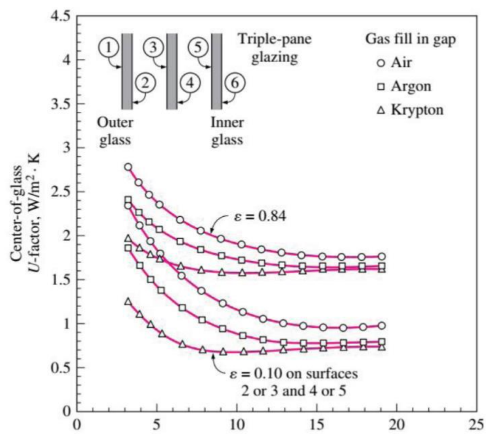
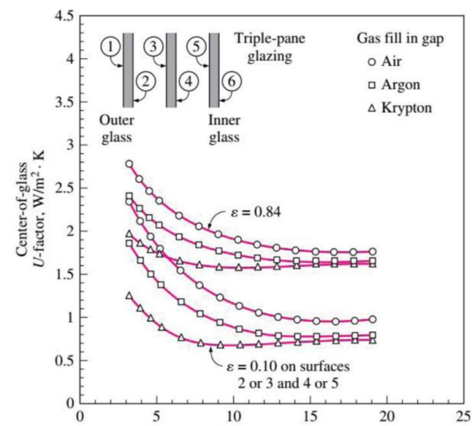
Task 1 Using the diagrams given in the presentation calculate how much (%) is the effect of applying different modifications (changing the gas, adding an extra pane, using a low emissivity coating) on the U value with respect to a benchmark case ofdouble layer with air and no coating ? ( keep the gap thickenss to be 13 mm)




From the diagram，

1. For double-pane(13mm) glazing:

$U_{air}$ =2.8 W/㎡·$K$

$U_{argon}$ =2.7 W/㎡·K

$U_{krypton}$ =2.6 W/㎡·$K$

So, when changing the gas,
From Air to Argon: decrease about 4.57%
From Air to Krypton: decrease about 7.14%

2. For triple-pane(13mm) glazing:

$U_{double}$ =2.8 W/㎡·$K$

$U_{triple}$ =1.8 W/㎡·$K$

So, when adding an extra pane, the U value decrease about 35.71%

3. For double-pane(13mm) glazing:

$U_{\_double0.1}$ =2.8 W/㎡·$K$

$U_{\_triple0.1}$ =1W/㎡·$K$

So, when using a low emissivity coating, the U value decrease about 35.71%

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 thesouth 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 ?

**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) |

**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 |

| 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 |

**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 |

$$q_{fen} = A \times \mathrm{CF}_{fen}$$

$$\mathrm{CF}_{fen} = U(\Delta t - 0.46\,\mathrm{DR}) + \mathrm{PXI} \times \mathrm{SHGC} \times \mathrm{IAC} \times \mathrm{FF}_s$$

*where*

$q_{fen}$ = fenestration cooling load, W
$A$ = fenestration area (including frame), m²
$\mathrm{CF}_{fen}$ = surface cooling factor, W/m²
$U$ = fenestration NFRC *heating* U-factor, W/(m²·K)
$\Delta t$ = cooling design temperature difference, K
PXI = peak exterior irradiance, including shading modifications, W/m² [see Equations (26) or (27)]
SHGC = fenestration rated or estimated NFRC solar heat gain coefficient
IAC = interior shading attenuation coefficient, Equation (29)
$\mathrm{FF}_s$ = fenestration solar load factor, Table 13

$\Delta T_{cooling}$ =31.9−24=7.9℃

$\Delta T_{heating}$ =20−(−4.8)=24.8℃

DR=11.9℃

## Wood Frames

**Window1(east, wood frame, fixed)**

$A_{window1} = 14.4$㎡

Heating:

$U_{window1}$=2.84W/㎡·$K$

$HF_{window1} = U_{window1} \times \Delta T_{cooling} = 2.84 \times 24.8 = 70.44W/$㎡

$Q_{window1} = HF_{window1} \times A_{window} = 70.44 \times 14.44 = 1014.2W$

Cooling:

Heat transfer:

$CF_{window1} = U_{window1}(\Delta T_{cooling} - 0.46DR) = 2.84(7.9 - 0.46 \times 11.9) = 6.9W/$㎡

Irradiation：

$ED$= 559, $E_d$ = 188, $FF_{seast}$ = 0.31 $PXI_{window1}$= $E_D + E_d$ =559+188=747

$CF_{window1} = PXI \times SHGC \times IAC \times FF_{seast} = 747 \times 0.54 \times 1 \times 0.31 = 125.1$

$CF_{fenestration1} = U_{window1}(\Delta T_{cooling} - 0.46DR) + PXI \times SHGC \times IAC \times FF_{seast}$

$= 6.9 + 125.1 = 132W/$㎡

$\dot{Q}_{window1} = CF_{fenestration1} \times A_{window1} = 132 \times 14.4 = 1900.8W$

**Window2(west, wood frame, fixed)**

$A_{window2}$=14.4㎡

Heating:

