SEOUL SYMPOSIUM ON UNDERGROUND SPACE AND CONSTRUCTION TECHNOLOGY/October, 1993/SEOUL/KOREA

Planning, design and construction of the cavern arena: Heating, Ventilation and Air Conditioning

HANS MARTIN MATHISEN, PH.D,
THE FOUNDATION FOR SCIENTIFIC AND INDUSTRIAL RESEARCH AT THE NORWEGIAN INSTITUTE OF TECHNOLOGY, APPLIED THERMODYNAMICS

D-W LEE, PH.D, HYUNDAI ENGINEERING AND CONSTRUCTION, SEOUL, KOREA

ABSTRACT

This paper deals with problems connected with heating and ventilation of underground premises for public use. Some properties of rock and special problems connected with designing ventilation systems for underground spaces are first briefly discussed. The rest of the paper deals with design of ventilation and heating systems. The conclusion is that there are no large problems with heating and ventilation of underground premises, but there are still problems connected with for instance thermal properties of rock when water flows in the cracks. An optimum design demands better knowledge of these properties.

1. INTRODUCTION

In connection with the Winter Olympic Games 1994 in Norway it was decided to build an ice-hockey rink at Gjøvik inside a mountain in the centre of the city. After the Olympic games the premises will serve several purposes, like sports arena, concert hall and as exhibition hall.

Usually large enclosures have high energy consumption, but there is a hypothesis that underground spaces have a lower use of energy than other buildings. Many places in the world it is a quite high interest for using underground space, and the premises at Gjøvik could serve as a demonstration of Norwegian technology in this field. Therefore, it was decided to connect a research programme to the design, construction and operation of the premises, including the hypothesis fo lower energy use.

The HVAC plant in underground facilities is not much different from what is used in conventional buildings, but during the design some problems must be addressed, like the properties of rock, humidity and smoke distribution in case of a fire. This paper draws the attention to some problems of general interest, but the solutions are not discussed in detail.

2. DESIGN CRITERIA

Compared to ordinary insulation materials the thermodynamic properties of rock including much higher heat accumulation capacity, heat transfer capacity and density. However, since the walls are "infinitely" thick, the insulation theoretically becomes very good. If the premises have a constant air temperature about 10 K above the deep rock temperature, a temperature gradient of 0,1 K/m is reached at a depth of size 50m. In the deeper part, the temperature change becomes very slow, the time constant is some hundred days. However, this applies only when the rock is dry. If it is circulation or flows of water inside the rock this picture could be heavily disturbed.

Short period changes in the room temperature, for instance from day to night, will only cause changes in the rock temperature in a thin layer. Using the thermal properties for rock, the active thickness can be estimated to be about 15 cm, (Rømen 1993). If the rock is covered by for instance a suspended ceiling and/or insulation of any kind, this thickness of course changes. In the calculation of necessary heat to change the room air temperature from one day to another, these data are important.

Compared to conventional buildings changes in the outdoor climate do not have influence on the transmission heat loss, but the heating of the ventilation air is of cause influenced.

The rock is completely airtight compared to the shell of most other building types. The only infiltration of air could be through doors in the tunnels leading into the cavern, which means that the leakage airflow rate is a fraction of the air leakage in other buildings.

It must be taken special care for radon and humidity, elsewhere the necessary ventilation airflow rate due to air quality should be calculated as for any other building, (Grande 1993).

A suspended watertight ceiling is often used to avoid humidity to be released to the room air, see figure 1. Along the walls, water that flows along on top of the ceiling is drained away. The walls are often covered with shotcrete. Nevertheless, some humidity often seems to diffuse through the joint between the shotcrete and the suspended ceiling. The result is often growth of fungi as a band along the corner between wall and ceiling. These fungi release spores that for sensitive people could cause allergenic reactions and could also damage the shotcrete.

