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)

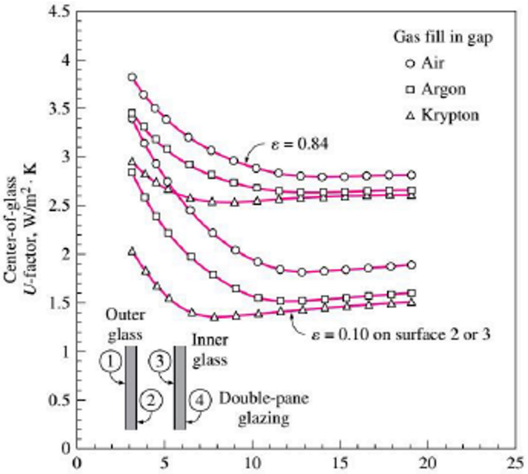
*Answer*

$To\ calculate\ the\ U - value\ of\ a\ window,$

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

$If\ it\ is\ a\ double - pane\ window, disregard\ the\ thermal\ resistances\ of\ \ glass\ layers,$

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



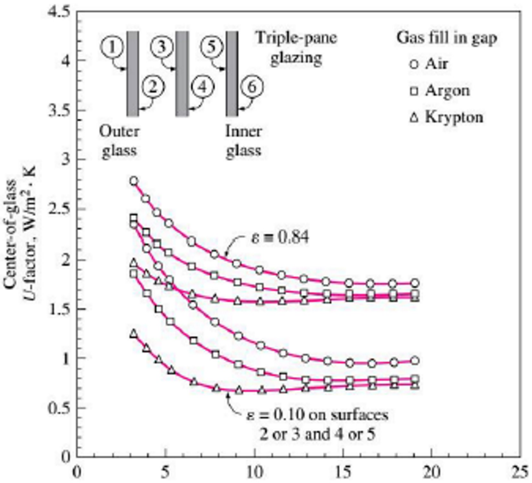
$The\ U_{center}, i.e. the\ h_{space}\ changes\ by\ changing\ the\ gas\ that\ fills\ the\ gap.$

*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 6.43%;*

*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 55.6%.*

$Another\ way\ to\ change\ the\ \ U_{center}, is\ to\ coat\ the\ glass\ surfaces$ *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,*

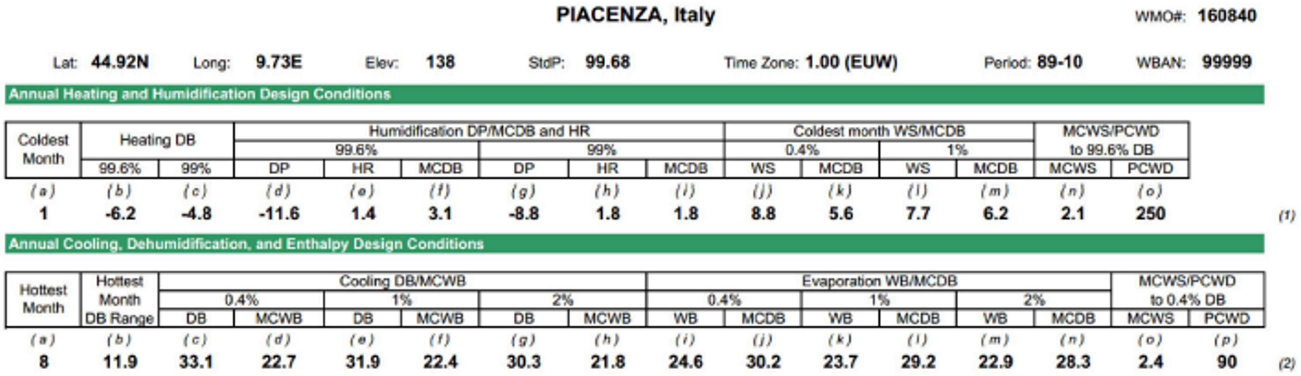
*By coating the glass surfaces with a film that has the emissivity of 0.1, the U-value of the center of the glass decreases from* $2.8\frac{W}{m^2K}$ *to* $1.8\frac{W}{m^2K}$*, which means the U-value decreases about 55.6%.*

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 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) |

***Answer:***

***First of all, define the cooling design temperature $T_{cooling} = 24\ °C$, and heating design temperature $T_{heating} = 20\ °C$, 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,* $DR = 11.9\ °C = 11.9K$

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

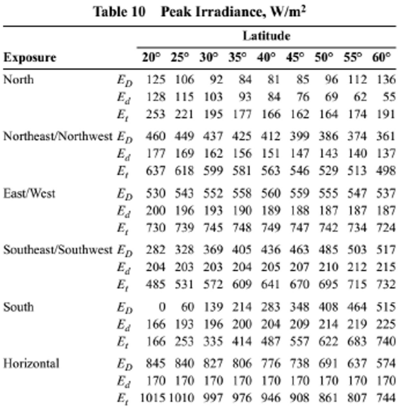


Table 10 Peak Irradiance, W/m$^2$

| 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 |

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

$A = 14.4m^2$,

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

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

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

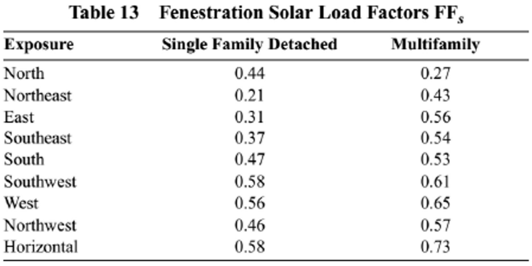


**Table 13 Fenestration Solar Load Factors FF$_s$**

| 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 |

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

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

$SHGC = 0.54$

*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:***

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

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

***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:***

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

$A = 3.6\ m^2,$

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

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

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

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

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

$SHGC = 0.55$

*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,*** $U_{window_{south}} = 3.61\frac{W}{m^2K},\ HSGC = 0.56$

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

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

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

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

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

*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:***

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

$A = 3.6\ m^2,$

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

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

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

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

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

$SHGC = 0.46$

*No internal shading, so IAC* =1

$FF_s = 0.47$

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

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

$$\approx 3.6\ m^2 \times (6.96 + 557 \times 0.54 \times 1 \times 0.47)\,\frac{W}{m^2} \approx 553.98\ W$$

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

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

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

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

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

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

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

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