Guideline for Infection Control

Natural Ventilation Use

By Yuguo Li, Ph.D., Fellow ASHRAE

The World Health Organization's first infection control guideline to consider natural ventilation as a potentially effective measure to manage infections from a serious respiratory disease in health-care settings was published in 2007.[1] Subsequently, WHO published "Natural Ventilation for Infection Control in Health-Care Settings,"[2] which describes the basic principles of how to design, construct, operate and maintain an effective natural ventilation system.

The most beneficial feature of natural ventilation is its potential for achieving a high ventilation rate with minimum cost. Lack of ventilation or low ventilation rates are known to be associated with an increase of infection rates or disease outbreak for either airborne transmission or opportunistic airborne transmission. High ventilation rates, therefore, should lead to a measureable decrease of infection rates.

However, the least beneficial feature is the possibility of spreading disease because of the difficulty controlling airflow direction. Airflow direction plays dual roles in disease transmission when airborne or opportunistic airborne routes exist. The airflow from the "dirty source" space to the "clean" (without source) space can transmit infection if either the dirty space or the clean space is not properly ventilated. Existing guidelines for mechanically ventilated isolation rooms require that a minimum negative pressure be maintained to ensure a consistent airflow direction.

Airflow can protect the upstream locations from downstream "dirty source" locations. In principle, the airflow from a contaminated source location (such as a room or a ward) can lead to infection farther away from the source. The rate of infection (attack) reduces as the physical distance from the source increases. One of the essential conditions for airflow-induced infection occurring is that the airborne pathogen concentration in the source location must be sufficiently high, usually due to either high source strength or a low ventilation rate.

An argument for the use of natural ventilation is based on the fact that the airflow from a contaminated source location with *sufficiently high dilution* should not lead to further infection. However, information is not yet available on the exact amount of *minimum dilution* that is needed. Absolute values may require substantial further research focused on specific organisms and diseases and, likely, specific climates, infectious doses, activities, and patient health status.

How Much Natural Ventilation?

There are at least three major difficulties in determining the required natural ventilation flow rates.

1. There is insufficient data to recommend a minimum ventilation flow rate for infection control in isolation rooms (this is also the case for mechanical ventilation).

2. Natural ventilation flow rates always fluctuate due to fluctuating driving forces and opening sizes.

3. Ultimately, ventilation can only reduce risks; the precise amount is always subject to assumptions about the acceptability of an anticipated level of risk.

Although higher ventilation rates can more rapidly dilute contaminated air inside a space and are expected to decrease the risk of cross infection, at a certain level the benefit of additional ventilation may be expected to be marginal. This upper ventilation rate level for airborne infection control is, however, not known at this time. The choice of the minimal and maximal ventilation flow rates may be also influenced by the needs of reducing energy consumption.

Most existing infection control guidelines for isolation rooms used two rationales[2] to justify the specification of ventilation requirements:

- The effect of air change rate on decay of droplet nuclei concentration, which favors the use of air changes per hour (ACH); and
- Mathematical modeling of risk using the Wells–Riley equation to estimate the effect of ventilation rate on infection risk for known airborne diseases, which favors the use of L/s (cfm) per patient.

Whichever is used, there is an implicit assumption about the infectious dose, which is unknown. Ventilation is of limited effectiveness in protecting against the so-called short-range airborne transmission of diseases.[3]

When ACH is used, the volume of the enclosed room is also important. A ward with a larger volume will obviously require a larger volumetric airflow rate (m^3/s [ft^3/s]) than one with a smaller volume for the same ACH.

Existing guidelines for mechanical isolation rooms contain a provision of the minimum ventilation rate of 12 ach. If natural

