# Ice rink arena energy calculation tool

Aalto-yliopisto
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korkeakoulu

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# Energy calculation tool for air heated ice rink arenas

## Abstract

The present calculation tool is intended for early stage preliminary design purposes in order to calculate the total energy use/cost of an ice rink. In ice rinks, energy use of the refrigeration process dominates making these buildings highly energy intensive. Especially if poorly designed, the operation cost can be very high. The ice making process is not taken into account in official E-value calculation for energy performance certificate and this value typically represents only one third of the total energy use. The tool allows to study the effects of design options of air handling unit, refrigeration, air distribution, structural and waste heat utilization solutions, and provides energy use breakdown and energy cost which can be highly useful in decision making. The main objective of the tool is to complement the official E-value calculation procedure which excludes processes. For comparative purposes, E-value based on actual energy use of the entire system including the refrigeration process is calculated. The accuracy of the tool is within ±5% which is very good for early stage decision making. In the final design phase, it is recommended to conduct detailed energy simulation with IDA-ICE ice rink application.

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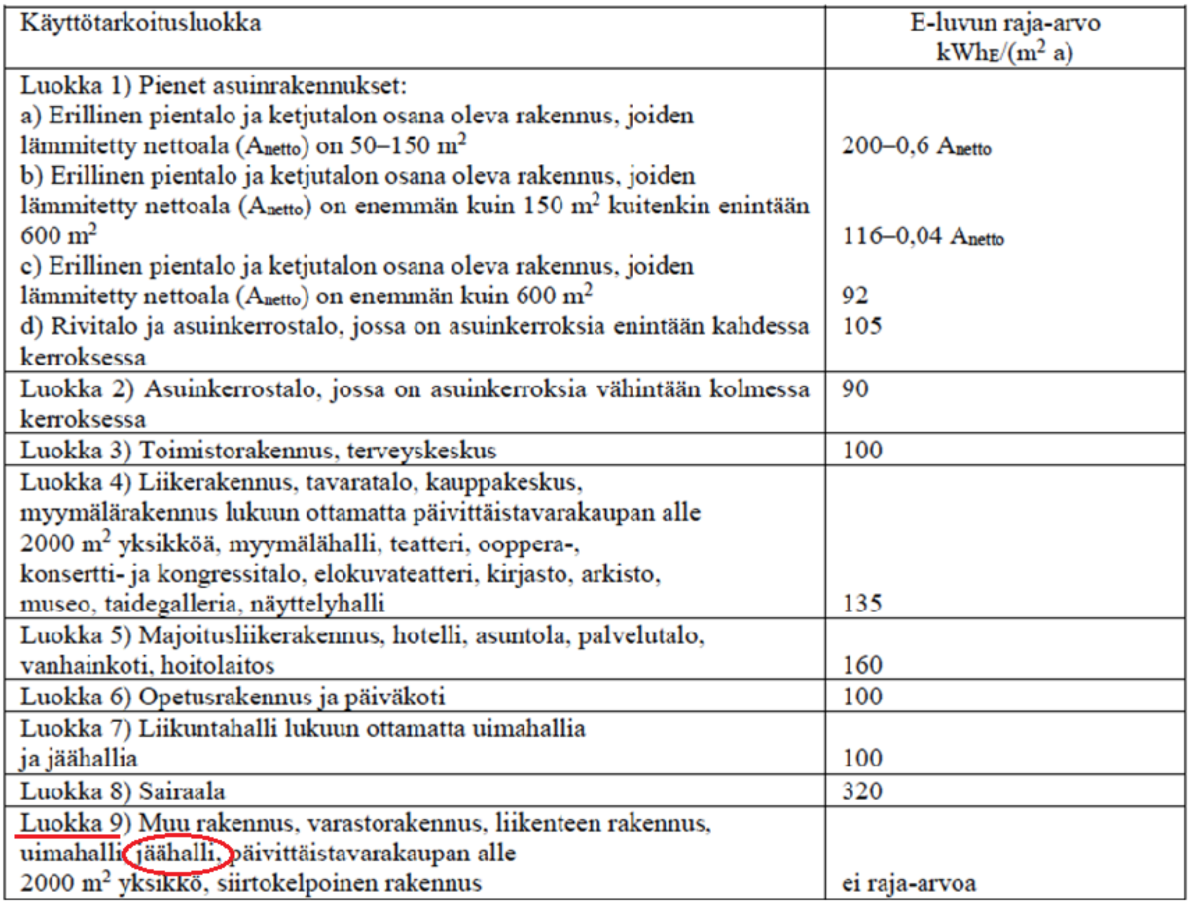
# 1. Introduction

The regulations and guidelines regarding energy efficiency of buildings consists of two parts; first calculating energy performance (E-value) which must comply with the general principles, second to determine energy performance classification certificate according to the reference list in the guideline. The requirements for Energy performance calculation include all energy uses of the building such as: lighting, appliance, domestic hot water, space heating and ventilation to maintain appropriate indoor climate, cooling, fans and pumps, but exclude the processes as refrigeration for ice making.

To calculate the E-value the delivered energy of all energy carriers is multiplied by primary energy (weighting) factors then summing up and finally divided by the total building area in order to convert it to the form of energy per heated area (kWh/m$^2$ a).

According to Finnish regulation of energy performance, primary energy "Energy Performance" E-value (E-luku in Finnish) is required for all "ordinary" buildings which stated in the regulations except for ice rinks as shown in Fig.1. Ice rink belongs to 'other buildings' which has no limit for E-value, but the E-value has to be calculated for energy performance certificate.

System boundaries for energy calculation include: energy need, energy use (building technical systems) and on-site renewable energy calculation results in delivered energy. However exported energy is not taken into account in E-value, only the on-site production which is used in the building. Appliances (small power plug loads) and lighting are taken into account and finally delivered energy is multiplied by primary energy (weighting) factors.



| Käyttötarkoitusluokka | E-luvun raja-arvo kWh$_E$/(m$^2$ a) |
|---|---|
| Luokka 1) Pienet asuinrakennukset:<br>a) Erillinen pientalo ja ketjutalon osana oleva rakennus, joiden lämmitetty nettoala ($A_{netto}$) on 50–150 m$^2$<br>b) Erillinen pientalo ja ketjutalon osana oleva rakennus, joiden lämmitetty nettoala ($A_{netto}$) on enemmän kuin 150 m$^2$ kuitenkin enintään 600 m$^2$<br>c) Erillinen pientalo ja ketjutalon osana oleva rakennus, joiden lämmitetty nettoala ($A_{netto}$) on enemmän kuin 600 m$^2$<br>d) Rivitalo ja asuinkerrostalo, jossa on asuinkerroksia enintään kahdessa kerroksessa | <br>200–0,6 $A_{netto}$<br>116–0,04 $A_{netto}$<br>92<br>105 |
| Luokka 2) Asuinkerrostalo, jossa on asuinkerroksia vähintään kolmessa kerroksessa | 90 |
| Luokka 3) Toimistorakennus, terveyskeskus | 100 |
| Luokka 4) Liikerakennus, tavaratalo, kauppakeskus, myymälärakennus lukuun ottamatta päivittäistavarakaupan alle 2000 m$^2$ yksikköä, myymälähalli, teatteri, ooppera-, konsertti- ja kongressitalo, elokuvateatteri, kirjasto, arkisto, museo, taidegalleria, näyttelyhalli | 135 |
| Luokka 5) Majoitusliikerakennus, hotelli, asuntola, palvelutalo, vanhainkoti, hoitolaitos | 160 |
| Luokka 6) Opetusrakennus ja päiväkoti | 100 |
| Luokka 7) Liikuntahalli lukuun ottamatta uimahallia ja jäähallia | 100 |
| Luokka 8) Sairaala | 320 |
| Luokka 9) Muu rakennus, varastorakennus, liikenteen rakennus, uimahalli, jäähalli, päivittäistavarakaupan alle 2000 m$^2$ yksikkö, siirtokelpoinen rakennus | ei raja-arvoa |

*Fig. 1. Ice rink belongs to other buildings with no limited E-value requirement*

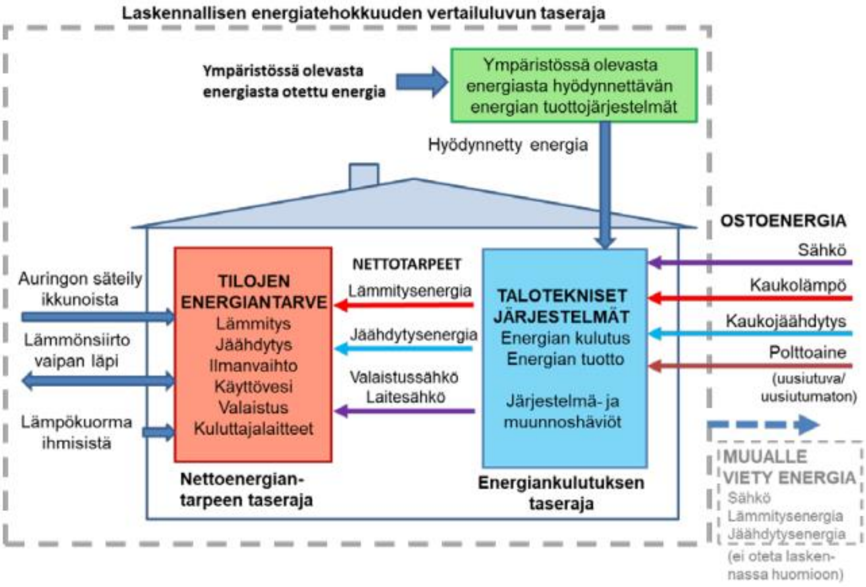


*Fig. 2. Building site & System boundaries for energy calculation and for Net delivered Energy on site*

The E-value method is developed for ordinary buildings and it is not suitable for energy certification of process dominated buildings such as ice rinks, swimming pools, grocery stores, data centers, commercial kitchens etc., because in these buildings the real energy use might be much higher than represented by the E-value. Therefore, it is important to notice that in ice rinks the refrigeration processes is not included in the E-value calculation.

