$R_{Proof} = \frac{L}{KA} = \frac{0.01}{(0.3)(21.5)} = 0.00155\,K/W$$

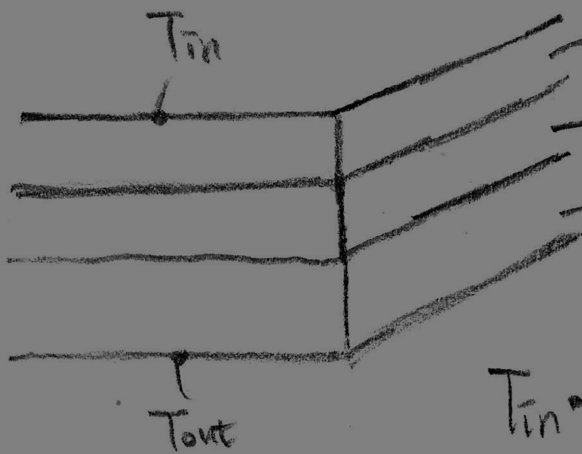
$$R_{Brick} = \frac{L}{KA} = \frac{0.04}{(1.3)(21.5)} = 0.00143\,K/W$$

Thus,

$$R_{CD-B1,2,3,4} = \underbrace{R_{Dry}}_{4.228\times10^{-4}} + \underbrace{R_{Fiber}}_{0.0321} + \underbrace{R_{Proof}}_{0.00155} + \underbrace{R_{brick}}_{0.00143}$$

$$\left[R_{CD-B1} = R_{CD-B2} = R_{CD-B3} = R_{CD-B4} = 0.0355\ K/W \right]$$

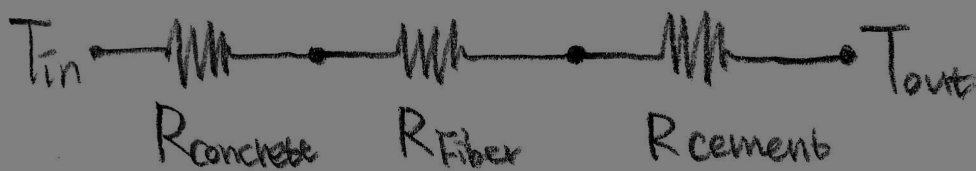
B5 Analysis



Concrete: $L = 5\text{cm}, k = 0.2 \, W/mk, A = 35m^2$

Fiberglass: $L = 5\text{cm}, k = 0.058 \, W/mk, A = 35m^2$

Cement: $L = 7.5\text{cm}, k = 0.22 \, W/mk, A = 35m^2$



$$R_{concrete} = \frac{L}{KA} = \frac{0.05}{(0.2)(35)} = 0.00714 \; K/W$$

$$R_{Fiber} = \frac{L}{KA} = \frac{0.05}{(0.058)(35)} = 0.02463 \; K/W$$

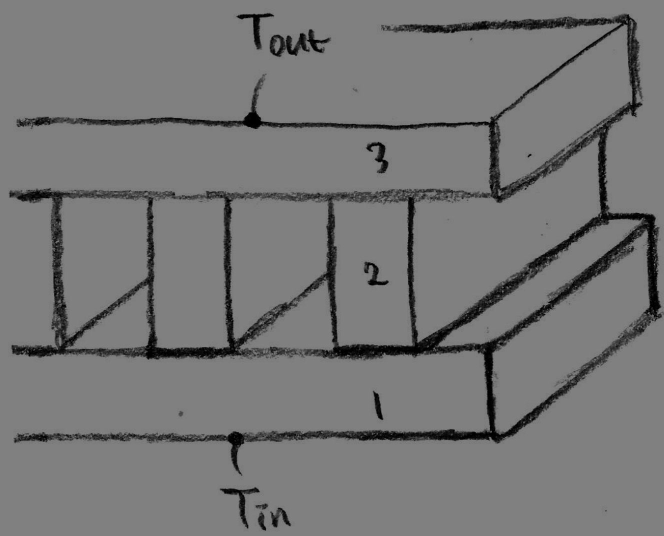
$$R_{cement} = \frac{L}{KA} = \frac{0.075}{(0.22)(35)} = 0.00974 \; K/W$$

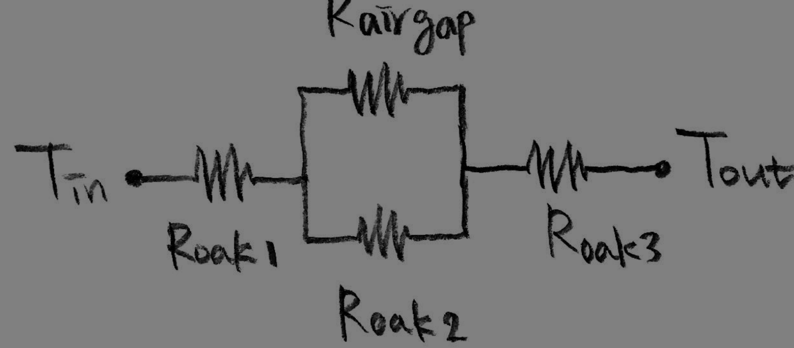
Thus,

$$R_{CD-B5} = \underbrace{R_{concrete}}_{0.00714} + \underbrace{R_{Fiber}}_{0.02463} + \underbrace{R_{cement}}_{0.00974}$$

