Operational research on implementation of tuberculosis guidelines in Mozambique

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Citation for published version (APA):
Brouwer, M. A. (2015). Operational research on implementation of tuberculosis guidelines in Mozambique

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7. Assessing ventilation of health facilities using a vaneometer.

In preparation
Abstract

Setting: Urban and district health care facilities in Mozambique and Uganda.

Objective: To evaluate the position to measure air velocity using a vaneometer to assess ventilation with air changes per hour, validating a single measurement taken in Mozambique. Assess influence of ambient temperature and the weather.

Design: Experimental in six facilities in Uganda measuring air velocity on nine separate moments in five positions in each opening of the rooms using a vaneometer. Cross sectional assessment of ventilation in 29 health care facilities in Mozambique.

Results: A total of 189 measurements showed no significant influence of ambient temperature and a small but significant influence when the sun was shining. The position and the moment of the measurement did not influence the air velocity. Ventilation was adequate in 177/189 (94%) of the measurements in Uganda and in 101/119 (86%) rooms assessed in Mozambique.

Conclusion: Most rooms had adequate ventilation. A single measurement of air velocity is adequate to assess ventilation using a vaneometer. These findings provide input for clear guidelines on how to assess ventilation using such a device.
Introduction

Tuberculosis (TB) is an airborne disease of which transmission occurs through infectious droplets in the air originating mostly from coughing. This makes health care facilities high-risk areas for TB transmission because coughing patients, including those with (undiagnosed) TB, gather there when seeking care. Therefore, by the nature of their work, health care workers have an increased exposure to TB, and a higher risk of TB disease compared to the general population. \(^1\) To reduce the risk of TB transmission in health care facilities, the World Health Organization recommends a set of TB infection prevention and control (TB-IPC) measures. \(^2\) These measures include the use of ventilation systems. In existing health care facilities maximizing natural ventilation takes priority before considering other ventilation systems.

Evaluation of the adequacy of ventilation is through assessment of the number of air changes per hour (ACH). \(^2\) This is the number of times per hour that air from outside the room replaces the air in the room. International guidelines recommend at least 12 ACH for airborne precaution rooms \(^2,3\), and at least 6-12 ACH for laboratories performing low risk investigations such as smear microscopy. \(^4\) If individual health care workers or health care facilities had a simple tool to assess ventilation in their workrooms, it may encourage them to maximize natural ventilation. If adequate ventilation is not possible, they could use additional measures to reduce the airborne transmission risk.

Assessment of the ventilation in health care facilities is part of the overall airborne infection control assessment. Different studies have used different methods to assess ventilation. A study from Pakistan asked health care workers about ventilation in their consultation rooms, but did not assess it quantitatively. \(^5\) Other studies used relatively complicated methods such as tracer gasses to assess ventilation. \(^6,7\) However, the document on implementation of the WHO infection prevention and control policy suggests a relative simple tool, a vaneometer, to assess ventilation. \(^8\) The tool is developed for industry to measure air velocity. This air velocity together with the volume of the room and the surface of openings through which air enters the room, provide the inputs to calculate the ACH.

Unfortunately there is no guidance nor experiences from published studies on how to measure air velocity using the vaneometer, precluding the answers to some basic questions such as (1) Is a single air velocity measurement sufficient?, or (2) Is the position in the opening relevant for the air velocity measurement? For widespread implementation of ventilation assessments it would be of great help if a single measurement of air velocity would suffice. Therefore the main question in this study is: is a single air velocity measurement at openings in a room sufficient to assess ventilation through air changes per hour?

Methods

In a TB-IPC study in Mozambique we used a single air velocity measurement to calculate the ACH. We published the details of the conduct of these assessments elsewhere. \(^9\) In short, provincial and district TB supervisors performed TB-IPC assessments using a purposely developed tool in 119 health care facilities in 2010. To assess ventilation in selected rooms, they measured the surface of all openings, the volume of the room, and took a single air velocity measurement at all openings where air entered the room.

