Week 8

Task 1

Using the diagrams given in the presentation calculate how much (%) is the effect of applying different modifications (changing the gas, adding an extra pane, using a low emissivity coating) on the U value with respect to a benchmark case of double layer with air and no coating ? (keep the gap thickenss to be 13 mm)

Answer:

The U value of window:

$$U_{\text{window}} = \frac{(U_{center}A_{center} + U_{edge}A_{edge} + U_{frame}A_{frame})}{A_{window}}$$

Without considering the thermal resistance of the glass layer, the thermal resistance and U-factor of the double-glazed window can be expressed as:

$$\frac{1}{U_{double-pane(centerregion)}} \cong \frac{1}{h_i} + \frac{1}{h_{space}} + \frac{1}{h_o}$$
$$h_{space} = h_{rad,space} + h_{conv,space}$$

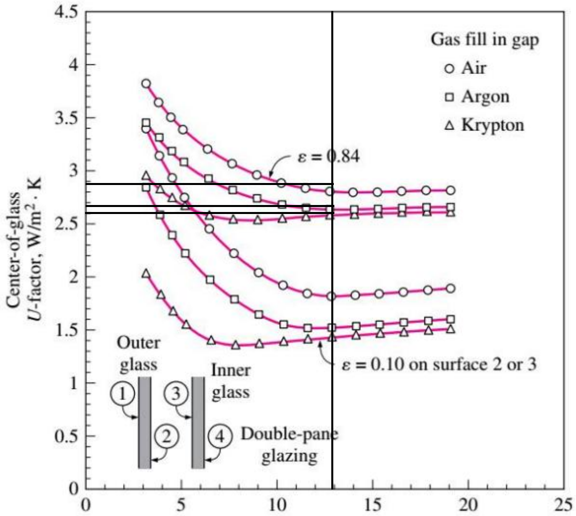
From the formula, we can conclude that the U value is related to the h space. About half of the heat transfer through the double-glazed air space is through radiation, and the other half is through conduction. Therefore, there are two ways to minimize the h-space, thereby minimizing the rate of heat transfer through the dual pane window: Minimize conduction heat transfer through air space. Minimize radiation heat transfer through the air space.

<u>According to different modifications:</u>

Changing the gas

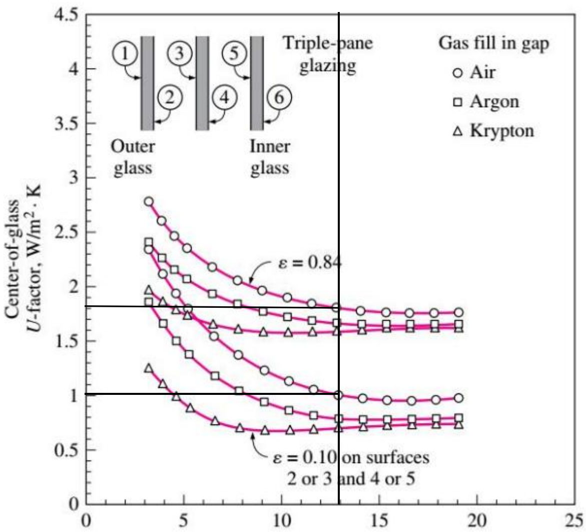
Filling the gaps between glasses with low-substitution fluids such as argon gas or krypton instead of air is one way to reduce the conversion through double-pane glass substitution.

Note from the figure that when the thickness of gas is 13mm, if we change the air into less-conducting fluid like Argon , the value of U-FACTOR changes from 2.8 W/m^2 • k into 2.65W/m^2 • k, which means the value decrease by 6.43%. And if we change the air into less-conducting fluid like Krypton , the value of U-FACTOR changes from 2.8W/m^2 • k into 2.6 W/m^2 • k, which means the value of U_factor decrease by 7.14%.



