Course Projects: "Indoor Climate" and "Snow and Ice"

Anna Subiós de Arriaga
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Collaborators:
Andrew Jephson
Lauri Kaipainen
Cameron Mackie
Christoffer Nordström
Mugisha Ruhweza
Vincent Voinot
Indoor Climate
F0034T

Project Work
Part 1. Heat

Energy department

Christoffer Nordström
Mugisha Ruhweza
Anna Subirós de Arriaga
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1. U-values for walls and doors inside the building

1.1. Inside Wall

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Name</th>
<th>Dimension (m)</th>
<th>( \lambda ) (W/m(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Insulation</td>
<td>0.070</td>
<td>0.036</td>
</tr>
<tr>
<td>2</td>
<td>Wall board</td>
<td>0.012</td>
<td>0.14</td>
</tr>
<tr>
<td>3</td>
<td>Bar of wood</td>
<td>0.045</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Table 1. Showing all dimensions and properties of the wall

<table>
<thead>
<tr>
<th>Homogenous parts</th>
<th>Dimension (m)</th>
<th>( \lambda ) (W/m(^2))</th>
<th>( R ) (m(^2)°C/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall board</td>
<td>0.012</td>
<td>0.14</td>
<td>( R = 2 \cdot \left( \frac{d}{\lambda} \right) = 0.171 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R_u )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total ( R_{\text{Hom}} )</td>
<td></td>
<td></td>
<td>0.431</td>
</tr>
</tbody>
</table>

Table 2. Heat resistance for all homogenous parts of the inside wall

Higher limit (\( R_f' \))

\[
R_f' = \frac{A_1 + A_2}{R_{\text{Hom}} + \frac{d_1}{\lambda_2}} + \frac{A_3}{R_{\text{Hom}} + \frac{d_3}{\lambda_3}} = \frac{0.555 + 0.045}{0.055 + 0.045} + \frac{0.07}{0.036 + 0.07} = 2.127848
\]

Lower limit (\( R_f'' \))

\[
\lambda'' = \frac{0.14 \cdot 0.045 + 0.036 \cdot 0.555}{0.6} = 0.0438 \text{ (W/m°C)}
\]

\[
R_f'' = \frac{0.431 + \frac{0.07}{0.0438}}{2} = 2.02917 \text{ (m}^2\text{°C/W)}
\]

\[
R_f = \frac{2.127848 + 2.02917}{2} = 2.0785 \text{ (m}^2\text{°C/W)}
\]
\[ U_c = \frac{1}{R_r} = \frac{1}{2.0785} = 0.4841367 \text{ (W/m}^2\text{K)} \]

Correction

\[ U_p = U_c + \Delta U_g + \Delta U_{\text{construction}} = 0.48111367 + 0.02 + 0.02 \]

\[ U_{p,\text{inside wall}} = 0.5211 \text{ (W/m}^2\text{K)} \]

1.2. Inside door

<table>
<thead>
<tr>
<th>Homogenous parts</th>
<th>Dimension (m)</th>
<th>( \lambda ) (W/m(^2))</th>
<th>( R ) (m(^2)K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (Times two because it is on both sides)</td>
<td>0.04</td>
<td>0.14</td>
<td>[ R = 2 \cdot \left( \frac{d}{\lambda} \right) = 0.2857 ]</td>
</tr>
<tr>
<td>( R_{\text{si}} )</td>
<td></td>
<td></td>
<td>2\cdot0.13= 0.26</td>
</tr>
<tr>
<td>Total ( R_{\text{Hom}} )</td>
<td></td>
<td></td>
<td>0.5457</td>
</tr>
</tbody>
</table>

Table 3. Heat resistance of all homogenous parts on the inside door

\[ U_c = \frac{1}{R_r} = \frac{1}{0.5457} = 1.83246 \text{ (W/m}^2\text{K)} \]

\[ U_{p,\text{inside door}} = U_c + \Delta U_g + \Delta U_{\text{construction}} = 1.83245 + 0.10 + 0 \]

\[ U_{p,\text{inside door}} = 1.93246 \text{ (W/m}^2\text{K)} \]

2. DOT\(_{20}\)

To determine the design outdoor temperature at for Lulea. The mean temperature for Lulea in January had to first be analyzed from table 4. The selected mean temperature was then used on figure 1 to determine the DOT\(_{20}\) as shown below.
Table 4. Mean temperature for year and each month in some Swedish places (year 1931-1960)
Figure 1. Showing design outdoor temperatures at 20 degrees for different time constants and mean temperatures for January

\[ \tau = 25 \text{h} \]

\[ \text{DOT}_{20} = -29^\circ\text{C}. \]

3. Heat losses for each room on the first floor

The heat losses for each room can be through transmission, infiltration and supply air.

<table>
<thead>
<tr>
<th>Component</th>
<th>U-Value (W/m²°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside Door</td>
<td>1,932</td>
</tr>
<tr>
<td>Outside Door</td>
<td>1</td>
</tr>
<tr>
<td>Balcony Door</td>
<td>2</td>
</tr>
<tr>
<td>Window 1st Floor</td>
<td>1,8</td>
</tr>
<tr>
<td>Inside Wall</td>
<td>0,521</td>
</tr>
<tr>
<td>Outside Wall</td>
<td>0,184</td>
</tr>
<tr>
<td>Floor</td>
<td>0,231</td>
</tr>
<tr>
<td>Roof</td>
<td>0,134</td>
</tr>
</tbody>
</table>

Table 5. Transmission losses for all components
3.1. Entrance Hall

3.1.1. Transmission loss

<table>
<thead>
<tr>
<th>Components</th>
<th>U-Value (W/m²°C)</th>
<th>Area (m²)</th>
<th>UA (W/°C)</th>
<th>Difference of temperatures (°C)</th>
<th>Q (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Wall</td>
<td>0,184</td>
<td>7,5</td>
<td>1,380</td>
<td>20{-29}=49</td>
<td>67,62</td>
</tr>
<tr>
<td>Floor</td>
<td>0,231</td>
<td>13,3</td>
<td>3,072</td>
<td>49</td>
<td>150,528</td>
</tr>
<tr>
<td>Outside Door</td>
<td>1</td>
<td>2,1</td>
<td>2,1</td>
<td>49</td>
<td>102,9</td>
</tr>
<tr>
<td>Inside Wall (Bathroom)</td>
<td>0,521</td>
<td>4,59</td>
<td>2,391</td>
<td>20-25=-5</td>
<td>-11,955</td>
</tr>
<tr>
<td>Inside Door (Bathroom)</td>
<td>1,932</td>
<td>1,89</td>
<td>3,652</td>
<td>-5</td>
<td>-18,26</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>12,595</td>
<td></td>
<td></td>
<td>290,833</td>
</tr>
</tbody>
</table>

Table 6, Transmission losses through the entrance hall

3.1.2. Infiltration rate

<table>
<thead>
<tr>
<th>Rate</th>
<th>0,1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (m³)</td>
<td>31,92</td>
</tr>
</tbody>
</table>

Table 7, Infiltration and flow rate

\[ Q_{\text{inf}} = \rho \cdot V \cdot 0,1 \cdot c_p (T_{\text{in}} - DOT_{20}) = 52,66W \]

3.1.3. Supply Air

There is no \( Q_{\text{supply}} \) in the entrance hall because air is neither supplied nor exhausted.