The energy performance of buildings is required in order to determine the energy performance certificate rating of the building on a scale from A as the best scale to G as the poorest class and it include the following steps:

- The primary energy use E-value (E-luku) is calculated using primary energy factors
- The main requirement directing design and construction
- Air tightness of the building – building leakage rate $q_{50}$ limited to 4,0 $\text{m}^3/(\text{h m}^2)$
- Additional requirements for thermal insulation of the building components, for instance the thermal transmittance coefficient of a wall may not exceed 0.60 $\text{W}/(\text{m}^2\,\text{K})$, window or a doors may not exceed 1.8 $\text{W}/(\text{m}^2\,\text{K})$
- The energy efficiency of the ventilation system requires that the specific fan power SFP may not exceed 2 $\text{kW}/(\text{m}^3/\text{s})$

The steps implemented for the energy performance certificate of the ice rinks are:

- E-value is calculated with input data taken from design documentation (if available) for new and existing buildings
- The refrigeration process of the ice rink is not included in the E-value calculation
- If design values are not available, the E-value is calculated based on real measured or estimated ventilation air flow rates, indoor temperatures, running times and internal heat gains
- EPC class is determined based on E-value calculated and according the E-value ranges of the following table:

| Energiatehokkuusluokka | E-luku ($\text{kWh}_E/(\text{m}^2\text{vuosi})$) |
|---|---|
| A | E-luku ≤ 90 |
| B | 91 ≤ E-luku ≤ 130 |
| C | 131 ≤ E-luku ≤ 170 |
| D | 171 ≤ E-luku ≤ 190 |
| E | 191 ≤ E-luku ≤ 240 |
| F | 241 ≤ E-luku ≤ 280 |
| G | 281 ≤ E-luku |

*Table 1. Energy performance certificate is determined according to the class ranges in the table*

## 2. input data provided by the users

In the first page of the calculator called as “Rakennuksen tiedot”, the user has to provide the basic input data required for the calculation process. An overview of the first page of the calculator “Rakennuksen tiedot” is shown in Fig.3.

### *2.1. Dimensioning of the building and supplementary facilities*

In the first step the length, width and the height of the arena hall, the length and width of the ice pad also the area of supplementary building facilities are asked. The tool then calculates the hall and the ice pad area, the additional building area and the volume of the arena space. Then the maximum number of spectators that arena designed for is asked in the next step.

### *2.2. Indoor environment and the ice specifications*

Indoor air temperatures at the heights of 1.5 m and 4 meter also relative humidity at the height of 1.5 m are given as input by the user of the tool. The ice surface temperature and the ice thickness is asked in the next step. Then the important information about the ice pad resurfacing and the water temperature for the resurfacing process is asked in this stage. Pragmatic

### *2.3. Lighting*

In this stage lighting power required per square meter, the lighting utilization factor and the coating emissivity factor (k: 0.2 or 0.8) are asked and have to be provided for the calculator. The tool calculates the total power required for the lighting at the time in the same page.

### *2.4. Building envelope U-Value*

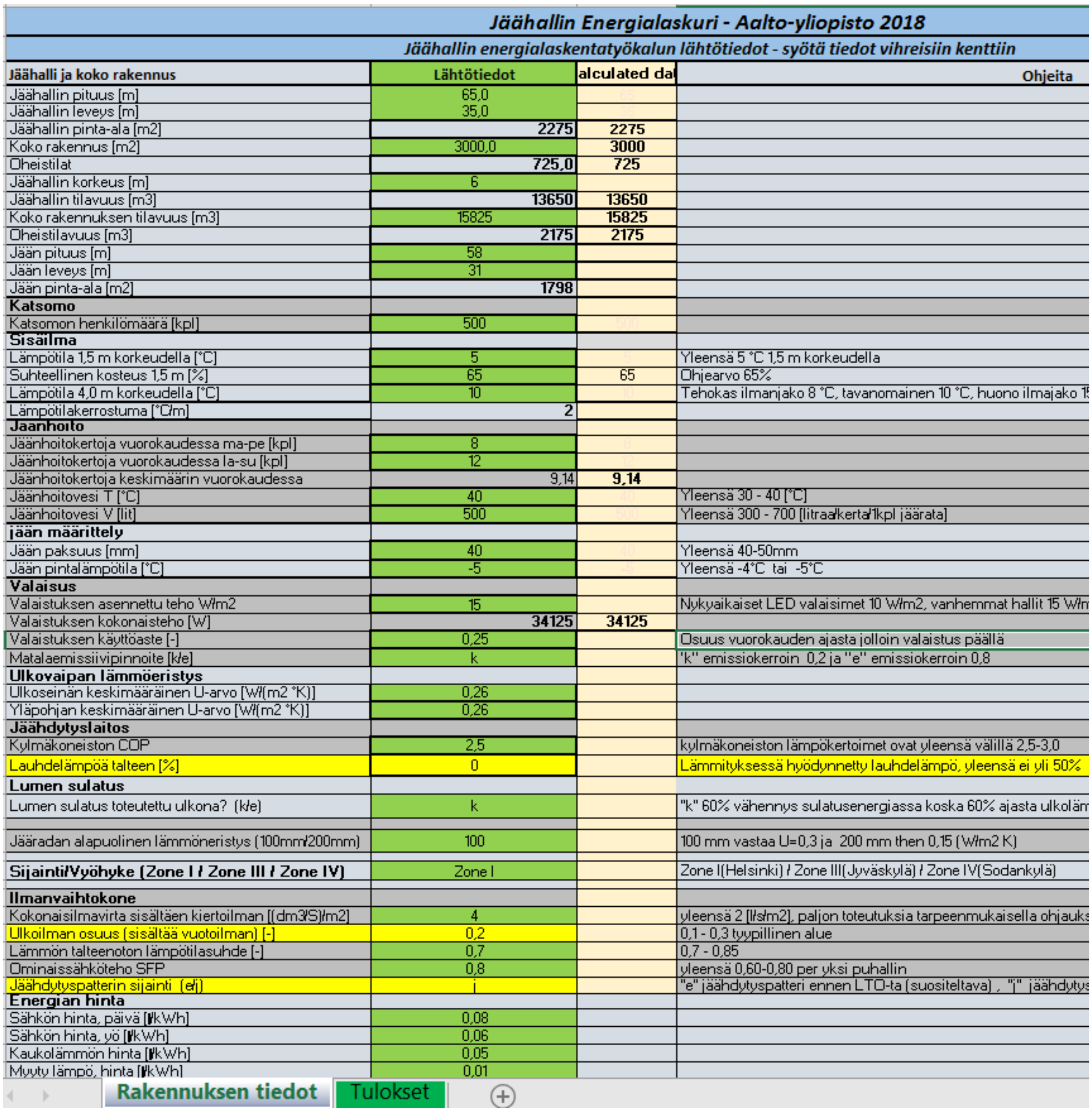
The U-values walls and the ceiling are aske din this stage [Page: “Rakennuksen tiedot”, Rows: 38&39]. Also the thickness of the insulation layer under the ice pad is asked [Page: “Rakennuksen tiedot”, Row: 46].

### *2.5. Refrigeration plant and snow melting*

The COP of the refrigeration machines, the percentage of recovered condensate heat. The tool also asks whether or not snow melting is implemented indoor or outdoor. [Page: “Rakennuksen tiedot”, Rows: 41, 42 & 44]

### *2.6. Location*

The tool is able to make the calculations based on three climatic zones of Finland, ZoneI, ZoneIII and ZoneIV. For the “ZoneI” weather data of Vantaa, for the ZoneIII weather data of Jyväskylä and for the Zone IV weather data of Sodankylä have been used. The location where the ice rink located is asked in the row 48 of the”Rakennuksen tiedot” page with the three options. Consequently all the calculations will be implemented based on the yearly outdoor temperature and humidity of the selected zone.



