Estimation of air cooling requirement for the soebali 2.0 laboratory

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Abstract. To support the operational safety of Soebali 2.0 (Sophisticated electron beam accelerator launched by Indonesia version 2.0), laboratory room condition with clean and dust-free, low temperature and humidity was required, and also maintained its stability using Air Conditioner (AC). In this regard, it was conducted to estimate the calculation of air cooling loads as a reference in determining the technical specification of AC that will be installed in Soebali 2.0 laboratory. Estimation was conducted to determine the air cooling loads that arise related to the construction of the building and supporting equipment for Soebali 2.0, which generates heat as the air cooling loads. Based on the estimation result, the total cooling capacity of the air conditioning system was about 153.585 BTU/hours or 15 kW. It was used for cooling the Soebali 2.0 laboratory room with 900 m³ of volume along with the operational supporting equipment was about 20 °C and relative humidity was 50 %.

1. Introduction
One mission of The Center for Accelerator Science and Technology (CAST)-BATAN as an institution in Indonesia is developing accelerator technology. One type of accelerator that is being developed is Soebali 2.0 (Sophisticated electron beam accelerator launched by Indonesian version 2.0). Soebali 2.0 is a self-shielding electron beam machine operated in a building with 900 m³ of room air volume. It can be seen in Figure 1. Soebali 2.0 is a development of Soebali 1.0 which was established by the Ministry of Research and Technology in 2003. In the operation of Soebali 2.0, an air conditioning system (AC) is needed to support the operating safety system.

Figure 1. A schematic diagram of Soebali 2.0.
In general, an air conditioner was applied to regulate humidity, heating and cooling the air in the room. It also aims to provide comfort, so as to reduce fatigue, especially for workers who are in the room [1].

AC has been widely used for public facilities such as residences, offices, laboratories, etc. It can be proven by some references that electricity consumption for AC was 60-70 % of the total electricity consumption in Indonesia [2], and 25-30 % of the total world energy consumption was air conditioning and refrigeration [3]. Furthermore, energy consumption for heating, ventilation, and air conditioning (HVAC) systems was more than 60% of the total building energy consumption [4].

Several studies on estimating the need for air conditioners have been carried out for smart buildings [5], operating theaters [6], livestock vessels [7], seminar room [8] and laboratory [9]. Different from previous research, this study was to determine the cooling capacity of the AC equipment to be installed in Soebali 2.0 laboratory. In Soebali 2.0 laboratory, there is a high voltage generator with 250 kV of voltage in order air laboratory should be conditioned with 20 °C of temperature and 50 % of relative humidity. It was conducted to prevent the discharge of electrons at locations with a high-voltage electric field [10].

2. Basic theory

The need for air conditioning was estimated by determining the cooling load. The cooling load can be calculated by several methods based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) including cooling load temperature difference (CLTD), transfer function method (TFM), and radiant time series (RTS) [11]. Cooling load also can be determined by prediction methods such as multiple nonlinear regression (MNR) [4], K-means clustering method and k-nearest neighbor [12], artificial neural network [13], and others.

According to ASHRAE, the cooling load is classified into three categories [11]:

- The external cooling loads, comprising of: solar heat gain through fenestration areas \( (Q_{fes}) \), conduction heat gain through fenestration areas \( (Q_{fe}) \), conduction heat gain through roofs \( (Q_{rs}) \) and external walls \( (Q_{ws}) \), and conduction heat gain through interior partitions, ceilings and floors \( (Q_{ic}) \), etc.
- The internal cooling loads, comprising of: electric lighting (sensible load only); people (sensible heat and latent heat); and power equipment and appliances (either sensible or latent loads, and sometimes both).
- Load from infiltration and ventilation (both sensible and latent cooling loads).