3.1.4. Total heat loss

The total heat loss of the entrance hall is the sum of all the values from the previous sections.

\[ Q = Q_{\text{trans}} + Q_{\text{inf}} + Q_{\text{sup}} = 343,546W \]
3.2. Living Room

3.2.1. Transmission loss

<table>
<thead>
<tr>
<th>Components</th>
<th>U-Value (W/m²·K)</th>
<th>Area (m²)</th>
<th>UA (W/°C)</th>
<th>Difference of temperatures (°C)</th>
<th>Q (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Wall</td>
<td>0,184</td>
<td>28,88</td>
<td>5,314</td>
<td>20-(-29)=49</td>
<td>260,386</td>
</tr>
<tr>
<td>Floor</td>
<td>0,231</td>
<td>27,265</td>
<td>6,296</td>
<td>49</td>
<td>308,504</td>
</tr>
<tr>
<td>Window 1st Floor</td>
<td>1,8</td>
<td>6,76</td>
<td>12,168</td>
<td>49</td>
<td>596,232</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1165,122</td>
</tr>
</tbody>
</table>

Table 8, Transmission losses in the living room

3.2.2. Infiltration rate

<table>
<thead>
<tr>
<th>Rate</th>
<th>0,1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (m³)</td>
<td>65,436</td>
</tr>
</tbody>
</table>

Table 9, Infiltration and flow rate

\[ Q_{inf} = \rho \cdot V \cdot 0,1 \cdot c_p \cdot (T_{in} - DOT_{20}) = 107,9W \]

3.2.3. Supply Air
There is \( Q_{supply} \) in the living room because air is supplied at a rate of 0,017 m³/s.

\[ Q_{sup} = \rho \cdot V \cdot 0,017 \cdot c_p \cdot (T_{in} - T_{sup}) = 41,21W \]

3.2.4. Total heat loss
The total heat loss of the living hall is the sum of all the values from the previous sections.

\[ Q = Q_{trans} + Q_{inf} + Q_{sup} = 1314,38W \]
3.3. Laundry

3.3.1. Transmission losses

<table>
<thead>
<tr>
<th>Components</th>
<th>U-Value (W/m²°C)</th>
<th>Area (m²)</th>
<th>UA (W/°C)</th>
<th>Difference of temperatures (°C)</th>
<th>Q (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Wall</td>
<td>0,184</td>
<td>4,83</td>
<td>0,889</td>
<td>20-(−29)=49</td>
<td>43,561</td>
</tr>
<tr>
<td>Floor</td>
<td>0,231</td>
<td>7,56</td>
<td>1,746</td>
<td>49</td>
<td>85,554</td>
</tr>
<tr>
<td>Balcony Door</td>
<td>2</td>
<td>1,89</td>
<td>3,780</td>
<td>49</td>
<td>185,22</td>
</tr>
<tr>
<td>Inside Door (Garage)</td>
<td>1,932</td>
<td>1,89</td>
<td>3,651</td>
<td>20-15=5</td>
<td>18,255</td>
</tr>
<tr>
<td>Garage Wall</td>
<td>0,184</td>
<td>4,59</td>
<td>0,845</td>
<td>5</td>
<td>4,225</td>
</tr>
<tr>
<td>Inside Wall (Bathroom)</td>
<td>0,521</td>
<td>6,48</td>
<td>3,376</td>
<td>20-25=−5</td>
<td>−16,88</td>
</tr>
</tbody>
</table>

**Table 10. Transmission losses in the laundry**

3.3.2. Infiltration rate

<table>
<thead>
<tr>
<th>Rate</th>
<th>0,1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (m³)</td>
<td>16,144</td>
</tr>
</tbody>
</table>

**Table 11. Infiltration and flow rate**

\[
Q_{\text{inf}} = \rho \cdot V \cdot 0,1 \cdot c_p \cdot (T_{\text{in}} - D\cdot T_{\text{avg}}) = 29,93W
\]

3.3.3. Supply Air

There is no \( Q_{\text{supply}} \) in the laundry because air is neither supplied nor exhausted.

3.3.4. Total heat loss

The total heat loss of the laundry is the sum of all the values from the previous sections.

\[
Q = Q_{\text{trans}} + Q_{\text{inf}} + Q_{\text{supply}} = 349,870W
\]
3.4. Bathroom

3.4.1. Transmission losses

<table>
<thead>
<tr>
<th>Components</th>
<th>U-Value (W/m²°C)</th>
<th>Area (m²)</th>
<th>UA (W/°C)</th>
<th>Difference of temperatures (°C)</th>
<th>Q (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Wall</td>
<td>0,184</td>
<td>2,51</td>
<td>0,462</td>
<td>25-(-29)=54</td>
<td>24,948</td>
</tr>
<tr>
<td>Floor</td>
<td>0,231</td>
<td>4,725</td>
<td>1,091</td>
<td>54</td>
<td>58,914</td>
</tr>
<tr>
<td>Window 1st Floor</td>
<td>1,8</td>
<td>1,69</td>
<td>3,042</td>
<td>54</td>
<td>164,268</td>
</tr>
<tr>
<td>Inside Door</td>
<td>1,932</td>
<td>1,89</td>
<td>3,651</td>
<td>25-20=5</td>
<td>18,255</td>
</tr>
<tr>
<td>Inside Wall</td>
<td>0,521</td>
<td>15,27</td>
<td>7,956</td>
<td>25-20=5</td>
<td>39,78</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>306,165</td>
</tr>
</tbody>
</table>

Table 12, Transmission losses in the bathroom

3.4.2. Infiltration rate

<table>
<thead>
<tr>
<th>Rate</th>
<th>0,1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (m³)</td>
<td>11,34</td>
</tr>
</tbody>
</table>

Table 13, Infiltration and flow rate

\[ Q_{\text{inf}} = \rho \cdot V \cdot 0,1 \cdot c_p \cdot (T_{\text{in}} - DOT_{20}) = 20,62W \]

3.4.3. Exhaust Air

There is no \( Q_{\text{supply air}} \) in the bathroom but there air is exhausted.

\[ Q_{\text{sup}} = \rho \cdot V \cdot 0,017 \cdot c_p \cdot (T_{\text{in}} - T_{\text{sup}}) = 60,6W \]

3.4.4. Total heat loss

To get the total heat loss of the bathroom we had add the heat losses through transmission and through infiltration and subtract of the heat loss through exhaust air.

\[ Q = Q_{\text{trans}} + Q_{\text{inf}} - Q_{\text{sup}} = 387,399W \]
3.5. Kitchen

3.5.1. Transmission losses

<table>
<thead>
<tr>
<th>Components</th>
<th>U-Value (W/m²°C)</th>
<th>Area (m²)</th>
<th>UA (W/°C)</th>
<th>Difference of temperatures (°C)</th>
<th>Q (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Wall</td>
<td>0,184</td>
<td>17,02</td>
<td>3,132</td>
<td>20-(-29)=49</td>
<td>153,468</td>
</tr>
<tr>
<td>Floor</td>
<td>0,231</td>
<td>17,972</td>
<td>4,152</td>
<td>49</td>
<td>203,448</td>
</tr>
<tr>
<td>Window 1st Floor</td>
<td>1,8</td>
<td>3,38</td>
<td>6,084</td>
<td>49</td>
<td>298,116</td>
</tr>
<tr>
<td>Inside Wall (Bathroom)</td>
<td>0,521</td>
<td>4,2</td>
<td>2,188</td>
<td>20-25=-5</td>
<td>-10,94</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>644,092</td>
</tr>
</tbody>
</table>

Table 14. Transmission losses in the kitchen

3.5.2. Infiltration rate

<table>
<thead>
<tr>
<th>Rate</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,1</td>
<td>43,134</td>
</tr>
</tbody>
</table>

Table 15. Infiltration and flow rate

\[ Q_{\text{inf}} = \rho \cdot V \cdot 0,1 \cdot c_p (T_{\text{in}} - DOT_{20}) = 71,16W \]

3.5.3. Supply Air

There is no \( Q_{\text{supply air}} \) in the kitchen but air is being exhausted.

