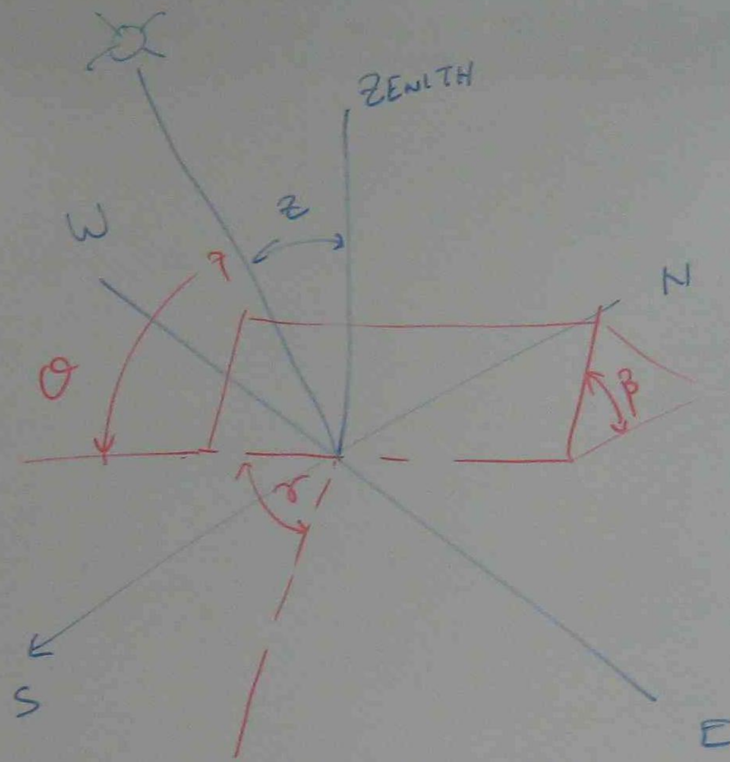


Z = ZENITH ANGLE

β = TILT ANGLE

θ = INCIDENCE ANGLE

γ = ORIENTATION ANGLE

δ = DECLINATION ANGLE

$$\delta = 23.45 \sin\left(0.973 \times (n - 80)\right)$$

n = No. of DAYS FROM 1st JANUARY

$$\underline{\text{AIR MASS}} = m = \frac{1}{\cos z}$$

OPTICAL THICKNESS
of
ATMOSPHERE

$$G_{T\beta} \text{ IRRADATION} = R_b G_{bo} + \left(\frac{1+\cos\beta}{2}\right) G_{do} + \rho \left(\frac{1-\cos\beta}{2}\right)(G_{do} + G_{bo})$$

R_b: RATIO OF BEAM IRRADIANCE ON PLANE WITH TILT ANGLE β

G_{bo}: DIRECT SUN HIT IRRADATION

G_{do}: DIFFUSE IRRADATION

ρ: DENSITY

THERMODYNAMIC PRINCIPLES AND HEAT FLOW

THE THERMAL PERFORMANCE OF A BUILDING IS DEPENDENT ON THE PHYSICAL PROPERTIES OF THE BUILDING STRUCTURE AS WELL AS THE ENVIRONMENTAL CONDITIONS INSIDE THE BUILDING

FIRST LAW OF THERMODYNAMIC

ΔU = INCREASE IN INTERNAL ENERGY OF A BODY (J)

$$\boxed{\Delta U = Q - W}$$

Q = HEAT ADDED TO BODY (J)

W = WORK DONE BY BODY (J)

SECOND LAW OF THERMODYNAMICS

THE AMOUNT OF HEAT THAT CAN BE CHANGED TO WORK, TRANSFER OF THERMAL ENERGY OR HEAT ALWAYS OCCURS IN THE DIRECTION OF DECREASING TEMPERATURE.

$$\boxed{Q = m\,c\,(T_{FINAL} - T_{INITIAL})}$$

Q = HEAT ENERGY (J)

m = MASS (Kg)

c = SPECIFIC HEAT CAPACITY

$T_{FINAL} - T_{INITIAL}$ = TEMPERATURE DIFFERENCE

HEAT FLOW RATE

$$\boxed{P = h\,A\,\Delta T}$$

P = HEAT FLOW RATE J/s (WATT)

A = AREA (m^2)