Adding an extra pane

Note from the figure that when the thickness of air gap is 13mm and filled gas is air, the U-factor in triple-panes glazing is 1.8 $W/m^2 \cdot k$. So from the double-pane to triple-pane, the value of U changes from 2.8$W/m^2 \cdot k$ into 1.8$W/m^2 \cdot k$, which means the value decreases by 55.6%, about one-third.



Using a low emissivity coating

By coating low-emissivity materials on glass surfaces, their emissivity can be reduced. The effective emissivity of two parallel plates with emissivity ε1 and ε1 are informed by:

$$\varepsilon_{\text{effective}} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

The emissivity of an ordinary glass surface is 0.84.

$$\varepsilon_{\text{effective}} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = \frac{1}{\frac{1}{0.84} + \frac{1}{0.84} - 1} \approx 0.72$$

Therefore, the effective emissivity of two parallel glass surfaces facing each other is 0.72.

But when the glass surfaces are coated with a film that has an emissivity of 0.1.

$$\varepsilon_{\text{effective}} = \frac{1}{\frac{1}{\varepsilon_{\text{coat1}}} + \frac{1}{\varepsilon_{\text{coat2}}} - 1} = \frac{1}{\frac{1}{0.1} + \frac{1}{0.1} - 1} \approx 0.05$$

the effective emissivity reduces to 0.05, which is one-fourteenth of 0.72. Using a low-emissivity coating, the value of U changes from $1.8 W/m^2 \cdot k$ into $1.0 W/m^2 \cdot k$, which means the value decreases by 44.4%.

Task 2

Consider the house that we analysed in the alst two examples, calculate the heating and cooling load of the other windows which are fixed 14.4 m2 on the west, fixed 3.6 m2 on the south and an operable 3.6 m2 on the south (the same window and frame type). How much does the total value change if I change the frame of the window from wooden one to aluminium ?

The question:The net area of wall(excluding doors and windows) of a building located in Piacenza is 105.8 ㎡， the calculated U value is $0.43 W/m^2 \cdot k$ for the winter and $0.435 W/m^2 \cdot k$ for the summer. Find the corresponding heating and cooling load.A fixed heat absorbing double layer glass(with a wooden frame) window at the east side of a building located in Piacenza has a surface of 14.4 ㎡. In case there are no internal and external shading factors. Calculate the heating and cooling load of the corresponding to that window.

Answer:

PIACENZA, Italy WMO#: **160840**

Lat: **44.92N** Long: **9.73E** Elev: **138** StdP: **99.68** Time Zone: **1.00 (EUW)** Period: **89-10** WBAN: **99999**

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB		
			99.6%			99%			0.4%		1%				
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD	
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	
1	**-6.2**	**-4.8**	**-11.6**	**1.4**	**3.1**	**-8.8**	**1.8**	**1.8**	**8.8**	**5.6**	**7.7**	**6.2**	**2.1**	**250**	(1)

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB		
		0.4%		1%		2%		0.4%		1%		2%				
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD	
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
8	**11.9**	**33.1**	**22.7**	**31.9**	**22.4**	**30.3**	**21.8**	**24.6**	**30.2**	**23.7**	**29.2**	**22.9**	**28.3**	**2.4**	**90**	(2)

From the table above,

The cooling design temperature ：

$$T_{\mathrm{cooling}} = 24°C$$

The heating design temperature:

$$T_{\mathrm{heating}} = 20°C$$

Thus,

$$\Delta T_{cooling} = 31.9°C - 24°C = 7.9°C$$
$$\Delta T_{heating} = 20°C - (-4.8)°C = 24.8°C$$
$$DR = 11.9°C$$

