Airborne Infection Prevention & Control in Health Facility Settings in Ethiopia

Building Design and Environmental Engineering Requirements

Federal Ministry of Health
Public Health Infrastructure Directorate
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Disclaimer

This document on Airborne Infection Prevention and Control in Health Facility Settings has been developed by the Federal Ministry of Health of Ethiopia and implementing partners. It aims to provide guidance on building design and environmental engineering requirements for the benefit of all involved in the procurement, design, construction, commissioning and use of the health-care infrastructure across both public and private sectors.

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All drawings are conceptual and should be used with care, and the author accepts no responsibility for correctness, completeness or quality of the information provided.

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Preface

Tuberculosis (TB) is a major cause of morbidity and mortality in Ethiopia. Ethiopia is among the 22 High TB Burden Countries and also among the 27 high Multi-Drug Resistant TB (MDR-TB) burden countries in the world. Aggravated and compounded by HIV pandemic, TB has become a formidable threat to the country.

Cognizant of the burden, the prevention and control of TB, MDR-TB and TB/HIV remains top priority in all phases of the Health Sector Development Program.
To guide the successful implementation of the interventions, a five year Tuberculosis, Leprosy and TB/HIV Strategic plan has been developed (2010/11 – 2014/15) with a clear focus on TB prevention and control across all levels of the health system.

One of the areas which TB prevention intervention should target is health facility construction or renovation/upgrading with clear guidance on preventing airborne infectious diseases transmission.
However, so far there has been no specific guiding document on building design and engineering requirements which could be followed by professionals who deal with health facility design, construction and upgrading.
This new guide includes the basic requirements needed to control the transmission of airborne infections especially tuberculosis, it references current global standards and best practices tailored to Ethiopian settings and is intended to close the national gap. This guide outlines building design and engineering requirements which are necessary in addition to the national physical standards for health care facilities, so as to address airborne infection prevention and control issues starting from design stage; construction to optimum and efficient utilization of available local resources.

This guide is primarily intended for architects and engineers, but it is also believed that it will benefit policy makers, regulatory agencies, health program managers, health care workers, and development partners who are involved in health systems, private health care facilities and teaching institutions.

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Acronyms and Abbreviations

ACH	Air Changes per Hour
AIIR	Airborne Infection Isolation Room
BSC	Biosafety cabinet
BSL	Biosafety level
DR-TB	Drug-resistant tuberculosis
DST	Drug Susceptibility Testing
FMHACA	Food Medicine and Health Care Administration and Control Authority
FMOH	Federal Ministry of Health
HAI	Healthcare-associated infection
HEPA	High Efficiency Particulate Air
HVAC	Heating Ventilation and Air-Conditioning system
HIV	Human Immunodeficiency Virus
IFIC	International Federation of Infection Control
LTBI	Latent TB Infection
MDR-TB	Multi-drug resistant tuberculosis
MERS	Middle East Respiratory Syndrome
Mtb	Mycobacterium tuberculosis
PLHIV	People living with HIV
PPE	Personal Protection Equipment
RH	Relative humidity
RIF	Rifampicin
SARS	Severe Acute Respiratory Syndrome
TB	Tuberculosis
USAID	United States Agency for International Development
UVGI	Ultraviolet Germicidal Irradiation
WHO	World Health Organisation
XDR-TB	Extremely drug-resistant tuberculosis

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Chapter 1: Introduction

1.1 Background

The emergence of antimicrobial resistant strains of disease pose a serious threat to global public health. An example is the emergence of drug-resistant tuberculosis (DR-TB), an infectious disease which is transmitted from one person to another by airborne particles.

Health-care facilities can be potential areas of disease transmission unless appropriate precautions are put in place. The risk of airborne infection transmission is high in areas where infectious and susceptible persons come into close proximity.

In 2009, the World Health Organisation (WHO) published policy recommendations for TB infection control in health-care facilities, congregate settings and households [1]. The policy recommendations include architectural and engineering control measures to curb the on-going risk of transmission of airborne infections through the proper design, construction, operation and maintenance of health-care facilities.

The National TB Control Programme of Ethiopia has adopted the WHO policy and is implementing the set of control measures prescribed in the Guidelines for Prevention of Transmission of Tuberculosis in Health-care facilities, Congregate and Community Settings in Ethiopia [2]. The implementation of the guidelines includes the renovation of existing buildings and the construction of new structures.

In 2009, the WHO also published occupancy-based guidelines on natural ventilation for infection control in health-care settings [3]. Occupancy-based ventilation standards consider that each person in a space should have a certain supply of fresh (uncontaminated) air. The publication recognises the role of (natural) ventilation in airborne infection prevention and control.

1.2 Objectives

The majority of TB patients must be treated on ambulatory basis, with community-based models of care which include regular check-ups at the health-care facility and regular collection of medication. However, a small number of TB patients, such as those who are recently enrolled on DR-TB treatment or who are severely ill, have severe adverse effects, have more than one health concern (co-morbidity), or interrupted treatment, may have to be admitted for inpatient care in dedicated TB wards or in specialised dedicated infectious disease facilities.

Airborne infection prevention and control is strongly recommended in these settings. Where strict isolation in single-patient airborne infection isolation rooms (AIIRs) is not possible, separation or patient cohorting i.e. patient management (by clustering patients with the most similar diagnoses in well-ventilated areas) must be applied until a patient is diagnosed and started on an effective treatment regimen.

However, unsuspected and undiagnosed TB patients, drug-susceptible and drug-resistant cases, in general medical settings may pose the highest risk of transmission. National requirements on health facility design concepts and environmental engineering methods for the prevention and control of airborne infections in health-care facilities, general medical settings or specialised TB settings, had not previously been developed. This document is expected to fill this gap by providing key recommendations in applying the basic principles of airborne infection prevention and control, especially through improving natural ventilation systems.

This document provides distinct building design and engineering requirements, system quantities or capacities of best practices which are applicable to health facility settings in Ethiopia.

The objectives of this guidance document are:

- To describe the requirements and recommended best practices for the design, construction, operation and maintenance of an effective ventila tion or air disinfection system which prevents and controls airborne

infections;
- To ensure that building design, construction, renovations and installations are appropriate for the building's intended use and for ease of operation;
- To maximise the impact of available resources; and
- To advocate for increases in resources as needed.

1.3 Target audience

This document will serve as a guide for:

- Architects and engineers, including biomedical engineers
- Policy makers
- Regulatory bodies:Ministry of Urban Housing and Construction,Municipality
- Health programme managers at different levels
- Health facility administrators and health professionals
- Funding agencies
- Private health-care institutions and non-governmental organisations.

1.4 Scope

This document encompasses the basic architectural and engineering principles of design, construction and use for airborne infection prevention and control. It provides building design and engineering requirements supplementary to the national physical standards of health-care facilities [4] published by the Food Medicine and Health Care Administration and Control Authority (FMHACA) in 2011.

This document recommends and prioritises the use of natural ventilation systems which are most applicable to the health facility settings in Ethiopia.

Though the main emphasis of this document is on measures preventing and controlling TB transmission, it can also be adapted and used to prevent and control other airborne infectious diseases in health facility settings.

