How to Measure Natural Ventilation in Resource-Limited Settings using Carbon Dioxide (CO2)
By Julia Fischer-Mackey, Reviewed by Dr. Ed Nardell

According to the World Health Organization (WHO), adequate ventilation in health-care facilities is essential for preventing transmission of airborne infections, and it is strongly recommended for controlling spread of TB. Evidence shows that for non-isolation rooms, low ventilation rates are associated with higher TST conversion rates among health care staff. Also, existing data suggests that increasing ventilation may decrease airborne infection rates. Good ventilation reduces the concentration of TB droplet nuclei in the air, which may decrease the risk that it will be inhaled and lead to infection. Therefore, ventilation is an important consideration for health implementers working with TB patients (WHO policy on TB infection control in health-care facilities, congregate settings and households, World Health Organization (WHO) 2009, p 13; Natural Ventilation for Infection Control in Health Care Settings, WHO, 2009, p 18-19).

The WHO and the Centers for Disease Control and Prevention (CDC) have established guidelines for ventilation in health care facilities. Health implementers must be able to measure the ventilation in their facilities in order to know if they are achieving the recommended rates of ventilation. This guide defines natural ventilation, summarizes the international recommendations for ventilation rates in health care facilities, and describes one method of measuring natural ventilation which is feasible in resource-limited settings.

What is Natural Ventilation?
Natural ventilation relies on pressure differences caused by wind and thermal buoyancy (or stack effect) to move fresh air through buildings. Natural ventilation is inexpensive to maintain because it requires no electricity or mechanical parts, so it is often the sole form of ventilation in resource-limited health care facilities. The drawback of natural ventilation is that for optimal performance, doors and windows must be opened, which may not be possible due to extreme temperatures, precipitation, security, or privacy issues.

International Ventilation Guidelines
There are two ways to measure ventilation rate: one uses the volume of the space (i.e. air changes per hour or ACH) while the other takes into account the number of people in a space (i.e. litres/second/person). Occupancy-based measurement of ventilation rates takes into account the fact that each person in a space should have a certain supply of fresh air.

- Generally, the WHO and CDC recommend that ventilation in a health care facility should be between 6 and 12 air changes per hour (ACH). Existing buildings should have at least 6 ACH, and new or renovated buildings should have at least 12 ACH. This is equivalent to 80 l/s/patient for a room of 24 m3. For airborne precaution rooms for infectious TB patients, at least 12 ACH is strongly recommended (WHO policy on TB infection control in health-care facilities, congregate settings and households, WHO, 2009 p13; Guidelines for Preventing the transmission of Mycobacterium tuberculosis in health care settings, CDC, 2005).
- When health care facilities rely solely on natural ventilation, a substantially higher minimum ventilation rate is recommended:
  - 160 l/s/patient for airborne precaution rooms in new and renovated health care facilities, with a minimum of 80 l/s/patient. 160 l/s/patient is roughly equivalent to 24 ACH
  - 60 l/s/patient for general wards and outpatient departments (Natural Ventilation for Infection Control in Health-Care Settings, WHO 2009 p 22-23). Note: WHO is currently updating specific guidelines on requirements for ventilation rates for different spaces (e.g. general wards, outpatient facilities, corridors) (WHO policy on TB infection control in health-care facilities, congregate settings and households, 2009 p 13).
In resource-limited settings, these ventilation guidelines should serve as targets against which current ventilation rates should be compared. Once a facility’s ventilation rate is measured, it is possible to proceed with ventilation improvement interventions as necessary.

**Measuring Natural Ventilation using a Tracer Gas**

By adding a gas (known as a “tracer gas”) to the air of a room, and then measuring how fast the gas is diluted, you can calculate the ventilation rate of the room. Carbon Dioxide (CO2) is a good choice for a tracer gas in resource-limited settings, because it is inexpensive, easy to find (a standard fire extinguisher is filled with CO2), and safe for humans. The following method allows you to calculate ACH using common, relatively inexpensive equipment.

**How to Measure Ventilation using CO2:**

1. Bring a fire extinguisher, a stop watch, portable fans, and a CO2 meter into the room you are testing
2. Open/close doors and windows, depending on what ventilation scenario you are testing, and measure the baseline CO2 in the room using the CO2 meter
3. Release the CO2 in the fire extinguisher continually until the concentration of CO2 in the room is constant, between 5,000-10,000 ppm
4. Make sure the CO2 is mixing with the air by using fans. If you have two CO2 meters, take measurements from two points in the room and use the average to get a more accurate measurement
5. Use the CO2 meter (and stop watch, if no timer exists on the meter) to record the concentration of CO2 in the room over time as the gas disperses. Stop recording once the CO2 is within 200 ppm of the baseline measurement
6. Calculate ACH:
   o Plot natural log of CO2 concentration over time (units=ppm, hours)
   o To calculate ACH, one would draw a straight line through the curves obtained by CO2 dilution, attempting a best fit through the experimental points. This is critical as the slope used could vary the ACH by a lot. For this reason, and others, CO2 dilution is an approximation, not exact, measure of ACH. Generally one can say there is a lot or very little ventilation, but not much more.

**Limitations of this method of ventilation measurement**

- Wind: direction and velocity both change constantly and are not reflected in this measurement
- Temperatures: inside/outside temperature differences influence airflow, and these change regularly
- Windows and doors: Their position in a room or building, how much they open, and how airtight they are when closed all affect the room’s ventilation
- Air Mixing: fans improve air circulation and can impact ventilation. Using the CO2 tracer gas method, the CO2 may not mix evenly in the air, even with the use of fans, making the calculations less accurate
- Calibration: in general, CO2 meters need to be calibrated regularly
- Other considerations when using CO2 meters: a relatively high concentration of CO2 in the room at the beginning of the test is needed. The higher your baseline CO2 (for example, 5,000-10,000 ppm) the more points you will have on your decay graph, and the better your calculation of ACH will be
- Most ventilation studies using this method have used an artificial gas, sulfur hexafluoride (SF6), as a tracer gas. Unlike SF6, CO2 exists naturally in the air and is exhaled by humans, so it may produce less reliable results when used as a tracer gas. However, CO2 is preferable to SF6 in resource-limited settings because it is cheaper and easier to find, the meter to test it is cheaper, and it is proven to be safe for humans and can be used to test a working facility.
Key References

- *Overview: Airborne Infections and Control Strategies*, presented by Dr. Edward Nardell at the Building Design and Engineering Approaches to Airborne Infection Control course at the Harvard School of Public Health, 2008
- *Measuring Air Changes per Hour with Carbon Dioxide*, presented by Dr. Rod Escombe at the Building Design and Engineering Approaches to Airborne Infection Control course at the Harvard School of Public Health, 2008

Enrich the GHDonline Knowledge Base

Please consider starting a discussion with:

- Recommendations on brands and suppliers of good CO2 meters, by region
- Experiences you have had measuring natural ventilation using this method
- Other methods for testing ventilation in resource-limited settings

Recommendations

You may also be interested in the following discussions and resources in GHDonline communities:

- [Windows and design details for MDR-TB isolation rooms](#)
- [TB Infection Control in single-room homes](#)