**DESIGN OF INNOVATIVE AND AUTOMATED RESPIRATORY BUILDINGS FOR PATIENTS AND HEALTH WORKERS AGAINST CORONA CIRUS DISEASE OUTBREAK**

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**ABSTRACT**

The coronavirus is a pandemic that is causing worldwide panic and unrest. This documentation is to review mean by which design of innovative and automated respiratory buildings can help to combat the disease.

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**CHAPTER 1: INTRODUCTION**

**1.1 COVID-19**

*coronavirus fig 1.1*

Coronavirus disease (COVID-19) is an infectious disease caused by a new virus.

The disease causes respiratory illness (like the flu) with symptoms such as a cough, fever, and in more severe cases, difficulty breathing. You can protect yourself by washing your hands frequently, avoiding touching your face, and avoiding close contact (1 meter or 3 feet) with people who are unwell.

**1.2 HOW IT SPREADS**

Coronavirus disease spreads primarily through contact with an infected person when they cough or sneeze. It also spreads when a person touches a surface or object that has the virus on it, then touches their eyes, nose, or mouth. This is why a worldwide curfew has been stated to isolate the virus so it dies out.

**1.3 VENTILATION**

Ventilation moves outdoor air into a building or a room, and distributes the air within the building or room. The general purpose of ventilation in buildings is to provide healthy air for breathing by both diluting the pollutants originating in the building and removing the pollutants from it.

**1.3.1 WHAT IS NATURAL VENTILATION?**

Natural forces (e.g. winds and thermal buoyancy force due to indoor and outdoor air density differences) drive outdoor air through purpose-built, building envelope openings. Purpose-built openings include windows, doors, solar chimneys, wind towers and trickle ventilators. This natural ventilation of buildings depends on climate, building design and human behavior.

**1.3.2 WHAT IS MECHANICAL VENTILATION?**

Mechanical fans drive mechanical ventilation. Fans can either be installed directly in windows or walls, or installed in air ducts for supplying air into, or exhausting air from, a room.

 The type of mechanical ventilation used depends on climate. For example, in warm and humid climates, infiltration may need to be minimized or prevented to reduce interstitial condensation (which occurs when warm, moist air from inside a building penetrates a wall, roof or floor and meets a cold surface). In these cases, a positive pressure mechanical ventilation system is often used. Conversely, in cold climates, exfiltration needs to be prevented to reduce interstitial condensation, and negative pressure ventilation is used. For a room with locally generated pollutants, such as a bathroom, toilet or kitchen, the negative pressure system is often used.

The understanding of natural and mechanical ventilation is crucial for a civil engineers’ job in the designing of functional respiratory buildings. The decision whether to use mechanical or natural ventilation for infection control should be based on needs, the availability of the resources and the cost of the system to provide the best control to counteract the risks.

**1.4 THE ASSOCIATION BETWEEN VENTILATION AND INFECTION**

There is little evidence that ventilation directly reduces the risk of disease transmission, but many studies suggest that insufficient ventilation increases disease transmission. A number of studies have looked at the possible transmission routes of diseases, but few have looked at the direct impact of ventilation on disease transmission.

**CHAPTER** **2: UNDERSTANDING OF NATURAL VENTILATION**

**2.1 THE DRIVING FORCES OF NATURAL VENTILATION**

 Three forces can move the air inside buildings:

* wind pressure
* stack pressure (buoyancy)
* mechanical force.

The first two forces are explained in the following sections. Natural forces drive natural ventilation, while mechanical fans drive mechanical ventilation. Mechanical force can be combined with natural forces in a hybrid, or mixed-mode, ventilation system.

**2.1.1 WIND PRESSURE**

 When wind strikes a building, it induces a positive pressure on the windward face and negative pressure on the leeward face. This drives the air to flow through windward openings into the building to the low-pressure openings at the leeward face (see Figure 2.1). It is possible to estimate the wind pressures for simple buildings.

*Wind direction Figure 2.1*

 *Wind-induced flow directions in a building*

For single-sided ventilation with the rooms otherwise hermetically sealed, there is no contribution from mean wind pressures, only from the fluctuating components (see Figure 2.1). Etheridge & Sandberg (1996) covered the topic of unsteady pressures in some detail. This is a common design; however, over time, there becomes significant leakage around doors and other room penetrations. It must be remembered that just because a window is open, sufficient air changes per hour (ACH) may not necessarily be achieved.