1.5 Related National Guidance

Aside from the aforementioned FMOH Guidelines for Prevention of Transmission of Tuberculosis in Health-care facilities in Ethiopia and the FMHACA National Minimum Standard for Health Facility Settings, the building design and engineering requirements for airborne infection prevention and control in this document are recommended within the framework of the wider set of national codes and proclamations providing and maintaining a safe, conducive and accessible environment for patients, personnel and the public:

- The Ethiopian Building Proclamation No. 624/2009.
- The Ethiopian Building Code Standards, EBCS-1-95through11-95.
- Ethiopian Building regulation, 201.
- Ethiopian "Convention on the Rights of Persons with Disability Ratification Proclamation No.676/2010".
- Ethiopian "Radiation Protection Proclamation No.571/2008", Ethiopian Radiation Protection Authority.
- Ethiopian Federal Ministry of Health, Hygiene and Environmental Health Department, Health Care Waste Management National Guidelines,2008.
- International (National) Life Safety and fire protection Code.

Chapter 2: Health-care Associated Infections

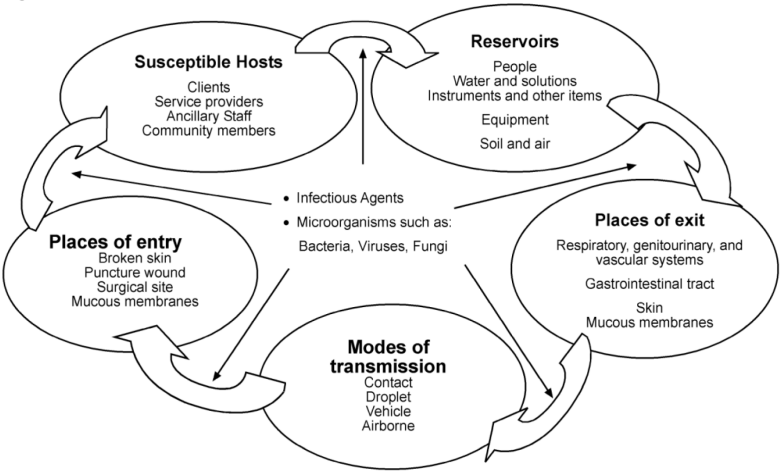
2.1 Chain of Infection

Infection is a result of an interaction between an infectious agent and a susceptible host. This interaction occurs when there is contact between the agent and the host and is affected by the environment. Breaking the chain of infection by interrupting transmission is generally the best way to prevent health-care associated infections (HAIs).

The chain of infection is well described in the Basic Concepts of Infection Control Handbook [5] published by the International Federation of Infection Control (IFIC).

The chain of infection consists of the following components: Infectious agent, reservoir, portal of exit, mode of transmission, portal of entry and susceptible host. (See Figure 1)

Figure 1: Chain of Infection



The ability of a germ to cause an infection and disease depends on its infectivity, strength, the number of germs, and the immune system response of the host.

Reservoir: a place in which an infectious agent can survive but may or may not multiply. Common reservoirs in health-care facilities are persons with an infectious disease and contaminated medical devices or equipment (usually called vehicles).

There are three types of human reservoirs:

- Persons who are ill (have signs and symptoms of disease)
- Colonised persons (harbour an infectious agent but do not have an infection)
- Carriers (are infected but do not show any signs or symptoms; but they can still transmit the infection to others).

Place of exit: the path by which an infectious agent leaves the reservoir. The place of exit can be the respiratory tract, genitourinary tract, gastrointestinal tract, skin/mucous membrane, blood or transplacental (transmission of disease from a mother to her child during pregnancy).

Mode of transmission: the movement of pathogens from the reservoir to the host. A pathogen may be transmitted by a single route or it can be transmitted in several ways.

The modes of transmission of HAIs are as follows:

- Contact transmission
- Droplet transmission
- Airborne transmission
- Vehicle transmission
- Vector transmission.

Contact Transmission: contact is the most important and frequent mode of HAI transmission; it is divided into two subgroups: direct-contact and indirect-contact. Direct-contact transmission involves a direct body-to-body contact and physical transfer of microorganisms between a an infected or colonised person and a susceptible host. For instance, direct contact occurs when a nurse turns a patient, gives a patient a bath or performs other patient-care activities which

require direct personal contact. Direct-contact transmission also can occur between two patients. Indirect-contact transmission involves contact of a susceptible host with an intermediate object, usually inanimate, such as contaminated instruments, needles, dressings or contaminated gloves which are not changed between patients.

Droplet Transmission: occurs when droplets are generated from a human reservoir, mainly during coughing, sneezing or talking, and during the performance of certain procedures such as intubation. Transmission occurs when droplets containing pathogens from the infected person are propelled a short distance (< 1 metre) through the air.

Airborne Transmission: occurs by the dissemination of either airborne droplet nuclei (small-particles, <5 micrometre in size) of evaporated droplets containing microorganisms which remain suspended in the air for long periods of time or dust particles containing the infectious agent. Droplet nuclei containing microorganisms are transmitted by air currents and may be inhaled by a susceptible person (patient, member of staff or visitor) within the same room or further away from the source patient, depending on environmental factors. Microorganisms transmitted in this manner include the Mycobacterium tuberculosis (Mtb), Rubeola (measles) and Varicella (chickenpox) viruses.

Vehicle Transmission: applies to microorganisms transmitted through contaminated items such as food, water, medications, medical devices and equipment, toys and biological products, such as blood, tissues or organs.

Vector Transmission: vector-borne transmission occurs when vectors such as mosquitoes, flies, rats and other vermin transmit microorganisms. Transmission occurs through simple contamination by animal or arthropod vectors or their actual penetration of the skin or mucous membranes. This mode of transmission plays a minor role in transmission of HAIs.

Place of entry: the path by which an infectious agent enters the host. The place of entry can be via the respiratory tract, genitourinary tract, gastrointestinal tract, skin/mucous membrane, parenteral or transplacental.

Susceptible host: a person lacking effective resistance to a particular germ. In health-care facilities, many patients are susceptible to infections as they are seriously ill.

2.2 Airborne Transmission

When considering airborne transmission, it is unclear how many infectious particles are required to infect. Compounding this uncertainty, there are marked differences in the numbers of organisms released by coughing and sneezing. Despite these limiting factors, which are the subject of on-going speculation, investigation and scientific research, the general principles of contagious potential apply.

In any form of transmission, the probability of infection increases with the degree of exposure to the infection. The factors implicated in the potential to be contagious are:

- The presence of susceptible persons
- The presence of infectious persons
- The effective contact rate (opportunities for transmission) influenced by variables which in the airborne example are factors such as exposure time, the breathing rates of patient and susceptible host, the virulence (strength) of the bacteria, and the environment (the qualities of the room, such as relative humidity and air volume).

Airborne transmission occurs through either:

a) Droplets < 5 micrometres in diameter (airborne transmission and 'droplet nuclei'), or
b) Droplets > 5 micrometres in diameter (droplet transmission).

Airborne transmission can be further categorised into obligate or preferential airborne transmission: Obligate airborne pathogens are only transmitted through the deposition of droplet nuclei whereas preferential airborne pathogens can be transmitted via multiple routes.

Airborne transmitted disease refers to any disease which is caused by pathogens and transmitted through the air. The pathogens may be viruses, bacteria or fungi, and they may be spread by coughing, sneezing, spraying of liquids or similar activities likely to generate aerosol particles or droplets.

The following table shows the characteristics and modes of transmission for different airborne infections.