$$\left[R_{CD-B5} = 0.04151 \; K/W \right]$$

F1, F2 Analysis





Roak1 : $L = 2\,cm,\ k = 0.19\ W/mK,\ A = 35\,m^2$

Roak2 : $L = 2.5\,cm,\ k = 0.19\ W/mK,\ A = 17\,m^2$

Roak3 : $L = 2\,cm,\ k = 0.19\ W/mK,\ A = 35\,m^2$

Airgap : $L = 2.5\,cm,\ k = 0.024\ W/mK,\ A = 18\,m^2$

$$R_{oak1} = \frac{L}{KA} = \frac{0.02}{(0.19)(35)} = 0.00301\ K/W$$

$$R_{oak2} = \frac{L}{KA} = \frac{0.025}{(0.19)(17)} = 0.0077\ K/W$$

$$R_{oak3} = \frac{L}{KA} = \frac{0.02}{(0.19)(35)} = 0.003\ K/W$$

$$R_{airgap} = \frac{L}{KA} = \frac{0.025}{(0.024)(18)} = 0.05787\ K/W$$

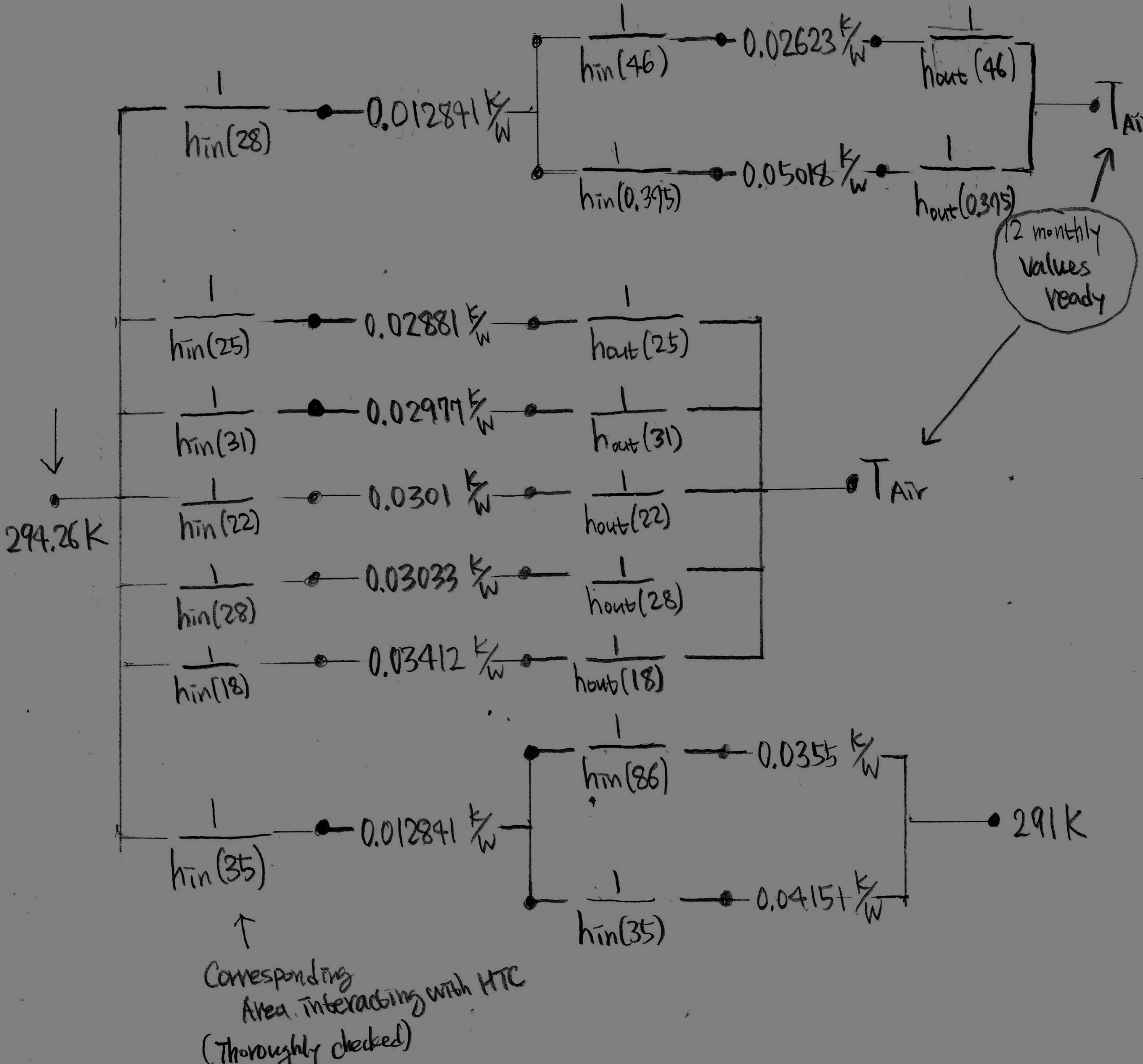
Thus,

$$R_{CD-F1,F2} = \underbrace{R_{oak1}}_{0.00301} + \left(\frac{1}{\underbrace{R_{airgap}}_{0.05787}} + \frac{1}{\underbrace{R_{oak2}}_{0.0077}}\right)^{-1} + \underbrace{R_{oak3}}_{0.003}$$

Thus,

$$\boxed{R_{CD-F1} = R_{CD-F2} = 0.012841 \ K/W}$$

Thus! So far, we have...



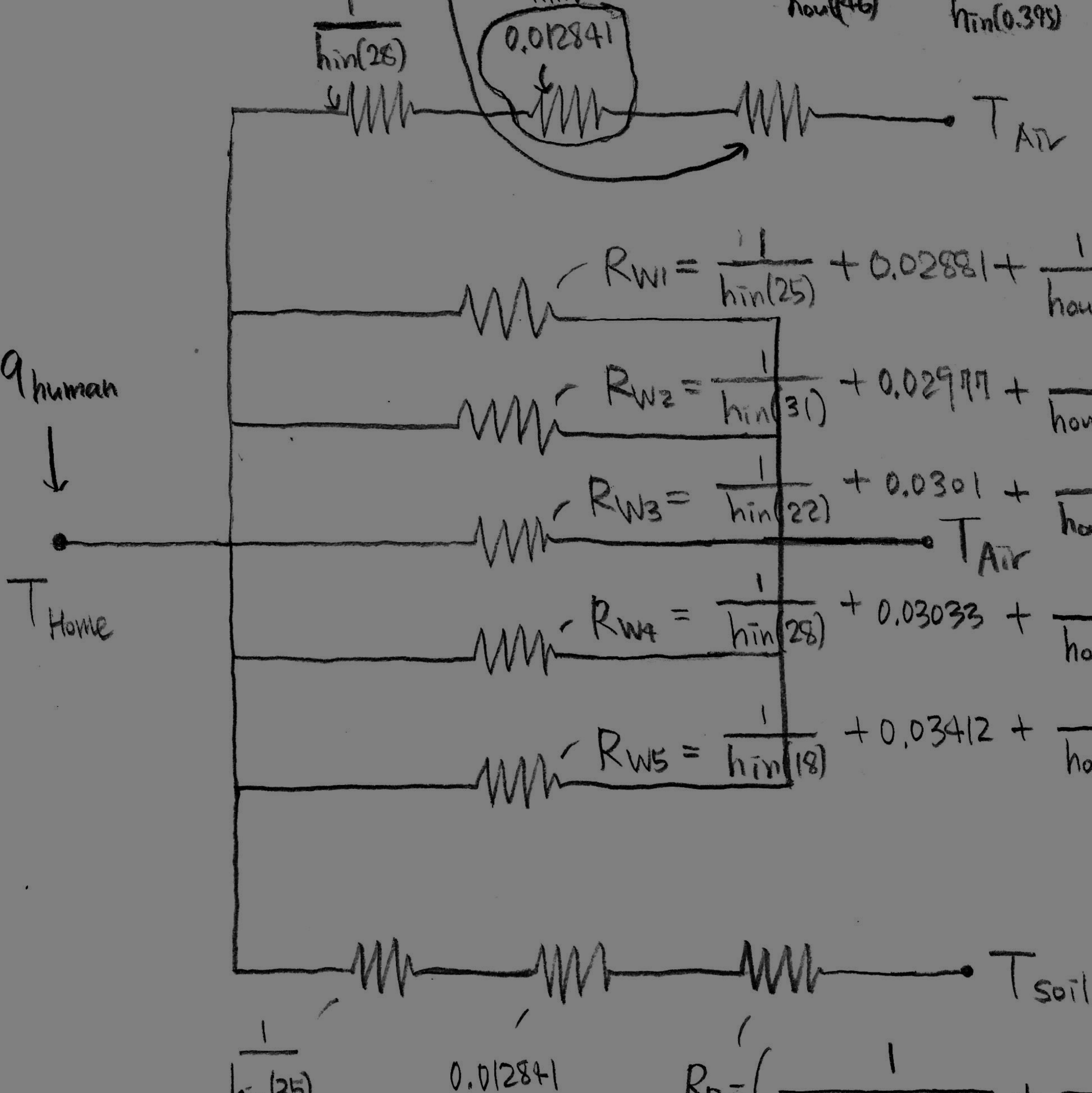
Now, we need hin in 12 monthly values,

and hout in 12 monthly values.

