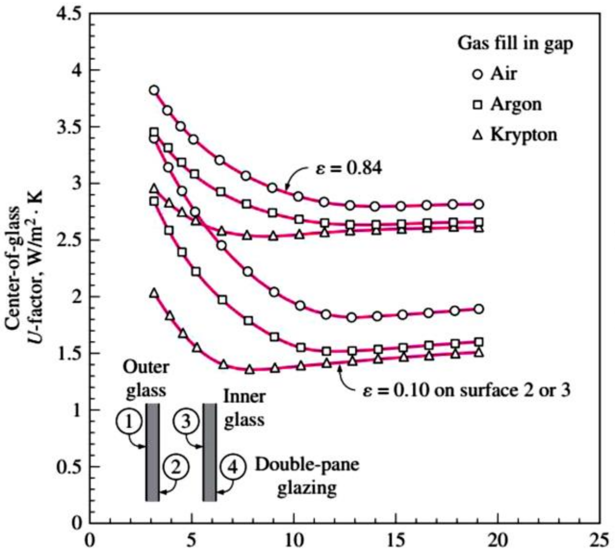
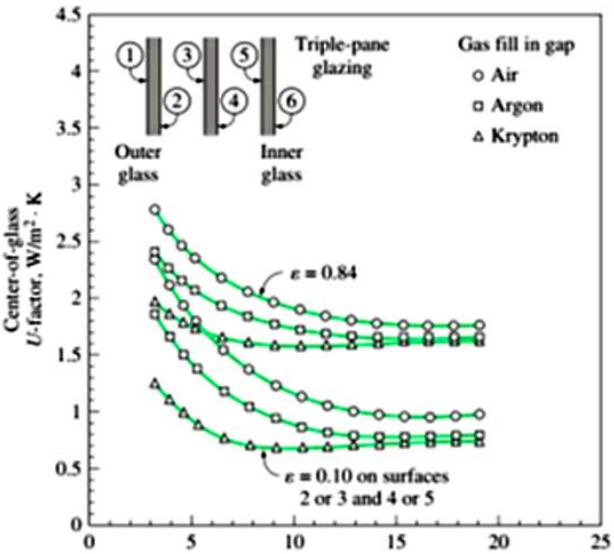
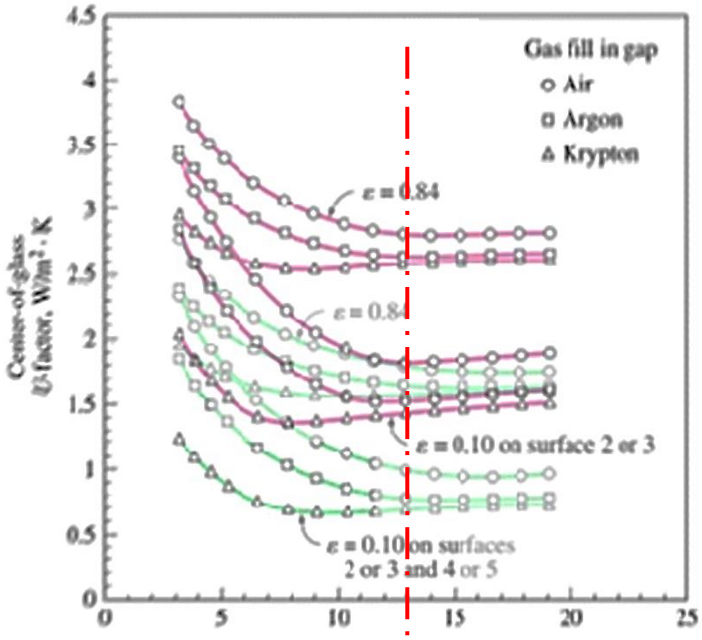
Task 1

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 the double layer with air and no coating? (keep the gap thickness to be 13 mm).