**Jäähallin Energialaskuri - Aalto-yliopisto 2018**

**Jäähallin energialaskentatyökalun lähtötiedot - syötä tiedot vihreisiin kenttiin**

| **Jäähalli ja koko rakennus** | **Lähtötiedot** | **alculated da** | **Ohjeita** |
|---|---|---|---|
| Jäähallin pituus [m] | 65,0 | 65 | |
| Jäähallin leveys [m] | 35,0 | 35 | |
| Jäähallin pinta-ala [m2] | **2275** | **2275** | |
| Koko rakennus [m2] | 3000,0 | **3000** | |
| Oheistilat | **725,0** | **725** | |
| Jäähallin korkeus [m] | 6 | | |
| Jäähallin tilavuus [m3] | **13650** | **13650** | |
| Koko rakennuksen tilavuus [m3] | 15825 | **15825** | |
| Oheistilavuus [m3] | **2175** | **2175** | |
| Jään pituus [m] | 58 | | |
| Jään leveys [m] | 31 | | |
| Jään pinta-ala [m2] | **1798** | | |
| **Katsomo** | | | |
| Katsomon henkilömäärä [kpl] | 500 | 500 | |
| **Sisäilma** | | | |
| Lämpötila 1,5 m korkeudella [°C] | 5 | 5 | Yleensä 5 °C 1,5 m korkeudella |
| Suhteellinen kosteus 1,5 m [%] | 65 | 65 | Ohjearvo 65% |
| Lämpötila 4,0 m korkeudella [°C] | 10 | 10 | Tehokas ilmanjako 8 °C, tavanomainen 10 °C, huono ilmajako 1 |
| Lämpötilakerrostuma [°C/m] | **2** | | |
| **Jaanhoito** | | | |
| Jäänhoitokertoja vuorokaudessa ma-pe [kpl] | 8 | 8 | |
| Jäänhoitokertoja vuorokaudessa la-su [kpl] | 12 | 12 | |
| Jäänhoitokertoja keskimäärin vuorokaudessa | 9,14 | **9,14** | |
| Jäänhoitovesi T [°C] | 40 | 40 | Yleensä 30 - 40 [°C] |
| Jäänhoitovesi V [lit] | 500 | 500 | Yleensä 300 - 700 [litraa/kerta/1kpl jäärata] |
| **jään määrittely** | | | |
| Jään paksuus [mm] | 40 | 40 | Yleensä 40-50mm |
| Jään pintalämpötila [°C] | -5 | -5 | Yleensä -4°C tai -5°C |
| **Valaisus** | | | |
| Valaistuksen asennettu teho W/m2 | 15 | | Nykyaikaiset LED valaisimet 10 W/m2, vanhemmat hallit 15 W/m |
| Valaistuksen kokonaisteho [W] | **34125** | **34125** | |
| Valaistuksen käyttöaste [-] | 0,25 | | Osuus vuorokauden ajasta jolloin valaistus päällä |
| Matalaemissiivipinnoite [k/e] | k | | "k" emissiokerroin 0,2 ja "e" emissiokerroin 0,8 |
| **Ulkovaipan lämmöeristys** | | | |
| Ulkoseinän keskimääräinen U-arvo [W/(m2 *K)] | 0,26 | | |
| Yläpohjan keskimääräinen U-arvo [W/(m2 *K)] | 0,26 | | |
| **Jäähdytyslaitos** | | | |
| Kylmäkoneiston COP | 2,5 | | kylmäkoneiston lämpökertoimet ovat yleensä välillä 2,5-3,0 |
| Lauhdelämpöä talteen [%] | 0 | | Lämmityksessä hyödynnetty lauhdelämpö, yleensä ei yli 50% |
| **Lumen sulatus** | | | |
| Lumen sulatus toteutettu ulkona? (k/e) | k | | "k" 60% vähennys sulatusenergiassa koska 60% ajasta ulkoläm |
| | | | |
| Jääradan alapuolinen lämmöneristys (100mm/200mm) | 100 | | 100 mm vastaa U=0,3 ja 200 mm then 0,15 (W/m2 K) |
| | | | |
| **Sijainti/Vyöhyke (Zone I / Zone III / Zone IV)** | Zone I | | Zone I(Helsinki) / Zone III(Jyväskylä) / Zone IV(Sodankylä) |
| | | | |
| **Ilmanvaihtokone** | | | |
| Kokonaisilmavirta sisältäen kiertoilman [(dm3/S)/m2] | 4 | | yleensä 2 [l/s/m2], paljon toteutuksia tarpeenmukaisella ohjauks |
| Ulkoilman osuus (sisältää vuotoilman) [-] | 0,2 | | 0,1 - 0,3 tyypillinen alue |
| Lämmön talteenoton lämpötilasuhde [-] | 0,7 | | 0,7 - 0,85 |
| Ominaissähköteho SFP | 0,8 | | yleensä 0,60-0,80 per yksi puhallin |
| Jäähdytyspatterin sijainti (e/j) | j | | "e" jäähdytyspatteri ennen LTO-ta (suositeltava) , "j" jäähdytys |
| **Energian hinta** | | | |
| Sähkön hinta, päivä [€/kWh] | 0,08 | | |
| Sähkön hinta, yö [€/kWh] | 0,06 | | |
| Kaukolämmön hinta [€/kWh] | 0,05 | | |
| Myyty lämpö, hinta [€/kWh] | 0,01 | | |

*Fig. 3. An overview of the first page of the calculator where the users enter input data*

## *2.7. Ventilation machines and Air handling Units*

In this section the tool asks total air flow including recirculating air, outdoor share of the supply air heat recovery temperature ratio, Specific fan power SFP. The user must also provide the information about the cooling coil location with the two option either placed before the heat recovery or after that.

## *2.8. Condensate heat recovery*

The user has to provide percentage of condensate heat utilized in the heating system which is generally not more than 50%.

## *2.9. Outdoor air contribution of the supply air*

The user has to provide the outdoor share of the supply air. The typical range is instructed to be within 0.1 to 0.3.

### 2.10. *The cooling coil location*

The user must specify wheather the cooling coil position is before or after the heat recovery by selectin “e” as before (ennen) or “j” as after (jälkeen).

### 2.11. *Energy prices*

The tool requires to be fed with the prices of various energy forms, Electricity prices day price and night price, district heat prices both purchase and selling prices.

## 3. Theoretical principles of the calculation

In order to calculate the heating and cooling demands, we need to analyze various possible thermal interactions including:

a) The heat losses between the indoor and outdoor air through the building envelopes
b) The heat loads between the ice pad and surrounding environment either upward to the indoor environment or downward to the ground underneath the ice.
c) Internal loads
d) Loads due to ice resurfacing process

The theoretical principles for each of the above mentioned item will be discussed in detailed in the following sub sections.

### 3.1. *The ice surface modeling*

To calculate the heat exchanged between the ice surface and indoor air, we need to concentrate on the transient layer above the ice. To do so, it is initially required to determine heat transfer coefficients of the air layer on the ice. Theoretical challenges on how accurate the model calculates the U_FILM, the $H_{\text{Conv,}}$ and condensation heat transfer, through the ice surface to the hall space, are described as:

$$P_{in} = 10^5 \exp(17.391 - \frac{6142.83}{273.15 + T_{in}}) \tag{1}$$

$$P_{ice} = 10^5 \exp(17.391 - \frac{6142.83}{273.15 + T_s}) \tag{2}$$

The relative humidity at the height of h = 0.1m above the ice surface are calculated:

$$RH_h = \left(\frac{h}{1,5}\right) \times \ (90 - RH_{1,5}) \tag{3}$$

$$dp = \left(\frac{RH_h}{100}\right) \times (p_h - p_{ice}) \tag{4}$$

$$dp_{atm} = \left(\frac{dp_{pa}}{101325}\right) \tag{5}$$

The heat transfer coefficient for condensation is also calculated as:

$$hd = 1750 \times h\_conv \times \Delta P / \Delta T (RH_h / 100) \tag{6}$$

$$q_{cond} = h_d \times (T_{in} - T_{ice}) \tag{7}$$

### 3.2. *Airflow balance equations*

The calculated and measured airflow rates, along with measured temperature and RH changes over the components were used to calculate the components theoretical energy output over the measurement periods. The heating coils and heat exchangers heating powers were calculated as:

$$P_{heat} = q_{air \times} \rho_{air} \times c_{air} \times \Delta T_{air} \tag{8}$$

and the required cooling powers for the cooling coil as:

$$P_{cool} = q_{air} \times \rho_{air} \times \Delta h_{air} \ , \tag{9}$$

Where the enthalpy of air can be expressed as

$$h_{air} = c_{air}T_{air} + x_{air}(c_w T_{air} + h_{we}) \ . \tag{10}$$

The fresh air intake of the AHU was calculated based on $CO_2$-level differences between the extract, supply, and fresh airs. Any decrease in $CO_2$ level from extract to supply air means a portion of the supply air is fresh air since it is reasonable to assume no other $CO_2$ sources within the unit exist. Fresh air intake can be calculated as:

$$q_{fresh\ air} = q_{sup}\left(\frac{C_{ext} - C_{sup}}{C_{ext} - C_{fresh}}\right) . \tag{11}$$

The resulting flow rate for fresh air intake serves more like an approximation than an exact value, but its accuracy is sufficient to determine when the unit operated in full or partial recirculation mode.