Reducing...

$$R_c = \left(\frac{1}{\frac{1}{h_{in}(46)} + 0.02623 + \frac{1}{h_{out}(46)}} + \frac{1}{\frac{1}{h_{in}(0.395)} + 0.05018 + \frac{1}{h_{out}(0.375)}} \right)^{-1}$$

29



$$R_{W1} = \frac{1}{h_{in}(25)} + 0.02881 + \frac{1}{h_{out}(25)}$$

$$R_{W2} = \frac{1}{h_{in}(31)} + 0.02977 + \frac{1}{h_{out}(31)}$$

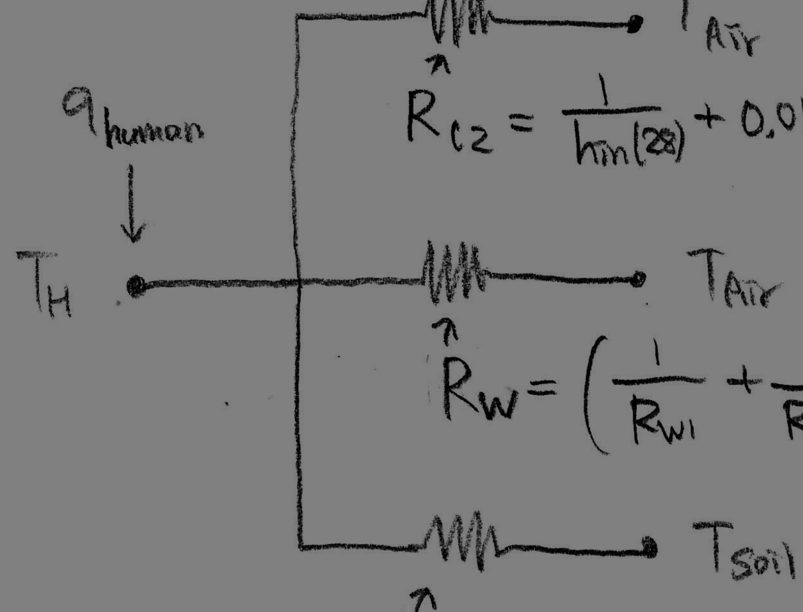
$$R_{W3} = \frac{1}{h_{in}(22)} + 0.0301 + \frac{1}{h_{out}(22)}$$

$$R_{W4} = \frac{1}{h_{in}(28)} + 0.03033 + \frac{1}{h_{out}(28)}$$

$$R_{W5} = \frac{1}{h_{in}(18)} + 0.03412 + \frac{1}{h_{out}(18)}$$

$$R_B = \left(\frac{1}{\frac{1}{h_{in}(86)} + 0.0355} + \frac{1}{\frac{1}{h_{in}(35)} + 0.04151} \right)^{-1}$$

Reducing Further...

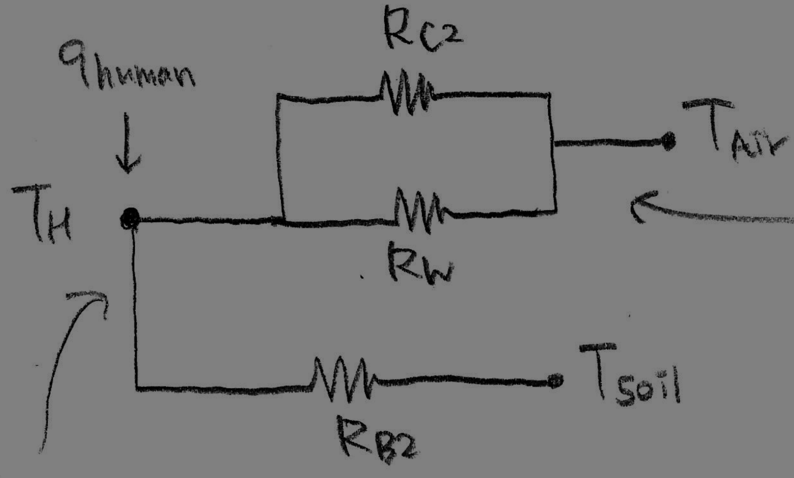


$$R_{C2} = \frac{1}{h\bar{n}(28)} + 0.012841 + R_c$$

$$R_W = \left(\frac{1}{R_{W1}} + \frac{1}{R_{W2}} + \frac{1}{R_{W3}} + \frac{1}{R_{W4}} + \frac{1}{R_{W5}}\right)^{-1}$$

$$R_{B2} = \frac{1}{h\bar{n}(35)} + 0.012841 + R_B$$

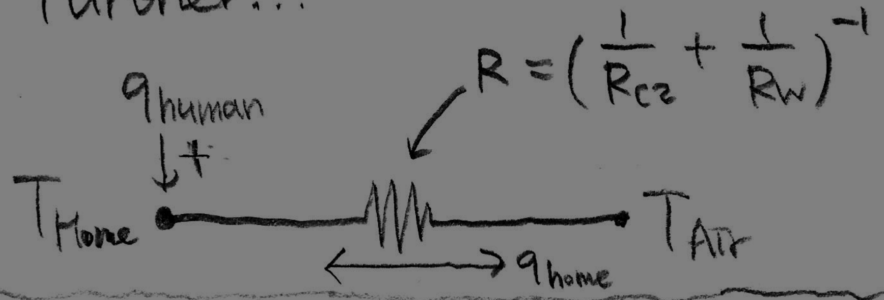
Further...

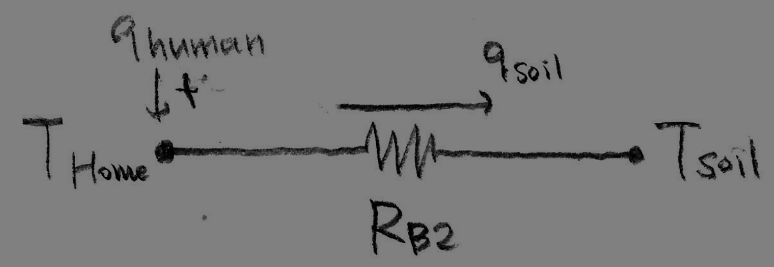


"combine the destination b/c they have the same temperature, T_{Air}"

"separate T_{soil} branch b/c $T_{soil} \neq T_{Air}$."

Further...





Thus, I examine the system in two separate system..

Thus, q can be computed..

$$\left[\, q^{\text{Home}}_{\substack{\text{required}\\ \text{to keep}\\ T_H=21^\circ C}} = \underbrace{\frac{T_{Home}-T_{Air}}{R}}_{q_{Home}} - q_{human} \;\; (\text{if } T_{Home} > T_{Air}) \,\right]$$

$$\left[\, q^{\text{Home}}_{\substack{\text{required}\\ \text{to keep}\\ T_H=21^\circ C}} = \underbrace{\frac{T_{Air}-T_{Home}}{R}}_{q_{home}} + q_{human} \;\; (\text{if } T_{Air} > T_{Home}) \,\right]$$