<u>EAST WINDOW (14.4 ㎡， fixed， wooden frame)</u>

HEATING:

$$A_{\mathrm{east}} = 14.4\text{�}$$
$$\mathrm{U}_{\mathrm{window}_{\mathrm{east}}} = 2.84\mathrm{W/m^2 \cdot K}$$
$$\mathrm{HF}_{\mathrm{window}_{\mathrm{east}}} = \mathrm{U}_{\mathrm{window}_{\mathrm{east}}} \times \Delta T_{\mathrm{heating}} = 2.84 \times 24.8 = 70.4\mathrm{W/m^2 \cdot K}$$
$$\mathrm{Q}_{\mathrm{window}_{\mathrm{east}}} = \mathrm{HF}_{\mathrm{window}_{\mathrm{east}}} \times \mathrm{A}_{\mathrm{window}_{\mathrm{east}}} = 70.4 \times 14.4 = 1014.2W$$

COOLING:

$$CF_{\mathrm{window}_{east} heatTransferPart} = U_{window_{east}}(\Delta T_{cooling} - 0.46DR) = 2.84*(7.9 - 0.46*11.9) = 6.9W/\mathrm{m}^2$$

we are assuming that there is no internal or external shading!

Table 10 Peak Irradiance, W/m²

Exposure		Latitude 20°	25°	30°	35°	40°	~~45°~~	50°	55°	60°
North	E_D	125	106	92	84	81	85	96	112	136
	E_d	128	115	103	93	84	76	69	62	55
	E_t	253	221	195	177	166	162	164	174	191
Northeast/Northwest	E_D	460	449	437	425	412	399	386	374	361
	E_d	177	169	162	156	151	147	143	140	137
	E_t	637	618	599	581	563	546	529	513	498
East/West	E_D	530	543	552	558	560	~~559~~	555	547	537
	E_d	200	196	193	190	189	~~188~~	187	187	187
	E_t	730	739	745	748	749	747	742	734	724
Southeast/Southwest	E_D	282	328	369	405	436	463	485	503	517
	E_d	204	203	203	204	205	207	210	212	215
	E_t	485	531	572	609	641	670	695	715	732
South	E_D	0	60	139	214	283	348	408	464	515
	E_d	166	193	196	200	204	209	214	219	225
	E_t	166	253	335	414	487	557	622	683	740
Horizontal	E_D	845	840	827	806	776	738	691	637	574
	E_d	170	170	170	170	170	170	170	170	170
	E_t	1015	1010	997	976	946	908	861	807	744

Exposure	Single Family Detached	Multifamily
North	0.44	0.27
Northeast	0.21	0.43
East	0.31	0.56
Southeast	0.37	0.54
South	0.47	0.53
Southwest	0.58	0.61
West	0.56	0.65
Northwest	0.46	0.57
Horizontal	0.58	0.73

$$PXI_{\text{window}_{east}} = E_D + E_d = 559 + 188 = 747$$

$$SHGC = 0.54$$

$$IAC = 1$$

$$FF\text{s} = 0.31$$

$$CF_{\text{window}_{\text{east}}\text{irradiation}P\text{art}} = PXI \times SHGC \times IAC \times FF\text{s} = 747 * 0.54 * 1 * 0.31 = 125.1$$

$$CF_{\text{window}_{\text{east}}} = CF_{\text{window}_{\text{east}} heatTransferPart} + CF_{\text{window}_{\text{east}}\text{irradiation}P\text{art}} = 6.9 + 125.1 = 132W/m^2$$

$$Q_{window_{east}} = CF_{\text{window}_{\text{east}}} \times A_{\text{window}_{\text{east}}} = 132 * 14.4 = 1900.8W$$