3.5.4. Total heat loss

The total heat loss of the laundry is the sum of all the values from the previous sections.

\[ Q = Q_{\text{trans}} + Q_{\text{inf}} + Q_{\text{sup}} = 715,215W \]

3.6. Total Heat Loss of the house

The total heat loss for the entire house was determined by summing up all heat losses in each room i.e. both the first and second floor.

\[ Q_{\text{total}} = Q_{\text{kitchen}} + Q_{\text{entrancehall}} + Q_{\text{laundry}} + Q_{\text{bathroom}} + Q_{\text{livingroom}} + Q_{2nd floor} = 5648,372W \]
4. Radiators

<table>
<thead>
<tr>
<th>Room</th>
<th>Radiators</th>
<th>Width</th>
<th>Heat</th>
<th>Heat/Radiator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance Hall</td>
<td>1</td>
<td>1000</td>
<td>343,506</td>
<td>343,506</td>
</tr>
<tr>
<td>Living Room</td>
<td>4</td>
<td>1000</td>
<td>1314,382</td>
<td>328,596</td>
</tr>
<tr>
<td>Laundry</td>
<td>1</td>
<td>500</td>
<td>349,872</td>
<td>349,872</td>
</tr>
<tr>
<td>Kitchen</td>
<td>1</td>
<td>1250</td>
<td>715,215</td>
<td>715,215</td>
</tr>
<tr>
<td>Bathroom</td>
<td>1</td>
<td>1000</td>
<td>387,399</td>
<td>387,399</td>
</tr>
</tbody>
</table>

Table 16, Size of radiators and heat supplied by each radiator in the first floor of the house

<table>
<thead>
<tr>
<th>Room</th>
<th>Type</th>
<th>Symbol</th>
<th>Height (m)</th>
<th>Width (m)</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance Hall</td>
<td>TP-11</td>
<td>510</td>
<td>500</td>
<td>1000</td>
<td>416</td>
</tr>
<tr>
<td>Living Room</td>
<td>TP-11</td>
<td>410</td>
<td>400</td>
<td>1000</td>
<td>340</td>
</tr>
<tr>
<td>Laundry</td>
<td>TP-22</td>
<td>604</td>
<td>600</td>
<td>400</td>
<td>364</td>
</tr>
<tr>
<td>Kitchen</td>
<td>TP-21</td>
<td>512</td>
<td>500</td>
<td>1200</td>
<td>763</td>
</tr>
<tr>
<td>Bathroom</td>
<td>TP-11</td>
<td>510</td>
<td>500</td>
<td>1000</td>
<td>416</td>
</tr>
</tbody>
</table>

Table 17, Showing the selected radiators for each room in the first floor of the house
5. Heat demand for the building

5.1. Transmission losses

<table>
<thead>
<tr>
<th>Components</th>
<th>U-Value (W/m²°C)</th>
<th>Area (m²)</th>
<th>UA (W/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathroom Wall</td>
<td>0.184</td>
<td>2.51</td>
<td>0.462</td>
</tr>
<tr>
<td>Windows 1st Floor (Bathroom)</td>
<td>1.8</td>
<td>1.69</td>
<td>3.042</td>
</tr>
<tr>
<td>Garage Wall</td>
<td>0.184</td>
<td>4.59</td>
<td>0.845</td>
</tr>
<tr>
<td>Inside Door (Garage)</td>
<td>1.932</td>
<td>1.89</td>
<td>3.651</td>
</tr>
<tr>
<td>Floor</td>
<td>0.231</td>
<td>70.823</td>
<td>16.36</td>
</tr>
<tr>
<td>Window 1st Floor</td>
<td>1.8</td>
<td>10.14</td>
<td>16.252</td>
</tr>
<tr>
<td>Balcony Door</td>
<td>2</td>
<td>1.89</td>
<td>3.78</td>
</tr>
<tr>
<td>Outside Door</td>
<td>1</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Outside Wall</td>
<td>0.184</td>
<td>56.23</td>
<td>10.7143</td>
</tr>
</tbody>
</table>

Table 18, UA values for each component of the building

| TOTAL UA Bathroom             | 3,504 (W/°C)  |
| TOTAL UA Garage              | 4,496 (W/°C)  |
| TOTAL UA Outside             | 51,206 (W/°C) |
| TOTAL UA 1st floor           | 59,206 (W/°C) |
| TOTAL UA 2on floor           | 47,43 (W/°C)  |
| TOTAL UA                     | 106,636 (W/°C)|

Table 19, Total UA values for rooms with transmission losses

5.2. Infiltration rate

| Volume 1st Floor             | 169,974 m³     |
| Volume 2on Floor             | 152,465 m³     |
| Total Volume                 | 322,439 m³     |

Table 20, Flow rate of the building
5.3. Total annual heat demand for the building

The specific heat demand for the heating system of the building was determined by first selecting the mean temperature of Lulea in a year. This was as shown in table 4. As determined to be 149900 as shown below in table 22.

\[ Q_{\text{year}} = \left( \sum UA + \rho V \cdot c_p \right) \times \left( 106,636 + 1.2 \cdot V_{\text{tot}} \times 0.01 \times 1010 \right) \times 149900 = 17,611 \text{ MWh} \]

6. Area due to geometry changes

<table>
<thead>
<tr>
<th>Nr</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bend</td>
<td>4.1</td>
<td>4.1</td>
<td>-</td>
</tr>
<tr>
<td>Split</td>
<td>-</td>
<td>-</td>
<td>1.2</td>
</tr>
<tr>
<td>Mix</td>
<td>-</td>
<td>-</td>
<td>1.1</td>
</tr>
<tr>
<td>Area Change</td>
<td>-</td>
<td>2.0,2</td>
<td>2.0,2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4</td>
<td>4.4</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Table 21. Specific heat demand for heating systems and duratime time

Table 22. Showing minor losses in the pipes

To determine the dimensions and pressure drops in each pipe. The flow rates for each pipe had to first be determined. The flow rates were then used to determine the pressure drops, dimensions and velocities in each pipe as shown below on table 24.
\[ \dot{V} = \frac{\dot{Q}}{\rho c_p \Delta T} \]

Where water properties are at

Table 23: Pressure drop for CU-pipes
## 7. Dimension of the pipes and pressure drop

<table>
<thead>
<tr>
<th>Nr</th>
<th>Q (W)</th>
<th>Flow rate (l/h)</th>
<th>Length (m)</th>
<th>DN</th>
<th>ΔP_f (Pa/m)</th>
<th>Velocity (m/s)</th>
<th>Σ ζ</th>
<th>ΔP_fricion (Pa)</th>
<th>ΔP_loss (Pa)</th>
<th>ΔP_total (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Kitchen</td>
<td>715,2</td>
<td>62,4</td>
<td>2,5</td>
<td>15</td>
<td>45</td>
<td>0,15</td>
<td>4,1</td>
<td>112,5</td>
<td>45,6</td>
<td>158,1</td>
</tr>
<tr>
<td>2. Entrance Hall</td>
<td>343</td>
<td>29,9</td>
<td>4,5</td>
<td>12</td>
<td>49</td>
<td>0,14</td>
<td>3,4</td>
<td>220,5</td>
<td>32,9</td>
<td>253,4</td>
</tr>
<tr>
<td>3. Heater</td>
<td>5648,4</td>
<td>492</td>
<td>6</td>
<td>28</td>
<td>70</td>
<td>0,3</td>
<td>4</td>
<td>420</td>
<td>177,9</td>
<td>597,9</td>
</tr>
<tr>
<td>4. Between</td>
<td>1058,2</td>
<td>92,3</td>
<td>7</td>
<td>15</td>
<td>96</td>
<td>0,24</td>
<td>-</td>
<td>672</td>
<td>-</td>
<td>672</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1681,3</td>
</tr>
</tbody>
</table>

Table 24, showing the dimensions of pipes and total pressure drop.
Figure 2, showing the piping system to the kitchen and entrance hall.
8. \( k_v \) value for radiators

\[ k_v = 0.01 \cdot \frac{\dot{V}}{\sqrt{\Delta P}} \]