The existence of solar radiation on the walls and roof of the building changes the condition of the Soebali 2.0 laboratory through the process of heat transfer by conduction or convection. It also increases the air temperature of the Soebali 2.0 room. The generated heat as a cooling load on an AC device can be calculated based on equation (1).

\[
Q_{RG} = U \cdot A \cdot \Delta T, \tag{1}
\]

with, \( Q_{RG} \) is cooling load due to solar radiation on building structures (Watts), \( U \) is heat absorption coefficient of the building structure (Watt/m²°C), \( A \) is the cross-sectional area of building the wall (m²), and \( \Delta T \) is the difference of temperature between the outside and indoor air (°C).

Air leakage of Soebali 2.0 building construction will add cooling load. It is determined by the rate of mass air flow due to leakage on the wall, as well as the difference of air temperature on the outside surface of the building against the air temperature in Soebali 2.0 laboratory It can be calculated by equation (2)[3]:

\[
Q = M \cdot C_p \cdot \Delta T, \tag{2}
\]
with, $M$ is air mass flow rate due to air leakage (kg/sec), $C_p$ is the specific heat of Soebali 2.0 temperature (kJ/kg°C), and $\Delta T$ is the difference of temperature between the outside and indoor air (°C).

When the electron beam passes through the scanning window of Soebali 2.0 (titanium foil with a thickness of 30 µm), it loses some of its energy and dissipates into heat as energy loss along the surface of the scanning window. In accordance with the energy loss when operating the electron accelerator, the generated heat of Soebali 2.0 can be calculated based on equation (3) [14]:

$$Q_{MBE} = E_L \cdot N_{EL}.$$  

(3)

with, $Q_{MBE}$ is the generated heat due to dissipation of the Soebali 2.0 scanning window (kW), $E_L$ is the dissipated energy of the scanning window (keV / electron particles), and $N_{EL}$ is the number of electron particles corresponds to the beam current (particles/sec).

Furthermore, when the electron beam comes out of the scanning window and hits the target, not all of the electron energy is absorbed on the surface but some of the energy will be dissipated into heat energy on the surface of the target. The dissipated heat energy of the target surface will be the cooling load of Soebali 2.0. It can be calculated by equation (4) [14]:

$$Q_T = E_T \cdot N_{EL} \cdot K.$$  

(4)

with, $Q_T$ is generated heat due to the heat dissipation of the surface of the target (kW), $E_T$ is net energy of electron beams that hit the surface of the target (keV), $N_{EL}$ is the number of electron particles corresponds to the beam current (particles/sec), and $K$ is the probability of electron energy is absorbed and transformed into heat.

In the air conditioning process of the Soebali 2.0 laboratory, there will be an enthalpy change caused by latent heat due to changes in water vapor content and sensible heat due to changes in temperature in the room. The produced enthalpy changes become cooling load and it can be determined using the Psychrometric chart as shown in Figure 2.

![Figure 2. Psychrometric chart.](image)

3. Methodology
This research was conducted in Soebali 2.0 laboratory, CAST-BATAN, Yogyakarta. In Soebali 2.0 operation, an air conditioner is needed to obtain ideal air condition according to requirements including temperature and relative humidity. It is used to prevent high voltage discharge especially at around high voltage generators. Required conditions are air condition with 1 atm of pressure, 20 °C of temperature and 50% of relative humidity.

Some equipment used to support this research such as anemometer, thermometer, hygrometer, anemometer, and infrared ruler.
The estimated air conditioner system refers to ASHRAE with a cooling load temperature difference CLTD method. CLTD method was chosen in this research due to simple in the calculation. There are no mathematical equations in this method. To estimate the need for Soebali 2.0 laboratory air conditioners, a calculation analysis should be conducted by determining the amount of cooling load available based on the construction of the building and supporting equipment for Soebali 2.0 operation. From the results of the field observation, several factors resulted in the cooling loads, include:

- Solar radiation on the walls, roofs and floors of the Soebali 2.0 building.
- Air leakage of Soebali 2.0 building construction.
- Heat dissipation of Soebali 2.0 units and target units
- Heat dissipation of equipment supporting the Soebali 2.0 operation.
- Changes of enthalpy in the air conditioning process for the Soebali 2.0 laboratory.
- Heat losses due to operating the dehumidifier.

