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)

$$U_{window} = \frac{U_{center}A_{center} + U_{edge}A_{edge} + U_{fram}A_{fram}}{A_{window}},$$

$$\frac{1}{U_{double\ -pane\ (center\ region)}} \approx \frac{1}{h_i} + \frac{1}{h_{space}} + \frac{1}{h_0},\ h_{space} = h_{rad,\ space} + h_{conv,\ space}$$

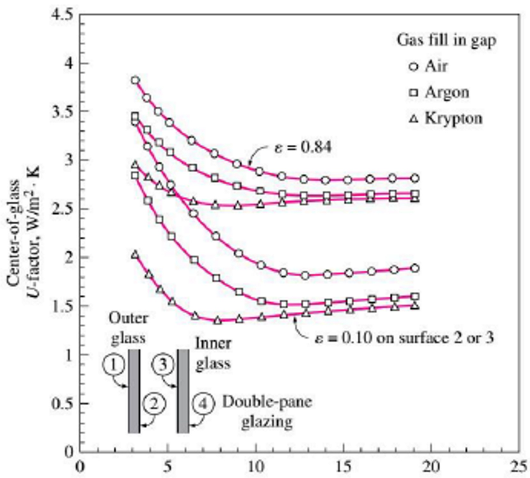
The U_{center}*, i.e. the* h_{space} *changes by changing the gas that fills the gap.*

From the diagram in the right side, we can see that:

When the gap thickenss is 13 mm,

By changing the gas that fills the gap from air to argon, the U-value of the center of the glass decreases from $2.8\ \frac{W}{m^2K}$ *to* $2.65\ \frac{W}{m^2K}$, which means the U-value decreases about 5.36%;

By changing the gas that fills the gap from air to krypton, the U-value of the center of the glass decrease from $2.8\ \frac{W}{m^2K}$ *to* $2.6\ \frac{W}{m^2K}$, which means the U-value decreases abouth 7.14%.



The U_{center}*, i.e. the* h_{space} *changes by adding an extra pane.*

From the diagram in the right side, we can see that:

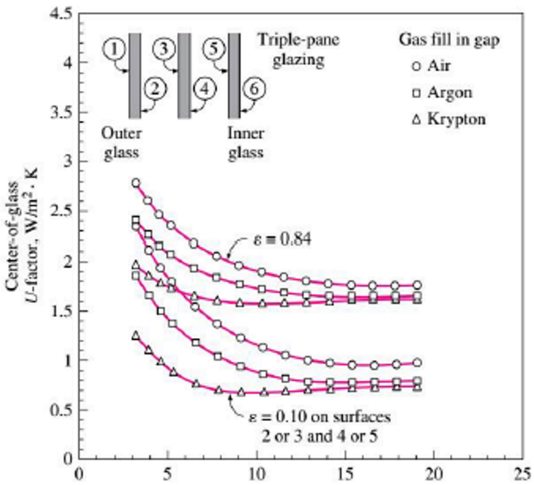
When the gap thickenss is 13 mm, and the gas that fills the gap is air,

By *adding an extra pane*, the U-value of the center of the glass decreases from $2.8\frac{W}{m^2K}$ *to* $1.8\frac{W}{m^2K}$, which means the U-value decreases about 35.71%.

Another way to change the U_{center}*, is to coat the glass surfaces* with a film that has a low emissivity.

From the diagram in the right we can see that:

When the gap thickenss is 13 mm, and the gas fills the gap is air,



By coating the glass surfaces with a film that has the emissivity of 0.1, the U-value of the center of the glass decreases from 2.8 $\frac{W}{m^2K}$ *to* 1.8 $\frac{W}{m^2K}$, which means the U-value decreases about 35.71%.

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 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 aluminium ?

(The questions *exempli gratia*:

1. 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^{2}K for the winter and 0.435 W/m^{2}K for the summer. Find the corresponding heating and cooling load.

2. 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 m^2. In case there are no internal and external shading factors. Calculate the heating and cooling load of the corresponding to that window.)