Table 1: Scope and definition of transmission models

Mode of transmission	Definition	Examples of agents
Airborne <5 micrometres	Transmission caused by dissemination of droplet nuclei which remain infectious when suspended in air over long distance (>1metre) and time.	Tuberculosis Measles Chickenpox
Droplet >5 micrometres	Transmission occurs when these droplets containing microorganisms are propelled a short distance (usually <1metre)	Adenovirus Respiratory syncytial virus Influenza SARS* (Corona virus) MERS** (Corona virus)

*SARS = Severe Acute Respiratory Syndrome
** MERS = Middle East Respiratory Syndrome

Chapter 3: Tuberculosis

3.1 Transmission of Tuberculosis

The FMOH Guidelines for Prevention of Transmission of Tuberculosis in Health-care facilities, Congregate and Community settings in Ethiopia describe the following important facts for understanding the risk of TB transmission:

- The main source of TB infection is a person with active TB of the lungs.
- TB bacilli are carried in airborne particles (also called droplet nuclei), which can be generated when persons suffering from TB disease of the lungs sneeze, cough, laugh or speak.
- Droplet nuclei are approximately 1-5 micrometres in diameter, and normal air currents can keep them suspended in the air for prolonged periods of time, potentially long after the infectious patient has left the room.
- Infection, which is usually asymptomatic, occurs when a susceptible person inhales droplet nuclei containing TB bacilli and the organisms reach the lungs.
- Once in the lungs, the organisms may be contained or spread further throughout the body depending on the immune system response.
- Disease, which is usually accompanied by focal and generalized symp toms, may develop soon after infection, but an immune response is usually generated within 2-10 weeks of infection, which limits further multiplication and the spread of the TB bacilli.
- Some of the bacilli may remain dormant and viable for many years i.e. latent infection with TB.
- The risk of developing TB disease is high in the first few years following infection.
- Various factors can make infection progress to TB disease, the most important being the weakening of the immune system, especially by HIV infection.

3.2 TB Infection

- TB infection is the state of having a small number of bacteria in the body which are unable to grow due to control by the immune system. The

bacteria are inactive, but remain alive in the body and can become active later. This condition is also referred to as latent TB infection (LTBI).

- The probability that a person who is exposed to TB will become infected depends primarily on: The concentration of infectious droplet nuclei in the air (which is influenced by the number of organisms generated by the TB patient and the amount of ventilation in the area of exposure), the duration of exposure to the infectious droplet nuclei, and the proximity to the source of the infectious droplet nuclei.

3.3 TB Disease

- Most TB disease occurs in the lungs. In people living with HIV (PLHIV), up to half of TB patients have disease in other parts of the body.
- With standard treatment, TB disease can be cured, even in PLHIV. However, untreated TB is often fatal, especially in PLHIV.

3.4 Factors increasing Transmission

The transmission of TB can be attributable to patient factors, environmental factors and host (or recipient) factors.

Patient factors influence the number of organisms generated and thereby increase the risk of transmission. Such characteristics include:

- Disease in the lungs, airways or throat
- Presence of cough or other forceful expiratory symptoms
- Presence of TB bacilli in the sputum
- Presence and extent of cavitations in the lungs
- Failure of the patient to cover his or her cough
- Untreated or ineffective anti-tuberculosis treatment.

Environmental factors which enhance transmission include:

- Exposure in relatively small, enclosed spaces
- Lack of adequate ventilation
- Re-circulation of air containing infectious droplet nuclei.

Recipient factors which may affect the risk of becoming infected are:

- Severe immune suppression, especially due to HIV infection
- Tobacco abuse
- Alcohol abuse
- Malnutrition
- Diabetes
- Renal failure
- Silicosis.

3.5 High Risk Areas and Procedures

The IUSS Health Facility Guide for TB Services [6] indicates that areas where large groups of patients are kept in close proximity to each other are potentially high-risk areas. The highest risks are usually in crowded waiting areas where undiagnosed or untreated patients congregate. Waiting areas need to be adequately ventilated at all times in order to dilute concentrations of infectious airborne bacteria. Places such as consulting, examination, counselling or treatment areas where staff spend long times in relatively small and enclosed rooms in close proximity to patients should also be considered high-risk areas. Small enclosed waiting areas or other functional areas, such as radiology (X-ray) departments or even multi-patient wards can pose an equal risk.

Minimum areas of open windows are prescribed but are often not complied with, but improved natural ventilation alone is usually not enough to reduce risk, as the directional flow of air to and from adjacent areas also needs to be addressed.

The shape and volume of a space can also be an indicator of risk. Occupied spaces with minimal floor to ceiling heights (often found in multi-story buildings) are generally higher risk areas than those with high ceilings or high (top) level windows. Shape and volume is usually linked to ventilation flow patterns and rates. The position/ease of opening of both high and low level windows is important. Staff need to be aware of the need to keep windows open to allow unobstructed ventilation. “Open window” stickers are frequently used to provide visible reminders of the open window policy.

Adjacency - the distance between carriers and staff or other patients is a risk factor. Narrow spacing between beds (less than 1.20 m) also presents a risk of

both fine droplet and droplet nuclei contamination.

Areas where aerosol-generating procedures are undertaken (defined as 'high-risk procedures') may increase the potential of generating droplet nuclei because of the mechanical force used in the procedure. These aerosol-generating procedures include intubation, cardiopulmonary resuscitation, bronchoscopy, autopsy, surgery where high-speed devices are used, sputum induction, and laboratory techniques such as decapping, centrifuging, pipetting, heating and amplification. A facility risk assessment aimed at identifying potential risk for cross-infection and patient or staff susceptibility to infection must always be conducted to identify areas with a high-risk of airborne disease transmission.
Table 2 provides ventilation standards which should be considered when planning and designing ventilation systems for airborne infection prevention and control.

Table 2: Ventilation standards for airborne infection prevention and control

Ventilation standards according to risk profile in litre/second/occupant (l/s/occupant)		Patient/Staff Susceptibility to Infection		
		Low	Moderate	High
Potential for cross infection	Low	Fresh air supply 7,5 l/s/occupant*	Fresh air supply 60 l/s/occupant	Fresh air supply 80 l/s/occupant 6-12 ACH
	Moderate	Fresh air supply 60 l/s/occupant	Fresh air supply 60 l/s/occupant Controlled access	Fresh air supply 80 l/s/occupant 6-12 ACH
	High	Fresh air supply 80 l/s/occupant 6-12 ACH Negative pressure Controlled access	Fresh air supply 80 l/s/occupant 6-12 ACH Negative pressure Controlled access	Supply-exhaust 160 l/s/occupant >12 ACH Negative pressure Controlled access

*7,5 l/s/occupant is the minimum fresh air supply required; for odour control 10 l/s/occupant is recommended

At least 6 Air Changes per Hour (ACH) should be achieved in existing buildings and 12 ACH in new buildings. 12 ACH provides a 99% reduction in suspended particles in 23 minutes (99.9% reduction in 35 minutes); equivalent to 80 l/s/

occupant for a room of 24 m3. See Chapter 6 for information on ACH, how to measure it and ventilation systems which may or may not be necessary to provide the above ventilation standards.

3.6 TB Laboratories

TB laboratories and particularly laboratories where liquid culture and Drug Susceptibility Testing (DST) are performed pose the highest risk of occupational TB. The risk is 3-9 times higher for laboratory workers than for general staff or the general population, and 3-5 times higher for TB laboratory workers performing these aerosol-generating procedures compared with other laboratory workers.

All TB laboratories, regardless of the procedures being undertaken or the level of procedural risk, should enact a set of essential biosafety measures to minimise risks. These measures affect:

1. Codes of practice
2. Equipment
3. Laboratory design and facilities
4. Health surveillance
5. Training
6. Waste handling.

For the purpose of this document the focus is on laboratory design. The proper design and construction of laboratory facilities contributes to the protection of all laboratory workers and provides a barrier which protects the community from TB aerosols which may be created by the laboratory.

Specific features of the laboratory, including separated laboratory areas and a ventilation system, are secondary containment measures. The secondary barriers which are recommended for a laboratory depend on the procedures conducted and their associated risk of transmission.