ΔT = TEMPERATURE DIFFERENCE

h = HEAT TRANSFER COEFFICIENT ($W/m^2 K$)

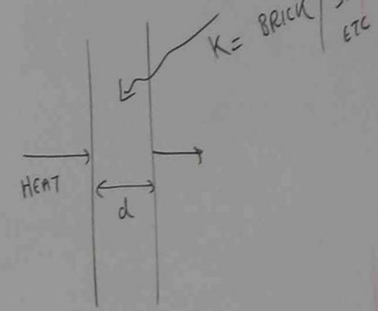
$$h = \frac{k}{d}$$

(k = THERMAL CONDUCTIVITY $W/m\,k$

d = HEAT FLOW PATH THICKNESS (m)

CONDUCTION

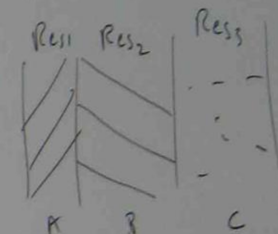
$$\boxed{P = \frac{kA\,\Delta T}{d}}$$



R_{es} = RESISTIVITY = INSULATION ABILITY

$$R_{es} = \frac{1}{k}$$

TOTAL RESISTANCE TO HEAT = $R_{es} \times d = \frac{1}{k} \times d$



$$R_T = Res_1 d_1 + Res_2 d_2 + Res_3 d_3$$

$$\boxed{R_T = \frac{1}{k_1} d_1 + \frac{1}{k_2} d_2 + \frac{1}{k_3} d_3}$$

C = CONDUCTANCE = THE HEAT CONDUCTION ABILITY OF PARTICULAR MATERIAL OF PARTICULAR THICKNESS

$$C = \frac{1}{R} \qquad \left(W/m^2 K \right)$$

P_{COND} = HEAT FLOW RATE FOR A SOLID DUE TO CONDUCTANCE

$$P_{COND} = C A \Delta T$$

K

pb

A MUD BRICK WALL HAS THE FOLLOWING DIMENSIONS

HEIGHT = 2.4 m, LENGTH = 5 m, THICKNESS = 300 mm.

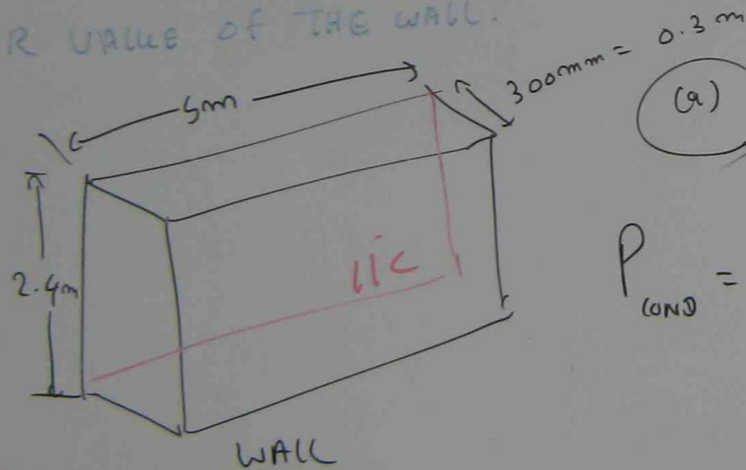
IF TWO WALL SURFACES ARE 19°C AND 11°C RESPECTIVELY,

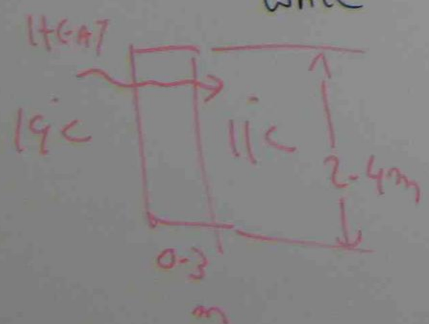
$(k = 1.25)$

CALCULATE

(a) THE RATE OF HEAT FLOW THROUGH THE WALL

(b) R VALUE OF THE WALL.