To validate this single measurement, we undertook a second study in Uganda. In six urban health care facilities in Kampala, we performed similar air velocity measurements in the TB clinic, the laboratory, an out-patient department (OPD) consultation room, and in the OPD waiting area. This time, data collectors took nine rounds of separate measurements for each opening using a vaneometer: three times a day on three consecutive working days. At each of these time points, they took the measurements at five positions in the opening: in the centre of the opening and in the middle of each of the sides of the opening. They
kept the vaneometer for a few seconds at each position and then read the air velocity. The measurements were taken with openings open or closed as in routine working conditions. They measured the height and width of all openings, as well as width, length and height of the rooms. They recorded information on ambient temperature (degrees centigrade) and weather conditions (cloudy, rainy, sunny, windy or a combination of these) at the time of the measurement. The data collectors used an android phone with pre-installed structured data capture forms using Open Data Kit Collect (version 1.4.2.). The forms were uploaded using Open Data Kit Aggregate to a server from which databases in the form of comma separated files were downloaded.

In both studies the data collectors used a DwyerTM vaneometer M480 with a vane (Dwyer Instruments, Inc, Michigan City, USA) to measure air velocity in meters per second.

Analysis

The data files were imported into STATA version 12 (StataCorp, College Station, Texas, USA). We used a hierarchical mixed effect model to estimate the air velocity at each opening taking into account the clustering of data at the level of the position and the opening, as well as the repeated measurements at a single opening. As input for the model, we used only measured air velocity that had an inward direction. The estimated air velocities for each opening provided the input for the formula of ACH

$$ACH = 3600 \times \frac{\text{average estimated air velocity} \times \text{area all openings with incoming air}}{\text{volume of the room}}$$

If the air velocity in an opening was not inward for all five positions, the area of the opening contributed proportionally to the ACH calculation. For example, if the direction of the airflow was inward in three of the five positions and outward in the remaining two positions, 60% of the total area of the opening contributed to the ACH calculation. We categorised the ventilation as inadequate if the ACH was below 6, as potentially adequate between 6-12, and as adequate if above 12.2,3,4

To assess the effect of weather, we collapsed the possible categories into two (sunny / not sunny) to obtain groups of similar size. Given the distribution of temperature, we grouped the data as below 25 degrees or 25 degrees and over.

We calculated the ACH for the Mozambican rooms using R statistics.10

Ethics

The Mozambican Ministry of Health’s National Bio-ethics Committee approved the Mozambique study. The Research and Ethics Committee of Makarere University and the Uganda National Council for Science and Technology in Kampala approved the Ugandan study.

Results

In Uganda, data collection took place from May to July 2014. In the six facilities the data collectors took 189 measurements out of the expected 216 (six facilities, four rooms, and nine rounds of measurements (three times a day on three days). Two TB clinics were tents with roofs only. In one of them we took measurements on one day only, in the other TB tent no measurements at all. In one facility we managed only two days of measurements. In one room in two facilities we did not manage three rounds of measurements in a day because the rooms were in use.
The air velocity did not vary significantly with the ambient temperature (p=0.259). In sunny weather the air velocity was higher compared to non-sunny weather (p=0.003), though the difference in the mean estimated air velocity in both weather conditions was rather small (0.07 meter/second). We calculated and categorised the ACH from the estimated air velocity, the total area of openings with inward airflow direction, and the volume of the room (Table 10).