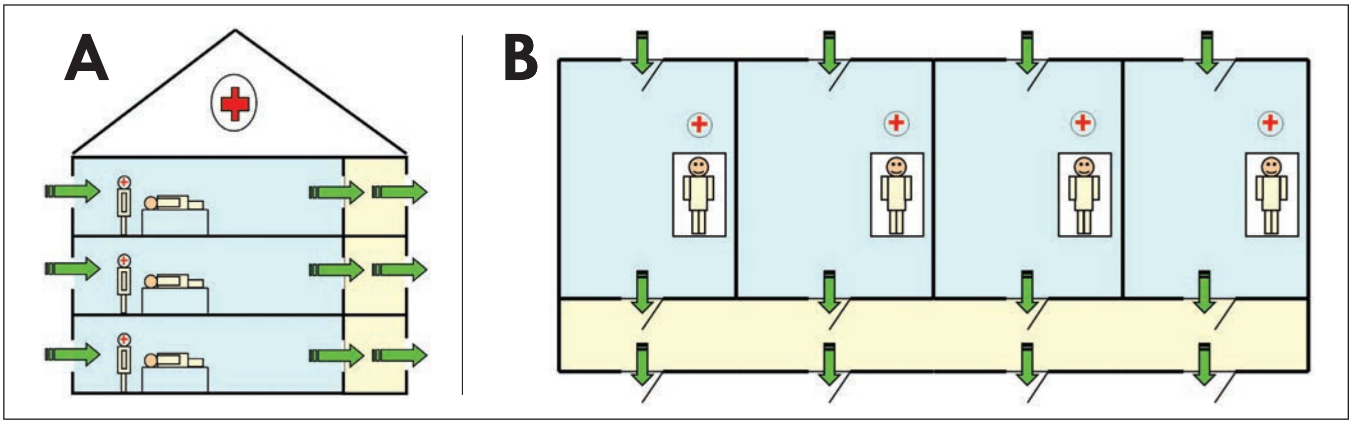

Figure 1: Wind-driven natural ventilation in the single corridor type hospital with wind entering the ward first. A) Section plan; B) floor plan.[2]

ventilation is used for infection control, the minimum ventilation should be much higher than the existing requirement for mechanical ventilation to significantly reduce the infection risk, as the airflow direction may not be fully controlled.

Although the airflow direction cannot be fully controlled, the strong dilution effect allows the diluted contaminated air being emitted to present a reduced risk. Still, the choice of airborne precaution areas and placement of patients within the areas need to be carefully planned and designedto further reduce the risk of infection for people in the surrounding areas.

The panel of WHO[2] suggests that the minimum ventilation rate is to be set as 24 ach for airborne precaution rooms when natural ventilation is used, doubling the ventilation requirement relative to mechanical airborne negative pressure isolation rooms. When natural ventilation alone cannot satisfy the recommended ventilation requirements, mechanical or mechanically assisted natural ventilation modes should be activated. 12 ach is equivalent to 80 L/s (170 cfm) for an isolation room of 4 m × 2 m × 3 m (13 ft × 7 ft × 10 ft).

This estimate has been the basis of WHO[2] specifying for natural ventilation a minimum hourly averaged ventilation rate of 160 L/s (339 cfm) per patient for airborne precaution rooms (with a minimum of 80 L/s [170 cfm] per patient). The specification of the minimum hourly averaged ventilation rate also addresses the issue of airflow fluctuation. WHO[2] made similar arguments and specifications for natural ventilation requirements in other wards, outpatient areas, and corridors.

Natural Ventilation Strategies

WHO[2] classifies suitable natural ventilation design strategies based on the relevant basic architecture design elements (corridors, courtyards, chimneys, wind catchers, etc.) and building layout. These design elements define the routes of airflow, and thereby, the basic natural ventilation strategy.

Five basic natural ventilation strategies are discussed. It is possible to combine some of these strategies to suit the local climate and particular needs of a given hospital. WHO[2] does include a note with each recommended strategy: "This conceptual drawing should be used with care, and sufficient attention is needed to consider realistic limitations."

1. Single-side corridor type (*Figure 1*). A corridor is placed on either side of the wards. The airflow will maintain a unidirectional flow either from the ward to the corridor or from the corridor to the ward depending on the incident wind direction. The former unidirectional flow is beneficial to prevent cross infection, while the latter is not. The design of operable openings (e.g., windows and doors) is crucial for this design. It is best to align operable openings and passageways within rooms and create a path of minimum resistance to flow for cross ventilation.[4]

The 18th century architect Beer is credited with having initiated the corridor hospital, where all the rooms are arranged alongside internal walkways. His hospital in Bern, Switzerland, built between 1718 and 1724, was the first of this type.[5]

2. Central corridor type. A central corridor type may be derived from the single-side corridor type by adding another series of wards on the other side of the corridor. The possible airflow path would be from one ward to the corridor, and then to the ward on the other side. When the wind is blowing parallel to the windows, adding a wing wall may help drive the outdoor air to enter the wards first, then meet and exit from the central corridor.