**2.1.2 STACK (OR BUOYANCY) PRESSURE**

 Stack (or buoyancy) pressure is generated from the air temperature or humidity difference (sometimes defined as density difference) between indoor and outdoor air. This difference generates an imbalance in the pressure gradients of the interior and exterior air columns, causing a vertical pressure difference.

When the room air is warmer than the outside air, the room air is less dense and rises. Air enters the building through lower openings and escapes from upper openings.

The flow direction reverses, to a lesser degree, when the room air is colder than the outside air; the room air is denser than the outside air. Air enters the building through the upper openings and escapes through the lower openings.

Stack (or buoyancy) driven flows in a building are driven by indoor and outdoor temperatures. The ventilation rate through a stack is a function of the pressure differential between the two openings of that stack.

Pressure differential can be calculated as follows:

Δ *Ps = (ρo- ρi)gH = ρo gH*$ =\frac{Ti-To}{To}$

where:

*Ps = stack (or buoyancy) pressure (Pa)*

*ρo = density of outdoor air (kg/m3)*

*ρi = density of indoor air (kg/m3)*

*g = gravity acceleration (9.8 m/s2)*

*H = height between two openings (m)*

*Ti = indoor air temperature (oK)*

*To = outdoor air temperature (oK).*

**CHAPTER 3: DESIGN AND OPERATION**

**3.1 NATURAL VENTILATION SYSTEMS**

As previously defined, natural ventilation is the use of natural forces to introduce and distribute outdoor air into or out of a building. These natural forces can be wind pressures or pressure generated by the density difference between indoor and outdoor air. There are four design methods available for natural ventilation systems:

* *cross flow* (no corridor) — the simplest natural ventilation system with no obstacles on either side of the prevailing wind (i.e. windows of similar size and geometry open on opposite sides of the building);
* *wind tower* (wind catcher/wind extractor) — the positive-pressure side of the wind tower acts as a wind catcher and the negative-pressure side of the wind tower acts as a wind extractor;
* *stack* (or buoyancy), simple flue — a vertical stack from each room, without any interconnections goes through the roof; this allows for air movement based on density gradients; and
* *stack* (or buoyancy), solar atrium — a large stack that heats due to solar radiant loading, which induces air movement due to density (temperature) differentials; without radiant loading, the atrium provides minimal ventilation.

**3.2 HYBRID (MIXED-MODE) VENTILATION SYSTEMS**

As previously defined, hybrid (mixed-mode) ventilation relies on natural driving forces to provide the desired (design) flow rate. It uses mechanical ventilation when the flow rate is lower than that required to produce natural ventilation. 34 Natural Ventilation for Infection Control in Health-Care Settings.

 Three design methods are available for hybrid ventilation systems.

* *Fan-assisted stack* — when there is insufficient solar radiant loading on the stack (i.e. evenings and inclement days) the ventilation rate is supplemented by extraction fans. Inlet air is heated and cooled to maintain comfort for building occupants.
* *Top-down ventilation* (fan-assisted stack plus a wind tower) — when there is insufficient solar radiant loading on the stack (i.e. evenings and inclement days) the exhaust ventilation rate is supplemented by extraction fans while the supply ventilation rate is supplemented by the wind tower (wind scoop). Inlet air is heated and cooled to maintain comfort for building occupants.
* *Buried pipes —* when land is available, ventilation pipes (ducts) can be buried. If air remains underground for long enough, the air will approach the steady-state underground temperature (i.e. warming or cooling the outside air). This system is not ideal for high ventilation rates.

Figure 3.1 illustrates the different systems of natural and hybrid ventilation.



*Figure 3.1 Different natural ventilation and hybrid ventilation systems*

**3.3 BASIC DESIGN CONCEPTS FOR NATURAL VENTILATION**

Developing the design concept for a naturally ventilated building that incorporates infection control involves three basic steps:

* Specify the desired airflow pattern from the inlet openings to the outlet openings.
* Identify the main available driving forces that allow the desired airflow pattern to be achieved.
* Size and locate the openings so that the required ventilation rates can be delivered under all operating regimes.

 A general procedure for natural ventilation starts from the architectural design, system layout and component selection, vent sizing and design-control strategy. The procedure is concluded by detailed design drawing.