For q_{soil}, $T_{Home} > T_{soil}$ always

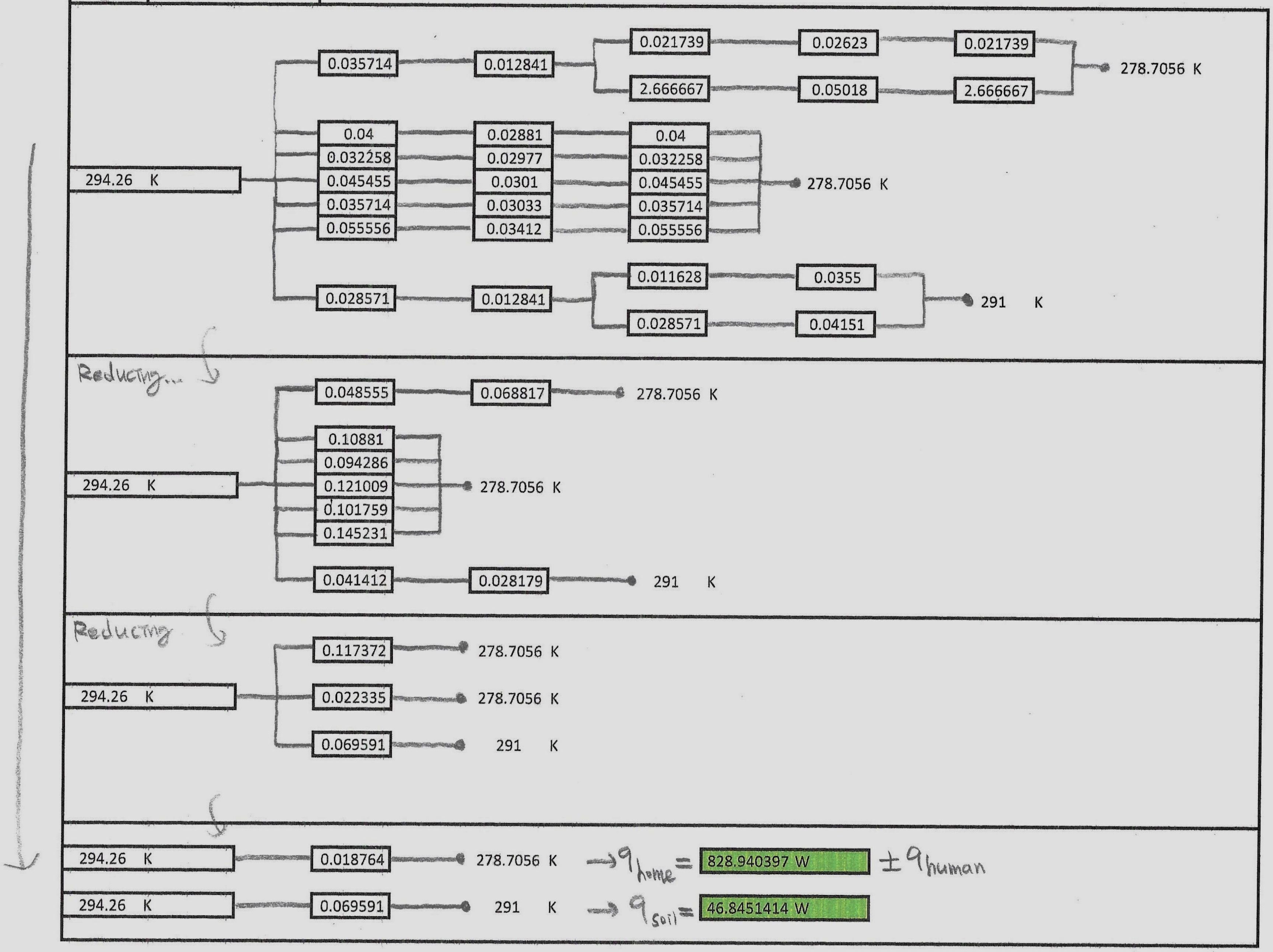
$$\left[\, q^{\text{Soil}}_{\substack{\text{required}\\ \text{to keep}\\ T_H=21^\circ C}} = \underbrace{\frac{T_{Home}-T_{soil}}{R_{B2}}}_{q_{soil}} \,\right]$$

Thus

$$\left[\, q_{\substack{\text{Total}\\ \text{required}}} = q^{\text{Home}}_{\substack{\text{required}\\ \text{to keep}\\ T_H=21^\circ C}} + q^{\text{Soil}}_{\substack{\text{Required}\\ \text{to keep}\\ T_H=21^\circ C}} \,\right]$$

h_IN	1	W/m2K
h_OUT	1	W/m2K
T_air	278.705556	K

← Variable (I can type in any number I want.)



To assist myself, excel model was created...

$\bar{h}$ outside Analysis

To find $\bar{h}_{OUT}$, I consider Raynold Number

$$Re_L = \frac{u_\infty L}{\nu}$$

where u_∞ : wind speed
(12 monthly data ready)
L : length of wall
(height of vertical wall)
(* $L = 2.25\,m$) ← I use this value throughout
ν : kinematic viscosity.

Next, after checking whether the wind is "turbulent" or "laminar" by compairing with $Re_{x,c} = 5 \times 10^5$.

EQ 7.38 is used to compute $\overline{Nu}_L$.

$$\overline{Nu}_L = (0.037\, Re_L^{\frac{4}{5}} - 871)\, P_r^{\frac{1}{3}}$$

(*also
condition that ($Re_L \leq 10^8$), ($0.6 \leq P_r \leq 60$) are all satisfied as well)

Next, knowing $\overline{Nu}_L = \dfrac{\bar{h}_{OUT} L}{k_{air}}$

$\bar{h}_{OUT}$ was computed ⟶ $\bar{h}_{OUT} = \dfrac{\overline{Nu}_L\, k_{air}}{L}$

NJ Data

All Pr is $0.6 \le Pr \le 60$ ✓

	Wind Speed (m/s)	Home Temp (F)	Home Temp (K)	Air Temp (F)	Air Temp (K)	Kinematic Viscosity (m2/s)	Thermal Conductivity (W/mK)	Prandlts Number	Reynolds Number	Condition	Nusselt Number	Heat Transfer Coefficient Outside (W/m2K)
January	6	70	294.261	42	278.706	0.0000140	0.0245964	0.713	964644.394	Turbulent	1248.007809	13.64291
February	6	70	294.261	46	280.928	0.0000142	0.0247742	0.712	951201.783	Turbulent	1225.058945	13.48884
March	7	70	294.261	55	285.928	0.0000146	0.0251742	0.711	1075998.107	Turbulent	1431.775458	16.01948
April	6	70	294.261	66	292.039	0.0000152	0.0256631	0.709	889242.472	Turbulent	1118.477118	12.75716
May	5	70	294.261	76	297.594	0.0000157	0.0261076	0.708	717661.889	Turbulent	819.2468091	9.50601
June	5	70	294.261	84	302.039	0.0000161	0.0264509	0.707	698969.963	Turbulent	785.5792451	9.23523
July	5	70	294.261	88	304.261	0.0000163	0.0266153	0.706	689394.511	Turbulent	768.3306373	9.08861
August	5	70	294.261	86	303.150	0.0000162	0.0265331	0.707	694149.217	Turbulent	776.9011374	9.16160
September	5	70	294.261	79	299.261	0.0000158	0.0262409	0.707	710934.667	Turbulent	807.1066889	9.41298
October	5	70	294.261	68	293.150	0.0000153	0.0257520	0.709	736239.680	Turbulent	852.6654992	9.75904
November	6	70	294.261	57	287.039	0.0000147	0.0252631	0.710	916095.113	Turbulent	1164.834516	13.07882
December	6	70	294.261	46	280.928	0.0000142	0.0247742	0.712	951201.783	Turbulent	1225.058945	13.48884

Interpolated air data

Table A4 Data	250	0.00001144	0.0223	0.72
	300	0.00001589	0.0263	0.707
	350	0.00002092	0.03	0.7

$\underbrace{\hphantom{xxxxxxxxxxxxxxxx}}_{\text{Air property}}$

all Re_L were greater than $Re_{x,c}$ and less than 10^8 ✓

Use EQ 7.38 is satisfied

$\bar{h}_{out}$

If you want to know more about the data, please check the attach excel document

Thank you

$\bar{h}_{inside}$ Analysis

To find $\bar{h}_{inside}$, I consider natural convection

Hot Month (Hot Wall) Cold Month (Cold Wall)

To find $\bar{h}_{in}$, I consider "Rayleigh Number"

$$Ra_L = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu\alpha}$$

where $g = 9.8\ m/s^2$

$\beta = 2/(T_s + T_\infty)$

$L_c = L$ (for vertical plate)

ν = K. Viscosity

α = T. Diffusivity

Next, I consider Nusselt Number EQ 9.26

$$\overline{Nu_L} = \left[0.825 + \frac{0.387\,Ra_L^{1/6}}{\left(1 + (0.492/Pr)^{9/16}\right)^{8/27}}\right] = \frac{\bar{h}_{IN} L_c}{K_{air}}$$

Therefore, by rearranging eq, I can find $\bar{h}_{IN}$

$$\bar{h}_{IN} = \frac{K_{air}}{L_c}\overline{Nu_L}$$

However! As we can see from rayleigh's number equation, we do not know the surface temperature of the inside wall. (We know $T_\infty = T_{home} = 70^\circ F$)

Thus, to find correct internal natural convection HTC, Iteration scheme must be implemented. Thanks to already developed excel model, although extremely challenging and though, solution was found.

