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Submission Date: 26/11/2019
Assignment #: 8th Week

Task 1

As we know from the presentations, in order to find the U value of the double pane window (center region) we should use the following formula:

$$\frac{1}{U_{double\ pane\ window(center\ region)}} \approx \frac{1}{h_i} + \frac{1}{h_{space}} + \frac{1}{h_o}$$

Another fact that we learned from the presentation is that air space coefficient (h_{space}) is equal to air space radiation coefficient (h_{rd}) plus air space convection coefficient (h_{cv}). Since our gap is within optimal range then convection coefficient doesn't exist, therefore $h_{space} = h_{rd}$.

By replacing winter design values of 8.29 and 34.0 $\frac{W}{C°m2}$ for the inner and outer surface heat transfer coefficients and also value of 5.3 (h_{space} in winter when $\varepsilon_{effective}$ = 0.72 for two parallel glass surfaces) we can calculate the benchmark U factor:

$$\frac{1}{U_{double\ pane\ window(center\ region)}} \approx \frac{1}{8.29} + \frac{1}{5.3} + \frac{1}{34} \approx 0.12 + 0.189 + 0.03$$

$$\Rightarrow \frac{1}{U_{double\ pane\ window(center\ region)}} \approx 0.339$$

$$\Rightarrow U_{double\ pane\ window(center\ region)} \approx \boxed{2.95}$$

- In case of using a **low emissivity coating**, due to the lower $\varepsilon_{effective}$ (0.1), our h_{space} is equal to 2.4 $\frac{W}{m2.k}$ in winter. by replacing this value instead of 5.3 our U factor will be **1.77** $\frac{W}{m2.k}$. then:

$$\frac{U_{double\ pane\ window\ (center\ region)-with\ coating}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{1.77}{2.95} \approx \boxed{60\ \%}$$

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- In case of injecting a **low conductive fluid**, due to lower conductivity of the gases , our U-factor is equal to **2.7** (when $\varepsilon_{effective}$ = 0.84) and **2.5** (when $\varepsilon_{effective}$ = 0.1) for the case of Argon gas and then for Krypton gas the corresponding values are **1.5** (when $\varepsilon_{effective}$ = 0.84) and **1.4** (when $\varepsilon_{effective}$ = 0.1), then:

$$\frac{U_{double\ pane\ window\ (center\ region)-Argon-\ \varepsilon=0.84}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{2.7}{2.95} \approx \boxed{92\ \%}$$

$$\frac{U_{double\ pane\ window\ (center\ region)-Argon-\ \varepsilon=0.1}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{2.5}{2.95} \approx \boxed{85\ \%}$$

$$\frac{U_{double\ pane\ window\ (center\ region)-Krypton-\varepsilon=0.84}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{1.5}{2.95} \approx \boxed{50\ \%}$$

$$\frac{U_{double\ pane\ window\ (center\ region)-Krypton-\varepsilon=0.1}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{1.4}{2.95} \approx \boxed{48\ \%}$$

- In case of using a **triple glazing**, due to the additional layer of air gap , our U-factor is equal to **2** (when $\varepsilon_{effective}$ = 0.84) and **1.3** (when $\varepsilon_{effective}$ = 0.1) for the case of air and then it equals to **1.8** (when $\varepsilon_{effective}$ = 0.84) and **1** (when $\varepsilon_{effective}$ = 0.1) when Argon gas replaces air. In case we replace Argon with Krypton then U-factor will be **1.6** (when $\varepsilon_{effective}$ = 0.84) and **0.7** (when $\varepsilon_{effective}$ = 0.1), then:

$$\frac{U_{triple\ pane\ window\ (center\ region)-air-\varepsilon=0.84}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{2}{2.95} \approx \boxed{68\ \%}$$

$$\frac{U_{triple\ pane\ window\ (center\ region)-air-\varepsilon=0.1}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{1.3}{2.95} \approx \boxed{45\ \%}$$