Direct comparison with two/tree pane glazing

Red vertical line for 13mm thickness

Comparing the two tables I can deduce that:

- In a windows with **two glass panes**, with a thickness more than 13 mm, the heat transfer coefficient is given by convection currents that appear in the air space: it means that the heat transfer remains nearly constant and so there isn't any benefit obtained by a thicker air layer (the lines in the graphic of each different gas material start to become horizontal).
  When the spacing d is less than about 13 mm, there is no convection, and heat transfer through the air is given by conduction (the line of the graphic in a decrescent curve).
  The emissivity in the exterior surfaces is 0.84, while in the interior surfaces is 0.1: these permit to have a heat transfer decrease-meant by half-ish (50%).
  One way to reduce the conduction heat transfer through a double-pane window is by using a less-conducting fluid. Confronting the different gas fill that can be used in the gap, the best is Krypton: it gives the lower value of heat transfer. The other in order of better heat transfer are Argon and Air.

- One way to increase the thermal resistance of the window is by using **tree glass panes**. Also, in this case, the best thickness is around 13mm, for the same causes of the double pane.
  Comparing the heat transfer between double pane windows and triple-pane windows I can deduce that in the last one the heat transfer decrease of about one third to the previous one (30%).
  Such as for the double pane, also in the triple pane windows, I can have a better heat transfer using Krypton and Argon (or void, even if it isn't practical).

- The last way to reduce the heat transfer is by using a 6.5 cm wide band of frame.

Frame material	*U*-factor, $W/m^2 \cdot °C$*
Aluminum:	
Single glazing (3 mm)	10.1
Double glazing (18 mm)	10.1
Triple glazing (33 mm)	10.1
Wood or vinyl:	
Single glazing (3 mm)	2.9
Double glazing (18 mm)	2.8
Triple glazing (33 mm)	2.7

By the table, in a base of the material of the frame, the best thermal resistance is given by wood or vinyl frame. The value is 30% less.

With a thickness of 13 mm, comparing the U factor with double and triple pane window I have that:

$U_{\text{Air double int}} = 1.5\ W/m^2K$
$U_{\text{Air triple int}} = 0.8\ W/m^2K$ the value is decreased by 47%

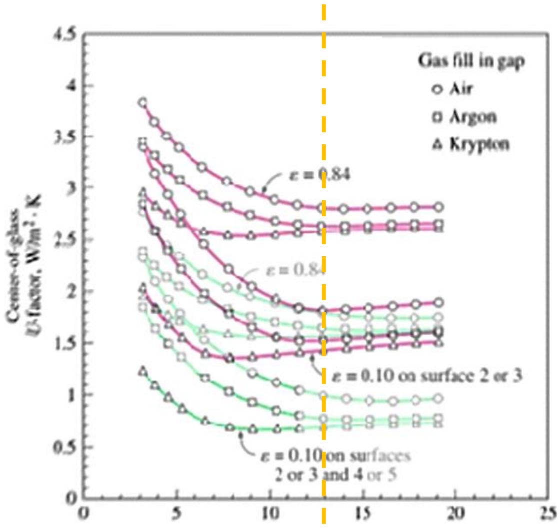
$U_{\text{Air double ext}} = 2.7\ W/m^2K$
$U_{\text{Air triple ext}} = 1.7\ W/m^2K$ the value is decreased by 37%

$U_{\text{Argon double int}} = 1.8\ W/m^2K$
$U_{\text{Argon triple int}} = 1\ W/m^2K$ the value is decreased by 44%

$U_{\text{Argon double exr}} = 2.8\ W/m^2K$
$U_{\text{Argon triple ext}} = 1.8\ W/m^2K$ the value is decreased by 35%

$U_{\text{Krypton double int}} = 1.4\ W/m^2K$
$U_{\text{Krypton triple int}} = 0.7\ W/m^2K$ the value is decreased by 50%

$U_{\text{Krypton double exr}} = 2.6\ W/m^2K$
$U_{\text{Krypton triple ext}} = 1.6\ W/m^2K$ the value is decreased by 38%



In conclusion, the best U-factor value is obtained by using the Krypton in the gap and a triple pane.