## 3.3. *Heat loss calculations through external envelopes of the building*

The thermal loss of the building is calculated using the conventional heat loss calculation equation as follows:

$$Q_{Heat\ loss} = \{\sum H_{Building} \times \sum(\Delta T \times \Delta t)_{Cold\ months}\} \tag{12}$$

$$\sum H_{Building} = \{\sum(U \times A)_{External\ wall} + \sum(U \times A)_{ceiling} + \sum(U \times A)_{Floor} + \sum(U \times A)_{doors\&windows}\} \tag{13}$$

The specific thermal transmittance of the building components are used when calculating the thermal loss of the design solution.

Thermal loss of leakage air is also calculated as:

$$Q_{Leakage\ air} = [\rho_{air} \times C_P \ \times q_v\ ]_{Leakage\ air} \times \sum(\Delta T \times \Delta t)_{months} \tag{14}$$

The heat loss is calculated using weather data of three zones: Zone I, Zone III, Zone IV. The calculator requests from the users to provide in which climatic zone the ice rink is located. The heat loss then will be calculated based on the outdoor yearly weather data of the selected zone. For each of these zones average monthly temperatures as well as total hours of each month are calculated. Finally those months that their average temperature are lower than the ice hall indoor temperature will be considered as cold months for the calculation. The average indoor temperature of the ice arena assumed to be as +10˚C.

$$q_{heat\ loss} = \{\sum(U \times A)_{External\ walls} + \sum(U \times A)_{ceiling} + \sum(U \times A)_{Floor} + \sum(U \times A)_{doors\&windows}\} \times [(\Delta T_1 \times \Delta t_1) + (\Delta T_2 \times \Delta t_2) + \cdots]_{cold\ months} \tag{15}$$

ΔT is the temperature difference between the average outdoor temperature of a cold month and the average indoor temperature which is assumed +10˚C, and $\Delta t$ is total time in hours of a cold month.

The number of cold months is chosen based on the average monthly temperature of month compared to average indoor temperature of the arena (~+10˚C). If the average temperature of the month is colder than +10 then it is assumed cold month in the tool. Accordingly, the Zone IV has two more cold months than other zones.

The total heating power is delivered through heating coil of the air handling unit to the air supplied in to the space.

## 3.4. *Heating Energy demand due to domestic hot water consumption*

There are basically three main consumers for domestic hot water; players showering in locker room, spectators' washroom and the third one which is a considerably big consumer is the hot water used in the resurfacing operation. The number of players for every match is similar in every arena except the active times of arenas may differ from each other. Thus the hot water consumption for players is approximately the same unless an arena is specified with higher or lower activity period than usual. The number of spectators depend on the space capacity of the arena and thus the user of the tool must specify the number of spectators. Then the spectators' consumption which is limited to wash room usage can be calculated based on the number of spectators.

Finally the amount of domestic hot water used for resurfacing operation which is the largest domestic hot water consumption is defined based on the information provided by the user about the hot water quantity and its temperature in addition to the sequence of daily weekdays and weekend operations used for resurfacing operation.

$$Q_{hot\,water} = Q_{resurf.water} + Q_{DHW} \qquad (16)$$

## 3.5. *Heat load of the ice pad*

There are various forms of heat transfer occur between the ice pad and with the surrounding environment both upward to the room and downward to the ground. The heat transfer forms will separately be analyzed in the following sections and their theoretical steps followed in the calculation tool are then described.

### 3.5.1. *Convection heat transfer*

One of the main form of thermal interaction between the ice pad and indoor air is the heat transfer due to convection occurring on the ice surface. The convection heat transfer is calculated using the following equation: We assume linear relationship between surface temperature of the ice and temperature at the height 1,5m.

$$T_{h=0.1} = T_s + \left(\frac{h=0.1}{1.5}\right) \times (T_{1,5m} - T_s) \qquad (17)$$

Where $T_s$ and $T_{1,5m}$ are asked in the first page of the tool. So, it is then provided as input by the users. Then heat transfer coefficient at the height of 0.1m above the ice will be calculated using the indoor air movement velocity at the $h_{Conv}$=0.1m.

$$h_{Conv.} = 3.41 + (3.55 \times V) \qquad (18)$$

| | | |
|---|---|---|
| indoor air velocity at the height of $h_{Conv.}$ = 0.1m, assumed to be: | V = 0.15 | [m/s] |
| heat transfer coefficient at the height of 0.1m above the ice: | $h_{Conv.}$ [m]: | 0.10 |

$$\dot{q}_{Conv.} = h_{Conv} \times (T_{in} - T_S) \tag{19}$$

| | | |
|---|---|---|
| Convection heat transfer between the ice and the indoor air: | $q_{conv}$ | [W/m$^2$] |
| Heat transfer coefficient: | $h_{conv}$ | [W/(m$^2$ °K)] |
| Ice surface temperature: | $T_S$ | [°C]: |
| Air temperature at height h = 0.1m is: | $T_{in} = T_{h=0.1m}$ | [°C] |

### 3.5.2. Radiation losses

The radiation heat transfer is calculated using radiation heat transfer coefficient, and for calculating the coefficient emission factor between the ice and the ceiling has to be calculated. The emission factor is calculated by the following equation:

$$\varepsilon_{12} = \left[\frac{1}{F_{ci}} + \left(\frac{1}{\varepsilon_{ceiling}} - 1\right) + \frac{A_{ceiling}}{A_{ice}} \times \left(\frac{1}{\varepsilon_{ice}} - 1\right)\right]^{-1} \tag{20}$$

| | | |
|---|---|---|
| Emission factor between the ceiling and the ice: | $\varepsilon_{12}$ | [-] |
| the view factor between the ice pad and the roof (=0.68) | $F_{ci}$ | [-] |
| Emissivity of the ceiling, depending on the emissivity of the sheet, | $\varepsilon_{Ceiling}$ | [-] |

$\varepsilon_{Ceiling}$ is provided by users as input in the first page: either k = 0.2 or 0.8

| | | |
|---|---|---|
| Surface area of the ceiling: | $A_{Ceiling}$ | [m$^2$] |
| Ice surface area: | $A_{ice}$ | [m$^2$] |
| Emissivity of the ice (0.98): | $\varepsilon_{ice}$ | [-] |

The heat transfer coefficient is calculated through the following equation:

$$h_{rad} = \varepsilon_{12} \times \sigma \times (T_{Ceiling}^2 + T_{Ice.sur}^2) \times (T_{Ceiling} + T_S \tag{21}$$

| | | |
|---|---|---|
| Radiation heat transfer coefficient: | $h_{rad}$ | [W/(m$^2$ °K)] |
| Stefan-Boltzmann constant (5.67037E-08): | $\sigma$ | [W/(m$^2$ °K$^4$)] |
| Ice surface temperature: | $T_S$ | [°K] |
| Surface temperature of the ceiling: | $T_{Ceiling}$ | [°K] |

The ceiling temperature assumed to be the same as the air temperature at the height of h=4m which is available as input to the tool.

And finally the radiation heat transfer is calculated using the equation below:

$$q_{rad.} = h_{rad.} \times (T_{Ceiling} - T_S) \tag{22}$$

| | | |
|---|---|---|
| Radiation heat flow rate: | $q_{rad}$ | [W/m$^2$] |

### 3.5.3. Thermal radiation due to lighting

The total heating generated in the space through the lighting radiation which absorbed by the ice surface to warm up the ice and subsequently the refrigeration machines must compensate:

$$q_{lighting} = P_{lighting} \times U \times 0.62 \tag{23}$$

| | | |
|---|---|---|
| Total radiation heating power generated by lighting: | $q_{lighting}$ | [W] |
| Total Lighting Power: [W]: | $P_{lighting}$ | [W] |
| Utilization percentage of the lighting: | $U$ | % |

### *3.5.4. Condensation heat load*

First, we need to calculate ($RH_{h=0.1}$) which is the relative humidity at the height of 0.1m above the ice. Relative humidity at height h=0.1m is calculated by assuming a linear relationship between the relative humidity on the ice surface which is assumed to be 100% and the relative humidity at 1.5 m above the ice which has to be 65% according to the guideline. This is calculated using the linear equation according the following equation:

$$RH_{h=0.1} = 100 - [\left(\frac{h_{Conv}}{1.5}\right) \times (100 - RH_{h=1.5})] \tag{24}$$

Where; $h_{conv} = 0.1m$ is the convection heat transfer coefficient at the height of 0,1m and $RH_{h=1.5}$ is the relative humidity at the height of 1,5m above the ice which is provided by the user.