(a) $C = \dfrac{k}{d} = \dfrac{1.25}{0.3} = 4.17 \ W/m^2K$

P_{COND} = HEAT FLOW RATE FOR A SOLID $= C \times A \times \Delta T$

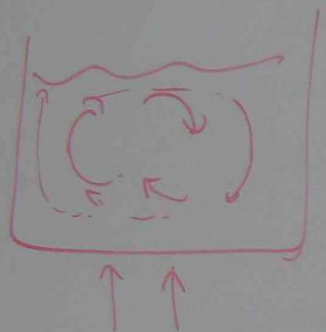
$= 4.17 \times (5 \times 2.4)(19 - 11)$

$= 4.17 \times \ldots 2.4 \times 8$

$= 400 W$

(b) $R = \dfrac{d}{k} = \dfrac{0.3 m}{1.25} = 0.24 \ m^2K/W$

CONVECTION



THERMAL CONVECTION INVOLVES ENERGY TRANSFER INTO A FLUID DUE TO MIXING OF LAYERS AT DIFFERENT TEMPERATURES.
HEAT TRANSFER IN FLUIDS INVOLVES BOTH CONVECTION AND CONDUCTION.

$$P_{conv|cond} = h_c A \Delta T$$

h_c = COMBINED CONDUCTION & CONVECTION HEAT TRANSFER COEFFICIENT

$h_c = 3$ (HORIZONTAL HEAT FLOW)

$h_c = 4.3$ (HEAT FLOW UPWARD)

$h_c = 1.5$ (HEAT FLOW DOWNWARD)

HEAT TRANSFER COEFFICIENT FOR FORCED CONVECTION

$$h_c = 5.8 + 4.1\,V$$

(V = AIR SPEED m/s)

RADIATION

THERMAL RADIATION (OR) RADIANT ENERGY IS THE ENERGY EMITTED BY A BODY AS A CONSEQUENCE OF IT'S TEMPERATURE.

RADIANT ENERGY IS ENERGY IN THE FORM OF ELECTROMAGNETIC WAVES OF PHOTONS.

$$\boxed{E_v = h\,V}$$

E_v = ENERGY ASSOCIATED WITH PHONTON

h = PLANK'S CONSTANT

V = PHOTON FREQUENCY

$$\boxed{c = \lambda V}$$

c = LIGHT SPEED

λ = WAVELENGTH

EMISSIVE POWER: $P_r = \delta A T^4$

δ = STEFAN - BOLTZMAN CONSTANT $(5.7 \times 10^{-8}\ W/m^2 K^4)$

A = SURFACE AREA (m^2)

T = TEMPERATURE (K)

<u>EMITTANCE</u>

MEASURE OF THE ABILITY OF A SURFACE TO RADIATE

MATERIAL	EMITTANCE
COPPER	0.03
WHITE PAINT	0.9
BLACK	0.98

ε = EMITTANCE OF SURFACE

RATE OF HEAT RADIATION TRANSFER

$$\boxed{P_{rad} = \delta \varepsilon A (T_1^4 - T_2^4)}$$

TIC

Y

P_A = RATE AT WHICH AN OBJECT ABSORBS THE SURFACE RADIATION

$$\boxed{P_A = \alpha \; A \; G}$$

α = ABSORPTANCE, A = SURFACE AREA (cm^2), G = IRRADIANCE (W/cm^2)

SURFACE CONDUCTANCE

$$P_{TOTAL} = P_{COND/CONV} + P_{rad}$$

$$= (h_c + h_r) \times A \; \Delta T$$

TEMPERATURE DIFFERENCE

CONDUCTION   RADIATION   SURFACE AREA

EXAMPLES OF U VALUE CALCULATIONS

(i) FIND THE RESISTANCE OF ANY BULK MATERIALS SUCH AS BRICK, GLASS, WOOD, BULK INSULATION

$$R = \frac{l}{k}$$

(ii) WRITE DOWN THE RESISTANCE OF INDIVIDUAL ELEMENT USING RESISTANCE TABLE

(iii) SUM INDIVIDUAL RESISTANCES TO FIND R_T

(iv) $U = \frac{1}{R_T}$

EX (1) CALCULATE "U" VALUE FOR A BRICK VENEER WALL WITH REFLECTIVE FOIL LAMINATE (RFL) ON THE OUTSIDE OF THE FRAME.