Task 2

Consider the house that we analyzed in the last two examples,

- The net area of walls (excluding doors and windows) of a building located in Piacenza is 105.8 m^2, the calculated U value is 0.438 W/m^2K for the winter and 0.435 w/m^2K for the summer. Find the corresponding heating and cooling load.

- A fixed heat-absorbing double-layer glass (with a wooden frame) window on the east side of a building located in Piacenza has a surface of 14.4 m^2. In case there are no internal and external shading factors. Calculate the heating and cooling load of the corresponding to that window.

calculate the heating and cooling load of the other windows which are fixed 14.4 m^2 on the west, fixed 3.6 m^2 on the south and an operable 3.6 m^2 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 aluminum?

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)

$\Delta T_{cooling} = 31.9 - 24 = 7.9$ °C

$\Delta T_{heating} = 20 - (-4.8) = 24.8$ °C

DR = 11.9 °C

The reason behind the difference between U values in the winter and summer is the difference in the outside convective coefficient, due to the wind.

Wall = opaque surface

Let's start with Heating (winter):

$HF = U_{heating} * \Delta T_{hating} = 0.438 * 24.8 = 10.862\ W/m^2$

$Q_{heating\_wall} = HF * A_{wall\ net} = 10.862 * 105.8 = 1149.2\ W$

For the cooling (summer):

The RLF method uses the following to estimate cooling load:

$$q_{opq} = A \times CF_{opq}$$

$$CF_{opq} = U(OF_t \Delta t + OF_b + OF_r DR)$$

where

q_{opq} = opaque surface cooling load, W
A = net surface area, m^2
CF = surface cooling factor, W/m^2
U = construction U-factor, W/(m^2·K)
Δt = cooling design temperature difference, K
OF_t, OF_b, OF_r = opaque-surface cooling factors (see Table 7)
DR = cooling daily range, K

Surface Type	OF_t	OF_b, K	OF_r
Ceiling or wall adjacent to vented attic	0.62	$14.3\alpha_{roof} - 4.5$	−0.19
Ceiling/roof assembly	1	$38.3\alpha_{roof} - 7.0$	−0.36
Wall (wood frame) or door with solar exposure	1	8.2	−0.36
Wall (wood frame) or door (shaded)	1	0	−0.36
Floor over ambient	1	0	−0.06
Floor over crawlspace	0.33	0	−0.28
Slab floor (see Slab Floor section)			

α_{roof} = roof solar absorptance (see Table 8).

$CF_{wall} = 0.435 * (1 * 7.9 + 8.2 - 0.36 * 11.9) = 5.14$ W/m^2

$Q_{cooling\_wall} = CF_{wall} * A_{wall} = 543.81$ W

Considering the fenestration heating:

$$q_{fen} = A \times CF_{fen}$$

$$CF_{fen} = U(\Delta t - 0.46DR) + PXI \times SHGC \times IAC \times FF_s$$

where

q_{fen} = fenestration cooling load, W
A = fenestration area (including frame), m^2
CF_{fen} = surface cooling factor, W/m^2
U = fenestration NFRC *heating* U-factor, W/(m^2·K)
Δt = cooling design temperature difference, K
PXI = peak exterior irradiance, including shading modifications, W/m^2 [see Equations (26) or (27)]
SHGC = fenestration rated or estimated NFRC solar heat gain coefficient
IAC = interior shading attenuation coefficient, Equation (29)
FF_s = fenestration solar load factor, Table 13

					Frame									
					Operable					Fixed				
Glazing Type	Glazing Layers	ID[b]	Property[c,d]	Center of Glazing	Aluminum	Aluminum with Thermal Break	Reinforced Vinyl/Aluminum Clad Wood	Wood/Vinyl	Insulated Fiberglass/Vinyl	Aluminum	Aluminum with Thermal Break	Reinforced Vinyl/Aluminum Clad Wood	Wood/Vinyl	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

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

Table 13 Fenestration Solar Load Factors FF_s

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

EAST WINDOW (frame fixed)

$U_{window\ east} = 2.84\ W/m^2K$ heat-absorbing double-layer glass (fixed with a wooden frame)