8.1. Kitchen

\[ \Delta P = 6900 - 2900 - (\Delta P_1 + \Delta P_3 + \Delta P_4) = 2572.07 \text{ Pa} = 2.57 \text{kPa} \]

\[ k_v = 0.01 \cdot \frac{\dot{V}}{\sqrt{\Delta P}} = 0.01 \cdot \frac{62.4}{\sqrt{2.57}} = 0.389 \]

8.2. Hall

\[ \Delta P = 6900 - 2900 - (\Delta P_2 + \Delta P_3 + \Delta P_4) = 2476.74 \text{ Pa} = 2.48 \text{kPa} \]

\[ k_v = 0.01 \cdot \frac{\dot{V}}{\sqrt{\Delta P}} = 0.01 \cdot \frac{29.9}{\sqrt{2.48}} = 0.190 \]

9. Expansion tank

<table>
<thead>
<tr>
<th>Room</th>
<th>Volume</th>
<th>Total Volume for the room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance Hall</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Living Room</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Laundry</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Kitchen</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Bathroom</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 25, Volume of expansion tank in every room
### Pipes

<table>
<thead>
<tr>
<th>Room</th>
<th>DN (m)</th>
<th>Length (m)</th>
<th>Volume (m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance Hall</td>
<td>0,015</td>
<td>1,25</td>
<td>0,000221</td>
</tr>
<tr>
<td>Kitchen</td>
<td>0,012</td>
<td>2,25</td>
<td>0,000254</td>
</tr>
<tr>
<td>Heat Source</td>
<td>0,028</td>
<td>0,25</td>
<td>0,000154</td>
</tr>
<tr>
<td>Transport-part</td>
<td>0,015</td>
<td>3,5</td>
<td>0,000619</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>0,001248</strong></td>
</tr>
</tbody>
</table>

### Volumes (l)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>60</td>
</tr>
<tr>
<td>Pipe</td>
<td>1,248</td>
</tr>
<tr>
<td>Radiator Kitchen</td>
<td>7</td>
</tr>
<tr>
<td>Radiator Entrance Hall</td>
<td>3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>71,248</strong></td>
</tr>
</tbody>
</table>

### Working Pressure (P\(_o\))

- 1,5 bar = 150000Pa
- Safety Valve Pressure (P) = 2,5 bar = 250000Pa
- Fill. Water Temperature = 5 °C
- Max. Water Temperature = 90 °C
- Density of water at 5 °C = 999,9668 kg/m\(^3\)
- Density of water at 90 °C = 965,323 kg/m\(^3\)

\[
\Delta V = V_1 \cdot \left( \frac{\rho_1}{\rho_2} - 1 \right) = 0,00256 m^3
\]

\[
V_v = \frac{P \cdot \Delta V}{P - P_o} = 6,3924 l
\]
10. Drawings
Indoor Climate

F0034T

Project Work

Part 2. Ventilation

Energy department

Christoffer Nordström
Mugisha Ruhweza
Anna Subirós de Arriaga
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Flow rates

<table>
<thead>
<tr>
<th>Rooms</th>
<th>Supply flow rate in (l/s)</th>
<th>Exhaust flow rate in (l/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Entrance hall</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kitchen</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Bathrooms in first and second floor</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Laundry</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>Closet for clothes</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Large bedroom in second floor</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Small bedrooms in second flow</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Showing flow rates in each room

According to the Swedish building regulations both the supply air and exhaust airflow rates were determined for each room in the building as shown on the table 1. To increase the efficiency of the ventilation system in the building, supply air was delivered through the clean rooms for example the bedrooms and the living room while the dirty air was exhausted through the bathrooms, kitchen and laundry.

Correct supply air

The values of supply air determined from the Swedish building regulations are 15 l/s less than values determined from the relationship between supply and exhaust air in a building. This had to be corrected by using equations shown below

\[
\sum \dot{V}_{\text{supply air}} = 10 + 8 + (2 \cdot 4) = 26 \text{ l/s} \tag{1}
\]

\[
\sum \dot{V}_{\text{exhaust air}} = 10 + 13 + (10 \cdot 2) + 2 = 45 \text{ l/s} \tag{2}
\]

Corrected the supply air using equation 3 below

\[
\sum \dot{V}_{\text{supply air}} = 0.9 \times \sum \dot{V}_{\text{exhaust air}} = 0.9 \times 45 = 41 \text{ l/s} \tag{3}
\]
Outdoor temperature before the heating coil

To determine the outdoor temperature, the temperature efficiency had to first be determined using the corrected supply air and proportion supply air/exhaust air which is 0.9 as shown in the figures below.

The exhaust temperature was determined by using exhaust flow rates in the bathroom and exhaust flow rate in the rest of the building with respective temperatures as shown in equation 4 below.

\[
t_{\text{exhaust air}} = \frac{(V_{25}T_{25})+(V_{20}T_{20})}{T_{25}+T_{20}} = \frac{[(10+2)2.25]+[(10+2+13)2.20]}{25+20} = 22.2^\circ C
\]

Figure 1. How the temperature efficiency was determined

Then the temperature efficiency equation 5 was used to determine the outdoor temperature where the supply air temperature was 18°C

\[
\eta_T = \frac{t_{\text{supply air}}-t_{\text{outdoor}}}{t_{\text{exhaust air}}-t_{\text{outdoor}}}
\]

\[
t_{\text{outdoor}} = 5.4^\circ C
\]
Pressure drop of circuits and dimension of ducts

Figure 2. Showing pipes on the first floor

Figure 3. Showing pipes on the second floor
Table 2. Showing pressure drop due to geometry changes

To determine the total pressure drop, values where calculated and then the recorded in the table as shown below.

<table>
<thead>
<tr>
<th>Rooms</th>
<th>Supply air l/s</th>
<th>Exhaust air l/s</th>
<th>Length m</th>
<th>DN</th>
<th>$\Delta P_{f}$ Pa/m</th>
<th>$V$ m/s</th>
<th>$\sum \xi$</th>
<th>$\Delta P_{prev}$ in Pa</th>
<th>$\Delta P_{loss}$ in Pa</th>
<th>$\Delta P_{tot}$ Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Supply air</td>
<td>41</td>
<td>4</td>
<td>0.12</td>
<td>1.9</td>
<td>3.3</td>
<td>4.4</td>
<td>7.6</td>
<td>28.7496</td>
<td>36.3496</td>
<td></td>
</tr>
<tr>
<td>Living room First floor</td>
<td>8.5</td>
<td>5.3</td>
<td>0.10</td>
<td>0.3</td>
<td>1</td>
<td>4</td>
<td>1.59</td>
<td>2.4</td>
<td>3.99</td>
<td></td>
</tr>
<tr>
<td>Small bedroom Second floor with 2 ducts</td>
<td>6</td>
<td>2.25</td>
<td>0.10</td>
<td>0.1</td>
<td>0.4</td>
<td>4</td>
<td>0.225</td>
<td>0.384</td>
<td>0.609</td>
<td></td>
</tr>
<tr>
<td>Bathroom Second floor</td>
<td>10</td>
<td>1.65</td>
<td>0.10</td>
<td>0.6</td>
<td>1.8</td>
<td>1</td>
<td>0.63</td>
<td>1.944</td>
<td>2.574</td>
<td></td>
</tr>
<tr>
<td>Closet</td>
<td>12</td>
<td>2.7</td>
<td>0.10</td>
<td>0.7</td>
<td>2.1</td>
<td>2</td>
<td>1.89</td>
<td>5.292</td>
<td>7.182</td>
<td></td>
</tr>
<tr>
<td>Bathroom first floor</td>
<td>10</td>
<td>2.65</td>
<td>0.10</td>
<td>0.6</td>
<td>1.8</td>
<td>-</td>
<td>1.59</td>
<td>0</td>
<td>1.59</td>
<td></td>
</tr>
<tr>
<td>Laundry</td>
<td>23</td>
<td>2.35</td>
<td>0.10</td>
<td>1.3</td>
<td>2.8</td>
<td>2.2</td>
<td>3.055</td>
<td>10.3488</td>
<td>13.4038</td>
<td></td>
</tr>
<tr>
<td>Kitchen</td>
<td>35</td>
<td>1.75</td>
<td>0.12</td>
<td>1.2</td>
<td>3.8</td>
<td>1.2</td>
<td>2.1</td>
<td>10.3968</td>
<td>12.4968</td>
<td></td>
</tr>
<tr>
<td>Supply tube</td>
<td>29</td>
<td>10.15</td>
<td>0.10</td>
<td>1.2</td>
<td>3.2</td>
<td>0.2</td>
<td>12.18</td>
<td>1.2288</td>
<td>13.4088</td>
<td></td>
</tr>
<tr>
<td>Large bedroom</td>
<td>12</td>
<td>2</td>
<td>0.10</td>
<td>0.7</td>
<td>2.1</td>
<td>2.2</td>
<td>1.4</td>
<td>5.842</td>
<td>7.242</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4.5</td>
<td>0.75</td>
<td>0.12</td>
<td>1.2</td>
<td>3.8</td>
<td>1</td>
<td>0.9</td>
<td>8.664</td>
<td>9.564</td>
<td></td>
</tr>
<tr>
<td>Pipe to second floor</td>
<td>17</td>
<td>2.4</td>
<td>0.10</td>
<td>0.5</td>
<td>1.8</td>
<td>-</td>
<td>1.2</td>
<td>0</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Showing the pressure drop