USE THE FOLLOWINGS

THICKNESS OF BRICK = 110mm

AIR GAP ADJACENT TO BRICK = 20mm

AIR GAP ADJACENT TO PLASTER BOARD = 100mm

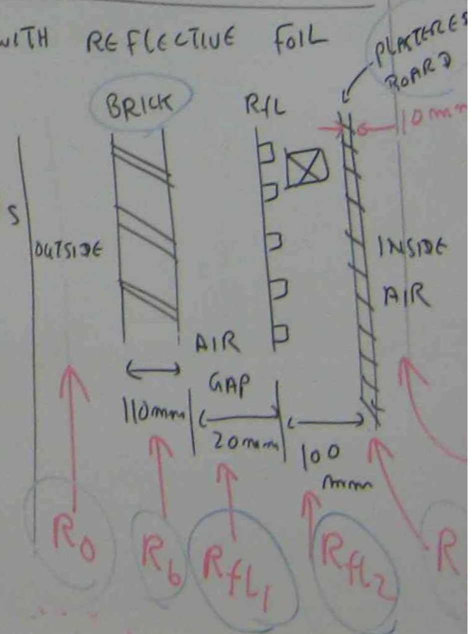
THICKNESS OF PLASTER BOARD = 10mm

OUTSIDE AIR

WIND SPEED = 3 m/s

k (BRICK) = 1.15

k (PLASTER) = 0.17



$$R_{brick} = \frac{d_{Brick}}{K_{Brick}} = \frac{110 \times 10^{-3}}{1.15} = 0.1\ m^2K/W$$

$$R_p = \frac{d_p}{K_p} = \frac{10 \times 10^{-3}}{0.17} = 0.06\ m^2K/W$$

$$R_o = 0.04\ m^2K/W$$

...TERED
...ARD
...10mm

RFL	POSITION (FOR WALL)	DIRECTION OF HEAT FLOW	RESISTANCE (m^2K/W) 20mm WIDTH	100 mm WIDTH
ONE SURFACE OF LOW EMITTANCE	VERTICAL	HORIZONTAL	0.58	0.61

...SIDE
...IR

R_{in}

R_p

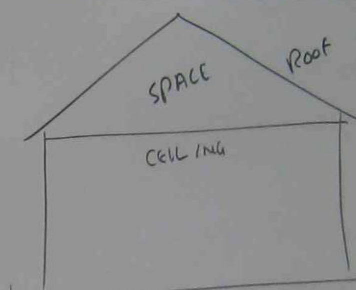
$R_{fl_1} = 0.58$

$R_{fl_2} = 0.61$

$R_{in} = 0.12$

INSIDE AIR STILL	POSITION	HEAT FLOW DIR	R
	VERTICAL	HORIZONTAL	0.12

THERMAL RESISTANCE OF PITCHED ROOF SPACE



R

ROOF SPACE	DIRECTION OF HEAT FLOW	RESISTANCE (m^2K/W) HEAT EMITTANCE SURFACE	LOW EMITTANCE SURFACE
VENTILATED SPACE	UP	0.11	0.39
	DOWN	0.46	1.36
NON VENTILATED SPACE	UP	0.18	0.56
	DOWN	0.28	1.09

SURFACE RESISTANCE

WIND SPEED m/s	POSITION OF SURFACE	DIRECTION OF HEAT FLOW	RESISTANCE m^2K/W	
			HIGH EMITTANCE SURFACE	LOW EMITTANCE SURFACE
STILL AIR	HORIZONTAL	UP	0.11	0.23
		DOWN	0.16	0.8
	45° SLOPE	UP	0.11	0.24
		DOWN	0.13	0.39
	22.5° SLOPE	UP	0.11	0.24
		DOWN	0.15	0.6
	VERTICAL	HORIZONTAL	0.12	0.3
6 m/s	ANY POSITION	ANY DIRECTION	0.03	
3 m/s	ANY POSITION	ANY DIRECTION	0.04	