The following list identifies the basic recommended design features of a TB laboratory:

- Adequate ventilation and directional airflow are required.
- Ample space must be provided for the safe conduct of laboratory work, and for cleaning and maintenance.
- Walls, ceilings and floors should be smooth and easy to clean. Floors should be slip-resistant.
- Bench tops should be impervious to water, and resistant to the chemicals and disinfectants normally used in the laboratory; they should also be impervious to moderate heat.
- Illumination should be adequate for all activities. Undesirable reflections and glare should be avoided. Curtains must not be used.
- Laboratory furniture should be sturdy. Furniture should be made of impervious materials and able to be cleaned easily. No cloth-covered furniture should be used.
- Open spaces between and under benches, cabinets and equipment should be accessible for cleaning.
- Storage space must be adequate enough to hold supplies for immediate use and prevent clutter on bench tops and in corridors outside the laboratory. Additional space for long-term storage should be provided and conveniently located, but outside work areas.
- An area for the safe preparation, handling and storage of acids, stains and solvents should be established.
- Facilities for storing outer garments and personal items should be provided outside work areas.
- Facilities for eating, drinking, and for rest, should be provided outside work areas.
- A sink for hand washing and soap should be provided in each room in the laboratory, preferably near the exit. Automated or hands free taps are recommended. A dispenser for paper towels should be near the sink.
- Laboratory doors should have a glass window panel and appropriate fire ratings; they should be self-closing.
- There should be an adequate and reliable electricity supply.

According to the latest WHO Tuberculosis Laboratory Biosafety Manual [7] TB laboratories can be classified into three main levels of procedural risk, based on the activities being performed and their associated risks:

- Low TB risk
- Moderate TB risk
- High TB risk.

The probability of aerosols being generated is a key factor to consider in determining the level of risk, and the necessary mitigation or control measures.

Low-risk laboratories can:

- Manipulate sputum specimens for direct sputum-smear microscopy
- Manipulate sputum specimens for the Xpert MTB/RIF® assay (Cepheid, Sunnyvale Ca., USA).

The following biosafety requirements should be established in a low-risk TB laboratory:

1. Use of bench spaces: The bench used to process specimens for direct sputum-smear microscopy or the Xpert MTB/RIF assay should be separate from areas used to receive specimens and from administrative areas used for paperwork, telephones, etc.
2. Ventilation: Smears performed directly on sputum samples, and processing specimens for the Xpert MTB/RIF assay, may both be carried out on an open bench when appropriate microbiological techniques are used in an adequately ventilated area. Directional airflow refers to air flowing from clean areas towards areas where aerosols may be generated; this air should be safely discharged from the room.

Moderate-risk laboratories can:

- Process specimens for inoculation on primary solid-culture media
- Perform direct DST.

Procedures which liquefy specimens (such as those used during specimen digestion and processing for culture inoculation, direct DST or direct line-probe assays) have an increased risk of generating aerosols when compared to other techniques, even when good microbiological technique is used;

therefore, these procedures should be performed in a biosafety cabinet (BSC).

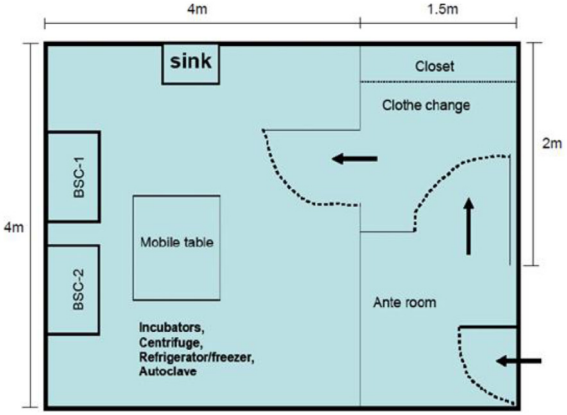
In a laboratory where there is a moderate risk of infection, there are two levels of containment: the BSC (primary containment) and the laboratory itself (secondary containment). To address the specific risks associated with a moderate-risk laboratory, the following mitigation and control measures should be established:

1. Biological safety cabinets: All processing and digestion of sputum samples and manipulation of liquefied sputum specimens must be conducted in a BSC. The cabinet is the primary form of containment while specimens are processed for culture inoculation or for performing direct DST. Hence, good microbiological techniques and proper use of the cabinet are critical to allow work to be conducted safely. Class I or Class II cabinets are recommended.
2. Ventilation: In addition to the BSC (the primary barrier), the secondary barrier is achieved by maintaining a unidirectional airflow into the laboratory, and by ensuring there is adequate ventilation.
3. Location: The laboratory must be separate from the areas which are open to unrestricted traffic flow within the building.

The moderate-risk laboratory can also be classified as a Biosafety level (BSL) 2 laboratory.

In summary, recommended building design requirements for BSL 2 laboratories are: separated from public areas, restricted access and lockable entrance door, impermeable and easily cleaned work surfaces, openable windows, air extraction system without re-circulation, separate areas for smear preparation and microscopy, culture and DST procedures, a BSC and a minimum size of 22 m^2.

Figure 2: Floor plan of a BSL 2 TB laboratory small



High-risk TB laboratories can:

- Manipulate cultures to identify TB bacilli
- Manipulate cultures or suspensions of TB bacilli for all indirect DST methods and molecular assays.

Manipulation of cultures for indirect DST or line-probe assays involves procedures where a high concentration of bacilli are present and a high risk of aerosol generation exists; such activities must be performed in a BSC within a TB containment laboratory.

Similar to moderate-risk laboratories, there are two levels of containment in a high-risk laboratory: the BSC (primary containment) and the laboratory itself (secondary containment).

In addition to the safety elements required for a moderate-risk laboratory, a high-risk laboratory requires the following additional enhancement:

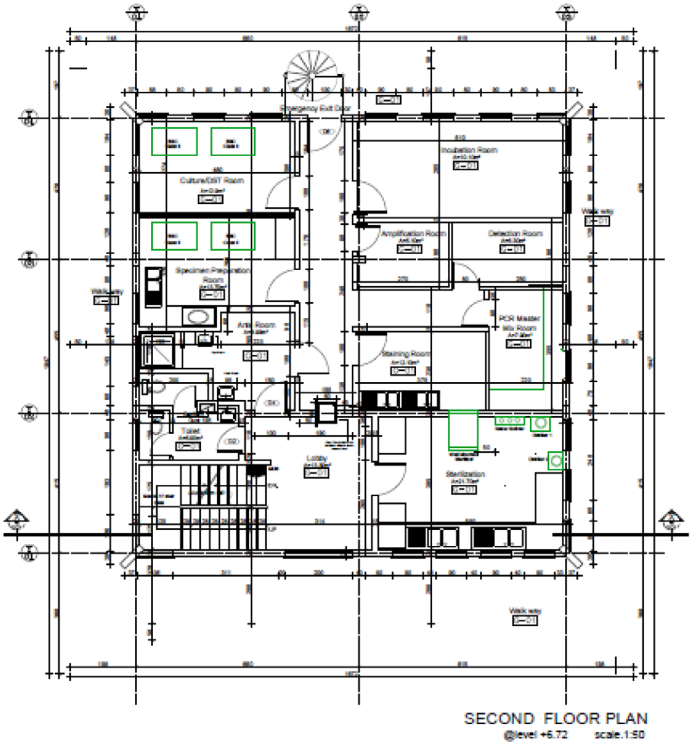
Anteroom: Two sets of entry doors are essential to create an anteroom to the containment laboratory. This design provides a physical barrier between the containment section of the laboratory and the outer laboratory areas. The anteroom should have facilities for separating clean clothing from dirty clothing. Doors to the anteroom should preferably be self-closing and interlocking so that only one door can be open at a time.