$HF_{window\ east} = U_{window\ east} * \Delta T_{heating} = 2.84 * 24.8 = 70.44\ W/m^2$

$Q_{window\ east} = HF_{window\ east} * A_{window\ east} = 70.4 * 14.4 = 1014.2\ W$

$CF_{fen} = U(\Delta t - 0.46 DR) + PXI \times SHGC \times IAC \times FF_s$ since there isn't any internal shading, the IAC is 1

$CF_{window\ east} = 2.84 * (7.9 – 0.46 * 11.9) + (559 + 188) * 0.54 * 1 * 0.31 = 132\ W/m^2$

$Q_{window\ east} = CF_{window\ east} * A_{window\ east} = 132 * 14.4 = 1900.8\ W$

WEST WINDOW (frame fixed)

$U_{window\ west} = 2.84\ W/m^2K$ heat-absorbing double-layer glass (fixed with a wooden frame)

$HF_{window\ west} = U_{window\ west} * \Delta T_{heating} = 2.84 * 24.8 = 70.44\ W/m^2$

$Q_{window\ west} = HF_{window\ west} * A_{window\ west} = 70.4 * 14.4 = 1014.2\ W$

$CF_{fen} = U(\Delta t - 0.46 DR) + PXI \times SHGC \times IAC \times FF_s$ since there isn't any internal shading, the IAC is 1

$CF_{window\ west} = 2.84 * (7.9 – 0.46 * 11.9) + (559 + 188) * 0.54 * 1 * 0.56 = 232.78\ W/m^2$

$Q_{window\ west} = CF_{window\ west} * A_{window\ west} = 232.78 * 14.4 = 3352.032\ W$

SOUTH WINDOW (frame fixed)

$U_{window\ south} = 2.84\ W/m^2K$ heat-absorbing double-layer glass (fixed with a wooden frame)

$HF_{window\ south} = U_{window\ south} * \Delta T_{heating} = 2.84 * 24.8 = 70.44\ W/m^2$

$Q_{window\ south} = HF_{window\ south} * A_{window\ south} = 70.4 * 3.6 = 253.44\ W$

$CF_{fen} = U(\Delta t - 0.46DR) + PXI \times SHGC \times IAC \times FF_s$ since there isn't any internal shading, the IAC is 1

$CF_{window\ south} = 2.84 * (7.9 - 0.46 * 11.9) + (348 + 209) * 0.54 * 1 * 0.47 = 148.26\ W/m^2$

$Q_{window\ south} = CF_{window\ south} * A_{window\ south} = 148.26 * 3.6 = 533.74\ W$

SOUTH WINDOW (frame operable)

$U_{window\ south} = 2.87\ W/m^2K$ heat-absorbing double-layer glass (operable with a wooden frame)

$HF_{window\ south} = U_{window\ south} * \Delta T_{heating} = 2.87 * 24.8 = 71.18\ W/m^2$

$Q_{window\ south} = HF_{window\ south} * A_{window\ south} = 71.18 * 3.6 = 256.23\ W$

$CF_{fen} = U(\Delta t - 0.46DR) + PXI \times SHGC \times IAC \times FF_s$ since there isn't any internal shading, the IAC is 1

$CF_{window\ south} = 2.87 * (7.9 - 0.46 * 11.9) + (348 + 209) * 0.46 * 1 * 0.47 = 127.39\ W/m^2$

$Q_{window\ south} = CF_{window\ south} * A_{window\ south} = 127.39 * 3.6 = 458.60\ W$

Changing the frame of the window from wooden to aluminum, I have to change the heat-absorbing U and SHGC:

- For the fixed frame the value changes:
  - U from 2.84 to 3.61
  - SHGC from 0.54 to 0.56
- For the operable frame the value changes:
  - U from 2.87 to 4.62
  - SHGC from 0.46 to 0.55

In particular, all the heating and cooling load will increase due to the increment of the values of the aluminum.