$U_{window2}$= 2.84W/㎡·K

$HF_{window2}$=$U_{window2}$ × $\Delta T_{cooling}$ =2.84×24.8=70.44 W/㎡$Q$

$Q_{window2}$= $HF_{window2}$ × $A_{window2}$ =70.44×14.4=1014.2W

Cooling:

Heat transfer:

$CF_{window2}$ = $U_{window2}$ ( $\Delta T_{cooling}$ −0.46DR) =2.84(7.9−0.46× 11.9)=6.9 W/㎡

Irradiation:

$ED$=559, $Ed$=188, $FF_{swest}$ =0.56, $PXI_{window1}$= $E_D + E_d$ =559+188=747

$CF_{window2} = PXI \times SHGC \times IAC \times FF_{swest} = 747 \times 0.56 \times 1 \times 0.56 = 225.9$

$CF_{fenestration2} = U_{window2}(\Delta T_{cooling} - 0.46DR) + PXI \times SHGC \times IAC \times FF_{swest}$

$= 6.9 + 225.9 = 232.8W/㎡$

$\dot{Q}_{window2} = CF_{fenestration2} \times A_{window2} = 232.8 \times 14.4 = 3352.32W$

**Window3(south, wood frame, fixed)**

$A_{window3} = 3.6㎡$

Heating:

$U_{window3}$=2.84 W/㎡$\cdot K$

$HF_{window3}$=$U_{window3} \times \Delta T_{cooling}$=2.84×24.8=70.44 W/㎡

$Q_{window3} = HF_{window3} \times A_{window3} = 70.44 \times 3.6 = 253.6W$

Cooling:

Heat transfer:

$CF_{window3} = U_{window3}(\Delta T_{cooling} - 0.46DR) = 2.84(7.9 - 0.46 \times 11.9) = 6.9W/㎡$

Irradiation:

$ED$=348, $Ed$=209, $FF_{ssouth}$=0.47 $PXI_{window3}$=$ED$+$Ed$=348+209=557

$CF_{window3} = PXI \times SHGC \times IAC \times FF_{ssouth} = 557 \times 0.54 \times 1 \times 0.47 = 141.4$

$CF_{fenestration3} = U_{window3}(\Delta T_{cooling} - 0.46DR) + PXI \times SHGC \times IAC \times FF_{ssouth}$

$= 6.9 + 141.4 = 148.3W/㎡$

$\dot{Q}_{window3} = CF_{fenestration3} \times A_{window3} = 148.3 \times 3.6 = 533.88W$

**Window4(south, wood frame, openable)**

$A_{window4} = 3.6㎡$

Heating:

$U_{window4}$=2.87 W/㎡$\cdot K$

$HF_{window4}$= $U_{window4} \times \Delta T_{cooling}$=2.87×24.8=71.17 W/㎡$Q$

$Q_{window4} = HF_{window4} \times A_{window4} = 71.17 \times 3.6 = 256.2W$

Cooling:

Heat transfer:

$CF_{window4} = U_{window4}(\Delta T_{cooling} - 0.46DR) = 2.87(7.9 - 0.46 \times 11.9) = 6.96W/㎡$

Irradiation:

$ED$=348, $Ed$=209, $SHGC$=0.46, $FF_{ssouth}$=0.47 $PXI_{window4}$=$ED$+$Ed$=348+209=557

$CF_{window4} = PXI \times SHGC \times IAC \times FF_{ssouth} = 557 \times 0.46 \times 1 \times 0.47 = 120.4$

$CF_{fenestration4} = U_{window4}(\Delta T_{cooling} - 0.46DR) + PXI \times SHGC \times IAC \times FF_{ssouth}$

$= 6.9 + 120.4 = 127.3W/㎡$

$\dot{Q}_{window4} = CF_{fenestration4} \times A_{window4} = 127.3 \times 3.6 = 458.28W$

$\dot{Q}_{totalcoolingwood}$ **=1900.8+3352.32+533.88+458.28=6245.3*w***

$\dot{Q}_{totalheatingwood}$ **=1014.2+1014.2+253.6+256.2=2538.2*w***

## Aluminum Frames

**Window1(south, aluminum frame, fixed)**

$A_{window1} = 14.4㎡$

<u>Heating:</u>

$U_{window1}$=3.61 $w/㎡ \cdot K$

$HF_{window1} = U_{window1} \times \Delta T_{cooling} = 3.61 \times 24.8 = 89.52W/㎡$

$Q_{window1} = HF_{window1} \times A_{window1} = 89.52 \times 14.4 = 1289.1W$

<u>Cooling:</u>

Heat transfer:

$CF_{window1} = U_{window1}(\Delta T_{cooling} - 0.46DR) = 3.61(7.9 - 0.46 \times 11.9) = 8.7W/㎡$

Irradiation：

$ED$= 559, $E_d = 188$, $SHGC$=0.56 $FF_{seast} = 0.31$ $PXI_{window1} = E_D + E_d$ =559+188=747

$CF_{window1} = PXI \times SHGC \times IAC \times FF_{seast} = 747 \times 0.56 \times 1 \times 0.31 = 129.6$