The high-risk laboratory can also be classified as a BSL 3 laboratory.

In summary, recommended building design requirements for BSL 3 laboratories are in addition to above BSL2 requirements: Stand alone building isolated and if necessary fenced from the general traffic patterns, double door entry (anteroom), pass through hatch, shower, emergency exit, surfaces which are water and disinfectant resistant, ventilation system providing 6-12 ACH, separate areas for smear preparation and microscopy, liquid culture, molecular testing, DST, disinfection and storage are required, and a minimum size of 75 m^2.

An example of a floor plan of a TB-containment laboratory is shown in Figure 3.

Figure 3: Floor plan of a BSL3 TB laboratory large (St Peter's TB laboratory)



Chapter 4: TB Infection Prevention & Control

4.1 Managerial Activities

The FMOH Guidelines for Prevention of Transmission of Tuberculosis in Health-care facilities, Congregate and Community settings in Ethiopia provide a package of interventions comprising of managerial activities, administrative controls, environmental controls and personal protective equipment.

Managerial activities include:

- Identify and strengthen coordinating bodies, and develop a facility plan which includes human resources, policies and procedures to ensure the proper implementation of the controls listed below
- Monitor and evaluate the implementation of the facility Infection Prevention and Control Plan
- Conduct facility risk assessments
- Rethink the use of available spaces and consider renovation and/or construction to optimise implementation of controls.

4.2 Administrative Control Measures

Administrative control measures are the first level of the hierarchy of controls and they include:

- Developing strategies to promptly identify potentially infectious cases (triage)
- Separating them
- Controlling the spread of pathogens (cough etiquette) and
- Minimising the time spent in health facility settings

Prioritising the early diagnosis of potentially infectious TB cases, promptly separating or isolating them safely and the prompt initiation of effective anti-tuberculosis treatment is known as the FAST strategy, where the acronym FAST in English stands for: Find cases Actively, Separate and Treat effectively.

Administrative control measures prevent the conditions for the spread of

contagions, by limiting the number and duration of encounters between susceptible persons and contaminated air. Ideally, if the risk of exposure can be eliminated, no further controls are needed. Unfortunately, the risk cannot usually be eliminated, but with proper the administrative control measures it can be significantly reduced.

Appropriate architectural design to support the functional and operational processes required for the administrative control measures, must be investigated as a priority and ensured via the design and layout of the facility. From a facility design perspective, administrative control measures can be addressed through the spatial separation techniques of functional separation, respiratory isolation, and separation for patient management.

Functional separation is the physical separation of functionally discrete parts of the health-care facility. Administrative functions and clinical support (admissions and discharge, accounts and finance, information services, medical records) should be substantially or exclusively reserved for staff use, and zoned separately. Nursing services, outpatient facilities, allied health services (radiology, pharmacy, rehabilitation) and visitors' spaces may be used by patients, staff and visitors, but should be laid out and managed so that the appropriate infection prevention and control measures are ensured. Finally, patient support, recreation settings and multi-patient wards should be accessible to patients, but not necessarily to all patients at all times, because of the risk of cross-infection.

Separation of paediatric and TB patients and by gender is generally required. It is highly recommended to have some accommodation for presumptive DR-TB patients and bacteriologically confirmed DR-TB patients requiring isolation whilst they are untreated or have been on treatment for less than 24-48 hours. The availability of several airborne precaution wards can allow patient cohorting according to DST pattern. Further refinement will be dependent on the individual facility policy, the size of facility (larger health-care facilities being more complex in nature) and whether it is primarily aimed at acute or sub-acute care.

Administrative control measures must also ensure the optimal operation of environmental control measures (see Section 4.3). This may include the

assignment of a member of staff to oversee environmental controls, open and close windows as appropriate, change filters, test environmental control measures periodically and perform preventive maintenance measures.

Whatever environmental control measures are in place, their adequate operation and preventive maintenance should be included in the administrative control measures through the facility Infection Prevention and Control Plan and their operational parameters and proper function should be documented and evaluated regularly.

4.3 Environmental Control Measures

Environmental protection methods should be the second most prioritised approach, after administrative control measures and before personal protection measures (which should be used as a last resort).

Two broad environmental control strategies can be identified:

- Dilution or ventilation, which results in the reduction in concentration of contaminated particles in a volume of air, and
- Disinfection by ultraviolet germicidal irradiation (UVGI), which is the partial or complete destruction (sterilisation) of micro-organisms in air. UVGI may be considered in very high-risk areas if the ventilation system does not achieve the recommended ventilation standard. Note: UVGI may be harmful to humans.

Dilution is most easily achieved by maximising air volume through the design of large spaces and by addressing ventilation, in particular the introduction of “fresh” air from a “safe” source (preferably outdoor air) to continually replenish indoor air as it is exposed to the occupants of the room.

The removal of contaminated air by dilution alone requires extremely large per-occupant ventilation rates to minimise risk. In most Ethiopian health-care facilities acceptable levels of room airborne contaminant removal cannot be sustainably accomplished by artificial ventilation alone. Its application is limited by engineering constraints and by cost.
The professional consultant team must consider the ventilation strategy in

the following prioritised sequence and only proceed to the next option if the previous one is not achievable or not feasible: natural ventilation, mixed-mode (hybrid) ventilation and finally mechanical ventilation.

The disadvantages of reliance on natural ventilation for infection prevention and control include climate dependence and impact on patient comfort, but the low cost of installation, operation and preventive maintenance should be considered as benefits. The continuous escalation in the cost of electricity and ever-present risk of power outages further support the need to design, wherever possible, for natural rather than artificial ventilation.

The ventilation capacity of any naturally ventilated building is dependent on:

- Wind direction and speed
- Building geometry
- Interior obstructions and flow paths
- Inner and outer temperature (buoyancy)
- Type and degree of envelope and building permeability
- Adjacent structures and building location
- Terrain
- Complimentary ventilation systems.

4.4 Personal Protection Equipment

In addition to administrative and environmental control measures, the recommended personal control measure for protecting facility staff from inhaling infectious droplet nuclei in high-risk DR-TB settings, is the use of respiratory protective devices. These are designed to fit over the mouth and nose and filter out infectious TB particles.

Respiratory protective devices for health-care workers which are capable of adequately filtering out infectious particles are more expensive than surgical or procedure masks. Nevertheless, their use in high-risk DR-TB settings is strongly recommended, particularly if the health-care worker themselves is HIV-infected. DR-TB settings pose a risk of undiagnosed extremely drug-resistant (XDR) TB. XDR-TB requires second-line DST which is currently not performed in Ethiopia.

Respiratory protection should only be used when other administrative and/or environmental control measures are fully implemented.

Acceptable types of particulate respirator include:

- NIOSH certified N95 respirators
- CEN certified FFP2/3 respirators.

Surgical (procedure) masks may be worn by patients in order to prevent the dispersion of respiratory droplets and to reduce the formation of droplet nuclei, but these do not adequately prevent airborne particles from being inhaled by the wearer.

An analysis of the facility design should be made with respect to where personal protective equipment (PPE) should be provided.

These include:

- Respiratory protection (typically FFP2 or N95 respirators for health-care workers, cleaning and maintenance staff, visiting consultants such as engineers and architects);
- Surgical masks (for patient use); and
- Protective eyewear for UV device monitoring and maintenance.

Dry, secure storage of bulk PPE supplies should be provided close to points of use. As respirators are costly and personalised (respirators cannot be shared) secure hanging/drying facilities which are clearly marked to avoid confusion are recommended. Stations are required for daily PPE supplies and for disposal facilities (bins) for discarded masks and respirators.

