Ventilation Performance of Solar Chimneys

2. THE SIMULATION METHOD

Unsteady-state simulation of the buildings was carried out using an unsteady-state simulation model introduced in an earlier paper [1]. This model takes the environmental variables, chimney properties, and airflow pattern inside the chimney into account. Some adjustment was made to the model due to the different circumstances.

2.1 Solar heat flux

Solar radiation can be divided into two radiation components: direct and indirect radiation. The Enhanced AMEDAS weather database [2] contains data for both of these components.

Direct solar heat flux

As the solar chimney can be oriented both vertically and horizontally, the incident fraction of the solar radiation must be calculated. Necessary equations to calculate the incident heat flux of a plane that is oriented both vertically and horizontally at any place on earth are the following:

Latitude: \( \Lambda \); time angle: \( t \)

Declination: \( \delta = 23.45 \sin \left( \frac{360 \times 284 + n}{365} \right) \) where \( n \) is the number of days from 1\( ^{\text{st}} \) January [3].

Altitude: \( h = \arcsin \left[ \sin \Lambda \sin \delta + \cos \Lambda \cos \delta \cos t \right] \)

Azimuth: \( \alpha = \arccos \left[ \frac{\cos h}{\cos \delta} \right] \)

Equation for the incident fraction of solar radiation of an inclined and horizontally oriented surface (see on Figure 1):

If an inclined surface is considered with inclined angle \( \theta \) and azimuth \( A \), and the angle of incidence at the inclined surface is \( i \), then

\[ \cos i = \sin h \cos \theta + \cos h \sin \theta \cos (\alpha - A) \]

With this equation the fraction of the global direct solar heat flux of AMEADS data that is incident on the solar chimney can be calculated.

Indirect solar radiation

Indirect solar flux data of AMEDAS database is valid for horizontal surfaces that see the whole sky without obstruction. As this study does not deal with existing situations, a simple method was used to calculate indirect radiation: the actual value was calculated using the AMEDAS data: its value was reduced with the factor of \( Z = \theta/180^\circ \), where \( \theta \) is the inclined angle of the chimney.

3. SIMULATION SETUPS

3.1 Building types considered

As basic types, two simple buildings were considered. The air-conditioned building

This setup is a single room building with constant room temperature. Whatever the performance of the chimney is, the room temperature remains 25 degrees. The purpose of this setup is to show the interaction between the ambient temperature, the heat flux and the flow rate of the chimney. As the ventilation is caused by temperature difference, not only the chimney temperature increase but also the difference of the room and ambient temperature determines the resulting flow rate.

The well-ventilated building

This setup is a building that is very well ventilated and the room temperature is always equal to the ambient temperature. This setup resembles a thin-wall building with a lot of ventilation opening and shaded from solar radiation. The purpose of this setup is to show the relation between the solar heat flux and the flow rate when the temperature difference between ambient and room temperature is zero, thus there is no stack effect other than the one generated by the chimney.

Opening inlet area in both cases was considered to be much bigger than the chimney inlet area.

3.2 Geographical location and time

Simulation was carried out for the following two cities:

- Toyonaka city (Osaka Prefecture), 135°26.9' E; 34°46.4' N
- Sapporo city (Hokkaido) 141°19.9' E; 43°3.5' N

The calculation was made using the weather data of the year 1995 starting with the 1\( ^{\text{st}} \) of July. The calculation period was one week. Weather data resolution was 1 hour.

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3.3 Boundary conditions

There are several operating conditions applied for the simulation to enable a chimney performance that is similar to a real situation. These were:
1. In reverse flow condition the chimney is closed to prevent the flow: this is the case when the ambient temperature is warmer than room temperature and the chimney wall temperature cannot heat up the air in the chimney above the ambient.
2. Stack effect is enabled: the temperature difference between the ambient and the room temperature assists or hampers the chimney performance in the air-conditioned case.

3.4 Chimney properties

These variables are summarized in Figure 3.

4. RESULTS AND DISCUSSION

Results from the setups are summarized in the following graphs.

Figure 4. Results for Toyonaka city

Figure 5. Results for Sapporo city

Figure 6. Relation between ambient temperature and flow rate: air-conditioned case

Figure 7. Relation between ambient temperature and flow rate: well ventilated case

5. REFERENCES

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