The total pressure drop on supply air was 62.8 Pa while for exhaust air was 46.8 Pa which gave the total of 109.61 Pa pressure drop in the ventilation system.
Fan speed

The pressure drop for both supply and exhaust air and their respective flow rates were used to determine the fan speed on the ventilation system in the building as shown below.

![Figure 4. How the fan speed was determined](image)

The pressure of the fan for supply is 70 Pa and the pressure for the fan for exhaust air is 65 Pa.
Location of supply devices

The building has a total of five devices that supply air i.e. two in the living room and one in each room. The locations at which the devices were placed was determined with help of the following figures below and multiplying the value with a correction factor of 1.4.

The location for the devices in the small bedrooms was determined to be 3mm

The location for the devices in the large bedroom was determined to be 5mm
Location of exhaust devices

The building has 4 devices that exhaust air i.e. one in each bathroom, one in the laundry and one in the closet. The ones in the bathrooms are angle duct exhaust devices while the laundry and closet has mounting ring exhaust devices. The location of exhaust devices where determined using the following figures.

The determined locations where -3mm for the bathrooms, -13mm for the closet and 0mm for the laundry.
**Annual heat and heating coil**

To be able to determine the annual heat demand for ventilation and the total annual heat demand for the building, some correction terms needed to be added to the calculation.

The correction terms where the internal generation of heat and the heat from the sun.

**Internal generation of heat**

\[ Q_{\text{internal heat}} = d\tau \times \text{Internal generation of heat} \]  \hspace{1cm} (6)

Where \( d\tau = 6770 \text{ hours/year} \) and \( \text{Internal generation of heat} = 300W \)

(6) with values gives:

\[ Q_{\text{internal heat}} = \frac{6770 \times 300}{100000} = 2.031 \text{ MWh/year} \]  \hspace{1cm} (7)

**Heat from the sun**

\[ Q_{\text{sun}} = \frac{\text{Annual heat demand}}{s} \times \text{Solar} \times d\tau \]  \hspace{1cm} (8)

(8) with values

\[ Q_{\text{sun}} = \frac{17.61}{149900} \times |3| \times 6770 = 2.386 \text{ MWh/year} \]  \hspace{1cm} (9)

Also energy estimations for a ventilation system using a heat recovery unit needed to be added for the corrected annual heat.

\[ Q_{\text{ventilation}} = Q_{\text{ventilation HEX}} + Q_{\text{supply}} \]  \hspace{1cm} (10)

\[ Q_{\text{supply}} = \rho \times V_{\text{supply}} \times C_p \times (T_{\text{room temperature}} - T_{\text{supply air}}) \times d\tau \]  \hspace{1cm} (11)

(11) with values gives

\[ Q_{\text{supply}} = 1.2 \times 0.041 \times 1010 \times (20 - 18) \times 6770 = 0.6728 \text{ MWh} \]  \hspace{1cm} (12)

\[ Q_{\text{vent}1} = \rho \times V_{\text{flow}} \times h_{v24} \]  \hspace{1cm} (13)

Where \( h_{v24} \text{(at 18°C)} = 142300 \)
(13) with values gives

\[ Q_{\text{vent}} = \frac{1,2 \times 0,041 \times 142300}{1000} = 7 \text{ MWh} \]  

\[(14)\]

Eq is interpolated from table

\[ E_{q \text{ from table}} = 0,1 \]

\[ Q_{\text{vent,HEX}} = E_{q} \times Q_{\text{vent}} \]  

\[(15)\]

(15) and (11) in (10) gives

\[ Q_{\text{ventilation}} = 1,37 \text{ MWh} \]  

\[(16)\]

Then the corrected annual heat demand is

\[ Q_{\text{annual heat}} = 17,1 \div 1,37 - 2,38 + 2,01 = 14,568 \text{ MWh/year} \]  

\[(17)\]

The heating coil can be determined by

\[ Q_{\text{coil}} = V_{\text{supply}} \times \rho_{\text{air}} \times C_{p_{\text{air}}} \times (T_{\text{supply}} - T_{\text{supply before heating coil}}) \]  

\[(18)\]

(18) with values gives

\[ Q_{\text{coil}} = 0,041 \times 1,2 \times 1010 \times (18 - 9,4) = 427,35 \text{ W} \]  

\[(19)\]
Indoor Climate

F0034T

Project Work
Part 3. Heat Pump

Energy department

Christoffer Nordström
Mugisha Ruhweza
Anna Subirós de Arriaga
**Task 1**

1. Determine the minimum outside air temperature for which the heat pump alone can deliver the necessary heat rate to the building

\[ T_{outside} = T_{inside} \times 0.7 \times (T_{inside} - T_{D0T20}) \]  

Equation (1) with values gives

\[ T_{outside} = 20 \times 0.7 \times (20 - (-29)) = 14.3 \text{ °C} \]  

2. Show the process in a P-h-diagram

![Figure 1, Heat process of the system](image)

Reading direct from the diagram above the enthalpy values are determined and recorded as shown below;

\[ h_3 = h_4 = 260 \frac{kJ}{kg} \]

\[ h_1 = 390 \frac{kJ}{kg} \]
h_{2g} = 430 \text{ kJ/kg}

3. Calculate the flow of R134a in the heat pump

Using the annual heat for the heating coil in the equation below can the flow rate of the working medium be determined as follows.

\[
\dot{m}_{R134a} = \frac{\dot{Q}_{Coil}}{(h_1-h_4)} = \frac{0.427K^1}{(390-260)K} = 0.00328 \frac{kg}{s}
\]

4. Determine the temperature of R134a after the compressor

The temperature after the compressor is determined by using values of enthalpy and equation below.

\[
\eta_C = \frac{h_2-h_1}{h_2-h_1} \rightarrow h_2 = h_1 + \frac{h_2-h_1}{\eta_C} \rightarrow 390 + \frac{420-390}{0.85} = 437.05 \text{ kJ/kg}
\]

\[T_2 \text{ from diagram is } +39^\circ C\]

5. Calculate the rate of heat transfer to the working fluid in the evaporator

Heat transfer rate to the working medium in the evaporator is determined as follows:

\[
\dot{W}_c = \dot{m}_{R134a}(h_2 - h_1) = 0.00328(437.05 - 390) = 0.1543KW
\]

\[
\dot{Q}_l = \dot{m}_{R134a}(h_2 - h_3) = 0.00328(437.05 - 260) = 0.5807KW
\]

\[
\dot{Q}_l = \dot{Q}_{Coil} + \dot{W}_c = 0.1543 + 0.427 = 0.5813KW \approx 581W
\]