Chapter 5: Basic Concepts of Ventilation

5.1 Definition of Ventilation

Ventilation is defined as the movement and distribution of air in a room or building for the purposes of providing fresh air for breathing, diluting contaminants within the building and removing them outside. Ventilation is also used for odour control, containment control and climatic control (temperature and relative humidity).

Ventilation in a building has three main aspects:

1. Air flow direction: Air should move from clean to dirty areas
2. Ventilation rate: the quantity of air removed from or introduced into a room, measured by volume in a given time
3. Airflow pattern and air distribution: efficient movement and distribution of air in a given space..

5.2 Types of Ventilation

Three types of ventilation are used to drive air in buildings: Natural, Mechanical and Mixed Mode (Hybrid) ventilation.

Natural ventilation is the movement of air through purpose built openings such as doors and windows, and permanent openings such as chimneys and wind towers because of wind and buoyancy brought about by differences in pressure or temperature. The natural ventilation of buildings depends on prevailing climate conditions, building design and human activity.

Natural ventilation can address ventilation needs while avoiding many of the economic and environmental costs of mechanical ventilation. Concepts of natural ventilation are well-known and can be used as the basis for the design and operation of health-care facilities with special appeal in resource-poor contexts. However, natural ventilation for infection control in health facilities requires rather high outdoor air change rates due to the greater dilution needs as the airflow direction is less controlled [8].

Where the air quality, quantity and consistency within a space can be

maintained to a satisfactory degree, natural ventilation should always be the preferred solution.

Where natural ventilation alone cannot achieve the required air quality, quantity and consistency, mixed mode ventilation should be considered as the preferred solution to full mechanical ventilation.

Where mixed mode ventilation cannot achieve the required air quality, quantity or consistency mechanical ventilation may be considered as a solution.

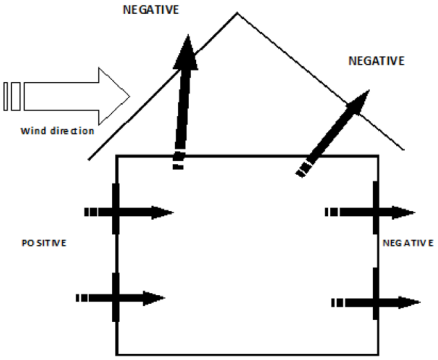
5.3 Driving Forces of Ventilation

The three driving forces moving air in a building are:

1. Wind pressure
2. Stack pressure (buoyancy)
3. Mechanical force.

Wind induces positive pressure on the windward side of the building and negative pressure on the leeward side. This causes air to move from the high pressure points to the low pressure points in the building and move outside through openings as shown in figure 4.

Figure 4: Wind induced flow directions in a building



Stack pressure or buoyancy is generated from temperature and humidity differences between the inside and outside of a building, causing an imbalance in pressure. When the room air is warmer than the outside air, the room air is less dense and rises, escaping through upper openings. Outside (cooler) air then moves into the room through the lower openings.

The natural forces of wind and stack drive natural ventilation, while mechanical fans drive mechanical ventilation.

Wind and stack forces are often combined to design an optimal natural ventilation system. Since the drivers of natural ventilation are inherently variable, natural ventilation has a high variability in effectiveness.

Natural forces and mechanical forces are combined in mixed mode (hybrid) ventilation. Mixed mode ventilation is considered as an assisted type of natural ventilation. Fans are used in combination with damper controlled ventilation openings to ensure minimum ventilation rates are achieved.

Chapter 6: Ventilation Systems

6.1 Natural Ventilation Systems

There are four design methods available for natural ventilation systems:

1. Cross flow (single loaded/side 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). For existing buildings with double loaded/central corridor type of architectural design, ways should be devised to improve natural ventilation (e.g. atrium or chimney type innovations).
2. Wind tower (wind catcher/wind extractor): the positive-pressure side of the wind tower acts as wind catcher and the negative-pressure side of the wind tower acts as wind extractor.
3. Stack (or buoyancy), simple flue/chimney: a vertical stack from each room goes through the roof without any interconnections; this allows for air movement based on density gradients.
4. Stack (or buoyancy), solar atrium: a large stack which heats up due to solar radiant loading, this induces air movement due to density (temperature) differentials; without radiant loading, the atrium provides minimal ventilation.

In the single-side corridor type of natural ventilation system, the corridor is on one side of the room (see Figures 5 and 6). The airflow is a single directional flow either from the room to the corridor or from the corridor to the room, depending on the incident wind direction. This single directional flow can help to prevent cross-infection. The design of the windows (see Figure 7) is crucial for this type of design: it is recommended to position the windows in line with the room's door to create a path for cross-ventilation.

Figure 5: Wind-driven natural ventilation in the single-side corridor type of design

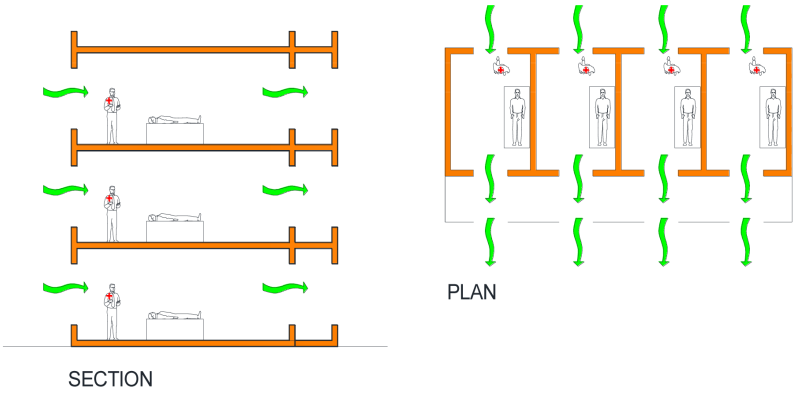


Figure 6: Wind-driven natural ventilation in the single-side corridor type of hospital with wind entering the corridor

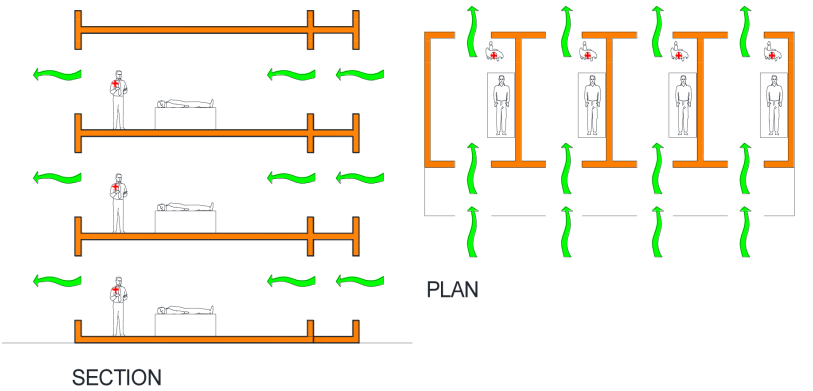
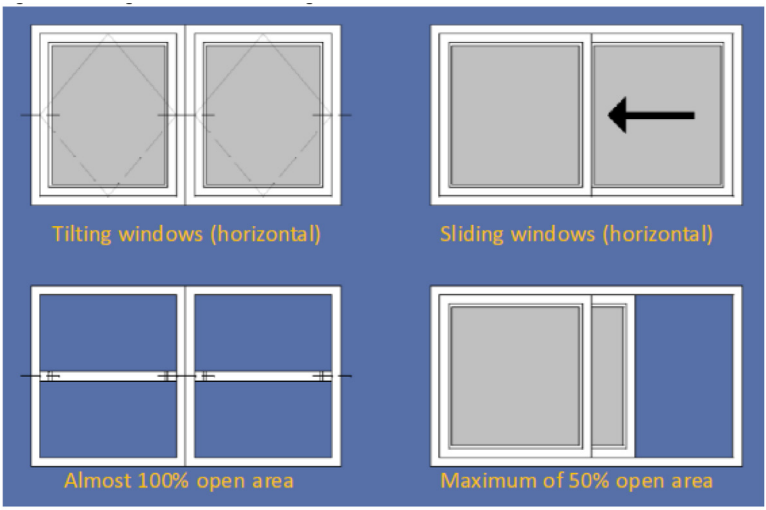