3. Courtyard type (*Figure 2*). Courtyards are traditionally enclosed outdoor zones that can help channel and direct the airflow that is promoted by large openings (gates, doors, arches, etc.) and thus modify the microclimate around the buildings. Based on the relative position between wards and corridor, this type of natural ventilation design can be divided into subtypes, i.e., an inner corridor and outer corridor type. In either case, the courtyard needs to be sufficiently large. The outer corridor type has the advantage over the inner one as it can avoid cross infection via the connected corridor by delivering clean outdoor air into the corridor first.

The first hospital designed according to these geometrical principles was during the Renaissance. The hospital, the Ospedale Maggiore, was founded in Milan in 1456 and designed by Antonio Averulino, better known as Filarete. It has a symmetrical rectangular plan with a large central courtyard; on both sides of it, the wings of the building delineate four smaller courtyards.[5]

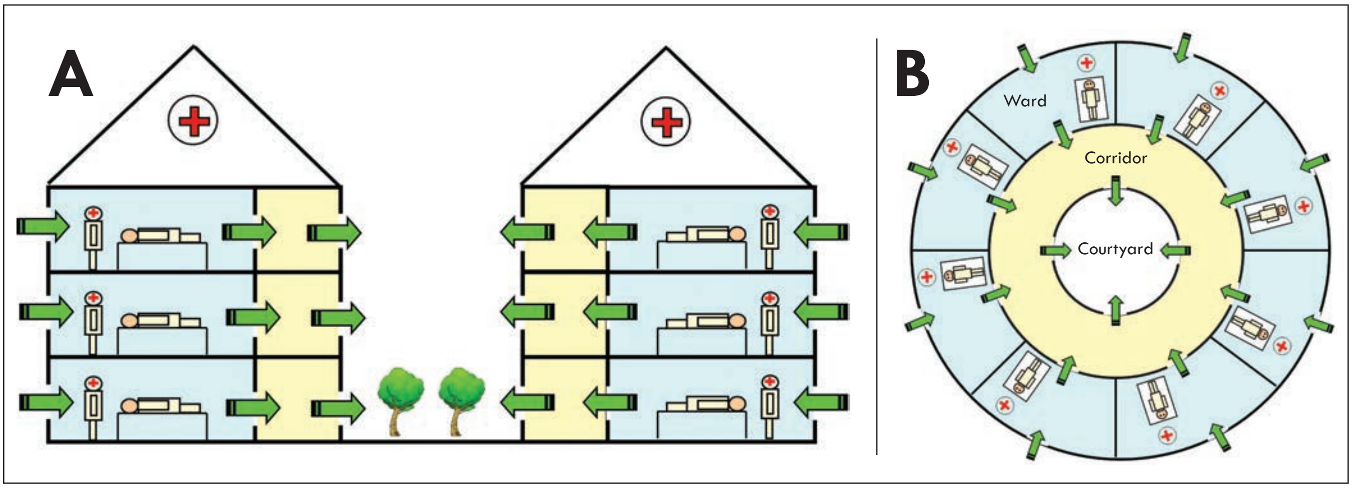

Figure 2: Combined wind- and buoyancy-driven natural ventilation in the courtyard type (inner corridor) hospital. A) Section plan; B) floor plan.[2]