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)

$\boldsymbol{T_{heating} = 20\ °C, thus}$

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

$\Delta\, T_{heating} = 20°C\ - (-4.8°C) = 24.8\ °C = 24.8K$ *From the table above, DR*

$= 11.9\ °C = 11.9K$

Table 10 Peak Irradiance, W/m^2

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

Calculating the cooling load of the fixed window on the west:

$q_{window_{west}} = A \times CF_{window_{west}}$

$A = 14.4m^2,$

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

$CF_{window_{west}(Heat\ Trasnfer\ Part)} = U_{window_{west}}(\Delta T_{cooling}\ - 0.46\ DR)$

$\because$ *The window has a fixed heat absorbing double layer glass with a wooden frame,*

$\therefore\ U_{window_{west}} = 2.84\,\frac{W}{m^2K}$

$i.e.,\ CF_{window_{west}(Heat\ Trasnfer\ Part)} = 2.84\,\frac{W}{m^2K} \times (7.9\ K\ - 0.46{\times}11.9\ K) \approx 6.89\ \frac{W}{m^2}$

$PXI_{window_{west}} = E_D + E_d = 559 + 188\ = 747$

$SHGC = 0.54$

No internal shading, so $IAC = 1$

$FF_s = 0.56$

$CF_{window_{west}(Irradiation\ Part)} = PXI \times SHGC \times IAC \times FF_s$

$q_{window_{west}} = A \times CF_{window_{west}} = A \times (CF_{window_{west}(Heat\ Trasnfer\ Part)} + CF_{window_{west}(Irradiation\ Part)})$

$\approx 14.4\ m^2 \times (6.89 + 747 \times 0.54 \times 1 \times 0.56)\frac{W}{m^2} \approx 3352.07\ W$

Calculating the heating load of the fixed window on the

west: $q_{window_{west}} = A \times HF_{window_{west}} = A \times U_{window_{west}}$

$\Delta T_{heating} \quad = 14.4\ m^2 \times 2.84 \frac{W}{m^2K} \times 24.8K \approx 1014.22\ W$

When the frame were to be aluminium, $U_{window_{west}} = 3.61 \frac{W}{m^2K}$, $HSGC = 0.56$

$CF'_{window_{west}(Heat\ Trasnfer\ Part)} = U'_{window_{west}} \left(\Delta T_{cooling} - 0.46\ DR\right)$

$= 3.61 \frac{W}{m^2K} \times (7.9\ K - 0.46 \times 11.9\ K) \approx 8.76 \frac{W}{m^2}$

Cooling load $q'_{window_{west}} = A \times CF'_{window_{west}}$

$= A \times \left(CF'_{window_{west}(Heat\ Trasnfer\ Part)} + CF'_{window_{west}(Irradiation\ Part)}\right)$

$\approx 14.4\ m^2 \times (8.76 + 747 \times 0.56 \times 1 \times 0.56)\frac{W}{m^2} \approx 3499.48\ W$

Heating load $q'_{window_{west}} = A \times HF'_{window_{west}} = A \times U'_{window_{west}} \Delta T_{heating}$

$= 14.4\ m^2 \times 3.61 \frac{W}{m^2K} \times 24.8\ K \approx 1289.20\ W$

Calculating the cooling load of the fixed window on the south:

$q_{window_{south}} = A \times CF_{window_{south}}$

$A = 3.6\ m^2$,

$CF_{window_{south}(Heat\ Trasnfer\ Part)} = U_{window_{south}} \left(\Delta T_{cooling} - 0.46\ DR\right)$

∵The window has a fixed heat absorbing double layer glass with a wooden frame,

$\therefore U_{window_{south}} = 2.84 \frac{W}{m^2K}$

$i.e.,\ CF_{window_{south}(Heat\ Trasnfer\ Part)} = 2.84 \frac{W}{m^2K} \times (7.9\ K - 0.46 \times 11.9\ K) \approx 6.89 \frac{W}{m^2}$

$PXI_{window_{south}} = E_D + E_d = 348 + 209 = 557$

$SHGC = 0.54$

No internal shading, so $IAC = 1$

$FF_s = 0.47$

$CF_{window_{south}(Irradiation\ Part)} = PXI \times SHGC \times IAC \times FF_s$

$q_{window_{south}} = A \times CF_{window_{south}} = A \times (CF_{window_{south}(Heat\ Trasnfer\ Part)} + CF_{window_{south}(Irradiation\ Part)})$

$\approx 3.6\ m^2 \times (6.89 + 557 \times 0.54 \times 1 \times 0.47)\frac{W}{m^2} \approx 553.72\ W$

Calculating the heating load of the fixed window on the south:

$q_{window_{south}} = A \times HF_{window_{south}} = A \times U_{window_{south}}\, \Delta T_{heating}$

$$= 3.6\, m^2 \times 2.84\, \frac{W}{m^2K} \times 24.8K \approx 253.56\, W$$

When the frame were to be aluminium, $U_{window_{south}} = 3.61\, \frac{W}{m^2K}$, $HSGC = 0.56$

$CF'_{window_{south}(Heat\ Trasnfer\ Part)} = U'_{window_{south}}\, (\Delta T_{cooling} - 0.46\, DR)$

$$= 3.61\, \frac{W}{m^2K} \times (7.9\, K - 0.46 \times 11.9\, K) \approx 8.76\, \frac{W}{m^2}$$

$Cooling\ load\ q'_{window_{south}} = A \times CF'_{window_{south}}$

$$= A \times (CF'_{window_{south}(Heat\ Trasnfer\ Part)} + CF'_{window_{south}(Irradiation\ Part)})$$

$$\approx 3.6\, m^2 \times (8.76 + 557 \times 0.56 \times 1 \times 0.47)\, \frac{W}{m^2} \approx 559.30\, W$$

$Heating\ load\ q'_{window_{south}} = A \times HF'_{window_{south}} = A \times U'_{window_{south}}\, \Delta T_{heating}$

$$= 3.6\, m^2 \times 3.61\, \frac{W}{m^2K} \times 24.8\, K \approx 322.30\, W$$

Calculating the cooling load of the operable window on the south:

$q_{window_{south}} = A \times CF_{window_{south}}$

$A = 3.6\, m^2$,

$CF_{window_{south}(Heat\ Trasnfer\ Part)} = U_{window_{south}}\, (\Delta T_{cooling} - 0.46\, DR)$

∵The window has an operable heat absorbing double layer glass with a wooden frame,

$\therefore U_{window_{south}} = 2.87\, \frac{W}{m^2K}$

$i.e.,\ CF_{window_{south}(Heat\ Trasnfer\ Part)} = 2.87\, \frac{W}{m^2K} \times (7.9\, K - 0.46 \times 11.9\, K) \approx 6.96\, \frac{W}{m^2}$

$PXI_{window_{south}} = E_D + E_d = 348 + 209 = 557$

$SHGC = 0.46$

No internal shading, so $IAC = 1$

$FF_s = 0.47$

$CF_{window_{south}(Irradiation\ Part)} = PXI \times SHGC \times IAC \times FF_s$

$q_{window_{south}} = A \times CF_{window_{south}} = A \times (CF_{window_{south}(Heat\ Trasnfer\ Part)} + CF_{window_{south}(Irradiation\ Part)})$

$$\approx 3.6\, m^2 \times (6.96 + 557 \times 0.46 \times 1 \times 0.47)\, \frac{W}{m^2} \approx 458.58\, W$$

Calculating the heating load of the operable window on the south:

$q_{window_{south}} = A \times HF_{window_{south}} = A \times U_{window_{south}}\, \Delta T_{heating}$

$$= 3.6\, m^2 \times 2.87\, \frac{W}{m^2K} \times 24.8K \approx 256.23\, W$$

When the frame were to be aluminium, $U_{window_{south}} = 4.62\, \frac{W}{m^2K}$, $HSGC = 0.55$

$CF'_{window_{south}(Heat\ Trasnfer\ Part)} = U'_{window_{south}}\, (\Delta T_{cooling} - 0.46\, DR)$

$$=4.62\ \frac{W}{m^2K} \times (7.9\ K\ - 0.46 \times 11.9\ K) \approx 11.21\ \frac{W}{m^2}$$

$$Cooling\ load\ q'_{window_{south}} = A \times CF'_{window_{south}}$$

$$= A \times \left(CF'_{window_{south}(Heat\ Trasnfer\ Part)} + CF'_{window_{south}(Irradiation\ Part)}\right)$$

$$\approx 3.6\ m^2 \times (11.21 + 557 \times 0.55 \times 1 \times 0.47)\frac{W}{m^2} \approx 558.70\ W$$

$$Heating\ load\ q'_{window_{south}} = A \times HF'_{window_{south}} = A \times U'_{window_{south}}\ \Delta T_{heating}$$

$$= 3.6\ m^2\ \times 4.62\,\frac{W}{m^2K}\ \times 24.8\ K \approx 412.47\ W$$