$$P_{in} = 10^5 \times \exp(17.391 - \frac{6142.83}{273.15+T_{in}}) \tag{25}$$

$$P_S = 10^5 \times \exp(17.391 - \frac{6142.83}{273.15+T_S}) \tag{26}$$

$$\Delta P = (\varphi_{in} \times p_{in}) - p_S \qquad [\Delta P\text{: Pa}] \tag{27}$$

$$\Delta P(atm) = \frac{\Delta P(Pa)}{101325} \tag{28}$$

$$h_{cond} = 1750 \times h_{conv} \times \frac{\Delta p}{\Delta T} \tag{29}$$

$$h_{conv} = 0.1m\ , \quad \Delta T = T_S - T_{0.1} \tag{30}$$

$$q_{condens.} = h_{cond} \times (T_{0.1} - T_S) \tag{31}$$

### *3.5.5. Heat load due to resurfacing operation*

The operation implemented here after spreading the hot water on the ice surface includes three stages; first, to cool down the hot water to zero degree centigrade. The energy need for this stage is calculated as:

$$Q_{water\ cooling} = m \times C_{water} \times (T_{hot\ water} - 0) \tag{32}$$

Then the refrigeration machine has to cool down the water in order to freeze to ice. The required freezing energy is calculated as:

$$Q_{water\ freezing} = m \times C_{freezing} \tag{29}$$

And finally the ice has to be cooled down to the extent that become equal to set surface temperature of the ice. The cooling energy required is then calculated as:

$$Q_{ice\ Cooling} = m \times C_{ice} \times (0 - T_{S.ice}) \tag{33}$$

And finally the overall heat load due to resurfacing is calculated as:

$$Q_{resurf.} = Q_{water\ cooling} + Q_{water\ freezing} + Q_{ice\ cooling} \tag{34}$$

### 3.5.6. Cooling load due to conduction to the ground (Routa)

Since there is considerable temperature difference between the ice pad and ground underneath the ice pad, therefore considerable amount of cooling energy of the ice is also conducted to the ground beneath. The heat transfer due to conduction in to the ground under the ice surface per surface area is calculated as:

$$Q_{Conduc.} = U_{ins.} \times (1 - T_{ice\,surface}) \qquad (35)$$

Where $U_{ins.}$ is the U value of the insulation layer under the ice pad and $T_{S.ice}$ is the ice surface temperature.

Refrigeration machinery has to compensate cooling energy loss to the extent transferred to the ground. At the same time the heating system must also warm up the ground to the same extent to protect the ground against freezing. Therefore the controllers of the ground heating will maintain ground temperature at the minimum temperature of +1 to ensure any risk of freezing.

## 3.6. Cooling demand of AHU's cooling coil

Dehumidification is mainly implemented during the warm months when the average outdoor temperature as well as the humidity is high.

$$Q_{AHU.Cooling} = \sum_{1}^{warm\,months} [(\alpha \times \dot{m}_{air} \times (\Delta h) \times t_{month})] \qquad (36)$$

Where:

| | |
|---|---|
| $\alpha$ | The outdoor air share of the supply air, (assumed to be 20%) |
| $\dot{m}_{air}$ | the mass flow of the supply air |
| $\Delta h$ | the enthalpy difference between the average outdoor air enthalpy of the month and the required enthalpy of the indoor air |
| $t_{month}$ | total time of every month in hours |

The enthalpy of the outdoor air is calculated using the weather data correspondent to the selected zone where the ice rink is located.

This is done by calculating the average enthalpy of outdoor air and comparing with the enthalpy of the indoor air which is to be maintained. The calculator chooses the months with higher average enthalpy than indoor enthalpy as the months which cooling is required. The differentiated enthalpies (outdoor with indoor) for all the warm months of the selected zone are added.

$$Q_{AHU.Cooling} = (Q_{External\,partition\,load} + Q_{fresh\,air\,cooling}) \qquad (37)$$

$$Q_{AHU.Cooling} = \{(Q_{External\,partition\,load}) + (Q_{Fresh\,air} \times 1.2 \times \sum(\Delta h \times \Delta t)_{warm\,months})\} \times \frac{\text{Imperical coefficient for cooling coil position}}{1000} \qquad (38)$$

The empirical coefficient reflecting the effects of cooling coil position is extracted from the published journal article by the authors. "Energy performance of air handling unit configurations in an air heated ice rink arena". This coefficient is either one (2,5) when the cooling coil is located prior to the heat recovery or “1” when the cooling coil is located after the heat recovery according to the results of the published paper.

### 3.7. Overall refrigeration power demand

The overall refrigeration power of the ice rink required to be generated by refrigeration machines is sum up of the following portions that earlier calculated:

a) Cooling power for the ice pad is summation of in different load portions calculated in sections 3.5.1 to 3.5.6

$$Q_{ice\ pad\ cooling\ power} = Q_{Conv.} + Q_{rad.} + Q_{lighting} + Q_{Condens.} + Q_{resurf.} + Q_{conduc.} \quad (39)$$

b) The cooling power required in cooling coil of the air handling unit was calculated in previous section 3.6.

$$Q_{total\ refrig.\ power} = Q_{Ice\ pad\ cooling.} + Q_{AHU\ cooling} \quad (40)$$

For the final refrigeration power a correlation coefficient is implemented reflecting the effects of the temperature gradient on the total heat load of the ice pad.

### 3.8. AHU heating demand

The overall heat loss is equal to heating energy requirement for space heating of the ice rink and it is calculated using the summation of the previously calculated values as:

| | |
|---|---|
| $Q_{Conv.}$ | Convection heat transfer |
| $Q_{rad.}$ | Radiation heat losses of the ice pad |
| $Q_{Condens.}$ | Condensation heat load |

$$Q_{cooling\ effects\ of\ ice\ pad} = Q_{Conv.} + Q_{rad.} + Q_{Condens.} \quad (41)$$

The overall required heating energy has to compensate the external partition heat loss, the heat loss through the cooling effects of the ice pad and the fresh air heating as described in the following equation:

$$Q_{AHU\ heating} = Q_{External\ partition} + Q_{cooling\ effects\ of\ ice\ pad} + Q_{Fresh\ air\ heating} \quad (42)$$

| | |
|---|---|
| $Q_{External\ partition}$ | Heat loss of the External envelope of the Building to outdoor |

$$Q_{AHU\ heating} = Q_{AHU\ heating} \times (emperical\ coefficient\ for\ location\ of\ cooling\ coil) \quad (43)$$

The empirical coefficient is extracted from the published paper by the authors and it is either

### 3.9. Overall heating demand

The reason for excluding the thermal radiation of lighting ($Q_{lighting}$) and the resurfacing ($Q_{resurf.}$) loads is because the cooling loss of them are compensated by the generated heat of lightings and resurfacing hot water heat respectively.

The total heating power required to be delivered by the AHU heating coil is the summation of:

$$Q_{total\ Heating} = Q_{AHU\ heating} + Q_{hot\ water} + Q_{ground} \quad (44)$$

| | |
|---|---|
| $Q_{ground}$: | energy loss due to thermal conduction of ice pad in to the ground |

## 3.10. COP calculation

The coefficient of performance (COP) for the entire cooling system is a key factor for calculating energy consumption. The COP of the cooling system is a function of several variables such as pumping power, the brine pumps, chiller, compressor and condensers etc. Andrea found that the volumetric flow and the pumping power corresponds to approximately 7% of the total electric consumption, and therefore the COP is not very sensitive to the volumetric flow. But the brine pumps, chiller, compressor and condensers account instead for the remaining 93% of the electric power consumption. Also choosing an optimal brine fluid, the secondary refrigerant, is instead crucial to achieve a higher COP. as the COPsys, through the cooling power, is particularly sensitive to the specific heat of the fluid. It is found that ammonia gives a higher COP than ethylene glycol, the latter to be preferred in any case at concentration between 20% and 34%. Therefore, choosing an optimal secondary coolant is determinant for a higher COPsys, which is particularly sensitive to the specific heat of the brine. It is concluded thet ammonia is more performing than ethylene glycol, and that glycol at concentration between 20% and 34% is to be preferred in any case. Design possibilities regarding pipe size and depth inside the concrete slab confirmed that do not enhance nor hinder the process significantly. However, increasing the number of pipes provides with a more uniform temperature profile at the ice surface. [Andrea]

This is normally obtained from the manufacturer of the refrigeration plant's machineries when purchased. The COP has to be fed as input to the first page of the tool by the users.

## 3.11. Total Electricity demand of the refrigeration plant

The overall electricity demand of the refrigeration plant is calculated using the total refrigeration load (described earlier in details) divided by COP of the refrigeration machines.

Total ice rink heat load kW = total heat load of the ice per surface area x surface area /1000

$$Required\ electricity\ power\ (kW) = \left\{\frac{\text{Heat load of the ice pad (kW)}}{\text{COP}} + \frac{\text{cooling power of the AHU (kW)}}{COP}\right\} \quad (45)$$

The yearly consumption of the refrigeration machineries are calculated as:

$$Total\ yearly\ cooling\ consumption\ (MWh) = \frac{Total\ cooling\ power \times 24 \times 365}{1000} \quad (46)$$

## 3.12. Correlation factors

There are some uncertainties in the building which cause inaccuracies in the calculation results. They relate to the factors that either cannot be accurately considered in the calculation process due to anonymity or make the calculations complicated if considered. For instance, the radiation heat transfer of the ice pad with the indoor environment plays major role on the indoor heat loss. But in the calculation tool the radiation heat loss is simplified by one dimensional calculation taking in to account only ice pad and ceiling surfaces. But, in fact all the indoor surrounding surfaces are in thermal interaction with the ice pad and they are simply ignored in the calculation, such as walls, as well as occupant's exposed body surfaces. As radiation heat transfer plays considerable role in the total cooling and heating energy demands, any inaccuracies on calculating radiation heat transfer makes the final results inaccurate. Therefore the correlation factors are required to cover the discrepancies between the calculation results of the heating and cooling demands with the experimental results which is assumed to match with simulation results. These correlation factors are implemented for total AHU heating demand, AHU cooling demand and total refrigeration plants. These factors mainly follow the results of earlier published article by the authors covering the gaps between the calculation results of energy demands and the presumed real demands. The factors fluctuate linearly with the temperature gradient of the arena. The general form of the correlation factors are describes as:

$$Y = aX + b \tag{47}$$

When “Y” is the final correlation factor, “X” is the temperature gradient, “a” and “b” are constants.