<u>NOW, I change the frame of the window from wooden one to ALUMINIUM :</u>

Glazing Type	Glazing Layers	ID[b]	Property[c,d]	Center of Glazing	Frame: Operable: Aluminum	Operable: Aluminum with Thermal Break	Operable: Reinforced Vinyl/Aluminum Clad Wood	Operable: Wood/Vinyl	Operable: Insulated Fiberglass/Vinyl	Fixed: Aluminum	Fixed: Aluminum with Thermal Break	Fixed: Reinforced Vinyl/Aluminum Clad Wood	Fixed: Wood/Vinyl	Fixed: Insulated Fiberglass/Vinyl
Clear	1	1a	U	5.91	7.24	6.12	5.14	5.05	4.61	6.42	6.07	5.55	5.55	5.35
			SHGC	0.86	0.75	0.75	0.64	0.64	0.64	0.78	0.78	0.75	0.75	0.75
	2	5a	U	2.73	4.62	3.42	3.00	2.87	5.83	3.61	3.22	2.86	2.84	2.72
			SHGC	0.76	0.67	0.67	0.57	0.57	0.57	0.69	0.69	0.67	0.67	0.67
	3	29a	U	1.76	3.80	2.60	2.25	2.19	1.91	2.76	2.39	2.05	2.01	1.93
			SHGC	0.68	0.60	0.60	0.51	0.51	0.51	0.62	0.62	0.60	0.60	0.60
Low-e, low-solar	2	25a	U	1.70	3.83	2.68	2.33	2.21	1.89	2.75	2.36	2.03	2.01	1.90
			SHGC	0.41	0.37	0.37	0.31	0.31	0.31	0.38	0.38	0.36	0.36	0.36
	3	40c	U	1.02	3.22	2.07	1.76	1.71	1.45	2.13	1.76	1.44	1.40	1.33
			SHGC	0.27	0.25	0.25	0.21	0.21	0.21	0.25	0.25	0.24	0.24	0.24
Low-e, high-solar	2	17c	U	1.99	4.05	2.89	2.52	2.39	2.07	2.99	2.60	2.26	2.24	2.13
			SHGC	0.70	0.62	0.62	0.52	0.52	0.52	0.64	0.64	0.61	0.61	0.61
	3	32c	U	1.42	3.54	2.36	2.02	1.97	1.70	2.47	2.10	1.77	1.73	1.66
			SHGC	0.62	0.55	0.55	0.46	0.46	0.46	0.56	0.56	0.54	0.54	0.54
Heat-absorbing	1	1c	U	5.91	7.24	6.12	5.14	5.05	4.61	6.42	6.07	5.55	5.55	5.35
			SHGC	0.73	0.64	0.64	0.54	0.54	0.54	0.66	0.66	0.64	0.64	0.64
	2	5c	U	2.73	4.62	3.42	3.00	2.87	2.53	3.61	3.22	2.86	2.84	2.72
			SHGC	0.62	0.55	0.55	0.46	0.46	0.46	0.56	0.56	0.54	0.54	0.54
	3	29c	U	1.76	3.80	2.60	2.25	2.19	1.91	2.76	2.39	2.05	2.01	1.93
			SHGC	0.34	0.31	0.31	0.26	0.26	0.26	0.31	0.31	0.30	0.30	0.30
Reflective	1	1l	U	5.91	7.24	6.12	5.14	5.05	4.61	6.42	6.07	5.55	5.55	5.35
			SHGC	0.31	0.28	0.28	0.24	0.24	0.24	0.29	0.29	0.27	0.27	0.27
	2	5p	U	2.73	4.62	3.42	3.00	2.87	2.53	3.61	3.22	2.86	2.84	2.72
			SHGC	0.29	0.27	0.27	0.22	0.22	0.22	0.27	0.27	0.26	0.26	0.26
	3	29c	U	1.76	3.80	2.60	2.25	2.19	1.91	2.76	2.39	2.05	2.01	1.93
			SHGC	0.34	0.31	0.31	0.26	0.26	0.26	0.31	0.31	0.30	0.30	0.30