<table>
<thead>
<tr>
<th>Facility</th>
<th>Round</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Median ACH</th>
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**Legend**
- **ACH**: Air changes per hour
- **OPD**: Out-patient department
- **<6**: Air changes per hour < 6
- **>=6 and <=12**: Air changes per hour >= 6 and <= 12
- **>12**: Air changes per hour > 12
- **No measurements to calculate air changes per hour**

Table 10 Ventilation status in four areas in six urban health care faculties in Uganda per round and per day

In 17 of the 24 rooms, all nine rounds of measurements provided adequate ventilation. In only one room, one round resulted in inadequate and one round in potentially adequate ventilation. The remaining rounds had adequate ventilation. The other six rooms had a combination of potentially adequate or adequate ventilation.
The mixed effect model showed a negligible error term for the position of the measurement and the round of the measurement, in relation to the error term for the different openings in all of the health facilities and rooms. The fixed effects for position and the round of the measurements were not statistically significant. These findings indicate that neither aspect of the measurements influenced the air velocity estimate. From here it follows that a single measurement at a single point in a specific opening is adequate for the air velocity measurement.

Because the Uganda data suggested the adequate use of a single measurement of air velocity, we used the single measurements in the Mozambican study to calculate the ACH for individual rooms. Table 11 shows the ACH in the TB clinic, the laboratory, the medical ward, one or two OPD consultation rooms, and the TB ward for 29 health facilities in Mozambique. Not all facilities had all these rooms. In two rooms we could not calculate the ACH due to incomplete data.

Of the 117 rooms with ACH assessed, 101 (86%) had adequate ventilation, seven (6%) had potentially adequate, and nine (8%) had inadequate ventilation. Eight (89%) of the nine rooms with inadequate ventilation were laboratories. Five of these laboratories had all openings closed of which four because of the presence of an air conditioner.

**Discussion**

Our results suggest that a single air velocity measurement using a vaneometer at openings in a room is sufficient to assess ventilation through air changes per hour in this setting. This facilitates development of a clear guideline on assessment of ventilation in rooms in health facilities using this simple tool.

The weather condition had a small effect on the air velocity. The effect was rather small and will probably not affect the ACH. However, different weather conditions may affect the opening of windows and doors compared to the routine working situation, which would affect ACH. Therefore, we recommend assessment of ACH under various weather conditions.

The ventilation of more than 83% of the rounds (Uganda) and 86% of rooms in Mozambique was adequate. This is surprising because we did expect poorer ventilation based on other studies from Africa reporting less than 50% of rooms adequately ventilated, though with a different assessment method.11,12 Even if the surfaces of the openings in Mozambique were half of what was measured, the ventilation would still be adequate in more 50% of the rooms.

We used 12 ACH as cut-off for adequate ventilation. This cut-off recommendation applies to mechanically ventilated airborne precaution rooms.2 The recommended cut-off for laboratories is 6-12 ACH.4 No clear recommendations on ACH exist for the other rooms such as TB clinics, OPD consultation and waiting rooms, or wards.

In a systematic review, Li et al. did not find evidence for a recommended quantification of ventilation requirements.13 A study in Canada found an association between general or non-isolation rooms having less than 2 ACH and the conversion of the tuberculin skin test in health care workers.14 The study did not find an association between skin test conversion and inadequately ventilated isolation rooms for which at the time of the study the cut-off was 6 ACH. If a lower cut-off of more than 6 ACH instead of more than 12 ACH would be acceptable to define adequate ventilation, only one room in one round in Uganda, and only 8% of rooms in Mozambique would have inadequate ventilation.
| 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Laboratory | 64 | 38 | 70 | 70 | 56 | 80 | 51 | 21 | 210 | 461 | 34 | 3 | - | 27 | 5 | 23 | 31 | 43 | 0 | 111 | 335 | 14 | 26 | 0 | 0 | 28 | 3 | 16 |
| Medical ward | 13 | 6 | 20 | | | 89 | 380 | 27 | 21 | 16 | 6 | | | & | | | & | | | & | | | & | | |
| OPD Consultation room 1 | | | | | | 185 | 72 | 52 | 37 | | | 10 | | 32 | | 23 | 22 | 68 | 23 | | 6 | 20 |
| OPD Consultation room 2 | 57 | 26 | 122 | 7 | | | 18 | 27 | 68 | 374 | 105 | 29 | 12 | 21 | 36 | 10 | 13 | 0 | 18 | 14 | 38 | 282 | 80 | 57 | 154 | 33 | 16 | 23 | 7 | 32 |
| TB clinic | 51 | 49 | 79 | 118 | 58 | 47 | 26 | 212 | 133 | 217 | 19 | 51 | 40 | 36 | 56 | 53 | 76 | 22 | 73 | 74 | 68 | 97 | 46 | 188 | 13 | 147 | 52 | 79 | 47 |
| TB ward | 34 | 71 | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Legend