SUMMER-UP
WINTER-DOWN

EXTERNAL AIR 3.5 m/s $\longrightarrow$ RESISTANCE = 0.04 m^2K/W

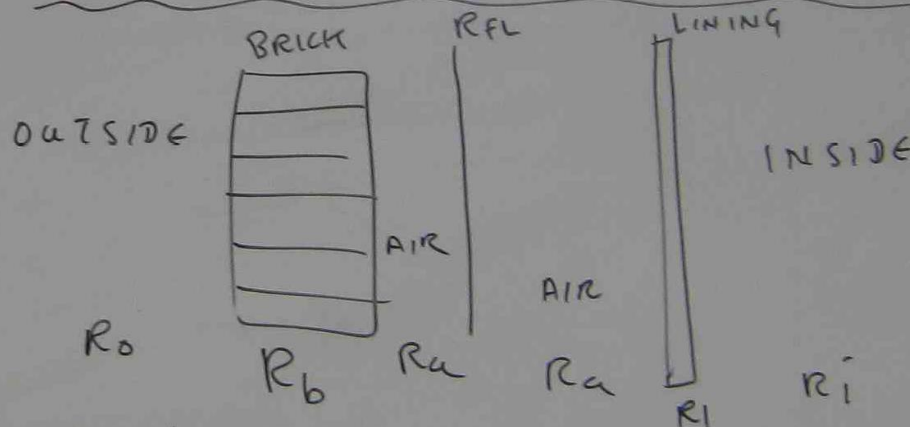
SURFACE RESISTANCE WHEN AIR SPEED IS GREATER THAN 5 m/s

$$R_o = \frac{1}{h_c} = \frac{1}{(5.8 + 4.1V)}$$

V = AIR SPEED m/s

OVER ALL HEAT TRANSFER COEFFICIENT (U VALUE) (W/m^2K)

OF BUILDING SECTIONS



RFL

REFLECTION SHEET

$$U = \frac{1}{R_T} = \frac{1}{R_o + R_b + R_a + R_a + R_1 + R_i}$$

U VALUE FOR FLOOR

FLOOR DIMENSION (m)	U
100 X 100	0.099
20 X 4	0.795
2 X 2	1.791

$$R_T = R_o + R_b + R_{fl_1} + R_{fl_2} + R_p + R_{im}$$

$$= 0.04 + 0.1 + 0.58 + 0.61 + 0.06 + 0.12$$

$$= 1.51 \ m^2K/W$$

$$U = \frac{1}{R_T} = \frac{1}{1.51} = 0.66 \ W/m^2K$$

pb (2)

CALCULATE "U" VALUE FOR A PITCHED METAL DECK ROOF WITH REFLECTIVE FOIL INSULATION AND RAKED CEILING WITH $R_{1.5}$ BULK INSULATION

USE THE FOLLOWINGS

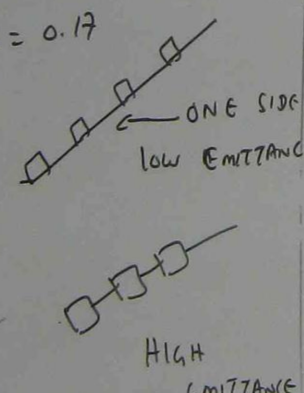
THICKNESS OF STEEL = 1 mm

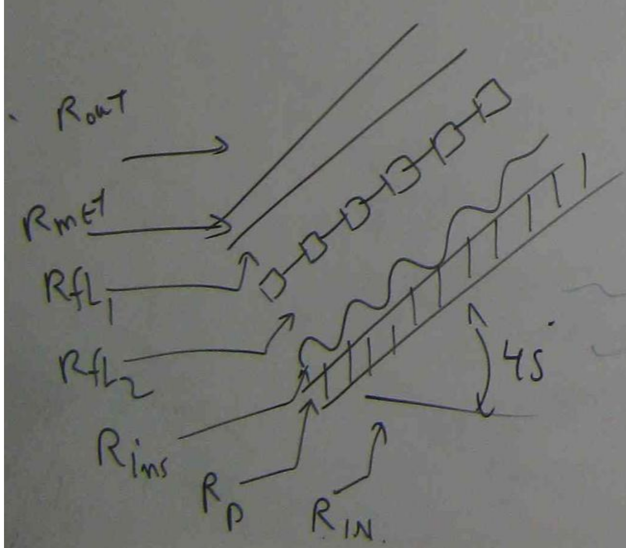
AIR GAP ADJACENT TO METAL DECK = 20 mm

AIR GAP ADJACENT TO INSULATION = 20 mm

THICKNESS OF PLASTERED BOARD = 13 mm

STEEL K = 47.5, PLASTER K = 0.17





$R_{OUT} = 0.04 \ m^2K/W$

$R_{MET} = \dfrac{d_{MET}}{K_{MET}} = \dfrac{1 \times 10^{-3}}{47.5} = 0.0002 \ m^2K/W$