Below is the iteration scheme

① h = guess (say 10) $\rightarrow$ ② Compute R_{cv} $\rightarrow$ ③ Solve circuit $\rightarrow$ ④ obtain q $\rightarrow$ ⑤ Compute $\Delta T = T_s - T_\infty$ using $q = \frac{\Delta T}{R}$

$\rightarrow$ ⑥ Find T_s $\rightarrow$ ⑦ Compute h using T_s $\rightarrow$ ⑧ Compare $\rightarrow$ ①

start with h=10

January				T_air	278.7056
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	2413.701	0.004	9.654806	294.26	284.6052
0.1849502	352.9401	0.216274	76.33193	294.26	217.9281
0.26244722	474.5262	0.152412	72.32329	294.26	221.9367
0.2598528	470.6621	0.153933	72.45057	294.26	221.8094
0.25993663	470.7872	0.153884	72.44645	294.26	221.8135
0.25993392	470.7831	0.153885	72.44658	294.26	221.8134
0.259934	470.7832	0.153885	72.44658	294.26	221.8134

February				T_air	280.9278
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	2067.098	0.004	8.268392	294.26	285.9916
0.18085637	296.6539	0.22117	65.61093	294.26	228.6491
0.25591703	398.3084	0.156301	62.25587	294.26	232.0041
0.25350645	395.2051	0.157787	62.3582	294.26	231.9018
0.25358128	395.3016	0.15774	62.35501	294.26	231.905
0.25357896	395.2986	0.157742	62.35511	294.26	231.9049
0.25357903	395.2987	0.157742	62.35511	294.26	231.9049

March				T_air	285.9278
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	1307.491	0.004	5.229963	294.26	289.03
0.16907875	175.0855	0.236576	41.42104	294.26	252.839
0.23732734	234.308	0.168544	39.49111	294.26	254.7689
0.23538793	232.7012	0.169932	39.54343	294.26	254.7166
0.23544143	232.7455	0.169894	39.54199	294.26	254.718
0.23543996	232.7443	0.169895	39.54203	294.26	254.718

April				T_air	292.0389
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	342.8889	0.004	1.371556	294.26	292.8884
0.138003	38.89131	0.289849	11.2726	294.26	282.9874
0.19258686	52.15352	0.207698	10.83221	294.26	283.4278
0.19135124	51.86474	0.20904	10.84179	294.26	283.4182
0.19137855	51.87113	0.20901	10.84158	294.26	283.4184
0.19137795	51.87099	0.20901	10.84158	294.26	283.4184

May				T_air	297.5944
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	501.1969	0.004	2.004787	294.26	296.2648
0.14722863	61.66383	0.271686	16.75322	294.26	311.0132
0.20487743	82.2116	0.195239	16.05089	294.26	310.3109
0.2035258	81.74953	0.196535	16.06667	294.26	310.3267
0.20355673	81.76012	0.196505	16.06631	294.26	310.3263
0.20355602	81.75987	0.196506	16.06631	294.26	310.3263

June				T_air	302.0389
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	1165.714	0.004	4.662856	294.26	298.9229
0.16866148	162.0897	0.237161	38.44143	294.26	332.7014
0.23356652	214.0649	0.171257	36.6602	294.26	330.9202
0.23190859	212.7971	0.172482	36.70361	294.26	330.9636
0.23194986	212.8286	0.172451	36.70253	294.26	330.9625
0.23194883	212.8279	0.172452	36.70255	294.26	330.9626
0.23194885	212.8279	0.172452	36.70255	294.26	330.9626

July				T_air	304.2611
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	1496.176	0.004	5.984704	294.26	300.2447
0.17565583	215.8524	0.227718	49.15348	294.26	343.4135
0.24267188	284.0097	0.164832	46.81379	294.26	341.0738
0.24092791	282.3182	0.166025	46.87181	294.26	341.1318
0.24097212	282.3611	0.165994	46.87033	294.26	341.1303
0.240971	282.36	0.165995	46.87037	294.26	341.1304
0.24097103	282.36	0.165995	46.87037	294.26	341.1304

August				T_air	303.15
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	1331.09	0.004	5.32436	294.26	299.5844
0.17233441	188.734	0.232107	43.80647	294.26	338.0665
0.23836649	248.7774	0.167809	41.74704	294.26	336.007
0.23666221	247.2985	0.169017	41.79772	294.26	336.0577
0.23670506	247.3358	0.168987	41.79645	294.26	336.0564
0.23670399	247.3348	0.168987	41.79648	294.26	336.0565
0.23670401	247.3349	0.168987	41.79648	294.26	336.0565

September				T_air	299.2611
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	750.9467	0.004	3.003787	294.26	297.2638
0.15710323	97.9409	0.25461	24.9367	294.26	319.1967
0.21822374	130.0518	0.183298	23.83825	294.26	318.0982
0.21672517	129.2983	0.184566	23.86401	294.26	318.124
0.216761	129.3163	0.184535	23.86339	294.26	318.1234
0.21676014	129.3159	0.184536	23.8634	294.26	318.1234

October				T_air	293.15
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	167.2902	0.004	0.669161	294.26	293.5908
0.12366665	17.56133	0.32345	5.680215	294.26	288.5798
0.17278081	23.64024	0.231507	5.472885	294.26	288.7871
0.17176226	23.51867	0.23288	5.477028	294.26	288.783
0.17178292	23.52114	0.232852	5.476944	294.26	288.7831
0.1717825	23.52109	0.232853	5.476946	294.26	288.7831

November				T_air	287.0389
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	1116.956	0.004	4.467826	294.26	289.7922
0.1651202	148.3278	0.242248	35.93209	294.26	258.3279
0.23191092	198.6643	0.17248	34.26562	294.26	259.9944
0.2300449	197.3213	0.173879	34.31005	294.26	259.95
0.23009553	197.3578	0.173841	34.30884	294.26	259.9512
0.23009416	197.3568	0.173842	34.30887	294.26	259.9511
0.2300942	197.3568	0.173842	34.30887	294.26	259.9511

December				T_air	280.9278
h_IN	q	R	qR = ΔT	T_inf	T_surf
10	2067.098	0.004	8.268392	294.26	285.9916
0.18085637	296.6539	0.22117	65.61093	294.26	228.6491
0.25591703	398.3084	0.156301	62.25587	294.26	232.0041
0.25350645	395.2051	0.157787	62.3582	294.26	231.9018
0.25358128	395.3016	0.15774	62.35501	294.26	231.905
0.25357896	395.2986	0.157742	62.35511	294.26	231.9049
0.25357903	395.2987	0.157742	62.35511	294.26	231.9049

As you can see, bottom two lines of all data converges. Thus, h_{in} and T_{surf} were successfully found.