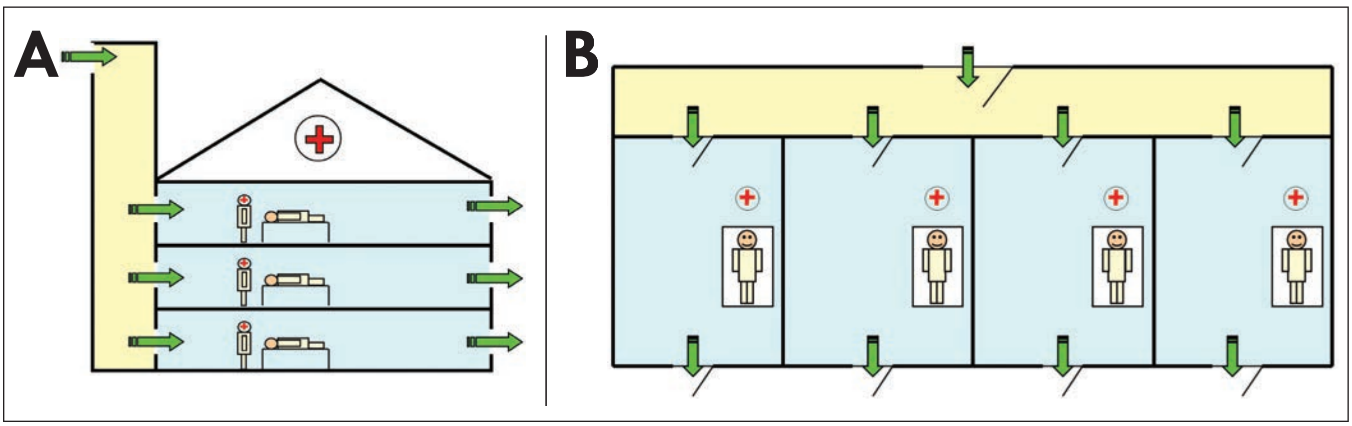

Figure 3: Wind-driven natural ventilation in the wind catcher type hospital. A) Section plan; B) floor plan.[2]

4. Wind catcher type (*Figure 3*). A wind catcher can capture the wind at the roof level and direct it down to the rest of the building. Weatherproof louvers are installed to protect the interior of the building, and volume control dampers are used to moderate flow. Stale air is often extracted at the leeward side of the wind catcher shaft. This device is often divided into four quadrants that can run the full length of the patient's body and become air intakes or extractors depending on wind direction.

5. Atrium and chimney type (*Figure 4*). The existence of an atrium or chimney may help enhance the natural ventilation potential. Based on the relative position between wards and atrium/chimney, there is a side-atrium/chimney type and a central atrium/chimney type. The outdoor air is sucked into the wards through the windows, typically, because of the combination of wind and buoyancy effects. After diluting the contaminated air in the ward, the warmer and polluted air converge in the atrium/chimney and discharge through the termination device at the top of the atrium or chimney. The efficacy of this type of design is generally improved by varying the height of the chimney or atrium and the detailed design of the termination device and, therefore, its ability to create a negative (suction) pressure that is independent of wind direction, and the indoor-outdoor temperature difference.

WHO[2] provides a comparison of the performance of different types of natural ventilation systems for hospital use in four major climates conditions: hot and humid, hot and dry, moderate, and cold. For example, at this time the atrium/chimney type design is not recommended for hot and humid or hot and dry climates without further research and development. One limitation of natural ventilation is that it can depend too much on the outdoor climate. For example, if the outdoor wind is too weak or the outdoor temperature is too high, the driving forces will be reduced. To overcome this, hybrid ventilation can be used. A hybrid ventilation system includes a mechanical component, i.e., a fan, to ensure that the minimum ventilation rate is met. In a simple hybrid ventilation system, mechanical and natural forces are combined in a two-mode system where the operating mode varies according to the season and within individual days, taking advantage of ambient conditions at any point of time.

Design Considerations

Allard[4] presented a comprehensive design guideline. WHO[2] gives a brief introduction to the topic. Design guides of natural