4. Result and discussion

4.1. Cooling load due to solar radiation on the wall, roof, and floor of the building

Solar radiation on the walls, floor, and roof of the Soebali 2.0 laboratory increases the air temperature of the Soebali 2.0 laboratory through conduction and convection [8]. The generated heat is the AC cooling load. It was calculated by equation (1) and shown in table 1.

**Table 1.** Estimation of cooling load due to solar radiation on the walls, floor and roof of the Soebali 2.0 laboratory.

| Material       | Thickness (m) | Broad (m²) | Quantity | Heat absorption coefficient (W/m².°C) | Temperature difference (°C) | Cooling load (kW) |
|----------------|---------------|------------|----------|---------------------------------------|-----------------------------|-------------------|
| Eastern wall   | Concrete      | 0.25       | 90       | 1                                     | 1.470                       | 15                | 1.984             |
| Western wall   | Concrete      | 0.25       | 90       | 1                                     | 1.470                       | 15                | 1.984             |
| Northern wall  | Concrete      | 0.25       | 50       | 1                                     | 1.470                       | 15                | 1.105             |
| Southern wall  | Concrete      | 0.25       | 50       | 1                                     | 1.470                       | 10                | 0.588             |
| Roof           | Concrete      | 0.25       | 150      | 1                                     | 1.470                       | 15                | 3.308             |
| Floor          | Concrete      | 0.25       | 150      | 1                                     | 1.838                       | 8                 | 2.206             |
| **Total**      |               |            |          |                                       |                             |                   | **11.175**         |

4.2. Cooling load due to air leakage of the building construction

According to observation and measurement on the condition of the Soebali 2.0 laboratory, it can be estimated that the cross-section area of the leakage is about 1 m² and the velocity of the wind in the air leakage is 7.5 m/minute or 0.125 m/second. With this data, the flow rate of the air mass due to leakage is 0.147 kg/second. Furthermore, the difference of temperature between the outside with indoor is 15 °C. Based on equation (2), the produced cooling load due to air leakage can be determined 2.227 kW.

4.3. Cooling load due to operating the supporting equipment of Soebali 2.0

An estimation of the cooling load generated due to operating the supporting equipment of Soebali 2.0 [15]. This estimation is based on the type, power, and the number of unit loads, as shown in Table 2.

**Table 2.** Estimation of cooling load due to dissipated heat of the scanning window and target.
| Quantity (unit) | Energy (keV) | Current (A) | Power factor | Cooling load (kW) |
|----------------|-------------|-------------|--------------|------------------|
| The dissipated heat of Soebali 2.0 window | 1 | 21.51 | 0.02 | 1 | 0.430 |
| The dissipated heat of Soebali 2.0 target | 1 | 278.49 | 0.02 | 0.1 | 0.560 |
| Total | | | | | 0.990 |

4.4. Cooling load due to operating the supporting equipment

According to the results of the field survey an estimation of the cooling load that will arise due to the performance of the supporting equipment for Soebali 2.0 operations is based on the type, power, and number of unit loads, as shown in Table 3

| Table 3. Estimation of cooling load due to operating the supporting equipment. |
|---------------------------------------------------------|
| Quantity (unit) | Power (kW) | Heat generation factor | Cooling load (kW) |
|----------------|------------|------------------------|------------------|
| Lighting | 12 | 1 | 0.50 | 0.6 |
| Rotary pump motor | 1 | 0.746 | 0.20 | 0.149 |
| Turbomolecular pump motor | 1 | 1 | 0.20 | 0.2 |
| Anode transformer | 1 | 30 | 0.15 | 4.5 |
| RF transformer | 1 | 15 | 0.15 | 2.25 |
| Electron gun transformer | 1 | 1.25 | 0.20 | 0.25 |
| Triode filament | 1 | 1.5 | 0.20 | 0.30 |
| Voltage multiplier system | 1 | 6 | 0.15 | 0.90 |
| Total | | | | 9.149 |

4.5. Cooling load due to enthalpy change of air conditioning process

During the air conditioning process in the Soebali 2.0 room, enthalpy changes will occur due to the emergence of latent heat to reduce levels of water vapor in the air and sensible heat due to a decrease in air temperature. According to the conditions it has been determined that the air of the Soebali 2.0 laboratory will be conditioned at a temperature of 20 °C with a relative humidity of 50 % to support the safe operation of Soebali 2.0.