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$$\frac{U_{triple\ pane\ window\ (center\ region)-Argon-\ \varepsilon=0.84}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{1.8}{2.95} \approx \boxed{61\ \%}$$

$$\frac{U_{triple\ pane\ window\ (center\ region)-Argon-\ \varepsilon=0.1}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{1}{2.95} \approx \boxed{33\ \%}$$

$$\frac{U_{triple\ pane\ window\ (center\ region)-Krypton-\ \varepsilon=0.84}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{1.6}{2.95} \approx \boxed{55\ \%}$$

$$\frac{U_{triple\ pane\ window\ (center\ region)-Krypton-\ \varepsilon=0.1}}{U_{double\ pane\ window\ (center\ region)-without\ coating}} \approx \frac{0.7}{2.95} \approx \boxed{24\ \%}$$

Task 2

We know from the last session that n order to calculate the heating and cooling load we need to use following formulas:

- $Q_{heating} = HF \times A$ where HF is the heating load factor and A is the fenestration area including frame. We can calculate the heating load factor by multiplying Window's U-factor by the heating temperature difference.
- $Q_{cooling} = HF \times A$ where CF is the surface cooling factor and A is the fenestration area including frame. CF can be calculated as following:

$$CF = U\,(\Delta T_{cooling} - 0.46DR) + PXI \times SHGC \times IAC \times \mathrm{FF}_3$$

Where DR is **cooling daily range**, PXI is **peak irradiance** and is equal to sum of $\boldsymbol{E_D}$ **(diffuse irradiance)** and $\boldsymbol{E_d}$ **(direct irradiance)** in case of no exterior shading (as we imagined), SHGC is solar hear gain coefficient, IAC is **interior shading attenuation coefficient** which equals to 1 in our case since we have no interior shading (as we imagined) and finally FF_3 is **fenestration solar load factor**.

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For the new windows the following values can be plotted from corresponding tables:

Window_West_Fixed	
U-factor	2.84 (Fixed Double Glazed Window with Wooden Frame)
PXI	$E_D + E_d$ = 559+ 188 = 747 (Based on Latitude of Piacenza)
SHGC	0.54 (Fixed Double Glazed Window with Wooden Frame)
IAC	1 (No Interior Shading)
FF_3	0.56 (Single Family Detached House)

Window_South_Fixed	
U-factor	2.84 (Fixed Double Glazed Window with Wooden Frame)
PXI	$E_D + E_d$ = 348+209 = 557 (Based on Latitude of Piacenza)
SHGC	0.54 (Fixed Double Glazed Window with Wooden Frame)
IAC	1 (No Interior Shading)
FF_3	0.47 (Single Family Detached House)

Window_South_Operable	
U-factor	2.87 (Fixed Double Glazed Window with Wooden Frame)
PXI	$E_D + E_d$ = 348+209 = 557 (Based on Latitude of Piacenza)
SHGC	0.46 (Fixed Double Glazed Window with Wooden Frame)
IAC	1 (No Interior Shading)
FF_3	0.47 (Single Family Detached House)

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We also know from the presentation that $\boldsymbol{\Delta T_{heating}}$ = **24.8** °$\boldsymbol{C}$, $\boldsymbol{\Delta T_{cooling}}$= **7.9** °$\boldsymbol{C}$ and ***DR*** = **11.9** °$\boldsymbol{C}$, then:

- $Q_{heating\_window_{west}} = HF_{window_{\text{west}}} \times A_{window_{\text{west}}}$
- $HF_{window_{west}} = U_{window_{west}} \times \Delta T_{heating} = 2.84 \times 24.8 \approx 70.44 \frac{W}{m2}$