$Rfl_1 = 0.17$

$Rfl_2 = 0.17$

$R_{INS} = 1.5$

$R_p = \dfrac{d_p}{K_p} = \dfrac{13 \times 10^{-3}}{0.17} = 0.08$

$R_{IN} = 0.11$

$R_T = R_{OUT} + R_{MET} + Rfl_1 + Rfl_2 + R_{INS} + R_p + R_{IN}$

$= 0.04 + 0.0002 + 0.17 + 0.17 + 1.5 + 0.08 + 0.11$

$= 2.07$

$R_{OUT} = 0.04 \; m^2 K/W$

$R_{MET} = \frac{d_{MET}}{K_{MET}} = \frac{1 \times 10^{-3}}{47.5} = 0.00002 \; m^2 K/W$

$R_{fl_1} = 0.17$

$R_{fl_2} = 0.17$

$R_{INS} = 1.5$

$R_p = \frac{d_p}{K_p} = \frac{13 \times 10^{-3}}{0.17} = 0.08$

$R_{IN} = 0.11$

$R_T = R_{OUT} + R_{MET} + R_{fl_1} + R_{fl_2} + R_{INS} + R_p + R_{IN}$

$= 0.04 + 0.00002 + 0.17 + 0.17 + 1.5 + 0.08 + 0.11$

$= 2.07$

$U = \frac{1}{R_T} = \frac{1}{2.07} = 0.483$

SURFACE RESISTANCE

WIND SPEED m/s	POSITION OF SURFACE	DIRECTION OF HEAT FLOW	RESISTANCE m^2K/W	
			HIGH EMITTANCE SURFACE	LOW EMITTANCE SURFACE
STILL AIR	HORIZONTAL	UP	0.11	0.23
		DOWN	0.16	0.8
	45° SLOPE	UP	0.11	0.24
		DOWN	0.13	0.39
	22.5° SLOPE	UP	0.11	0.24
		DOWN	0.15	0.6
	VERTICAL	HORIZONTAL	0.12	0.3
6 m/s	ANY POSITION	ANY DIRECTION	0.03	
3 m/s	ANY POSITION	ANY DIRECTION	0.04	

R

SUMMER-UP
WINTER-DOWN

EXTERNAL AIR 3.5 m/s $\longrightarrow$ RESISTANCE = 0.04 m^2K/W

U VALUE FOR FLOOR

FLOOR DIMENSION (m)	U
100 X 100	0.099
20 X 4	0.795
2 X 2	1.791

$$R_o + R_b + R_{fl_1} + R_{fl_2} + R_p + R_{im}$$

$$= 0.04 + 0.1 + 0.58 + 0.61 + 0.06 + 0.12$$

$$= 1.51 \ m^2K/W$$

$$= \frac{1}{R_T} = \frac{1}{1.51} = 0.66 \ W/m^2K$$

NATURE OF BONDING SURFACE	POSITION OF AIR SPACE	HEAT FLOW DIRECTION	RESISTANCE 20mm WIDTH	RESISTANCE 100mm WIDTH
HIGH EMITTANCE	HOR	UP	0.15	0.17
		DOWN	0.15	0.17
	45°	UP	0.17	0.17
		DOWN	0.15	0.16
	VER	HOR	0.15	0.16
ONE SIDE LOW EMITTANCE	HOR	UP	0.34	0.43
		DOWN	0.57	1.46
	45°	UP	0.44	0.57
		DOWN	0.53	0.72
	VER	HOR	0.58	0.61

m^2K/W

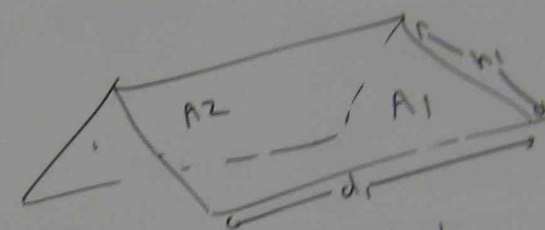
$$= \frac{1\times 10^{-3}}{47.5} = 0.00002\ m^2K/W$$