HEATING:

$$A_{\text{east}} = 14.4\text{�}$$

$$\text{U'}_{\text{window}_{\text{east}}} = 3.61\text{W/m}^2 \cdot \text{K}$$

$$\text{HF'}_{\text{window}_{\text{east}}} = \text{U'}_{\text{window}_{\text{east}}} \times \Delta T_{\text{heating}} = 3.61 \times 24.8 = 89.5\text{W/m}^2 \cdot \text{K}$$

$$\text{Q'}_{\text{window}_{\text{east}} =} \text{HF'}_{\text{window}_{\text{east}}} \times \text{A}_{\text{window}_{\text{east}}} = 89.5 \times 14.4 = 1289.2W$$

COOLING:

$$CF'_{\mathrm{window}_{east} heatTransferPart} = U'_{window_{east}}(\Delta T_{cooling} - 0.46DR) = 3.61*(7.9-0.46*11.9) = 8.7W/\mathrm{m}^2$$

$$PXI_{\mathrm{window}_{east}} = E_D + E_d = 559 + 188 = 747$$
$$SHGC' = 0.56$$
$$IAC = 1$$
$$FF\mathrm{s} = 0.31$$
$$CF'_{\mathrm{window}_{\mathrm{east}}\mathrm{irradiation}P\mathrm{art}} = PXI \times SHGC' \times IAC \times FF\mathrm{s} = 747 * 0.56 * 1 * 0.31 = 129.6$$
$$CF'_{\mathrm{window}_{\mathrm{east}}} = CF'_{\mathrm{window}_{\mathrm{east}} heatTransferPart} + CF'_{\mathrm{window}_{\mathrm{east}}\mathrm{irradiation}P\mathrm{art}} = 8.7 + 129.6 = 138.3W/m^2$$
$$Q'_{window_{east}} = CF'_{\mathrm{window}_{\mathrm{east}}} \times A_{\mathrm{window}_{\mathrm{east}}} = 138.3 * 14.4 = 1991.5W$$

WINDOW2: WEST (14.4 ㎡，fixed，wooden frame)
HEATING:

$$A_{\mathrm{west}} = 14.4�$$
$$\mathrm{U}_{\mathrm{window}_{\mathrm{west}}} = 2.84\mathrm{W/m^2 \cdot K}$$
$$\mathrm{HF}_{\mathrm{window}_{\mathrm{west}}} = \mathrm{U}_{\mathrm{window}_{\mathrm{west}}} \times \Delta T_{\mathrm{heating}} = 2.84 \times 24.8 = 70.4\mathrm{W/m^2 \cdot K}$$
$$\mathrm{Q}_{\mathrm{window}_{\mathrm{west}}} = \mathrm{HF}_{\mathrm{window}_{\mathrm{west}}} \times \mathrm{A}_{\mathrm{window}_{\mathrm{west}}} = 70.4 \times 14.4 = 1014.2W$$

COOLING:

$$CF_{\mathrm{window}_{west} heatTransferPart} = U_{window_{west}}(\Delta T_{cooling} - 0.46DR) = 2.84*(7.9-0.46*11.9) = 6.9W/\mathrm{m}^2$$

we are assuming that there is no internal or external shading!

$$PXI_{\mathrm{window}_{east}} = E_D + E_d = 559 + 188 = 747$$
$$SHGC = 0.54$$
$$IAC = 1$$
$$FF\mathrm{s} = 0.56$$
$$CF_{\mathrm{window}_{\mathrm{west}}\mathrm{irradiation}P\mathrm{art}} = PXI \times SHGC \times IAC \times FF\mathrm{s} = 747 * 0.54 * 1 * 0.56 = 225.9W/m^2$$
$$CF_{\mathrm{window}_{\mathrm{west}}} = CF_{\mathrm{window}_{\mathrm{west}} heatTransferPart} + CF_{\mathrm{window}_{\mathrm{west}}\mathrm{irradiation}P\mathrm{art}} = 6.9 + 225.9 = 232.8W/m^2$$
$$Q_{window_{west}} = CF_{\mathrm{window}_{\mathrm{west}}} \times A_{\mathrm{window}_{\mathrm{west}}} = 232.8 * 14.4 = 3352.3W$$