 Converting an existing building or designing a new building to use natural ventilation for controlling airborne infection would, ideally, include the presence of single-bedded isolation rooms with operable windows and ensuite toilets. However, in resource-poor contexts, the number of such isolation rooms may need to be limited, with additional cohort isolation being provided, when necessary, by contingency facilities (e.g. outdoor isolation tents open to the wind).

There is a need to develop effective and appropriate engineering technologies and innovative architectural features to maximize the use of natural ventilation for different climatic conditions worldwide.

Unlike other types of buildings, when the prevailing wind direction and average velocity may be used, the design of natural ventilation for infection control should consider the worst situation — that is, when the wind is absent, and where supplementary mechanical ventilation may be needed.

**3.4 CLIMATIC AND OTHER CONSIDERATIONS IN VENTILATION DESIGN**

A number of factors need to be considered when designing a building to effectively use natural ventilation for infection control.

High air-change rates are needed when infection control is the main building design objective. The impacts of the high air-change rates on the overall indoor environmental conditions should be considered; these include thermal comfort, indoor air quality and fire safety. Other likely unfavorable ambient environmental factors such as noise and air pollution, and their impacts on indoor environmental quality have to be assessed before building design starts. In cold climates, the need for warmth inside the building can be at odds with the high air-change rate needed for infection control. In transient seasons of hot and humid climates, moisture condensation in the ward interior can lead to wet beddings and floors, rainy ceilings, and mold and mildew growth — resulting in unpleasant and unhealthy conditions. However, large openings in the building envelope make it easier for insects, wild animals and other unwanted intruders, and may also cause problems relating to security and vector-borne infectious disease control.

**3.4.1 MAINTAINING THERMAL COMFORT**

In temperate and warm climates and under good ambient air quality conditions, a higher ventilation rate is good for both thermal comfort and indoor air quality. However, this is not true for cold climates where outdoor air infiltration should be minimized for thermal comfort. When the ambient air temperature stays above 30 °C, the thermal conditions in a naturally ventilated ward may become intolerable. Therefore, in a naturally ventilated building, more effort needs to be spent on the architectural and envelope design to achieve acceptable indoor thermal comfort than for a building with mechanical ventilation. This includes the selection of windows, proper external shading, envelope insulation and the properties of external surface materials with regard to solar absorption and thermal radiation. A design engineer must also understand that a final design is a compromise between the conflicting requirements in hot summer and cold winter conditions. Thermal performance simulation tools are available to help quantitatively assess and compare the effectiveness of different design options. A more detailed explanation of the technology options and simulation techniques are provided in ASHRAE (2009).

 **3.4.2 CONSIDERATIONS FOR HOT SUMMERS**

**Architectural design features**

When the land area allows, active use of ground-to-sky radiation will greatly reduce the effective radiant temperature. Semi-open architectural design is preferred, and should allow direct long-wave radiation from ground to sky to occur. The semi-opening should be on the shade side of a building to avoid direct solar irradiation — this is how a sunshade works (see Figure 3.2).

Solar heat gain should be minimized by using proper external shading or the more sophisticated glazing systems. The buoyancy effects of the solar heat on airflow can be used to lead the warm air to the higher levels of the building. Fortunately, this is in line with the desired airflow patterns for infection control.



*Figure 3.2-semi-open design allowing ground-to-sky thermal radiation can greatly improve the thermal comfort in hot summer*

**3.4.3 CONSIDERATIONS FOR WINTER**

In cold winter conditions, a high air-change rate is not desirable for thermal comfort, particularly as windows may be closed to keep the building warm. Even if normal heating is introduced, with a high air-change rate the effects might be insignificant, and energy efficiency will be low. Therefore, heating strategies must be planned carefully. Building envelope design should be able to capture the solar heat and minimize conduction loss through the wall. Proper insulation of walls and the use of double glazing are desirable. For extremely cold climates, a rigorous assessment using simulation techniques should be undertaken, so that the degree of coldness can be quantified. This can be used to determine whether the natural ventilation strategy could be adopted for the climate being considered.

When considering active heating strategies, targeted radiant or direct near-body heating methods are more effective, and are preferred for two reasons. First, due to buoyancy effects, the warm air from the common convective radiators tends to float to the upper part of a space. Second, at a high air-change rate, the heat loss is tremendous. Modern, electric radiant heaters are readily available, and are a better option than other commonly used electric radiators.