	Home Temp (F)	Home Temp (K)	Air Temp (F)	Air Temp (K)	Surface Temp (K)	Kinematic Viscosity (m2/s)	Thermal Conductivity (W/mK)	Thermal Diffusivity (m2/s)	Prandlts Number	Rayleigh Number	Nusselt Number	Heat Transfer Coefficient Inside (W/m2K)
January	70	294.261	42	278.706	221.8134	0.0000140	0.0245964	0.0000197	0.713	1.137423E+11	23.77789	0.25993
February	70	294.261	46	280.928	231.9049	0.0000142	0.0247742	0.0000200	0.712	9.329315E+10	23.03010	0.25358
March	70	294.261	55	285.928	254.7180	0.0000146	0.0251742	0.0000206	0.711	5.322145E+10	21.04295	0.23544
April	70	294.261	66	292.039	283.4184	0.0000152	0.0256631	0.0000214	0.709	1.286844E+10	16.77896	0.19138
May	70	294.261	76	297.594	310.3263	0.0000157	0.0261076	0.0000222	0.708	1.706047E+10	17.54285	0.20356
June	70	294.261	84	302.039	330.9626	0.0000161	0.0264509	0.0000228	0.707	3.571005E+10	19.73034	0.23195
July	70	294.261	88	304.261	341.1304	0.0000163	0.0266153	0.0000231	0.706	4.362938E+10	20.37115	0.24097
August	70	294.261	86	303.150	336.0565	0.0000162	0.0265331	0.0000230	0.707	3.977267E+10	20.07244	0.23670
September	70	294.261	79	299.261	318.1234	0.0000158	0.0262409	0.0000224	0.707	2.454001E+10	18.58589	0.21676
October	70	294.261	68	293.150	288.7831	0.0000153	0.0257520	0.0000216	0.709	6.356488E+09	15.00896	0.17178
November	70	294.261	57	287.039	259.9511	0.0000147	0.0252631	0.0000208	0.710	4.511460E+10	20.49280	0.23009
December	70	294.261	46	280.928	231.9049	0.0000142	0.0247742	0.0000200	0.712	9.329315E+10	23.03010	0.25358

Table A4 Data	250	0.00001144	0.0223	0.0000159	0.72
	300	0.00001589	0.0263	0.0000225	0.707
	350	0.00002092	0.03	0.0000299	0.7

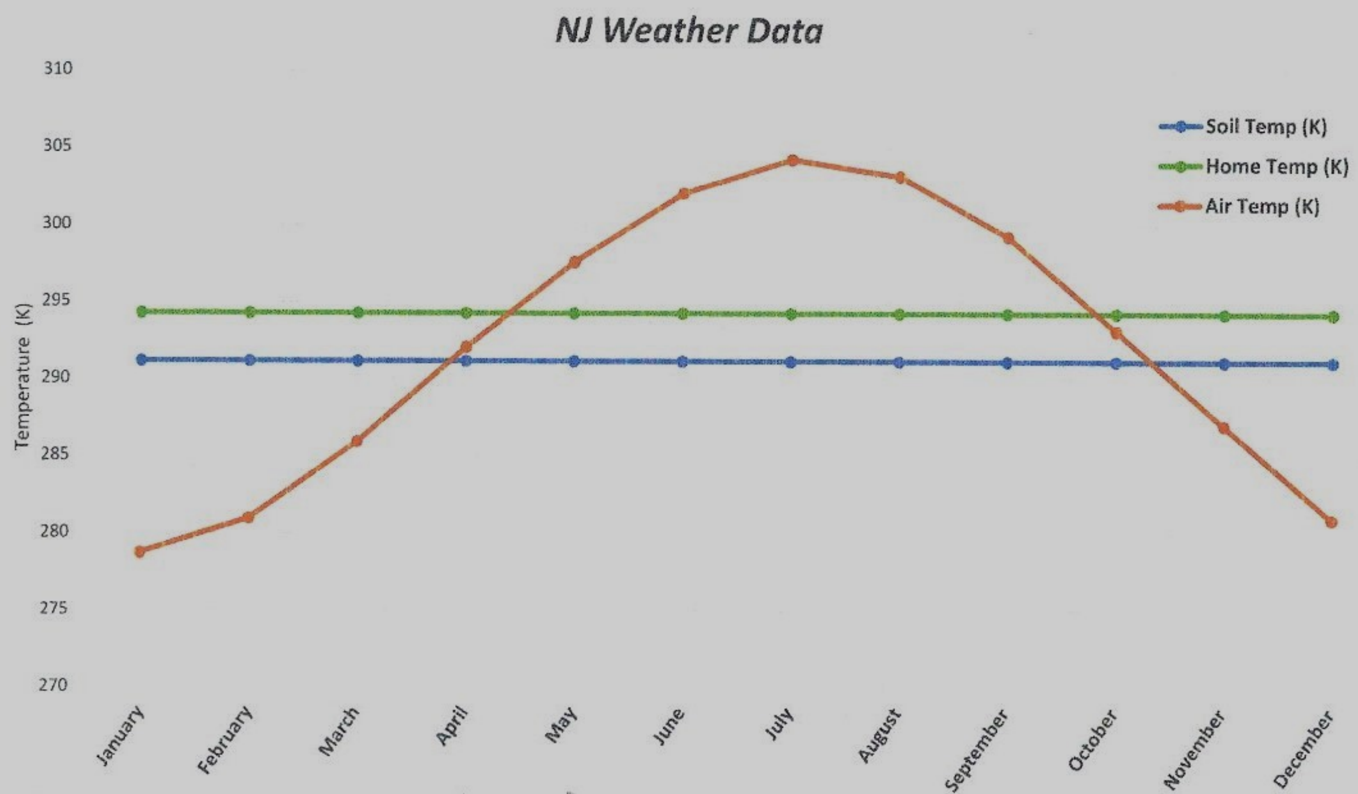
Next, after finding correct surface temperature of inside wall, corresponding $\bar{h}_{IN}$ is computed

Next, knowing h_{IN} & h_{out}, whole circuit can be solved and plotted...!

	Wind Speed (m/s)	Soil Temp (K)	Home Temp (K)	Air Temp (K)	Month	h_IN (W/m2K)	h_OUT (W/m2K)	R_Home (K/W)	R_Soil (K/W)	q_Home (W)	q_Soil (W)	q_5Human, 2Cat (W)	q_Required (W)
January	6	291.15	294.261	278.706	COLD	0.2599	13.6429	0.0330	0.1752	470.7832	18.6068	22.50	466.8900
February	6	291.15	294.261	280.928	COLD	0.2536	13.4888	0.0337	0.1788	395.2987	18.2359	22.50	391.0346
March	7	291.15	294.261	285.928	COLD	0.2354	16.0195	0.0358	0.1900	232.7443	17.1582	22.50	227.4025
April	6	291.15	294.261	292.039	COLD	0.1914	12.7572	0.0428	0.2261	51.8710	14.4174	22.50	43.7884
May	5	291.15	294.261	297.594	HOT	0.2036	9.5060	0.0408	0.2146	81.7599	15.1930	22.50	-119.4529
June	5	291.15	294.261	302.039	HOT	0.2319	9.2352	0.0366	0.1924	212.8279	16.9475	22.50	-252.2754
July	5	291.15	294.261	304.261	HOT	0.2410	9.0886	0.0354	0.1864	282.3600	17.4898	22.50	-322.3498
August	5	291.15	294.261	303.150	HOT	0.2367	9.1616	0.0359	0.1892	247.3349	17.2342	22.50	-287.0691
September	5	291.15	294.261	299.261	HOT	0.2168	9.4130	0.0387	0.2035	129.3159	16.0181	22.50	-167.8340
October	5	291.15	294.261	293.150	COLD	0.1718	9.7590	0.0472	0.2481	23.5211	13.1389	22.50	14.1600
November	6	291.15	294.261	287.039	COLD	0.2301	13.0788	0.0366	0.1936	197.3568	16.8351	22.50	191.6919
December	6	291.15	294.261	280.928	COLD	0.2536	13.4888	0.0337	0.1788	395.2987	18.2359	22.50	391.0346