<u>I change the frame of the window from wooden one to ALUMINIUM :</u>

HEATING:

$$A_{\mathrm{west}} = 14.4�$$
$$\mathrm{U'}_{\mathrm{window}_{\mathrm{west}}} = 3.61\mathrm{W/m^2 \cdot K}$$
$$\mathrm{HF'}_{\mathrm{window}_{\mathrm{west}}} = \mathrm{U'}_{\mathrm{window}_{\mathrm{west}}} \times \Delta T_{\mathrm{heating}} = 3.61 \times 24.8 = 89.52\mathrm{W/m^2}$$
$$\mathrm{Q'}_{\mathrm{window}_{\mathrm{west}}} = \mathrm{HF'}_{\mathrm{window}_{\mathrm{west}}} \times \mathrm{A}_{\mathrm{window}_{\mathrm{west}}} = 89.52 \times 14.4 = 1289.1W$$

COOLING:

$$CF'_{\text{window}_{\text{west}}heatTransferPart} = U'_{window_{west}}(\Delta T_{cooling} - 0.46DR) = 3.61*(7.9 - 0.46*11.9) = 8.7W/\text{m}^2$$

$$PXI_{\text{window}_{east}} = E_D + E_d = 559 + 188 = 747$$

$$SHGC' = 0.56$$

$$IAC = 1$$

$$FF\text{s} = 0.56$$

$$CF'_{\text{window}_{\text{west}}\text{irradiation}P\text{art}} = PXI \times SHGC' \times IAC \times FF\text{s} = 747 * 0.56 * 1 * 0.56 = 234.26W/m^2$$

$$CF'_{\text{window}_{\text{west}}} = CF'_{\text{window}_{\text{west}}heatTransferPart} + CF'_{\text{window}_{\text{west}}\text{irradiation}P\text{art}} = 8.7 + 234.26 = 242.96W/m^2$$

$$Q'_{window_{west}} = CF'_{\text{window}_{\text{west}}} \times A_{\text{window}_{\text{west}}} = 242.96 * 14.4 = 3498.6W$$

WINDOW3: SOUTH (3.6 ㎡，fixed; 3.6 ㎡ operable, wooden frame)

HEATING:

$$A_{\text{south}_{\text{fixed}}} = A_{\text{south}_{\text{operable}}} = 3.6 �$$

$$\text{U}_{\text{window}_{\text{southfixed}}} = 2.84\text{W/m}^2 \cdot \text{K}$$

$$\text{U}_{\text{window}_{\text{southoperable}}} = 2.87\text{W/m}^2 \cdot \text{K}$$

$$\text{HF}_{\text{window}_{\text{southfixed}}} = \text{U}_{\text{window}_{\text{southfixed}}} \times \Delta T_{\text{heating}} = 2.84 \times 24.8 = 70.4\text{W/m}^2$$

$$\text{HF}_{\text{window}_{\text{southoperable}}} = \text{U}_{\text{window}_{\text{southoperable}}} \times \Delta T_{\text{heating}} = 2.87 \times 24.8 = 71.17\text{W/m}^2$$

$$\text{Q}_{\text{window}_{\text{southfixed}}} = \text{HF}_{\text{window}_{\text{southfixed}}} \times \text{A}_{\text{window}_{\text{southfixed}}} = 70.4 \times 3.6 = 253.6W$$

$$\text{Q}_{\text{window}_{\text{southoperable}}} = \text{HF}_{\text{window}_{\text{southoperable}}} \times \text{A}_{\text{window}_{\text{southoperable}}} = 71.17 \times 3.6 = 256.2W$$

$$\text{Q}_{\text{window}_{\text{south}}} = \text{Q}_{\text{window}_{\text{southfixed}}} + \text{Q}_{\text{window}_{\text{southoperable}}} = 509.8W$$