  ➡ $Q_{heating\_window_{west}} = 70.44 \times 14.4 \approx \boxed{1014.34\ W}$

- $Q_{cooling\_window_{west}} = CF_{window_{west}} \times A_{window_{west}}$
- $CF_{window_{\text{west}}} = U_{window_{\text{west}}} (\Delta T_{cooling} - 0.46DR) + PXI_{window_{\text{west}}} \times SHGC_{window_{\text{west}}} \times IAC_{window_{\text{west}}} \times \text{FF}_{3\ window_{\text{west}}}$

  ➡ $= 2.84\ (7.9 - 0.46 \times 11.9) + 747 \times 0.54 \times 1 \times 0.56 \approx 226 \frac{W}{m2}$

  ➡ $Q_{cooling} = 190 \times 14.4 \approx \boxed{3255\ W}$

- $Q_{heating\_window_{south-f}} = HF_{window_{south-f}} \times A_{window_{south-f}}$
- $HF_{window_{south-f}} = U_{window_{south-f}} \times \Delta T_{heating}$

  ➡ $= 2.84 \times 24.8 \approx 70.44 \frac{W}{m2}$

  ➡ $Q_{heating\_window_{south-f}} = 70.44 \times 3.6 \approx \boxed{254\ W}$

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- $Q_{cooling\_window_{south-f}} = CF_{window_{south-f}} \times A_{window_{south-f}}$

- $CF_{window_{south-f}} = U_{window_{south-f}} (\Delta T_{cooling} - 0.46DR) + PXI_{window_{south-f}} \times SHGC_{window_{south-f}} \times IAC_{window_{south-f}} \times \mathrm{FF}_{3\ window_{south-f}}$

➡ $= 2.84\ (7.9 - 0.46 \times 11.9) + 557 \times 0.54 \times 1 \times 0.47 \approx 149 \frac{W}{m2}$

➡ $Q_{cooling} = 149 \times 3.6 = \boxed{536.4\ W}$

- $Q_{heating\_window_{south-o}} = HF_{window_{south-o}} \times A_{window_{south-o}}$

- $HF_{window_{south-o}} = U_{window_{south-o}} \times \Delta T_{heating}$

➡ $= 2.87 \times 24.8 \approx 71.2 \frac{W}{m2}$

➡ $Q_{heating\_window_{south-f}} = 71.2 \times 3.6 \approx \boxed{257\ W}$

- $Q_{cooling\_window_{south-o}} = CF_{window_{south-o}} \times A_{window_{south-o}}$

$CF_{window_{south-o}} = U_{window_{south-o}} (\Delta T_{cooling} - 0.46DR) + PXI_{window_{south-o}} \times SHGC_{window_{south-o}} \times IAC_{window_{south-o}} \times \mathrm{FF}_{3\ window_{south-o}}$

➡ $= 2.87\ (7.9 - 0.46 \times 11.9) + 557 \times 0.46 \times 1 \times 0.47 \approx 127.43 \frac{W}{m2}$

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$$\Rightarrow Q_{cooling} = 127.43 \times 3.6 = \boxed{458.8\ W}$$

Now we can calculate the values for Aluminum frames:

Window_West_Fixed	
U-factor	3.61 (Fixed Double Glazed Window with Aluminum Frame)
PXI	$E_D + E_d$ = 559+ 188 = 747 (Based on Latitude of Piacenza)
SHGC	0.56 (Fixed Double Glazed Window with Aluminum Frame)
IAC	1 (No Interior Shading)
FF_3	0.56 (Single Family Detached House)

Window_South_Fixed	
U-factor	3.61 (Fixed Double Glazed Window with Aluminum Frame)
PXI	$E_D + E_d$ = 348+209 = 557 (Based on Latitude of Piacenza)
SHGC	0.56 (Fixed Double Glazed Window with Aluminum Frame)
IAC	1 (No Interior Shading)
FF_3	0.47 (Single Family Detached House)

Window_South_Operable	
U-factor	4.62 (Fixed Double Glazed Window with Aluminum Frame)
PXI	$E_D + E_d$ = 348+209 = 557 (Based on Latitude of Piacenza)
SHGC	0.55 (Fixed Double Glazed Window with Aluminum Frame)
IAC	1 (No Interior Shading)
FF_3	0.47 (Single Family Detached House)