The exact correlation equation applied for the AHU heating is:

$$Y = 0.86 + (Temperature\ gradient \times 0{,}14)$$

The equation applied for the AHU cooling is:

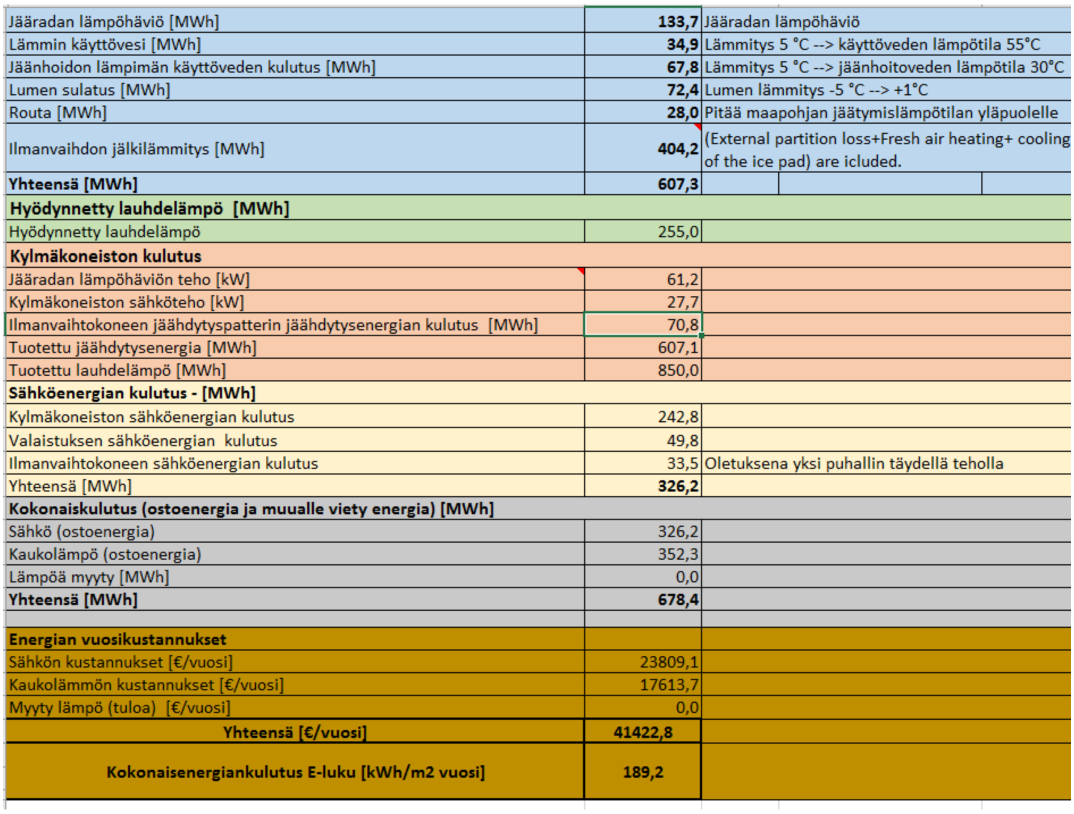
$$Y = 1 + (Temperature\ gradient \times 0{,}1)$$

The exact equation applied for the zone cooling is:

$$Y = 0.9 + (Temperature\ gradient \times 0{,}05)$$

## 4. *Output results*

The output data are shown in a separate page called as “Tulokset” which is is depicted in the following FIG.3. It also includes supplementary pie curves for heating energy consumption, electricity consumption, presenting contribution of each parts and entire energy consumptions presenting contribution of district heating, electricity and exported energy:



| | | |
|---|---|---|
| Jääradan lämpöhäviö [MWh] | **133,7** | Jääradan lämpöhäviö |
| Lämmin käyttövesi [MWh] | **34,9** | Lämmitys 5 °C --> käyttöveden lämpötila 55°C |
| Jäänhoidon lämpimän käyttöveden kulutus [MWh] | **67,8** | Lämmitys 5 °C --> jäänhoitoveden lämpötila 30°C |
| Lumen sulatus [MWh] | **72,4** | Lumen lämmitys -5 °C --> +1°C |
| Routa [MWh] | **28,0** | Pitää maapohjan jäätymislämpötilan yläpuolelle |
| Ilmanvaihdon jälkilämmitys [MWh] | **404,2** | (External partition loss+Fresh air heating+ cooling of the ice pad) are icluded. |
| **Yhteensä [MWh]** | **607,3** | |
| **Hyödynnetty lauhdelämpö [MWh]** | | |
| Hyödynnetty lauhdelämpö | 255,0 | |
| **Kylmäkoneiston kulutus** | | |
| Jääradan lämpöhäviön teho [kW] | 61,2 | |
| Kylmäkoneiston sähköteho [kW] | 27,7 | |
| Ilmanvaihtokoneen jäähdytyspatterin jäähdytysenergian kulutus [MWh] | 70,8 | |
| Tuotettu jäähdytysenergia [MWh] | 607,1 | |
| Tuotettu lauhdelämpö [MWh] | 850,0 | |
| **Sähköenergian kulutus - [MWh]** | | |
| Kylmäkoneiston sähköenergian kulutus | 242,8 | |
| Valaistuksen sähköenergian kulutus | 49,8 | |
| Ilmanvaihtokoneen sähköenergian kulutus | 33,5 | Oletuksena yksi puhallin täydellä teholla |
| Yhteensä [MWh] | **326,2** | |
| **Kokonaiskulutus (ostoenergia ja muualle viety energia) [MWh]** | | |
| Sähkö (ostoenergia) | 326,2 | |
| Kaukolämpö (ostoenergia) | 352,3 | |
| Lämpöä myyty [MWh] | 0,0 | |
| **Yhteensä [MWh]** | **678,4** | |
| | | |
| **Energian vuosikustannukset** | | |
| Sähkön kustannukset [€/vuosi] | 23809,1 | |
| Kaukolämmön kustannukset [€/vuosi] | 17613,7 | |
| Myyty lämpö (tuloa) [€/vuosi] | 0,0 | |
| **Yhteensä [€/vuosi]** | **41422,8** | |
| **Kokonaisenergiankulutus E-luku [kWh/m2 vuosi]** | **189,2** | |

*Fig. 4. Overview of the output page of the tool "Tulokset"*

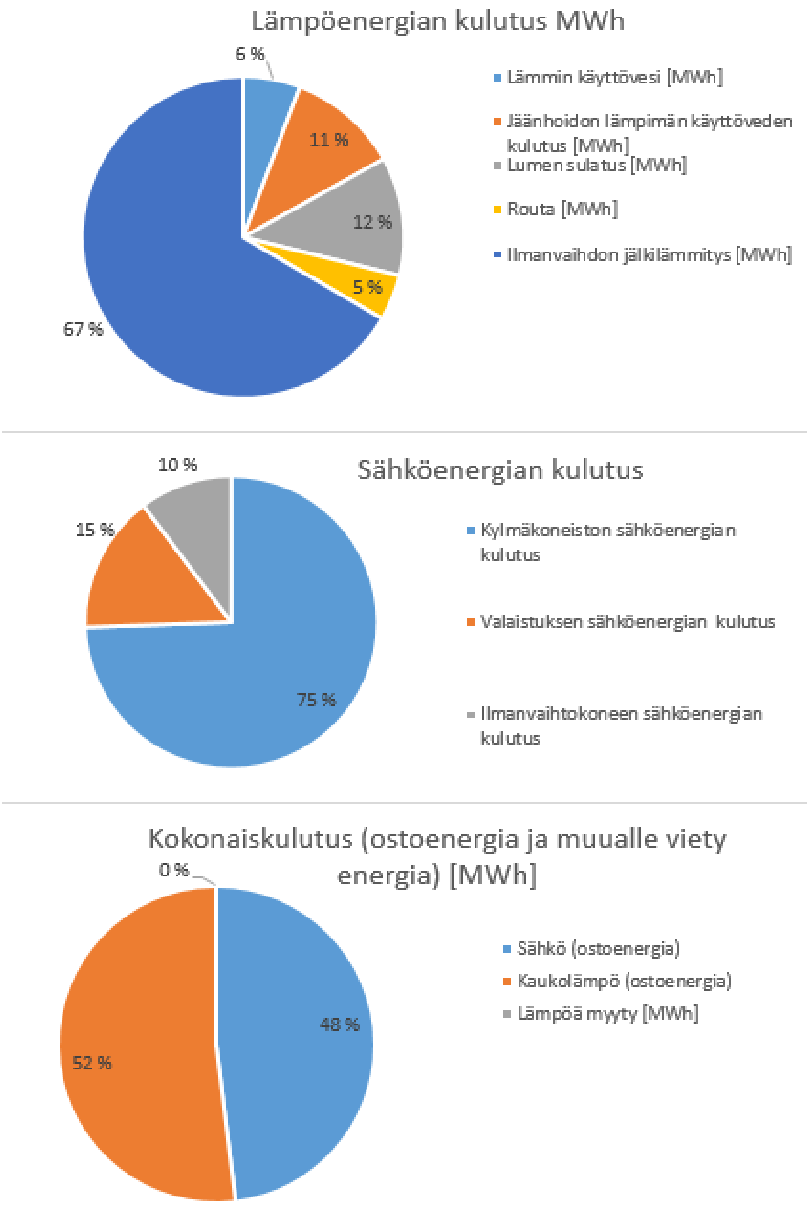


*Fig. 5. Pie curves of heating energy, electricity and total imported/exported energy consumptions*

The more essential parts of the output results are heating energy consumption, utilized condensate heat, cooling energy consumption, refrigeration plant's power consumption, electricity consumption, overall consumptions and yearly costs of energy as they are specified with different colors in the output page of the tool as shown the figure . Each of the parts are described with the details in the following sub-sections.