$CF_{fenestration1} = U_{window1}(\Delta T_{cooling} - 0.46DR) + PXI \times SHGC \times IAC \times FF_{seast}$

$= 8.7 + 129.6 = 138.3W/㎡$

$\dot{Q}_{window1} = CF_{fenestration1} \times A_{window1} = 138.3 \times 14.4 = 1991.5W$

**Window2(west, aluminum frame, fixed)**

$A_{window2} = 14.4㎡$

<u>Heating:</u>

$U_{window2}$=3.61 $w/㎡ \cdot K$

$HF_{window2} = U_{window2} \times \Delta T_{cooling} = 3.61 \times 24.8 = 89.52W/㎡\,Q$

$Q_{window2} = HF_{window2} \times A_{window2} = 89.52 \times 14.4 = 1289.1W$

<u>Cooling:</u>

Heat transfer:

$CF_{window2} = U_{window2}(\Delta T_{cooling} - 0.46DR) = 3.61(7.9 - 0.46 \times 11.9) = 8.7W/㎡$

Irradiation:

$ED$=559, $Ed$=188, $FF_{swest}$=0.56 $PXI_{window2}$=$ED$+$Ed$=559+188=747

$CF_{window2} = PXI \times SHGC \times IAC \times FF_{swest} = 747 \times 0.56 \times 1 \times 0.56 = 234.26$

$CF_{fenestration2} = U_{window2}(\Delta T_{cooling} - 0.46DR) + PXI \times SHGC \times IAC \times FF_{swest}$

$= 8.7 + 234.26 = 242.96W / ㎡$

$\dot{Q}_{window2} = CF_{fenestration2} \times A_{window2} = 242.96 \times 14.4 = 2398.6W$

**Window3(south, aluminum frame, fixed)**

$A_{window3} = 3.6㎡$

<u>Heating:</u>

$U_{window3}$=3.61 W/㎡·$K$

$HF_{window3} = U_{window3} \times \Delta T_{cooling} = 3.61 \times 24.8 = 89.52W / ㎡\, Q$

$Q_{window3} = HF_{window3} \times A_{window3} = 89.52 \times 3.6 = 322.2W$

<u>Cooling:</u>

Heat transfer:

$CF_{window3} = U_{window3}(\Delta T_{cooling} - 0.46DR) = 3.61(7.9 - 0.46 \times 11.9) = 8.7W / ㎡$

Irradiation:

$ED$=348, $Ed$=209, $FF_{ssouth}$=0.47 $PXI_{window3}$=$ED$+$Ed$=348+209=557

$CF_{window3} = PXI \times SHGC \times IAC \times FF_{ssouth} = 557 \times 0.56 \times 1 \times 0.47 = 146.6$

$CF_{fenestration3} = U_{window3}(\Delta T_{cooling} - 0.46DR) + PXI \times SHGC \times IAC \times FF_{ssouth}$

$= 8.7 + 146.6 = 155.3W / ㎡$

$\dot{Q}_{window3} = CF_{fenestration3} \times A_{window3} = 155.3 \times 3.6 = 559.08W$

**Window4(south, aluminum frame, openable)**

$A_{window4} = 3.6㎡$

<u>Heating:</u>

$U_{window4}$=4.62 W/㎡·$K$ $H$

$HF_{window4} = U_{window4} \times \Delta T_{cooling} = 4.62 \times 24.8 = 114.57W / ㎡\, Q$

$Q_{window4} = HF_{window4} \times A_{window4} = 114.57 \times 3.6 = 412.4W$

<u>Cooling:</u>

Heat transfer:

$CF_{window4} = U_{window4}(\Delta T_{cooling} - 0.46DR) = 4.62(7.9 - 0.46 \times 11.9) = 11.2W / ㎡$

Irradiation:

$ED$=348, $Ed$=209, $SHGC$=0.55, $FF_{ssouth}$=0.47 $PXI_{window4}$=$ED$+$Ed$=348+209=557

$CF_{window4} = PXI \times SHGC \times IAC \times FF_{ssouth} = 557 \times 0.55 \times 1 \times 0.47 = 143.98$

$$CF_{fenestration4} = U_{window4}(\Delta T_{cooling} - 0.46DR) + PXI \times SHGC \times IAC \times FF_{ssouth}$$

$$= 11.2 + 143.98 = 155.18W / \text{m}^2$$

$$\dot{Q}_{window4} = CF_{fenestration4} \times A_{window4} = 155.18 \times 3.6 = 558.65W$$

$\dot{Q}_{totalcoolingaluminum}$ **=1991.5+3498.6+559.08+558.65=6607.8*w***

$\dot{Q}_{totalheatingaluminum}$ **=1289.1+1289.1+322.2+412.4=3312.8*w***

**Conclusion:**

$\dot{Q}_{totalcoolingwood} / \dot{Q}_{totalcoolingaluminum}$ =6245.3/6607.8=94.5%

$\dot{Q}_{totalheatingwood} / \dot{Q}_{totalheatingaluminum}$ =2538.2/3312.8=76.6%

From the result we can conclude that window with wooden frame has better resistance than aluminum frame. 94.5% for cooling and 76.6% for heating.