With a graphical approach using Psychrometric diagrams, it can be determined the enthalpy change of Soebali 2.0 room air in the conditioning process from 35 °C with 70 % of relative humidity, to a temperature condition of 20 °C with a relative humidity of 50 %.

- The enthalpy change due to the sensible heat \( (E_s) \) = 17.0 kJ/kg dry air
- The enthalpy change due to the sensible heat \( (E_L) \) = 61.5 kJ/kg dry air
- The total of enthalpy change \( (E) \) = 78.5 kJ/kg dry air

Based on preliminary data from the results of field observation, it has been determined that the air mass flow rate is based on the optimum air leakage area at the Soebali 2.0 laboratory is 1 m² and the outer air velocity of 0.125 m / sec is 0.147 kg / sec. The amount of cooling load due to enthalpy changes in the air conditioning process can be calculated \( Q_e = 11.539 \) kW

4.6. Cooling load due to operating the dehumidifier
To support the performance of air conditioning in the Soebali 2.0 laboratory. The dehumidifier will be installed to take water vapor into the room air so that the humidity level of the existing room air decreases to the desired extent.

Based on the technical and construction considerations of the Soebali 2.0 laboratory with a size (16 x 10 x 5) m and a total volume of 900 m$^3$, a dehumidifier with a compressor power of 7.5 kW and a steam capacity up to 16.5 liters / hour was chosen. It can produce a relative humidity of 50%.

Thus, it can be determined that the cooling load due to operating the dehumidifier to regulate and maintain the humidity of the Soebali 2.0 laboratory air is around 7.5 kW.

### 4.7. Total cooling load of Soebali 2.0 laboratory

Based on the calculation of the cooling load that arises it can be determined the total value of the cooling load that must be borne by the AC equipment in Soebali 2.0 laboratory room as shown in Table 4.

**Table 4.** Estimation of cooling load due to dissipated heat of the scanning window and target.

|                                    | Cooling load (kW) |
|------------------------------------|-------------------|
| Solar radiation on the walls, floor and roof of the Soebali 2.0 laboratory | 11.175            |
| Air leakage of building construction | 2.227             |
| Dissipated heat of scanning window and target | 0.990             |
| Operating the supporting equipment  | 9.149             |
| Enthalpy change of air conditioning process | 11.539            |
| Operating the Dehumidifier         | 7.5               |
| **Total**                          | **42.580**        |

According to the calculation results, it can be estimated that the total cooling load to cool the Soebali 2.0 space is 42.580 kW. Based on the performance of the compressor unit on AC devices, empirically has a COP (Coefficient of Performance) value between 2 to 4. Therefore, if a COP value of 3 is set, to support the cooling load of 42.580 kW in Soebali 2.0 room, an AC device with compressor power specifications around 15 PK is needed.

Referring to the results of the estimated total cooling load arising in Soebali 2.0 laboratory space and the AC technical specifications that are appropriate and easily available on the market, then to condition the Soebali 2.0 room air condition, an AC device with a cooling capacity of 45 kW or 153.585 BTU/hour is required.

The results of the estimated air conditioning requirements that have been made can be used as a reference in the process of planning and installation of Soebali 2.0 laboratory room air conditioning systems further, to support the safety system.

### 5. Conclusion

Based on the estimation results, an air conditioning device with a cooling capacity of 153.585 BTU/hour or 45 kW is required to cool the air of the Soebali 2.0 laboratory room with a volume of 900 m$^3$ along with the supporting operating equipment in it to achieve the Soebali 2.0 laboratory room temperature of 20 °C and 50% of relative humidity.
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