6. Determine the COP_{HP} for the heat pump

The coefficient of performance of the heat pump was determined using the equation below;

\[
\text{COP}_{HP} = \frac{(h_2-h_4)}{\frac{h_2-h_1}{(437.05-260)}} = 3.77
\]
7. Calculate the mass flow in the brine circuit at maximum performance for the heat pump

To determine the mass flow in the system of the brine circuit the following equation was used and the total heat transfer rate in the evaporator.

\[
\dot{Q}_H = \dot{m}_{brine} (h_2 - h_3) \rightarrow \dot{m}_{brine} = \frac{\dot{Q}_H}{h_2 - h_3} = \frac{0.581 \text{ J}}{3.836 \text{ kg}} = 0.152 \text{ kg/s}
\]

(9)

Task 2-3

<table>
<thead>
<tr>
<th>Hot water production</th>
<th>System today</th>
<th>Heat Pump Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>With electric boiler (kWh)</td>
<td>4000</td>
<td>500</td>
</tr>
<tr>
<td>With heat pump (kWh)</td>
<td>3500</td>
<td>3500</td>
</tr>
<tr>
<td>Electricity to heat pump (kWh)</td>
<td></td>
<td>(\frac{3500}{\text{COP}} = \frac{3500}{3.77} = 928.38)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat production</th>
<th>System today</th>
<th>Heat Pump Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>With electric boiler (kWh)</td>
<td>14568</td>
<td>0.05 \cdot 14568 = 728.4</td>
</tr>
<tr>
<td>With heat pump (kWh)</td>
<td>0.95 \cdot 14568 = 13839.6</td>
<td></td>
</tr>
<tr>
<td>Electricity to heat pump (kWh)</td>
<td></td>
<td>(\frac{13839.6}{\text{COP}} = \frac{13839.6}{3.77} = 3670.98)</td>
</tr>
</tbody>
</table>

Calculate the yearly heat demand (heat + hot water) for the system without heat pump

\[4000 + 14568 = 18568 \text{kWh}\]

Calculate the yearly supply of electricity to cover this heat demand for a system with heat pump

\[500 + 928.38 + 728.4 + 3670.98 = 5827.76 \text{kWh}\]

Determine the annual energy costs for the system without heat pump

\[18568 \cdot 0.8694 + 2500 = 18643 \text{ SEK}\]

Determine the annual energy costs for the system with heat pump

\[5827.76 \cdot 0.8694 + 2190 = 7256.65 \text{ SEK}\]
Do you suggest that the house owner should install the heat pump?

| Cost for heat pump and installation: $c_{install}$ | 130000SEK |
| Depreciation time period: $n$ | 10 year |
| Interest rate for loan $i$ | 5% |
| Deposit rate $l_{savings}$ | 1.5% |

Investment costs

Total cost $= a \times n \times c_{install}$  
(10)

Where annual installment factor (a) is:

$$a = \frac{i}{1-(+i)^{-n}} = \frac{0.05}{1-(1+0.05)^{-10}} = 0.1295$$

(11)

(11) in (10) with values gives

Total cost $= 0.1295 \times 10 \times 130000 = 168355,9 SEK$  
(12)

Reduction of heating costs

$C_{saved, total} = b \times C_{saved, annual}$  
(13)

Where the difference in cost between the two system, $C_{saved, annual} = 11386,36 SEK$ and

$$b = \frac{(1+l_{savings})^{n}-1}{l_{savings}} = \frac{(1+0.015)^{10}-1}{0.015} = 10,70$$

(14)

(14) in (13) gives

$C_{saved, total} = 10,70 \times 11386,36 = 121865 SEK$  
(15)

The economic result $= C_{saved, total} - Total cost$  
(16)

(16) with values gives

The economic result $= 121865,0 - 168355,9 = -46490,88 SEK$  
(17)

In this case, with a ten years period, the owner should not install the heat pump because he does not have any benefits.
The Ideal Cross-Country Skier

Cameron Mackie, Andrew Jephson, Vincent Voinot, Anna Subirós and Lauri Kaipainen

3/16/2014
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Introduction

This report will look at the physiology of the ideal cross-country skier by exploring various aspects that combine to create the ideal athlete. Firstly, the body type of a skier will be covered with the body fat and muscular upper body being the most important aspects. Next the training required to reach your physical peak, with special care taken in reducing lactic acid effects and improving VO2 max. After this the various techniques that a cross-country skier needs to employ are studied. The athlete’s nutrition is then examined to determine the ideal food and drink to be consumed during training and the race. Finally the equipment of a cross-country will be explored, what clothing is required to maintain the ideal body temperature and the nature of the skis and other equipment. By combining all of these different aspects we should create the perfect cross-country skier.

The Body of the Cross-Country skier

Cross-Country skiing is a sport in which the athlete uses their entire body vigorously to overcome the gravity and friction to propel themself over the snow. In this sport every major muscle group is used simultaneously. There are some muscles working hard because they are being pushed and pulled but the rest of them are working to coordinate and balance the body. This leads to some consequences in the human body.

The first and probably one of the most important consequences is the need of the skier to have an excellent VO2 max. The VO2 max is the maximum amount of oxygen a person’s body can breathe in and use in a minute per kilograms of body weight. The athlete has to give oxygen to all the muscles in the body so he has to have the highest VO2 max as possible. This makes an efficient cardiovascular system to all skiers and the world record of VO2 max belongs to an elite cross-country skier.

The second consequence of the use of almost every muscle in cross-country sky is that no single muscle group is overstressed. In consequence of that, cross-country sky is an aerobic workout with only one exception: the sprint time. During the sprints of the race, the skier use all energy reserves stored in his muscles. After using all this energy they need a recovery period to have the energy in the muscles again and be able to sprint again.
The last consequence is that cross-country ski is a low impact sport because all muscles are working at the same time and there is not any muscle weaker than the others. In addition, there is no shock to the knees. The uni-directionality of the sport helps the tendons and cartilages to stay in their place and make them stronger.

The muscles that are being pulled and pushed depends on the technique the skier is using. The upper body muscles are used for the poling and the lower body muscles are used for the skating. In the following paragraphs we will describe in more detail the muscles that the skiers use.

In the classic stride technique; the muscles that the skier uses the most are biceps and triceps (Figure 1) of the upper body and the quadriceps and the gastrocnemius (Figure 2) of the lower body to get the forceful "kick" they need to skate.

In the double pooling technique there is only arm movement and the skier use the chest, the upper back, the upper arms and also the shoulders (Figure 3).
In the skating technique, the most useful muscles are the gluteus and upper leg muscles (Figure 2) for the skating and for the poles they use the upper arm (Figure 3).

The body fat in the bodies of the elite cross-country skiers is less than the one of an athletic person. This is because the high number of calories that the body burns during this sport. In the following table there is a comparison between these two groups.

<table>
<thead>
<tr>
<th></th>
<th>Cross-country skier</th>
<th>Athletic person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>11%</td>
<td>17%</td>
</tr>
<tr>
<td>Male</td>
<td>5%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Table 1

It is the combination of the low body fat, high V0₂ max and strong upper body that creates the optimal physiology for a cross-country skier.

**Ideal training for long distance cross-country ski athlete**

The goal of this chapter is to introduce ideal training for long distance cross-country ski athlete. In this case long distance is considered distance, which is 10 kilometres or more. Reasoning for this, is fact that when an athlete wants to gain optimal results on longer distances, he/she has to focus on aerobically produced power (Wilmore 2008). The elements that this section will discuss are training principles, physiological aspects and environment for training.