COOLING:

$$CF_{\text{window}_{\text{south}\mathit{fixed}}heatTransferPart} = U_{window_{southfixed}}(\Delta T_{cooling} - 0.46DR) = 2.84*(7.9 - 0.46*11.9) = 6.9W/\text{m}^2$$

$$CF_{\text{window}_{\text{south}\mathit{operable}}heatTransferPart} = U_{window_{southoperable}}(\Delta T_{cooling} - 0.46DR) = 2.87*(7.9 - 0.46*11.9) = 6.96W/\text{m}^2$$

$PXI_{\text{window}_{\text{south}}} = E_D + E_d = 348 + 209 = 557$

$SHGC_{\text{fixed}} = 0.54$

$SHGC_{\text{operable}} = 0.46$

$IAC = 1$

$FF\text{s} = 0.47$

$CF_{\text{window}_{\text{southfixed}}\text{irradiation}P\text{art}} = PXI \times SHGC_{\text{fixed}} \times IAC \times FF\text{s} = 557 * 0.54 * 1 * 0.47 = 120.4W / m^2$

$CF_{\text{window}_{\text{southsouth}}\text{irradiation}P\text{art}} = PXI \times SHGC_{\text{operable}} \times IAC \times FF\text{s} = 557 * 0.46 * 1 * 0.47 = 141.4W / m^2$

$CF_{\text{window}_{\text{southfixed}}} = CF_{\text{window}_{\text{southfixed}} heatTransferPart} + CF_{\text{window}_{\text{southfixed}}\text{irradiation}P\text{art}} = 6.9 + 120.4 = 127.3W / m^2$

$CF_{\text{window}_{\text{southoperable}}} = CF_{\text{window}_{\text{southoperable}} heatTransferPart} + CF_{\text{window}_{\text{southoperable}}\text{irradiation}P\text{art}} = 6.96 + 141.4 = 148.36W / m^2$

$Q_{window_{\text{southfixed}}} = CF_{\text{window}_{\text{southfixed}}} \times A_{\text{window}_{\text{southfixed}}} = 127.3 * 3.6 = 458.28W$

$Q_{window_{\text{southoperable}}} = CF_{\text{window}_{\text{southoperable}}} \times A_{\text{window}_{\text{southoperable}}} = 148.3 * 3.6 = 533.88W$

$Q_{window_{\text{south}}} = Q_{window_{\text{southoperable}}} + Q_{window_{\text{southfixed}}} = 533.88 + 458.28 = 992.16W$

<u>NOW, I change the frame of the window from wooden one to ALUMINIUM :</u>

HEATING:

$A_{\text{south}_{\text{fixed}}} = A_{\text{south}_{\text{operable}}} = 3.6$ �

$\text{U'}_{\text{window}_{\text{southfixed}}} = 3.61\text{W/m}^2 \cdot \text{K}$

$\text{U'}_{\text{window}_{\text{southoperable}}} = 4.62\text{W/m}^2 \cdot \text{K}$

$\text{HF'}_{\text{window}_{\text{southfixed}}} = \text{U'}_{\text{window}_{\text{southfixed}}} \times \Delta T_{\text{heating}} = 3.61 \times 24.8 = 89.5\text{W/m}^2$

$\text{HF'}_{\text{window}_{\text{southoperable}}} = \text{U'}_{\text{window}_{\text{southoperable}}} \times \Delta T_{\text{heating}} = 4.62 \times 24.8 = 114.58\text{W/m}^2$

$\text{Q'}_{\text{window}_{\text{southfixed}}} = \text{HF'}_{\text{window}_{\text{southfixed}}} \times \text{A}_{\text{window}_{\text{southfixed}}} = 89.6 \times 3.6 = 322.56W$