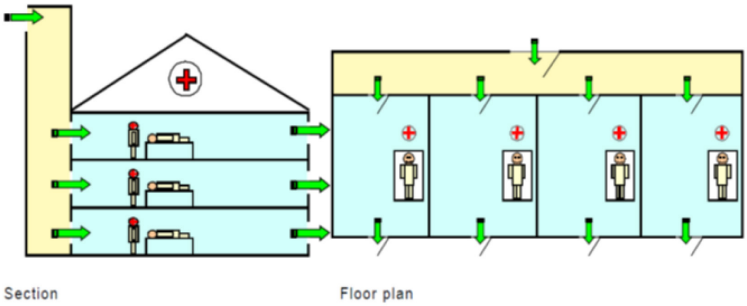
Figure 7: Tilting windows and Sliding windows



A wind tower type of natural ventilation system (see Photo 1 and Figure 8) can capture the wind at roof level and direct it down to the rest of the building. Weatherproof louvres are installed to protect the interior of the building and volume control dampers are used to moderate flow. Stale air is extracted on the leeward side. The wind tower can run the full length of the building and can extract or intake air depending on the wind direction.

Photo 1: Wind tower ventilation

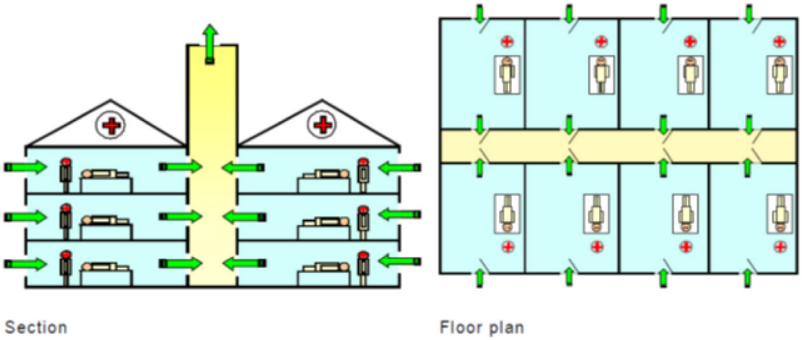
Figure 8: Wind tower over the full length



An atrium or chimney (see Figure 9) can help to increase the natural ventilation potential. An atrium or chimney type natural ventilation system can be a 'side-atrium or chimney type', or a 'central atrium or chimney type', depending on the relative position of the wards, and the atrium or chimney.

Outdoor air is sucked into the rooms through the windows by the stack (or buoyancy) effect. After diluting the contaminated air in the room, the hot and polluted air converges in the atrium or chimney and discharges through the top openings.

Figure 9: Buoyancy-driven natural ventilation in solar atrium or chimney type



The applicability of this type of design will mainly rely on the height of the chimney, the indoor–outdoor temperature difference and its interaction with the background wind. This approach may be combined with motor-driven dampers

and pressure sensors to control airflows and overcome some of the limitations of natural ventilation.

A limitation of natural ventilation systems is that they sometimes depend too much on the outdoor climate. For example, if the outdoor wind speed is too small or the outdoor temperature is too high, the availability of natural ventilation will be reduced. To overcome this, hybrid (mixed-mode) ventilation can be used.

6.2 Hybrid Ventilation Systems

Each of the natural ventilation solutions discussed above (single-corridor, wind tower, simple chimney and solar atrium) may be combined with mechanical fans to create a hybrid (mixed-mode) ventilation system.

In a simple hybrid (mixed-mode) ventilation system, mechanical and natural forces are combined in a two-mode system where the operating mode varies according to the season, and with individual days, reflecting the external environment and taking advantage of ambient conditions at any point in time. Mixed-mode ventilation systems are ventilation systems designed to use natural ventilation and change to mechanical ventilation when the airflow rate is not adequate.

The main hybrid (mixed-mode) ventilation types are:

- Switching between natural and mechanical ventilation: complementary systems
- Concurrent use of natural and fan assisted ventilation

Types of mixing fans include ceiling, standing on floor/desk, and window/wall mounted fans (see Photo 2). Mixing of air can disperse pockets of high concentrations of particles, such as those in the vicinity of the patients. They circulate air throughout a room but do not move it in any particular direction. The total number of infectious particles in the room will not change with mixing; the concentration of particles near the source may be reduced, and the concentration in other parts of the room may increase.

Exhaust fans are placed in windows, ducts, walls or the roof (e.g. wind-driven

whirlybirds as shown in Photo 3) to remove room air to the outside environment. Care must always be taken that contaminated air is removed to an outside area which is not frequented by people.

Photo 2: types of propeller fans: floor (A), desk (B), ceiling (C) and window (D) fan

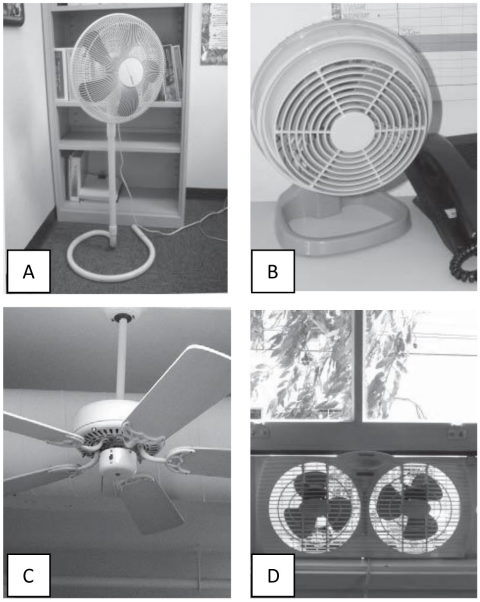
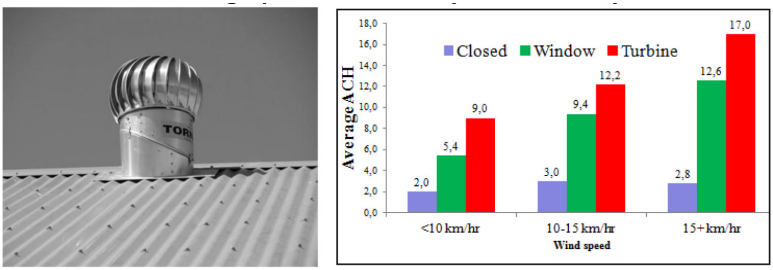


Photo 3: Whirlybird assisted natural ventilation resulting in increased air changes per hour as shown in the graph – the red bars (Source: H. Cox)

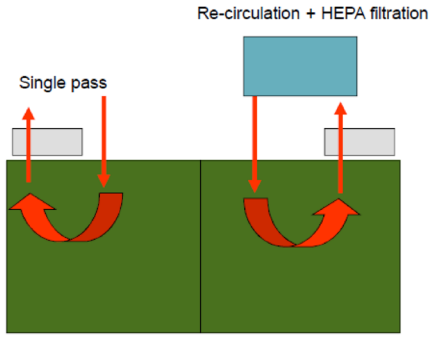


6.3 Mechanical Ventilation Systems

A ventilation system using fans which are installed directly into windows, walls or in air ducts for supplying air into or exhausting air from a room, is referred to as mechanical ventilation. Balanced mechanical ventilation refers to a system where air supplies and exhausts have been set to meet specific design specifications.