Electrically heated mattresses are also available and typically use about 50–100 watts. They are effective for in-bed patients, and may allow patients to tolerate much lower in-ward air temperatures associated with the high air-change rate. They also help to avoid the excessive energy consumption associated with the ordinary space-heating methods.

**3.4.4 MAINTAINING HEALTHY INDOOR AIR QUALITY**

With a higher air-change rate, the indoor air quality is more linked to the ambient air quality. The benefit is that the indoor air quality is less likely to be affected by the presence of common indoor pollutant sources, such as the off-gassing from common building materials.

**3.4.5 MANAGING AMBIENT AIR POLLUTION**

With the high air-change rate of untreated outdoor air, indoor air quality will be more affected by the ambient air pollution (Weschler & Shields, 2000; Ghiaus et al., 2005). In regions with severe ambient air pollution problems, the location of an infectious disease hospital should be chosen carefully. A hybrid (mixed-mode) ventilation design may be the only option. Solely relying on ordinary window openings will expose the occupants to a high ambient pollutants level.

**3.4.6 EXTERNAL NOISE**

As pointed out in CIBSE (2005), the presence of significant noise sources is one of the main barriers to using natural ventilation. However, this guideline recommends two solutions: one is to place the ventilation inlets on the sides of the building away from the principal noise sources; the other is to integrate acoustic baffles into the ventilation opening. However, this second solution will reduce the air-change rate, and is therefore best combined with hybrid (mixed-mode) ventilation where a mechanical fan can avoid the increased pressure loss over such a vent.

**3.4.7 SELECTING LOW-EMISSION INTERIOR MATERIALS**

A comprehensive understanding of air pollutant emissions from interior building materials has developed over the years (Levin, 1989; Li & Niu, 2007). Designers and contractors should be aware of the standards and regulations on building materials for indoor use. In particular, materials that can potentially release airborne respiratory-tract irritants should be avoided.

**3.4.8 HUMIDITY AND MOULD GROWTH**

Condensation can occur on ceilings, walls, floors and beddings for many reasons. For example, in buildings with a heavy structure and that use natural ventilation, a sudden change of weather with warm, moist ambient air may induce condensation when the surface temperature is lower than the dew-point temperature of the moist incoming air (Niu, 2001). While the conditions are a discomfort and annoyance during the condensation period, mold may also grow — which is a health hazard.

 When designing buildings with natural ventilation for a hot and humid climate, lightweight and insulated walls should be used. The surface temperature of a lightweight construction or a wall with internal insulation will respond rapidly to changes in air temperature, limiting the rise of surface and internal relative humidity when the sudden warm and humid air comes in contact with the wall (e.g. in the transient spring season).

 For existing buildings with massive concrete or masonry walls, several retrofitting, operation and maintenance strategies may be needed if a natural ventilation strategy is to be adopted. The first option would involve the interior surface treatment, which can either be long term or short term.

 **3.4.9** **SECURITY AND VECTOR-BORNE DISEASE SPREAD**

 Large openings in natural ventilation without any protection increase the risk of security breaches and the spread of vector-borne diseases. Purpose-designed barred windows and semi-transparent mosquito meshes can be used in these situations.

**3.4.10 HIGH-RISE CONSIDERATIONS**

Locating respiratory wards on the top floors may be desirable for high-rise buildings to minimize the possible re-entry of the exhausts into adjacent floors. This re-entry is caused by buoyancy as the exhaust air is normally warm and tends to flow upwards after leaving the wards (Wehrle et al., 1970).

**3.4.11 FIRE SAFETY CONSIDERATIONS**

Designing a building with openings connecting rooms may conflict with fire-safety and smoke-control requirements. Naturally ventilated buildings may also be zoned to be in line with the compartmentalization requirements for smoke control. Ventilation openings may also be shut during a fire. The fire escape route also needs special attention, because natural ventilation design also has an impact on smoke flow pattern.

**4.0 CONCLUSION**

Designing a naturally ventilated building for infection control follows three basic steps: selecting the desired airflow pattern, identifying the main driving forces, and sizing and locating openings. Although these steps are common to designing all such buildings, local conditions, such as the year-round climate and the impact this has on infection control, must also be taken into account. At a more specific level, the main design elements of natural and hybrid (mixed-mode) ventilation systems are dictated by the specific components used. Aspects of different ventilation systems can be selected and combined as needed to suit the local climate and the requirements of each individual hospital.

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