## 4.1. Total heating energy consumption [MWh]

The total heating energy consumption is calculated by the summation up the previously calculated/described items as:

$$\begin{aligned} &Overall\ heating\ energy\ required\ to\ be\ supplied\ (MWh) = External\ partition\ losses + \\ &Heat\ loss\ due\ to\ cooling\ effects\ of\ the\ ice\ pad + fresh\ air\ heating + \\ &heating\ energy\ for\ domestic\ hot\ water + hot\ water\ energy\ required\ for\ resurfacing + \\ &Heating\ energy\ for\ freezing\ protection\ of\ the\ ground\ under\ the\ icepad + \\ &Heating\ energy\ for\ snow\ melting (if\ applicable) \end{aligned} \tag{48}$$

$Total\ required\ ventilation\ heating\ (MWh) = \ External\ partition\ heat\ losses + Heat\ loss\ due\ to\ cooling\ effects\ of\ the\ ice\ pad\ \ + Heating\ required\ for\ fresh\ air\ heating$ (49)

## 4.2. Total produced cooling energy [MWh]

The total cooling energy of refrigeration plant is calculated summing up of various parts of yearly cooling energy demands as:

$\text{Total cooling energy demand } = \{\text{Cooling energy demand of ice pad} + Cooling\ energy\ demand\ for\ dehumidification + cooling\ energy\ demand\ to\ compensate\ summer\ heat\ load\ of\ external\ partition\}$ (50)

$\text{Cooling energy demand of ice pad} = Total\ calculated\ heat\ load\ of\ the\ ice\ surface \times correlation\ coefficient\ to\ reflect\ effects\ of\ temperature\ gradient$ (51)

## 4.3. Recovered Condensate heat [MWh]

The total produce condensate heat is calculate as summation of the items which were calculated in the earlier steps as:

$Produced\ condensate\ heat = \{Electricity\ consumtion\ of\ refrigeration\ machineries + Generated\ cooling\ energy\}$ (52)

The electricity consumption of refrigeration plant is calculated by:

$Electricity\ consumtion\ of\ refrigeration\ machineries\ [MWh] = refrigeration\ machines\ power\ \times 24 \times 365/1000$ (53)

The percentage of recovered condensate heat which was provided by the user in the first page as input data is used to calculate the share of utilized condensate heat simply by multiplication as:

$\text{Recovered condensate heat } = \{\text{percentage of recovered condensate heat} \times Generated\ condensate\ heat\}$ (54)

## 4.4. Electricity Consumption - [MWh]

The overall electricity consumption (El) is calculated summing up each parts of electricity consumption which also discussed in earlier sections:

Electricity consumption of refrigeration plant

Electricity consumption of lighting

Electricity consumption of ventilation machines

$$El_{\text{Refrigeration}} = \frac{cooling\ power\ of\ the\ Icerink}{COP} + \frac{cooling\ power\ of\ AHU}{COP} \quad (55)$$

$$El_{\text{Lighting}} = \ lighting\ pawer\ (W) \times Lighting\ utilisationfactor\ \times t_{total\ time\ (h)} \quad (56)$$

$$El_{\text{AHU}} = 1{,}25kW/m^3s \times SFP \times Q_v \times t_{totla\ times\ h} \quad (57)$$

## 4.5. *Annual consumed or sold energy [MWh]*

The overall electricity is calculated as the following equation: The overall consumed electricity calculated by summing up electricity consumption of refrigeration plant, lighting and AHU fans power consumptions.

$$\text{Overall Electricity Consumption [MWh]} = \left\{El_{\text{Refrigeration}} + El_{\text{Lighting}} + El_{\text{AHU}}\right\} \tag{58}$$

The overall electricity consumption is considered as purchased electricity as there is no on site electricity generation.

Since the total required heating energy is calculated as in section 4.1, and the total generated and recovered condensate heat is calculated in section 4.3, then the overall purchased or sold district heating energy is computed using a simple if-then logic. It is implemented so that if the recovered condensate heat is greater than the overall required heating energy then it subtract them and the resulted additional heat will be shown as sold heating energy. If the recovered condensate heat is less that the overall heating energy demand then it subtract them and the resulted additional would be purchased district heating.

$$Q_{\text{Purchased-DH}} = Overall\ required\ heating\ energy - recovered\ condensate\ heat \tag{59}$$

$$Q_{\text{Sold-DH}} = recovered\ condensate\ heat - Overall\ required\ heating\ energy \tag{60}$$

## 4.6. *Annual Energy Costs*

The primary energy factors (PEF) or weighting factors) in Finland are required in order in order to calculate the annual energy costs of the ice-rink. These factor for various energy forms in Finland are as follows:

The primary energy factors in Finland according to the latest guideline are as follows:

| | |
|---|---|
| Electricity: | 1.2 |
| District heating | 0.5 |
| District cooling: | 0.28 |
| Renewable fuels: | 0.5 |

*Table 2. Primary energy factor in Finland*

The annual energy costs (purchased or sold) are calculated using each of previously calculated parts of purchased (imported) or sold (exported) energy multiplied by subsequent energy prices [€/kWh] which provided by the user as input data.

The E-value (E-luku) is finally calculated summing up costs of each form of energy multiplied by its subsequent primary energy factors in Finland as following equation:

$$\text{Overall E value}[\text{MWh}/m^2 \times \text{a}] = \frac{\{(Yearly\ Elctricity\ costs \times PEF_{El}) + (Yearly\ Distric\ heating\ costs \times PEF_{DH}) + \cdots\}}{Total\ building\ area} \tag{61}$$

## 5. *Examples:*

The EP-value of the following example is calculated with two alternatives:

1. excluding the energy consumption for refrigeration process and subsequently excluding heating energy required to compensate cooling effects of the Ice pad
2. including the energy consumption for refrigeration process with the heating energy required to compensate cooling effects of the Ice pad

And we will show the differences between the realistic and the official E-values for such spaces like ice rinks where the process dominates.

As an example we assume a building with the dimension of 65 x 35 x 6 m, the ice pad size 31x58m, the occupants counted as 20 players and 100-500 spectators, with the indoor conditions as average temperature of +8°C and the maximum relative humidity of 60%, with minimum ventilation rate of 2dm3/(s.m2)~4 m3/s, the outdoor air fraction of 5% of the ventilation rate, minimum lighting of minimum lighting of 10 W/m2, with usage factor 25% and domestic hot water consumption is 500 dm3/(m2 a).

The results of E-value calculation using the tool and **excluding** the energy consumption for refrigeration process and heating energy required to compensate cooling effects of the Ice pad is :

External partitions heat loss: 58800 kWh/a , ~ 25,1 kWh/($m^2$ a)
Ventilation heating: 404200 kWh/a , 26,33 kWh/($m^2$ a)
Electricity:
Lighting: 49800 kW/a, 21,9kWh/($m^2$ a)
For the Ventilation fans: 33500 kWh/a, 14,7 kWh/($m^2$ a)
Domestic Hot Water
DHW: 34900 kW/a, 15,3kWh/($m^2$ a)
Total Heating Energy consumption = 25,1 + 26,3 + 15,3 = 66,7kWh/$m^2$ a)
Total Electricity consumption = 21,9 + 14,7 = 36,6 kWh/($m^2$ a)

$$\mathrm{E-Value:}\ [1{,}2\ \mathrm{x\ (total\ Electricity)}]\ +\ [0{,}5\ \mathrm{x\ (total\ Heating)}]$$

$$\text{E-Value: } [1{,}2 \text{ x } 36{,}6] + [0{,}5 \text{ x } 66{,}7] = 77{,}27 \mathrm{kWh/(m2\ a)}$$

$$\mathrm{E-luku:}\ 77{,}27\ \mathrm{kWh/(m2\ a)}\ = \text{"A" class in energy performance certificate}$$

The results of E-value calculation **including** the energy consumption for refrigeration process and heating energy required to compensate cooling effects of the Ice pad are as follows:

Cooling Energy demand due to cooling effects of the ice pad:604600 kWh/a ~ 265,8 kWh/$m^2$ a

External partitions heat loss: 58800 kWh/a ~ 25.1 kWh/$m^2$ a

Ventilation heating: 298200 kWh/a ~ 179,6 kWh/$m^2$ a

Heating energy demand of DHW resurfacing included: 102700 kWh/a, 45,1kWh/ ($m^2$a)

Electricity consumption of the refrigeration plant: 241900 kWh/a ~ 106,3 kWh/$m^2$a

Electricity consumption of lighting: 49800 kW/a, 21,9kW/($m^2$ a)

Electricity consumption of Ventilation fans: 33500 kwh/a, 14,7kWh/($m^2$ a)

Total Heating Energy consumption: = 25.1 + 179,6 + 45,1 = 249,8kWh/($m^2$ a)

Total Electricity consumption: = 14.7+ 21.9 +106.3 = 142,9 kWh/($m^2$ a)

E-Value: [1.2 x (total Electricity)] + [0,5 x (total Heating)]

E-Value: [1.2 x (142.9)] + [0.5 x (249.8)] = 296,4 kWh/($m^2$ a)

E-Value: 296.4 kWh/(m2 a): by factor 3,8 times higher compared to E-value 77,27 when refrigeration process is not included in the calculation.