All sport training has to be able to simulate physical demands that athlete needs. Since distances of 10 kilometres and more, athlete can’t reach optimal results with just anaerobic fitness. This leads to need of aerobic fitness. For that reason, longs distance cross-country skier need different kind of physical abilities than sprinter. In order for athlete to reach optimal performance they should train their physical abilities according to time each ability is needed during the race. Keeping this in mind, we come to following training principle:

- 80 % of training focuses on aerobic endurance training.
- 15 % of training focuses on anaerobic endurance
- 5 % of training focuses on anaerobic speed

Training should be based on interval training and continuous training. The idea on interval training is to change strain of the exercise according to pre set time periods. Continuous training should be focused on distance and slow pace on the aerobic endurance level, or below. (Wilmore 2008)

Measuring can conclude athlete’s endurance training speed or strain from their lactate levels during different strain levels. Lactate is substance that forms in your muscles during physical activity. If athlete stays on aerobic level, he/she can produce movement energy through aerobic processes. When strain gets too high lactate starts to pile up in muscles and make them feel tired and stiff. A study shows that athlete can endure lactate level of 2 a long time but that is not efficient for training endurance. Same research found out that athlete can endure lactate level on 4 from 45-60 minutes. If lactate level goes beyond level 4, it starts to accumulate significantly fast and exercise stops quite quickly (see figure 1). So, we can conclude from this that optimal pace to train athlete’s aerobic performance, is to stay on
lactate. This level is called anaerobic threshold, because lactate is its highest but does not accumulate fast (see Figure 2). (Kindermann 1979)

To improve athletes endurance his/her training should focus on developing maximum ventilation capacity, so called VO$_2$-max, which means capacity to take in oxygen in ones body. Other factor that determines endurance of athlete is tolerance of lactate in his/her body. VO$_2$-max training focuses on improving ability to produce movement energy via oxygen based burning proses. This ability is trained mainly on aerobic endurance level but also on harder levels. The point idea of aerobic endurance training is to develop the speed that athlete can keep on the anaerobic threshold, which will have an improving effect also on higher speed. The idea of training beyond anaerobic threshold is to improve ability to endure accumulation of lactate. (Kindermann 1979)

Figure 4

Figure 5
For the final boost to make ideal training for long distance cross-country skier would be living high and train low. This means that athlete should be exposed to the effects of high altitudes. And conduct training close to sea level. The idea behind this is to gain positive effects of high altitude on haemoglobin, while enjoying training efficiency close to sea level. When human is exposed to higher altitudes his/her body starts to adapt to smaller levels of oxygen in the air. This means that body is increasing haemoglobin level, which means more red blood cells to carry oxygen. This effect can be reached in altitude of 1500 metres up to 3000 metres. Beyond that level, strain gets too high for body. Unfortunately physical performance decreases in higher altitudes, which is why training should be done close to sea level in order to gain optimal training intensity. The high altitude adaptation can be reach minimum on two weeks but recommended time before the race is six weeks. (Wilmore 2008)

**Technique**

Technique of a cross country skier is vital, if you have the perfect physique and years of training without the proper technique all of the previously mentioned becomes useless. Cross country skiing has been around since prehistoric times and over that time the technique has been honed to provide the optimal motion for propelling yourself over the snow. Cross country skiing is used over a variety of different terrains and the technique will be examined for each of these.

**Flat**

On the flat is where most cross-country skiing, for pleasure and for competition, takes place. The technique that has been around for the longest is the diagonal stride. The diagonal stride has a very similar motion to walking, and is described as a walk with a glide. The skier should been upright with their weight on their front leg and the skier should be focused on leaning forward and hip rotation. Once you have the right stance you then kick off with your rear leg and then glide through with it. A method to improve your forward momentum is to swing the rear leg back as much as possible. Finally incorporating the poles into the motion with the opposite arm to leg drive at the same time creates the optimum performance for this style.

Another cross-country skiing style is the single kick double pole, which combines a double pole action and the simple walking motion used in the diagonal stride. A double poling action is the a very basic action in cross-country skiing where you pole plant both poles and the same time and propel yourself forwards. The single kick double pole uses the kick from the rear leg closely followed by a double pole action to propel them forwards (as shown in figure 6). The SKDP is a lot easier to maintain balance using this technique as the SKDP uses slower movements that the diagonal stride. Finally maintain a similar body position as with the diagonal stride and keep your body weight forward.

![Figure 6](image_url)

Finally there is the double kick double pole which is very similar to the single kick double pole apart from the fact that there are two kicks, one with each leg, then the double pole action.
This obviously provides more propulsion but is slightly more un-balanced than the single kick method.

**Uphill**
Travelling uphill on skis is arguably the most important part of any ski race as it’s where the most time can be won or lost. The diagonal stride technique can be used of uphill sections were the gradient isn’t too large but once the hills become steeper different style need to be adopted.
The diagonal stride technique is slightly altered when travelling uphill. Firstly there is no longer need for a large back kick as that reduces momentum when travelling; also a more upright body position is favourable when travelling uphill. When you reach a hill that is too steep to stride up you have to resort to different techniques such as the herringbone or the side step. In the herringbone technique the skis are placed in a V-shape up the hill (as shown in the Figure 7) where the steeper the hill the wider the v should be. The grip comes from the edge of the skis and you simple walk up the hill in this position, making sure to take small steps as that’s the most effective method for climbing hills. Again leaning forward is necessary and don’t forget to use the poles for balance as well as force.
Then there is the side step where your skis are placed across the slope and you simply step sideways up the slope. Here it is crucial to maintain the right angle of your skis to maintain grip from your edges and avoid slipping. This technique will never be used in competition as the courses would never have a hill steep enough in it that this would be necessary.

**Downhill**
Skiing downhill while on cross-country skis is completely different to normal alpine downhill, due to cross-country skis being a lot narrower and the heel not being attached. As the skis are narrower it means that you are a lot more prone to skidding and losing control while turning. Firstly there is the step turn this involves taking small steps to turn corners and can be used for a variety of different corners. By lifting the tip of inside ski on the corner you can move the tip from side to side and place it in the direction required, next you lift the outside and put it in the same direction as the inside ski. It is advisable to make lots of small steps for each turn as it creates a smoother turn and carries more momentum.

Then you can also use telemark turns where as the heel isn’t connected the inside leg on the turn is bent at a 90° angle as shown in the picture opposite. The lunge motion forces you onto your edges and helps you round the turn. This method is good at maintaining high speeds but isn’t as useful when being restricted to staying in ski tracks.
**Conditions**
Throughout the whole race cross-country skiers have to utilise all methods mentioned above and alternate between them. By switching between styles you can stop muscle fatigue in certain parts of the body and stay fresher for longer into the race. As well skiers have to adapt according to the conditions as icy conditions are a lot different to powdery snow. Finally the different stages of race will affect a skier’s style as the last few km’s will have a different intensity to them than the first. Combining all of these different variables means that a skier is constantly changing his style depending in all of the above mention, meaning that to be a top skier you need to excel in a lot of different techniques.

**Nutrition**
The nutrition is one of the most modifiable and controllable factor in athletic success, but too often it’s also the most ignored. Paying special attention to good sports nutrition, especially starting at a young age, may be the key to reaching new heights. As a young skier, you will need to “fuel the furnace” and keep your body both fueled and refueled at all times for training and races. It’s very important to take care of the nutrition; it must be consistently linked with personal progress and health throughout the season and year-round.

**Composition.**
The nutritional composition for an endurance athlete should be in the proportions indicated on the following graph:

![Proportions](Figure 9)

This graph is totally different from the amount of calories. Indeed the amount of calories must not be restricted in any way. The amount of total daily calories will be adjusted according to your size, level of training and individual metabolic differences. But it’s possible to follow some rules to calculate the minimum amount needed for the body thanks to the following frame.
As you can see before, the carbohydrates are the body's primary source of energy. A typical athlete's engine runs hot enough to burn fats and protein as well, but the working body prefers to start with carbs.

There are two types of carbohydrates - simple carbohydrates and complex carbohydrates.