$$\frac{13\times 10^{-3}}{0.17} = 0.08$$

$$R_{met} + Rfl_1 + Rfl_2 + R_{INS} + R_p + R_{IN}$$

$$0.00002 + 0.17 + 0.17 + 1.5 + 0.08 + 0.11$$

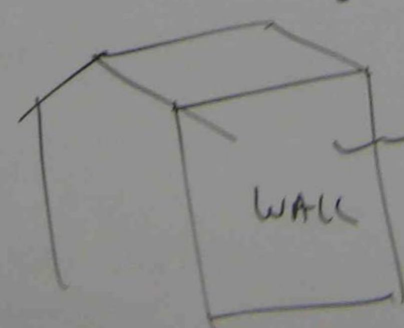
$$U = \frac{1}{R_T} = \frac{1}{2.07} = 0.483\ W/m^2K$$



$$A_T = A_1 + A_2 = 2\, d_1 h_1$$

TOTAL HEAT FLOW = $U \times A_T$

=



TOTAL HEAT = $U \times A_W$

Pb (3) CALCULATE U VALUE FOR A PITCHED AND VENTED TILED ROOF WITH REFLECTIVE FOIL LAMINATION UNDER THE TILES (ASSUME VENTILATE SPACE)

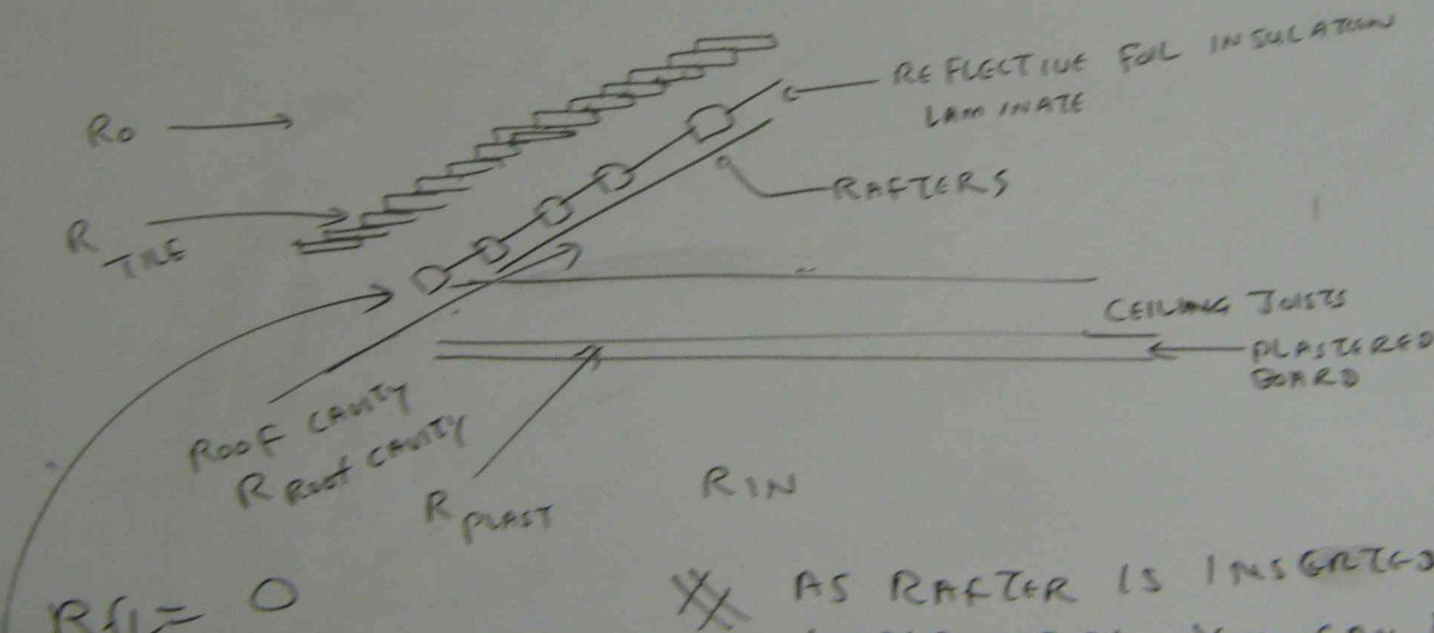
USE THE FOLLOWINGS

THICKNESS OF TILES = 19 mm

THICKNESS OF PLASTERED BOARD = 13 mm

TILE K = 0.81

PLASTER K = 0.17



$R_{fL} = 0$

** AS RAFTER IS INSERTED UNDER RFL, YOU CAN NEGLECT R_{fL} EFFECT.

R

R

R

R

ROOF WITH
[...]TILATE
SPACE)