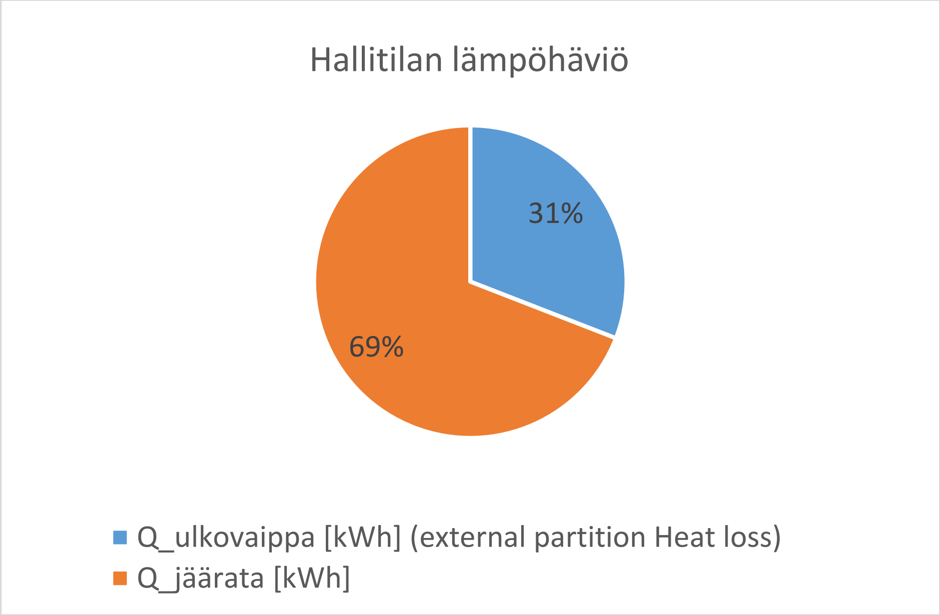


*Fig. 6. Heat loss through external partitions and due to ice pad*

The official E-value calculation takes in to account only 31% of the required heating which is the heat loss through the building envelope, fresh air heating and all other heating demands of the building except the cooling effect of the ice pad.

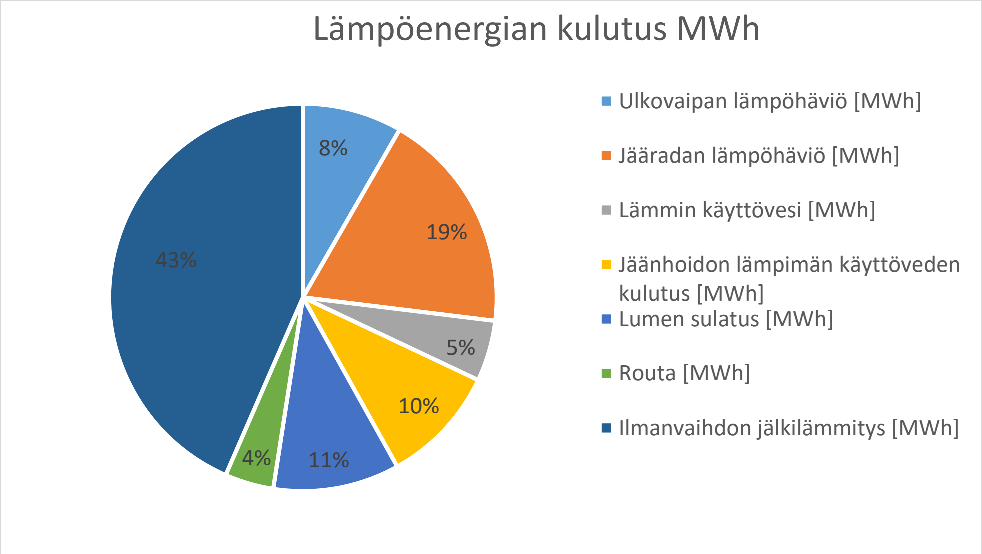


*Fig. 7. Heating energy consumption where most of the heating energy is not accounted*

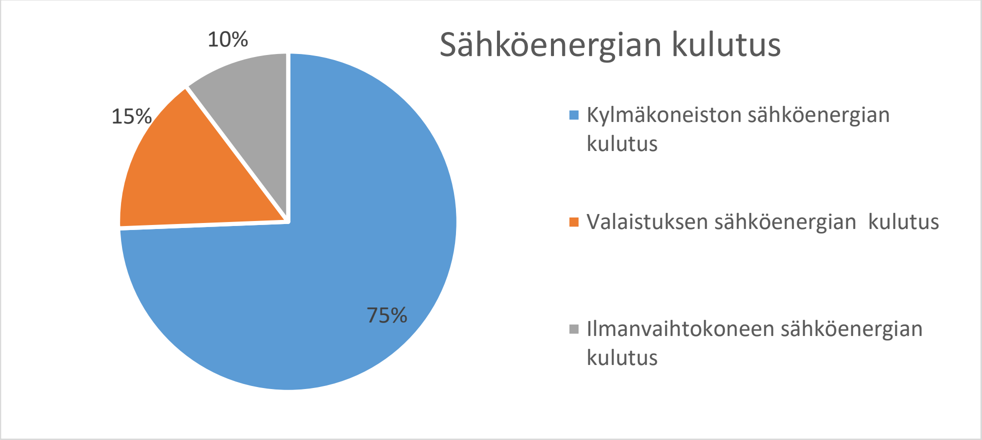


*Fig. 8. Electricity consumption scheme and contribution of each sector*

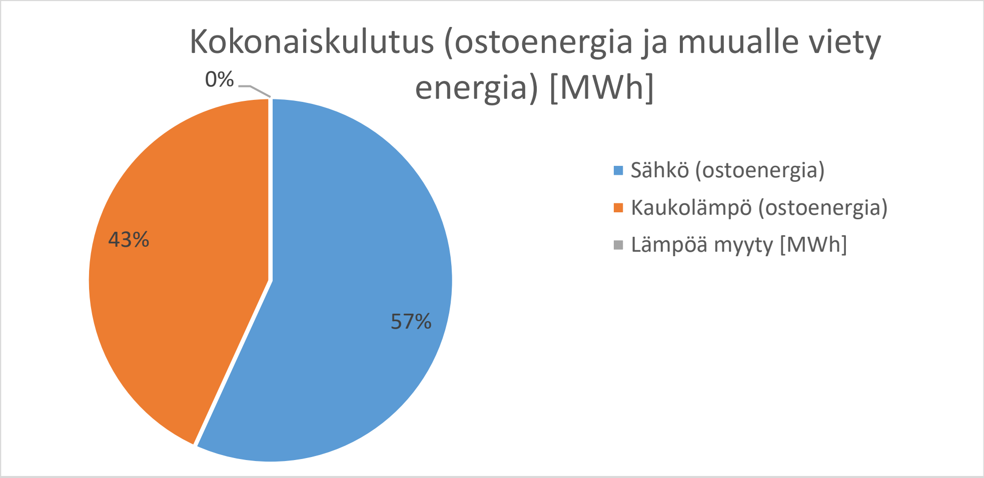


*Fig. 9. Overall imported/exported energy scheme*

The refrigeration plant of the ice pad consumes 75% of the entire electricity consumption as shown in Fig.8. But it is not also accounted when official E-value is calculated. The official E-value represents approximately 30% of the primary energy use only.

Finally, The ice pad is the major cause for the heat loss due to cooling effects of the ice pad to the indoor environment of the building. Therefore, the heating supply because of the ice pad dominates the entire heating energy demand of the building. On the other hand, the refrigeration plant of the ice pad is also the major consumer of electricity in the ice rinks (fig.8.). Therefore together consumed energy to generate required cooling power as well as supplied heating energy to the building because of the ice pad dominate the entire energy consumptions in the building. It subsequently causes big discrepancy between the real versus the official EP-values.