**Simple carbohydrates**

Simple carbohydrates aren't the best source of energy. They contain a lot of sugar like in soft drinks, candy bars, and pastries. If a food has large amounts of fat and sugar calories, then that particular source is unlikely to hold any significant amount of vitamins, minerals, or fiber. Nutritionists say that these kinds of foods hold "empty calories.”

However, some foods with high sugar content do have plenty to offer in the way of minerals or vitamins. Certain fruits such as bananas, oranges, apples, and raisins break down into fructose (a natural fruit sugar) but are good carbohydrate sources. These kinds of fruits are better snack choices than empty calorie foods such as most candies.

**Complex carbohydrates**

Complex carbohydrates are the best source of energy like grains, breads, vegetables, and beans. These foods take longer to convert to glucose (sugars) and are then stored as glycogen (stored dietary sugars) in the muscles or liver, to be used for energy when called upon during physical activity.

**Recommended food**

To remember what proper food you can think about eating the rainbow. It’s possible to divide all of the needed food in five color groups. Each one brings its own property. So more colors you eat then the more your food is healthy. These groups are as follows:

- **Blue/purple**: blueberries, plums, raisins, purple grapes
- **Green**: broccoli, lettuce, celery, cucumbers, green grapes, green apples, green beans, green peas, spinach.
- **White, tan, and brown**: potatoes, bananas, mushrooms, brown pears
- **Orange/yellow**: carrots, grapefruit, oranges, peaches, sweet corn, yellow apples
- **Red**: cherries, cranberries, red apples, tomatoes, strawberries, red/pink grapefruit, watermelon
Drinks.
The amount of water needed depends on your size, sweat rate, climate, and a host of other factors. In any case, you mustn’t be thirsty so you will be probably drink at least 2-3 litres of water per day.
Leading up to races you should drink four to eight extra glasses of water the day before, another two to three glasses at least two hours before, and one or two glasses 10-15 minutes before competition.
The majority of your fluid intake should be plain water; sports drinks can provide extra calories and electrolytes, but sodas and other soft drinks should be limited as much as possible.
The coffee and the energy drink are useless, the caffeine and the others stimulants aren’t needed because the body already produce a natural stimulant, epinephrine, in response to the anticipation and intense physical activity that comes with racing.

Equipment

Equipment is a very important aspect in any sport, it can mean winning or losing and can separate athletes that are at their absolute peak of physical fitness. For this reason, equipment plays a large role in maximising the performance of the athletes in the extremely demanding sport of endurance cross-country skiing.

According to a study conducted in Norway, involving numerous elite young athletes from high school clubs, the optimal ambient air temperature around the body is between -1 and 4°C. This is the temperature range that maximises performance at the highest level while using race equipment. If the body becomes too cold, the muscles will stiffen and essential enzyme activity will slow, causing a drop in performance. At the higher end of this temperature scale, the athlete will potentially overheat, producing increased sweat levels, which will cause the onset of dehydration sooner.

Layering

The athlete’s clothing is used to regulate their temperature, staying within the aforementioned temperature range, maximising performance. Layering is the best technique to achieve this. Several light layers are greatly preferred to one or two more bulky garments. When using numerous layers, the athlete has the ability to add or remove layers to efficiently regulate temperature. Layering also produces ‘dead air’ – pockets of air trapped between layers that are heated up by the body and keep the person warm.

Base layers

The base layer is a very important aspect of a layering system as it is directly adjacent to the skin. These garments have to fulfill several crucial criteria such as: wicking – transporting moisture away from the skin and also comfort as causing as little irritation against the skin as possible does not distract the athlete. Modern base layer garments are made almost entirely from plastics such as polypropylene and polyamide with some amounts of wool for its excellent thermal properties.
Recently, modern base layers incorporate compression. These garments utilize gradient compression, which targets the appropriate muscles with different magnitudes of pressure. The garments are designed to increase venous blood flow such as compressions socks have been used with recovering patients in hospitals for over fifty years. Secondly, the compression decelerates the uptake of lactic acid in the blood stream, as well as increasing the rate at which the body removes blood lactate. Furthermore, compression garments delay the onset of fatigue in the muscles due to minimal muscle vibration. Compression garments are used in training as it allows the athlete to train harder for a longer period of time, therefore maximising the efficiency of the workout. Also used to aid recovery, the effect of removing the blood lactate faster and a higher flow rate of oxygen through the muscles mean the athlete can resume maximal training earlier with faster muscle regrowth. It therefore follows that, in competition, when allowed to perform at a maximum physical output for a prolonged period of time, the athlete can have improved performance in a race situation.

**Outerwear**

The wind is an extremely large factor for limiting performance and, in cold conditions, is the most effective way for a body to be cooled into hypothermia in dry conditions. Therefore, outerwear is very important for maintaining the athlete's temperature as it blocks the wind, snow and rain as becoming wet will accelerate the cooling down process.

The layering concept is very important for the extremities and for the best performance; the athlete must keep their hands, feet and head warm and dry. As the feet and hands are in constant use with the skis and poles, it is essential for the athlete to have maximum feeling and therefore best control of the equipment. Another risk to athletes performing the same physical motions repeatedly is that of blisters forming on highly stressed skin areas on the feet. This can be combatted by layering very thin socks with thicker, warmer ones. This has the dual benefit of wicking moisture away from the feet and also the friction caused by the athlete's movement will occur between the socks and not between the layers of skin – the cause of blisters in sporting circumstances.
**The skis**

The most important part of the athlete’s equipment is, of course, the skis. These are manufactured to very high specifications in regard to the athlete’s height, weight and other attributes. The skis are also produced every year with new technologies, utilising the best materials and manufacturing available. Modern skis are made from plastics and composite materials to achieve a high strength to weight ratio. They have to have very specific flexural properties also as the technique for skiing relies on the bending of the ski under the weight of the skier.

The skis are cambered so that, un-weighted or partially weighted, the tip and tail of the ski is in contact with the ground. When the ski is fully weighted, the ski compresses and the ‘pocket’ (the area under the foot that, when the ski is un-weighted, is raised up from the ground) will come in contact with the snow. This area of the ski is designed to grip the snow as opposed to the tip and tail that are designed to glide over it with minimal friction.

**Wax**

Typically, there are two types of cross-country skis: waxless and waxable. The waxless skis are used for more occasional skiers that prefer the convenience of not having to wax skis. These skis are not as fast as waxable skis. Waxable skis are tailored to the specific day or event to produce the highest performance possible and therefore are the obvious choice for elite cross-country athletes. Wax is applied in accordance to the predicted temperature of the snow the day before a race, this means that a harder wax is applied to skis for a colder, more icy day so that the wax is more durable and is not worn off. Conversely, softer waxes are applied to warmer days as they repel moisture and therefore achieve minimal friction caused by surface tension on the water particles. Waxes preferred for this are high content fluorocarbon race waxes as these are hard wearing and have the lowest friction coefficients. On the day of the race, a final overlay is applied to the waxed ski, this can be very specifically chosen for the exact snow temperatures and minimises the friction of the ski. They often incorporate materials such as Teflon.

As these glide waxes and overlays are to reduce friction, they are applied to the tip and tail of the ski. The pocket of the ski is applied with kick wax. This kick wax is designed to introduce increased grip to the centre portion of the ski. As the ski is compressed by the weight of the skier, the kick wax grips the snow to propel the skier along or provide grip for when the skier is travelling uphill.

**Poles**

Another important piece of equipment for the skier to go uphill or on the flat is the poles. The best poles manufactured today are made from carbon fibre composites to give an excellent strength to weight ratio, allowing the athlete to perform for as long as possible as they do not have to expend extra energy when poling if the poles are heavier.
Conclusion
Cross country skiing is a very demanding sport, relying on all aspects of an athlete’s physicality and specialist equipment, hence some of the fittest athletes in the world are cross country skiers. The different sections of this report outline the integral parts of their physiology, therefore the ideal cross country skier, and consequently any elite endurance athlete, is the sum of all these idealistic parts.

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