$R_o = 0.04$

$R_{TILE} = \frac{d_{TILE}}{K_{TILE}} = \frac{19 \times 10^{-3}}{0.81} = 0.02$

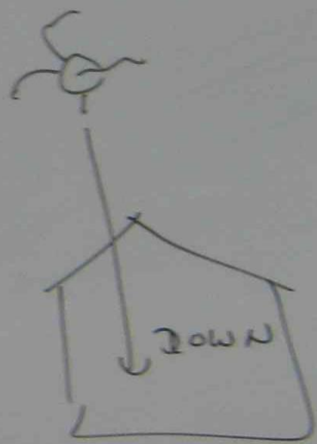
UP – WINTER
DOWN – SUMMER

$R_{FL} = 0$

$R_{ROOF\ CAVITY} = 1.36$

$R_{PLAST} = \frac{d_{PLAST}}{K_{PLAST}} = \frac{13 \times 10^{-3}}{0.17} = 0.08$

$R_{IN} = 0.16$ (SUMMER – DOWN HEAT FLOW

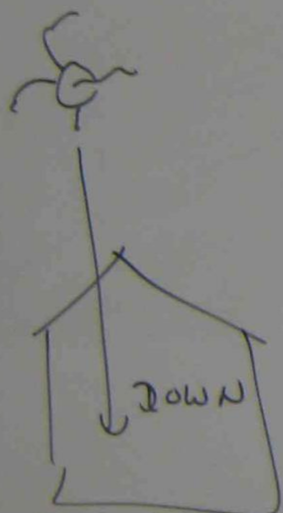


$R_T = R_o + R_{TILE} + R_{FL} + R_{ROOF\ CAVITY} + R_{PLAST} + R_{IN}$

$= 0.04 + 0.02 + 0 + 1.36 + 0.08 + 0.16 = 1.66$

up — WINTER

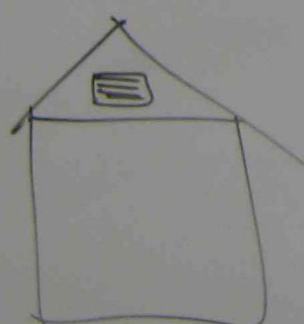
wn — SUMMER



RIN

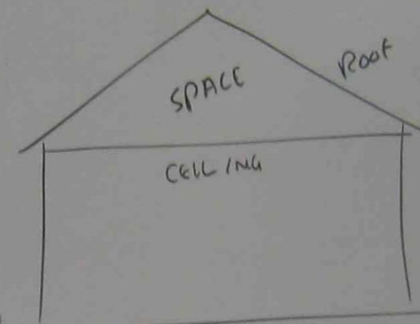
1.66

$$u = \frac{1}{R_T} = \frac{1}{1.66} = 0.6\ W/m^2K$$



W/

THERMAL RESISTANCE of PITCHED ROOF SPACE



R

ROOF SPACE	DIRECTION OF HEAT FLOW	RESISTANCE (m^2K/W)	
		HEAT EMITTANCE SURFACE	LOW EMITTANCE SURFACE
VENTILATED SPACE	UP WINTER	0.11	0.39
	DOWN SUMMER	0.46	1.36
NON VENTILATED SPACE	UP	0.18	0.56
	DOWN	0.28	1.09

SURFACE RESISTANCE

R

WIND SPEED m/s	POSITION OF SURFACE	DIRECTION OF HEAT FLOW	RESISTANCE m^2K/W	
			HIGH EMITTANCE SURFACE	LOW EMITTANCE SURFACE
STILL AIR	HORIZONTAL	UP	0.11	0.23
		DOWN	0.16	0.8
	45° SLOPE	UP	0.11	0.24
		DOWN	0.13	0.39
	22.5° SLOPE	UP	0.11	0.24
		DOWN	0.15	0.6
	VERTICAL	HORIZONTAL	0.12	0.3
6 m/s	ANY POSITION	ANY DIRECTION	0.03	
3 m/s	ANY POSITION	ANY DIRECTION	0.04	

SUMMER-UP
WINTER-DOWN

EXTERNAL AIR 3.5 m/s → RESISTANCE = 0.04 m^2K/W