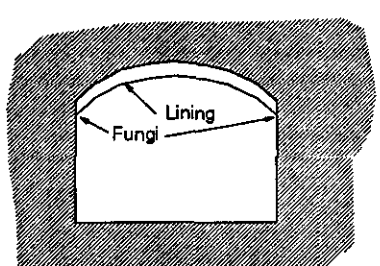

Fig. 1. In the joint between the sidewalls and the rock water diffusion can cause growth of fungi

When water diffuses through the surface heat from the room air is used to evaporate the water if the surface temperature is below the dew point temperature of the room air. This means that the room air is cooled and energy must be supplied to avoid the room air temperature to decrease. Since water flows exist in most types of rock, the resistance to water diffusion of shotcrete or interior ceilings/walls are crucial for calculating the energy consumption.

If water diffusion could not be avoided with absolute certainty, a minimum ventilation airflow rate should always be present to avoid damages due to humidity, like increased growth of fungi.

A way of redusing the diffusion of water and radon is to keep low pressure between the suspended ceiling/inner walls and the rock. This could be arranged by taking some of the ventilation exhaust air from this area.

In ventilation shafts and tunnels without a watertight lining, water will penetrate to the surface. In the winter time, when air below freezing point flows in, ice will build up. To avoid the last problem the air should be preheated before it enters the tunnels or shafts. Shafts and tunnels should also be supplied with a drainage system for water, see figure 2.

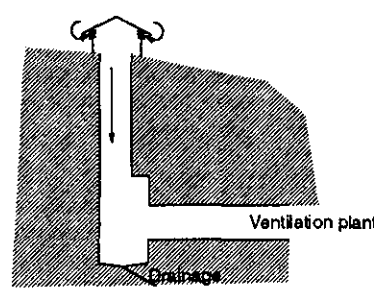

Fig. 2. There should be a drainage for water leaking into the borehole.

Another feature of underground facilities is that artificial lightning must always be used. This will also have some impact for the energy consumption used for climatizating the premises.

In case of a fire the ventilation system must act in a way so that smoke does not entrain into emergency routes.

2.1 Design of the ventilation plant

Outdoor air inlet: Care must be taken to avoid smoke to recirculate from exhaust air to the outdoor air inle in case of a fire. This is important since the smoke control system relies on the mechanical ventilation system.

Often the fresh air inlet is placed on top of a shaft with a construction on the top to avoid rain and snow to enter the shaft. This should not be placed to close to the ground to avoid dust and contaminants (microorganisms) to be drawn in with the fresh air, see figure 2.

Heat recovery: To save energy the system should include a heat recovery system for the ventilation air. There are several systems that could be used, but if the ventilation system is used also for smoke control, a system which excludes any kind of leakage from the exhaust air to the fresh air should be avoided. In regenerative systems like the rotary wheel shown in figure 3 there is a possibility for leakage, depending on the pressure conditions. Instead systems like the "run around" system shown in figure 4 should be used.

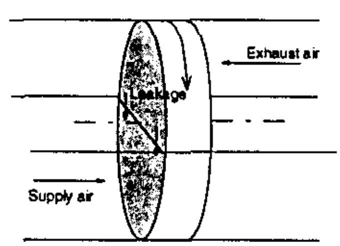

Fig. 3. Rotary heat exchanger

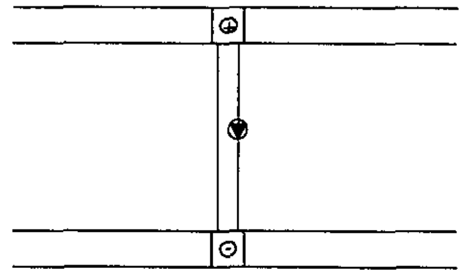

Fig. 4. Recuperative heat recovery system, "run around"

Filter: Often a filter is used in the exhaust duct to protect the components in the exhaust system, like the heat exchanger in the heat recovery system. In a fire, if the ventilation exhaust system is used for smoke control, a huge amount of smoke particles will be brought with the exhaust air. These particles will in a short time completely tighten the filter. Because of that the filter should be fitted with a bypass system that operates together with the rest of the smoke control system.