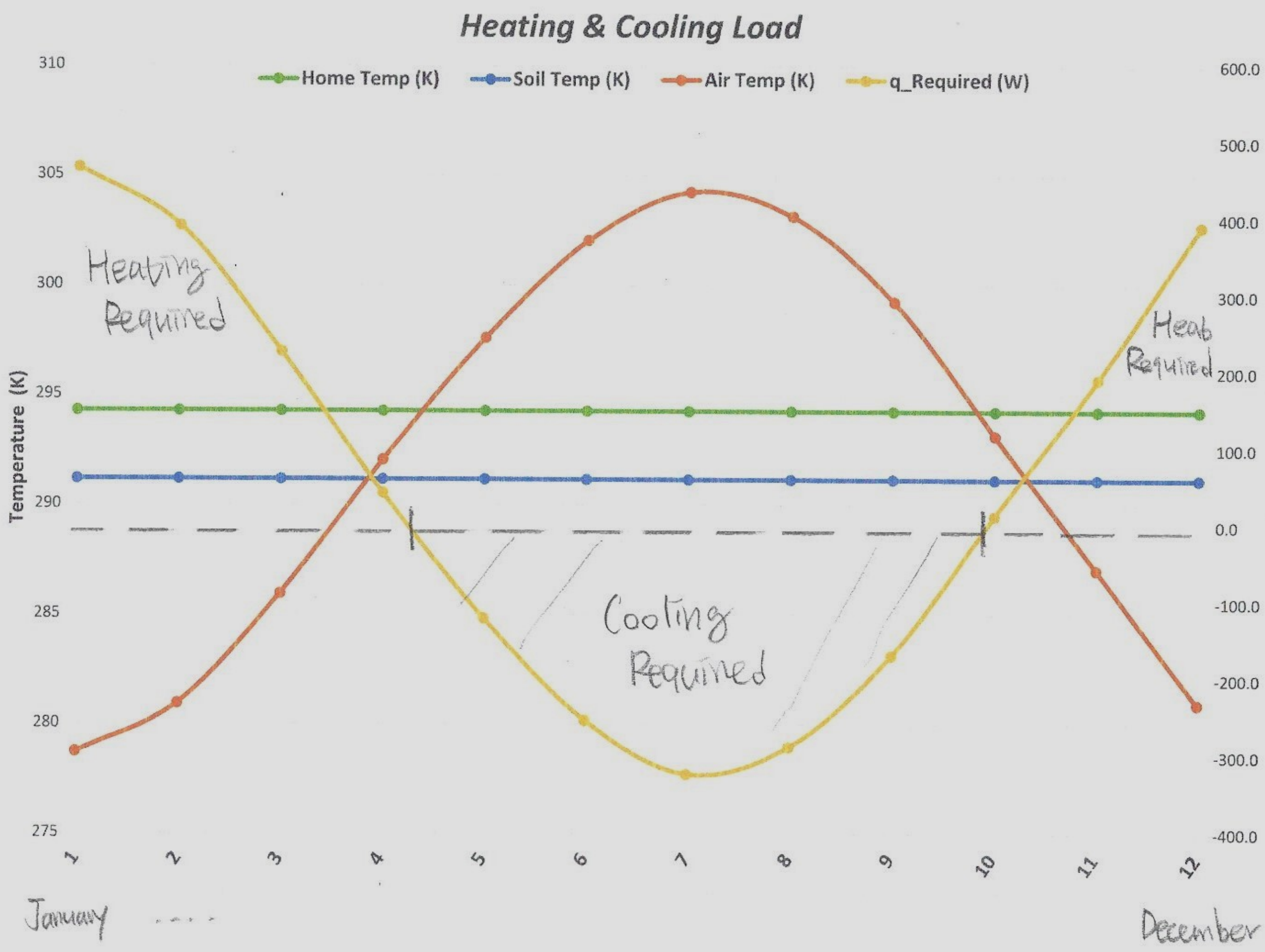
Negative due to Hot Month

Assumption; 5 human & 2 cats generate 22.5 W of energy...



Above is plot of whether data from NJ

Finally....


Heating & Cooling Load
Home Temp (K)
Soil Temp (K)
Air Temp (K)
q_Required (W)
Temperature (K)
Heat Rate (W)
310
305
300
295
290
285
280
275
600.0
500.0
400.0
300.0
200.0
100.0
0.0
-100.0
-200.0
-300.0
-400.0
1
2
3
4
5
6
7
8
9
10
11
12
Heating Required
Cooling Required
Heat Required
January ....
December

Required 6) How much cooling & heating change if I add fiberglass?

>> To answer this question, simulation will be run using my excel thermal circuit model.

A Fiberglass ($K = 0.058$ W/mK) will be added on
$L = 0.05$ m

W1, W2, W3, W4, W5, C_1, C_2, C_3, C_4, F_1, F_2

B1, B2, B3, B4, B5

with $R = \frac{L}{KA} = \frac{0.05}{(0.058)(A_{\text{corresponding wall}})}$

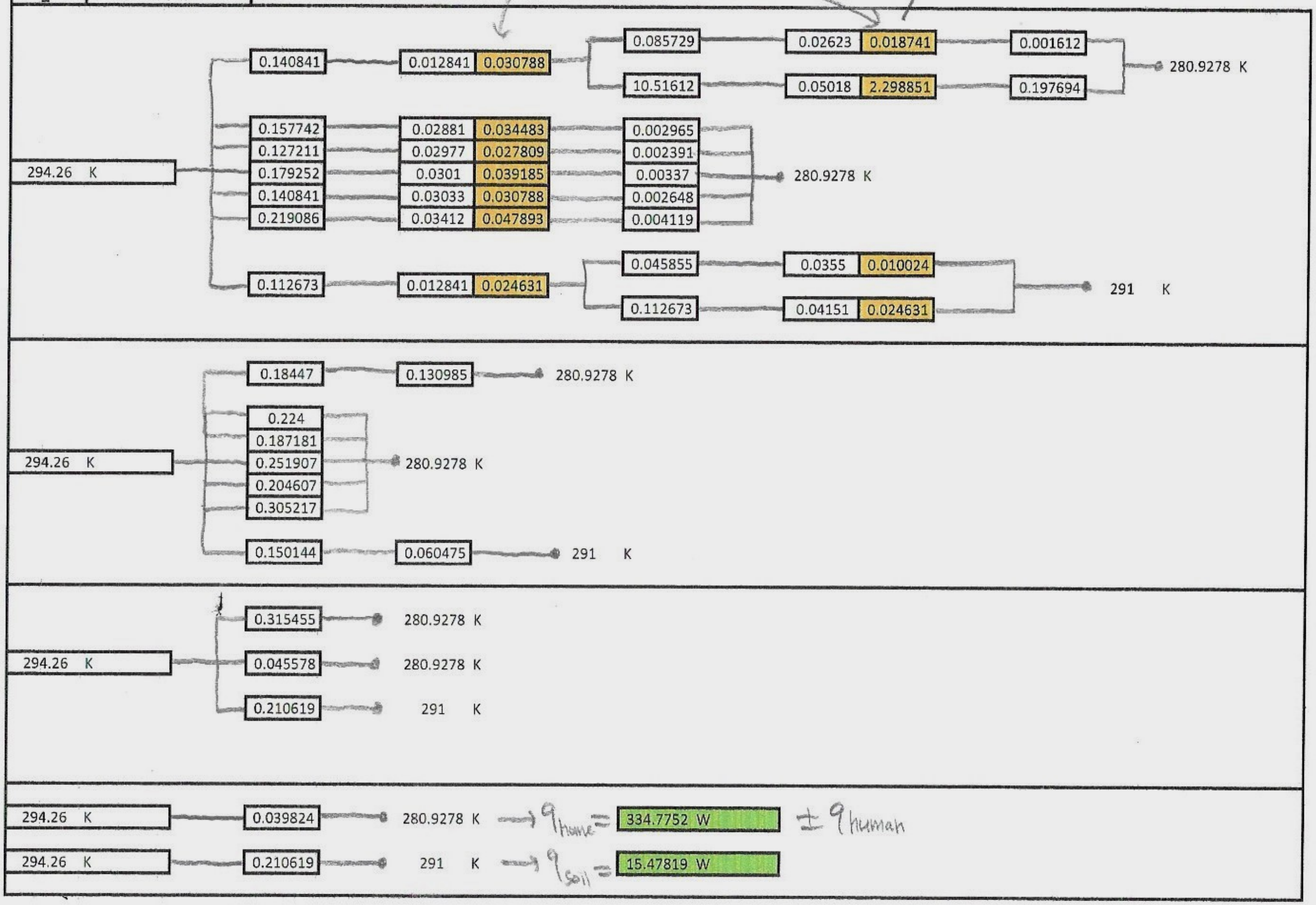
Thus, updating my thermal circuit...