ACH | Air changes per hour
OPD | Out-patient department
TB | Tuberculosis
- | Calculation ACH not possible because of incomplete data

20 | Air changes per hour > 12
7 | Air changes per hour >= 6 and <= 12
0 | Air changes per hour < 6

Health care facility does not have that area


Table 11 Air changes per hour in six areas in 29 health facilities in Mozambique
Natural ventilation has been shown to achieve higher ACH than mechanical ventilation. The disadvantage of natural ventilation is its variability in both velocity and direction. However, given the costs of mechanical ventilation systems, and the weak evidence available for specific recommendations regarding the quantification of ventilations requirements, natural ventilation seems the way forward for resource limited settings. Our study shows that in both Uganda and Mozambique, natural ventilation provides adequate ventilation in most facilities and rooms assessed.

Health facilities would need practical guidelines to assess ventilation in their rooms. Based on our findings, the practical guidelines should include at least the items listed in the box.

Items that should be covered by guidelines on assessing ventilation using a vaneometer:

- A single measurement of air velocity using a vaneometer and measurements of openings and rooms provides adequate input for the ACH calculation;
- If ACH is above 12 the ventilation is deemed adequate;
- If the ACH is between 6 and 12, several measurements of air velocity provides insight into the variability of ventilation; if persistently between 6 and 12, opening more openings will probably increase ventilation;
- Because of a potential effect of the weather, assessment of the ACH is necessary under different weather conditions;
- If opening of more openings is not possible, or the ACH is below 6, then health facility management should improve health care worker safety through additional measures for infection prevention and control;
- Training and support for ventilation assessments.

Additional measures to reduce the TB transmission risk in rooms with inadequate ventilation assume that all administrative controls are in place. Additional measures include positioning of health care workers such that infected air does not pass them, and fans to direct airflow out of the room. Exhaust systems, for example in the form of wind driven turbine, may assist in increasing the ventilation. Should all these measures be insufficient to contain the transmission risk, then health care workers may need to wear particulate respirators. To do that effectively, they need clear instructions on how and when to use these and how to handle the respirators in-between use should the respirators be used more than once.

Limitations

This method of ACH calculation assumes perfect mixing of air in the entire room. This may not happen in rooms that have obstacles such as partition walls or patient screens. Imperfect mixing means that some areas in the room are better ventilated than other areas. We did not take this into account when assessing the ventilation.

In Mozambique we potentially overestimated the ACH because we did not take into account the possibility that in one opening air could have an inward and an outward direction. However, because 65% of all ACHs were above 24, and a further 21% between 12 and 24, it would probably not affect overall results.

Our study provides only an assessment of the vaneometer and no comparison with the gold standard for the measurement of air velocity. To our knowledge such a gold standard or head-to-head comparisons with other methods do not exist. Given the easy use and low cost of this method, it provides a valid method in resource-limited settings.
Although the manufacturer instructions for the vaneometer states accuracy to ± 10% of the full scale, the vaneometer with the vane may have variability in its readings. A digital vaneometer probably provides more consistent readings.

Conclusion

Development of clear guidelines on assessment of ventilation in rooms in health care facilities using a vaneometer taking a single measurement of air velocity seems possible. Further studies need to validate our findings and find the easiest to use method to assess ventilation. An app to facilitate the ACH calculation would simplify the assessment even further.
References