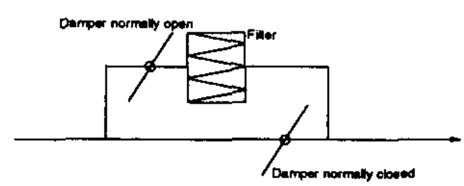

Fig. 5. Bypass around exhaust air filter

Heating coils: The heating coils should be sized to be able to change the room air temperature from one day to another. In the design all thermal properties and dimensions of the premises must be considered.

Reliability: Since there is no possibility to ventilate through windows or trapdoors one usually has to rely on mechanical ventilation, specially in case of a fire. This means that there should be a backup system in case of a malfunction of important components like for instance the exhaust fan.

Air distribution in large enclosures: In underground space for public use the ventilation has a more important role in smoke control than in most other buildings, as windows and trapdoors cannot be used for smoke control. In case of a fire the detection should be fast, and the system must give the public the possibility to evacuate before the room is filled with smoke.

Complete mixing ventilation systems are designed to dilute contaminants and eventual smoke down to acceptable concentration, see figure 6. This means that the concentration in the room will be almost uniform. The air is supplied with a high velocity outside the occupied zone, and this volume is used to smooth out temperature and velocity gradients to avoid draft in the occupied zone.

The time constant of the room becomes:

$$\tau = \frac{V}{\dot{V}}$$

where V is the room volume and $\dot{V}$ is the ventilation airflow rate.

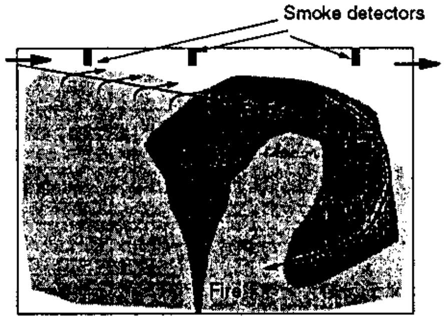

Fig. 6. Complete mixing

In the displacement ventilation system, see figure 7, the air supply is placed in the lower part of the room, and the exhaust is placed close to the ceiling. The supply air has a temperature moderately lower that the room air temperature. Heat released in the lower part of the room will cause convective plumes flowing upwards. Contaminants released from people, or smoke from a fire, will be transported towards the ceiling. Ambient air is entrained into the convective flows, at a certain level the entrained air equals the supply airflow rate. Above that level it develops a recirculation zone with contaminated air. In the lower part of the room a fresh air zone will be formed, (Mathisen 1989).

Because the air is supplied directly to the occupied zone, the air velocity must be low to avoid draft, and large supply areas and airflow rates must be used if much cooling is needed.

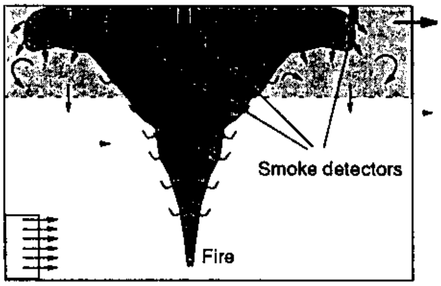

Fig. 7. Displacement ventilation

The time constant of the room becomes:

$$\tau < \frac{V}{\dot{V}}$$

because of the two zone flow patterns. This means that the displacement ventilation gives faster detection of the smoke than complete meixing in case of a fire. It also gives lower smoke concentration in the occupied zone.

At Gjøvik the supply of air is placed in the entrance hall and at the top of the sitting platform, as shown in figure 8. The air is blown into the entrance hall through ducts and low air velocity inlets.