Added Fiber Glass Thermal Resistors...

For ex: $R_{CD-C1,C2} = \frac{0.05}{(0.058)(46)}$

h_IN	0.25357903 W/m2K
h_OUT	13.4888367 W/m2K
T_air	280.927778 K

reduce



$\pm q_{human}$

Now let's plot & compare...

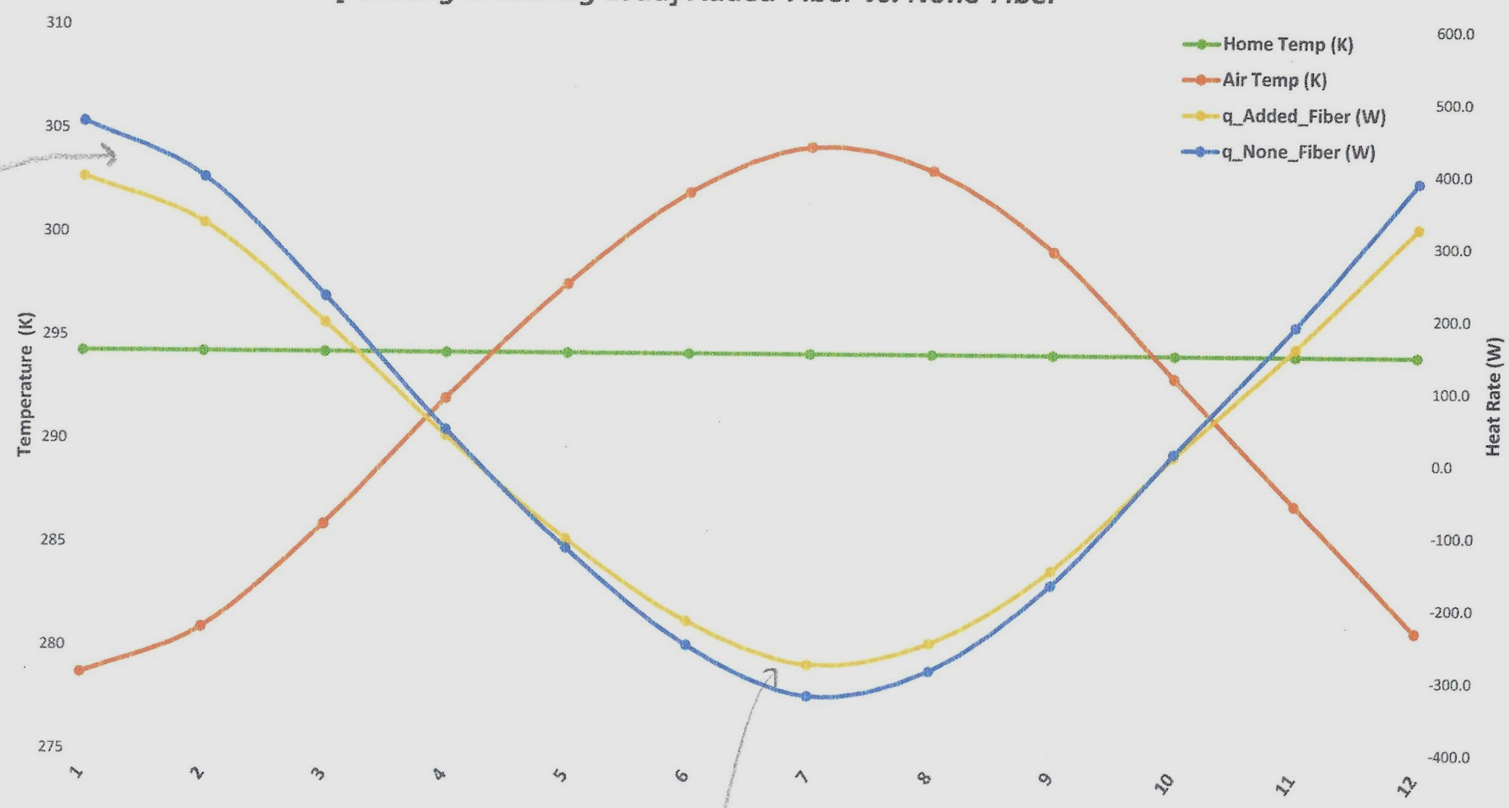
	Soil Temp (K)	Home Temp (K)	Air Temp (K)	Month	h_IN (W/m2K)	h_OUT (W/m2K)	R_Home (K/W)	R_Soil (K/W)	q_Home (W)	q_Soil (W)	q_5Human,2Cat (W)	q_Added_Fiber (W)	q_None_Fiber (W)	Difference (W)	% Change
January	291.15	294.261	278.706	COLD	0.2599	13.6429	0.039	0.207	397.435	15.744	22.50	390.6794	466.8900	76.211	**16%**
February	291.15	294.261	280.928	COLD	0.2536	13.4888	0.040	0.211	334.775	15.478	22.50	327.7534	391.0346	63.281	**16%**
March	291.15	294.261	285.928	COLD	0.2354	16.0195	0.042	0.222	198.874	14.695	22.50	191.0696	227.4025	36.333	**16%**
April	291.15	294.261	292.039	COLD	0.1914	12.7572	0.049	0.258	45.406	12.639	22.50	35.5453	43.7884	8.243	**19%**
May	291.15	294.261	297.594	HOT	0.2036	9.5060	0.047	0.246	71.127	13.231	22.50	-106.8579	-119.4529	12.595	**11%**
June	291.15	294.261	302.039	HOT	0.2319	9.2352	0.043	0.224	182.401	14.541	22.50	-219.4413	-252.2754	32.834	**13%**
July	291.15	294.261	304.261	HOT	0.2410	9.0886	0.042	0.218	240.892	14.938	22.50	-278.3296	-322.3498	44.020	**14%**
August	291.15	294.261	303.150	HOT	0.2367	9.1616	0.042	0.221	211.463	14.751	22.50	-248.7143	-287.0691	38.355	**13%**
September	291.15	294.261	299.261	HOT	0.2168	9.4130	0.045	0.235	111.706	13.852	22.50	-148.0573	-167.8340	19.777	**12%**
October	291.15	294.261	293.150	COLD	0.1718	9.7590	0.053	0.280	20.830	11.646	22.50	9.9761	14.1600	4.184	**30%**
November	291.15	294.261	287.039	COLD	0.2301	13.0788	0.043	0.225	169.168	14.458	22.50	161.1256	191.6919	30.566	**16%**
December	291.15	294.261	280.928	COLD	0.2536	13.4888	0.040	0.211	334.775	15.478	22.50	327.7534	391.0346	63.281	**16%**

on average 12% less Cooling required.

on average 18% less heating required.

[Heating & Cooling Load] Added-Fiber vs. None-Fiber

Heating saved by adding Fiber



Cooling Energy saved by adding Fiber