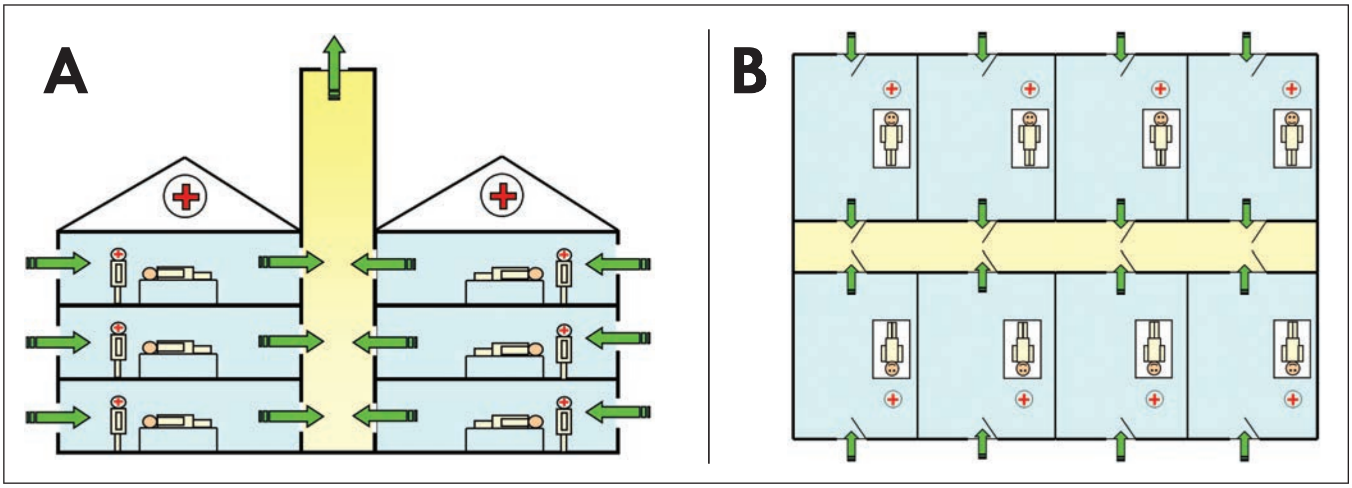

Figure 4: Combined wind- and buoyancy-driven (including solar chimney) natural ventilation in the (solar-assisted) chimney type of hospital. A) Section plan; B) floor plan.[2]

ventilation are also available in CIBSE[6] and Heiselberg.[7] Natural ventilation design needs imagination and number crunching. Many of us are often amazed by the imagination of some great architects and engineers in their designs. WHO[1] consider three hierarchies of design process:

1. Site design: building location, layout, building orientation, landscaping;
2. Building design: type of building, building function, building form, envelope, natural ventilation strategy, internal distribution of spaces and functions, thermal mass, HVAC system, if present; and
3. Vent opening design: position of openings, types of openings, size of openings, control strategy.

Other considerations include furniture and internal portioning, ward depth, shading, daylighting and glare control, heating and cold draft, and cooling. Design consideration should also include the limitations of natural ventilation, including ambient air pollution, noise, mold growth, security and fire safety.

Summary

WHO[2] provides the first international standard on the use of natural ventilation for infection control in health-care settings. Such a recommendation from WHO reflects the growing recognition that natural ventilation can be effective for airborne infection control.

When natural ventilation alone cannot satisfy the recommended ventilation requirements, a mechanical ventilation or mechanically assisted natural ventilation mode should be operated. The general hospital areas also can be designed with natural ventilation. However, as with mechanical ventilation, natural ventilation of buildings has its own design and operation challenges. Design methods are now available for natural ventilation design, and the effect of window covering, weather, and obstacles can be considered in some of the existing design methods. But, there is still a need to develop a detailed design and operation guide for hospital engineers, architects, and infection control personnel. There is also a lack of studies on natural ventilation for airborne infection control in hospitals,[8] which needs to be addressed.

Acknowledgments

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References

1. WHO. 2007. "Infection Prevention and Control of Epidemic—and Pandemic-Prone Acute Respiratory Diseases in Health Care." WHO Interim Guidelines, World Health Organization, Authors: P. Ching, et al.

2. WHO. 2009. "Natural Ventilation for Infection Control in Health-Care Settings." World Health Organization, Editors: Atkinson, J., et al.

3. Li, Y. 2011. The secret behind the mask (Editorial). *Indoor Air,* 2011.21(2):89–91.

4. Allard, F. (ed.) 1998. *Natural Ventilation in Buildings—A Design Handbook*. London: James & James.

5. Wagenaar, C. 2006. *The Architecture of Hospital*. Belgium: Nai Publishers.

6. CIBSE. 2005. *Natural Ventilation in Non-domestic Buildings*. Application Manual AM10, London: CIBSE.

7. Heiselberg, P. 2000. *Principles of Hybrid Ventilation*. International Energy Agency Annex 35, Final report.

8. Escombe, A.R., et al. 2007. "Natural ventilation for the prevention of airborne contagion." *Plos Medicine*. 4(2):309–317. ■