Aluminum frame:

<u>EAST WINDOW (frame fixed)</u>

$U_{window\ east}$ = 3.61 W/m^{2}K heat-absorbing double-layer glass (fixed with aluminum frame) (before 2.84)

$HF_{window\ east} = U_{window\ east} * \Delta T_{heating}$ = 3.61 * 24.8 = 89.53 W/m^2 (before 70.4)

$Q_{window\ east} = HF_{window\ east} * A_{window\ east}$ = 89.53 * 14.4 = 1289.20 W (before 1014.2)

$CF_{fen} = U(\Delta t - 0.46DR) + PXI \times SHGC \times IAC \times FF_s$ since there isn't any internal shading, the IAC is 1

$CF_{window\ east}$ = 3.61 * (7.9 – 0.46 * 11.9) + (559 + 188) * 0.56 * 1 * 0.31 = 138.43 W/m^2 (before 132)

$Q_{window\ east} = CF_{window\ east} * A_{window\ east}$ = 138.43 * 14.4 = 1993.39 W (before 1900.8)

<u>WEST WINDOW (frame fixed)</u>

$U_{window\ west}$ = 3.61 W/m^{2}K heat-absorbing double-layer glass (fixed with aluminum frame) (before 2.84)

$HF_{window\ west} = U_{window\ west} * \Delta T_{heating}$ = 3.61 * 24.8 = 89.53 W/m^2 (before 70.44)

$Q_{window\ west} = HF_{window\ west} * A_{window\ west}$ = 89.53 * 14.4 = 1289.20 W (before 1014.2)

$CF_{fen} = U(\Delta t - 0.46DR) + PXI \times SHGC \times IAC \times FF_s$ since there isn't any internal shading, the IAC is 1

$CF_{window\ west}$ = 3.61 * (7.9 – 0.46 * 11.9) + (559 + 188) * 0.56 * 1 * 0.56 = 243.02 W/m^2 (before 232.78)

$Q_{window\ west} = CF_{window\ west} * A_{window\ west}$ = 243.02 * 14.4 = 3499.49 W (before 3352.032)

<u>SOUTH WINDOW (frame fixed 3.6 m^2)</u>

$U_{window\ south}$ = 3.61 W/m^{2}K heat-absorbing double-layer glass (fixed with aluminum frame) (before 2.84)

$HF_{window\ south} = U_{window\ south} * \Delta T_{heating}$ = 3.61 * 24.8 = 89.53 W/m^2 (before 70.44)

$Q_{window\ south} = HF_{window\ south} * A_{window\ south}$ = 89.53 * 3.6 = 322.31 W (before 253.44)

$CF_{fen} = U(\Delta t - 0.46DR) + PXI \times SHGC \times IAC \times FF_s$ since there isn't any internal shading, the IAC is 1

$CF_{window\ south}$ = 3.61 * (7.9 – 0.46 * 11.9) + (348 + 209) * 0.56 * 1 * 0.47 = 155.36 W/m^2 (before 148.26)

$Q_{window\ south} = CF_{window\ south} * A_{window\ south}$ = 155.36 * 3.6 = 559.30 W (before 533.74)

<u>SOUTH WINDOW (frame operable 3.6 m^2)</u>

$U_{window\ south}$ = 4.62 W/m^{2}K heat-absorbing double-layer glass (operable with aluminum frame) (before 2.87)

$HF_{window\ south} = U_{window\ south} * \Delta T_{heating}$ = 4.62 * 24.8 = 114.58 W/m^2 (before 71.18)

$Q_{window\ south} = HF_{window\ south} * A_{window\ south}$ = 114.58 * 3.6 = 412.47 W (before 256.23)

$CF_{fen} = U(\Delta t - 0.46DR) + PXI \times SHGC \times IAC \times FF_s$ since there isn't any internal shading, the IAC is 1

$CF_{window\ south}$ = 4.62 * (7.9 – 0.46 * 11.9) + (348 + 209) * 0.55 * 1 * 0.47 = 155.19 W/m^2 (before 127.39)

$Q_{window\ south} = CF_{window\ south} * A_{window\ south}$ = 155.19 * 3.6 = 558.68 W (before 458.60)