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We also know from the presentation that $\boldsymbol{\Delta T_{heating}}$ = **24.8** °$\boldsymbol{C}$, $\boldsymbol{\Delta T_{cooling}}$= **7.9** °$\boldsymbol{C}$ and ***DR*** = **11.9** °$\boldsymbol{C}$, then:

- $Q_{heating\_window_{west}} = HF_{window_{\text{west}}} \times A_{window_{\text{west}}}$
- $HF_{window_{west}} = U_{window_{west}} \times \Delta T_{heating} = 3.61 \times 24.8 \approx 90 \frac{W}{m2}$

  ➡ $Q_{heating\_window_{west}} = 90 \times 14.4 \approx \boxed{1300\ W}$

- $Q_{cooling\_window_{west}} = CF_{window_{west}} \times A_{window_{west}}$
- $CF_{window_{\text{west}}} = U_{window_{\text{west}}} (\Delta T_{cooling} - 0.46DR) + PXI_{window_{\text{west}}} \times SHGC_{window_{\text{west}}} \times IAC_{window_{\text{west}}} \times \text{FF}_{3\ window_{\text{west}}}$

  ➡ $= 3.61\ (7.9 - 0.46 \times 11.9) + 747 \times 0.56 \times 1 \times 0.56 \approx 243 \frac{W}{m2}$

  ➡ $Q_{cooling} = 190 \times 14.4 \approx \boxed{3500\ W}$

- $Q_{heating\_window_{south-f}} = HF_{window_{south-f}} \times A_{window_{south-f}}$
- $HF_{window_{south-f}} = U_{window_{south-f}} \times \Delta T_{heating}$

  ➡ $= 3.61 \times 24.8 \approx 90 \frac{W}{m2}$

  ➡ $Q_{heating\_window_{south-f}} = 90 \times 3.6 \approx \boxed{324\ W}$

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- $Q_{cooling\_window_{south-f}} = CF_{window_{south-f}} \times A_{window_{south-f}}$

- $CF_{window_{south-f}} = U_{window_{south-f}} (\Delta T_{cooling} - 0.46DR) + PXI_{window_{south-f}} \times SHGC_{window_{south-f}} \times IAC_{window_{south-f}} \times \mathrm{FF}_{3\ window_{south-f}}$

  ➡ $= 3.61\ (7.9 - 0.46 \times 11.9) + 557 \times 0.56 \times 1 \times 0.47 \approx 155.4 \frac{W}{m2}$

  ➡ $Q_{cooling} = 155.4 \times 3.6 \approx \boxed{560\ W}$

- $Q_{heating\_window_{south-o}} = HF_{window_{south-o}} \times A_{window_{south-o}}$

- $HF_{window_{south-o}} = U_{window_{south-o}} \times \Delta T_{heating}$

  ➡ $= 4.62 \times 24.8 \approx 114.58 \frac{W}{m2}$

  ➡ $Q_{heating\_window_{south-f}} = 114.58 \times 3.6 \approx \boxed{413\ W}$

- $Q_{cooling\_window_{south-o}} = CF_{window_{south-o}} \times A_{window_{south-o}}$

$CF_{window_{south-o}} = U_{window_{south-o}} (\Delta T_{cooling} - 0.46DR) + PXI_{window_{south-o}} \times SHGC_{window_{south-o}} \times IAC_{window_{south-o}} \times \mathrm{FF}_{3\ window_{south-o}}$

➡ $= 4.62\ (7.9 - 0.46 \times 11.9) + 557 \times 0.55 \times 1 \times 0.47 \approx 155.21 \frac{W}{m2}$

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➡ $Q_{cooling} = 155.21 \times 3.6 = \boxed{559\ W}$

The increase of heat loss through our window after substituting the wooden frame by aluminum one is very significant.