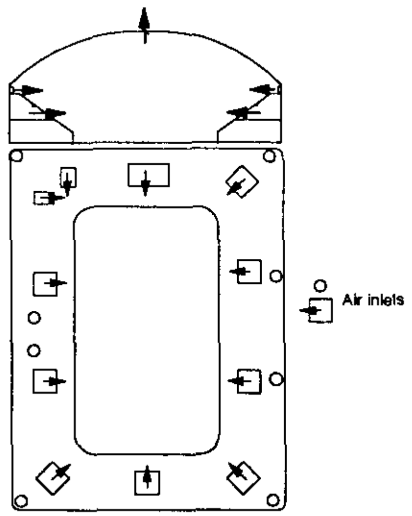

Fig. 8. Gjøvik Olympic Mountain Hall, air inlet and outlet in principle. Section and plan view.

This is a simple solution, which probably will give satisfactory thermal comfort for ice-hockey viewers, but for arrangements where people expect to wear lighter clothing probably local high air velocities could cause draft.

Smoke ventilation: In smoke ventilation all ports and doors in main entrance and the emergency tunnels should automatically open and the supply air fans stop. This means that outdoor air is drawn through the tunnels and into the entrance hall and further into the main hall. The exhaust fan has to work until all people are evacuated.

A system with automatic opening of all doors is quite complex and expensive if there are many doors. Alternatively systems with grilles and eventually dampers could be used, but the flow resistance should not be too high. A high pressure drop would make it difficult to open doors and the airflow rate would decrease.

Another problem is that the air that flows into the premises should be evenly distributed between different inlet openings and doors, and the velocity should not be so high that smoke is forced back into the occupied zone.

Recirculation of air: Recirculation of air is often used to reduce the energy consumption in periods when only heating is needed and the ventilation system is used for heating. However, this system also implies a risk of recirculation of smoke in case of a fire if the dampers and fans should not operate properly. Also, due to air quality recirculation should be avoided.

Heating systems: Using displacement ventilation preferably the heating system should be separated from the ventilation system. Warm air supplied with low velocity will flow towards the ceiling and short circuit with the exhaust. In large rooms the best system is probably radiant heating. To avoid moisture in the entrance tunnels these should also be heated.

3. ENERGY CONSUMPTION

Heating of buildings is connected with transmission, infiltration and ventilation heat losses. In rock premises the ventilation heat loss should be like in any other building while the infiltration heat loss should be lower than in other buildings. If the walls consist of dry rock the transmission heat loss should be low. However, if water moistens the inner surfaces, heat will be used to evaporate this water. Additionally, water flows inside the rock that does not flow into the room could also take up heat. Since these water flows are difficult to predict, all premises should be designed with diffusion tight suspened ceiling, inner walls and insulation. It does not exist much data for heat conduction in wet rock. The energy consumption should be calculated by appropriate tools taking relevant thermal properties and sizes into consideration.

4. EVALUATION OF DESIGN TOOLS

To calculate the energy consumption and sizing of heating components design tools will be developed during the research programme. Measurements at Gjøvik Olympic Mountain Hall will be used to verify the tools. These measurements started the summer 1993 and will last for one year. Some data are continously collected while other data will be collected during shorter measurement periods when the premises are fully occupied.

5. REFERENCES

1. Mathisen, H.M.: "Analysis and Evaluation of Displacement Ventilation", Dissertation, University of Trondheim, NTH, 1989.

2. Mathisen, H.M., Meland, Ø., Frydenlund, F.: "Design of Smoke Control in Large Rock Underground Premises", International Symposium on Room Air Convection and Ventilation Effectiveness, Tokyo, 1992.

3. Grande, L.B.: "Guidelines for ventilation requirements. Air Quality and Thermal Environment", SINTEF Report STF15 F93027, Trondheim, 1993.

4. Rømen, B.H.: "FRES-Version 2.0, Flexible Room Climate and Energy Simulator, Users manual", SINTEF Report STF15 A93071, Trondheim, 1993.