$\text{Q'}_{\text{window}_{\text{southoperable}}} = \text{HF'}_{\text{window}_{\text{southoperable}}} \times \text{A}_{\text{window}_{\text{southoperable}}} = 114.58 \times 3.6 = 411.488W$

$\text{Q'}_{\text{window}_{\text{south}}} = \text{Q'}_{\text{window}_{\text{southfixed}}} + \text{Q'}_{\text{window}_{\text{southoperable}}} = 735.05W$

COOLING:

$CF'_{\text{window}_{\text{south}fixed} heatTransferPart} = U'_{window_{southfixed}} (\Delta T_{cooling} - 0.46DR) = 3.61 * (7.9 - 0.46 * 11.9) = 8.76W / \text{m}^2$

$CF'_{\text{window}_{\text{south}operable} heatTransferPart} = U'_{window_{southoperable}} (\Delta T_{cooling} - 0.46DR) = 4.62 * (7.9 - 0.46 * 11.9) = 11.2W / \text{m}^2$

$$PXI_{\text{window}_{\text{south}}} = E_D + E_d = 348 + 209 = 557$$

$$SHGC'_{\text{fixed}} = 0.56$$

$$SHGC'_{\text{operable}} = 0.55$$

$$IAC = 1$$

$$FF\text{s} = 0.47$$

$$CF'_{\text{window}_{\text{southfixed}}\text{irradiation}Part} = PXI \times SHGC'_{\text{fixed}} \times IAC \times FF\text{s} = 557 * 0.56 * 1 * 0.47 = 146.6W / m^2$$

$$CF'_{\text{window}_{\text{southsouth}}\text{irradiation}Part} = PXI \times SHGC'_{\text{operable}} \times IAC \times FF\text{s} = 557 * 0.55 * 1 * 0.47 = 143.98W / m^2$$

$$CF'_{\text{window}_{\text{southfixed}}} = CF'_{\text{window}_{\text{southfixed}}heatTransferPart} + CF'_{\text{window}_{\text{southfixed}}\text{irradiation}Part} = 8.76 + 146.6 = 155.36W / m^2$$

$$CF'_{\text{window}_{\text{southoperable}}} = CF'_{\text{window}_{\text{southoperable}}heatTransferPart} + CF'_{\text{window}_{\text{southoperable}}\text{irradiation}Part} = 11.2 + 143.98 = 155.18W / m^2$$

$$Q'_{window_{\text{southfixed}}} = CF'_{\text{window}_{\text{southfixed}}} \times A_{\text{window}_{\text{southfixed}}} = 155.36 * 3.6 = 559.296W$$

$$Q'_{window_{\text{southoperable}}} = CF'_{\text{window}_{\text{southoperable}}} \times A_{\text{window}_{\text{southoperable}}} = 155.18 * 3.6 = 558.648W$$

$$Q'_{window_{\text{south}}} = Q'_{window_{\text{southoperable}}} + Q'_{window_{\text{southfixed}}} = 559.296 + 558.648 = 1117.944W$$

HEATING:

$$Q_{TOTAL_{HEATING-WOODEN}} = Q_{window_{east}} + Q_{window_{west}} + Q_{window_{\text{south}}} = 1014.2 + 1014.2 + 509.8 = 2538.2W$$

$$Q_{TOTAL_{HEATING-ALUMINUM}} = Q'_{window_{east}} + Q'_{window_{west}} + Q'_{window_{\text{south}}} = 1289.2 + 1289.1 + 735.05 = 3321.8W$$

COOLING:

$$Q_{TOTAL_{COOLING-WOODEN}} = Q_{window_{east}} + Q_{window_{west}} + Q_{window_{\text{south}}} = 1900.8 + 3352.3 + 992.16 = 6245.26W$$

$$Q_{TOTAL_{COOLING-ALUMINUM}} = Q'_{window_{east}} + Q'_{window_{west}} + Q'_{window_{\text{south}}} = 1991.5 + 3498.6 + 1117.944 = 6608.044W$$