Rooms can be either at positive or negative pressure. Mechanical ventilation systems for the prevention of airborne infections work by generating negative pressure in the room to drive airflow inward, thereby achieving the containment of contaminated air. To be effective, it is essential that all doors and windows are sealed or kept closed. Supply-exhaust mechanical ventilation systems may be single-pass air systems or High Efficiency Particulate Air (HEPA)-filtered recirculation systems (see Figure 10).

Figure 10: Single pass and re-circulation mechanical ventilation

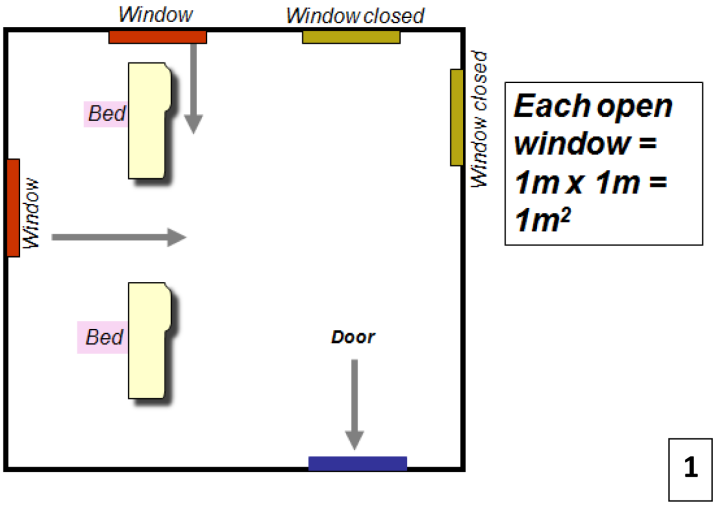


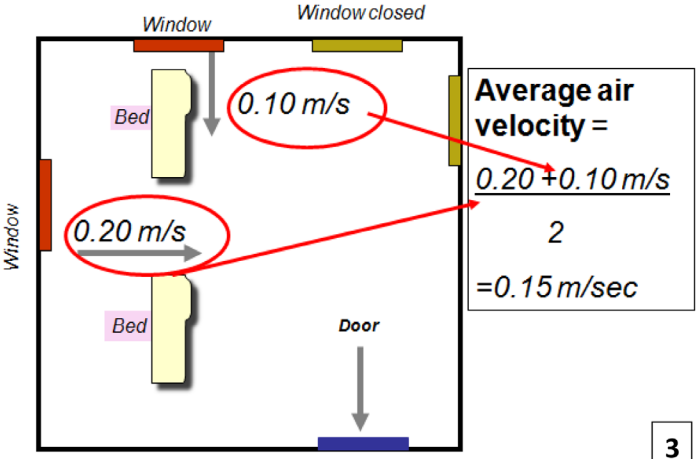
6.4 Assessing Ventilation Systems

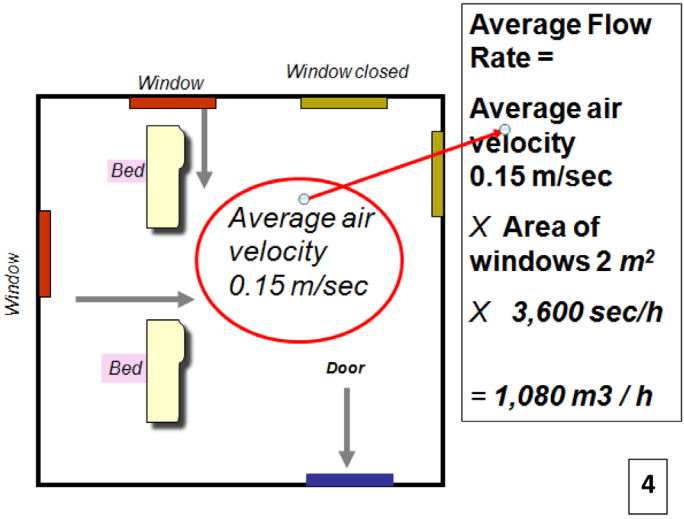
A room ventilation flow rate, also called Air Changes per Hour (ACH), can be calculated if both the volume of the room and airflow rate through the openings is known. The airflow rate is a function of speed of air in metres per hour, multiplied by the area of the openings. Keep in mind the direction of air changes frequently, especially with natural ventilation.

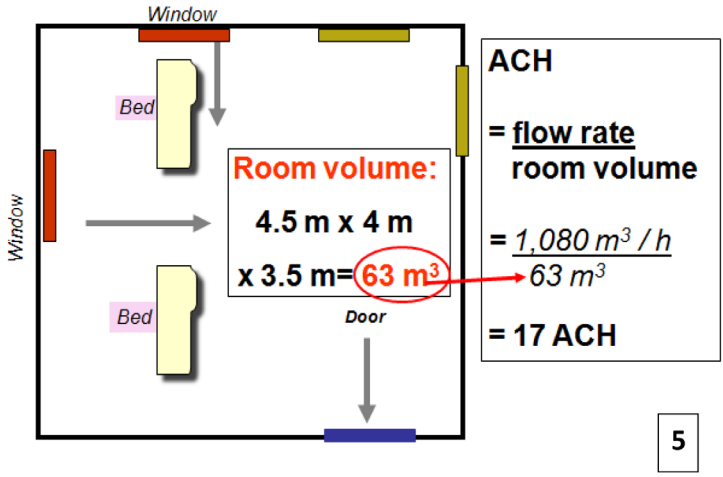
Average Flow rate = Average Air Velocity x Area of Window x 3,600 sec
ACH (Air Changes per Hour) = Average Flow Rate/Room Volume

Figure 11: ACH calculation (Source: Sondalo TB Infection Control course, G.B Migliori)




Window
Window closed
Bed
0.10 m/s
Average air velocity =
0.20 +0.10 m/s
2
=0.15 m/sec
Window
0.20 m/s
Bed
Door
3


Average Flow Rate =
Average air velocity 0.15 m/sec
X Area of windows 2 m²
X 3,600 sec/h
= 1,080 m3 / h
Window
Window closed
Bed
Average air velocity 0.15 m/sec
Window
Bed
Door
4



Ventilation systems should be monitored regularly to determine if they are functioning properly. The simplest evaluations use smoke, a tissue or a simple flow vaneometer or velocity meter (see Photo 4) to monitor proper airflow direction. The evaluation of negative pressure can also be done using a pressure sensor. Evaluations should be periodically documented in a maintenance logbook, by well-trained personnel.

The ventilation flow rate can also be measured by measuring how quickly injected tracer gas decays in a room, this method is not discussed in this document.

Photo 4: Deflecting vaneometer (A), rotating (B) and thermo anemometers (C)

Chapter 7: Design Concepts and Considerations for Natural Ventilation

7.1 Basic Design Concepts

There is a need to develop effective and appropriate engineering technologies and innovative architectural features to maximise the use of natural ventilation for different climatic conditions in Ethiopia. There are four major climate types: hot and humid, hot and dry, moderate, and cold. Natural ventilation systems should be designed to take the local climate into account.

The design of a natural ventilation system can have one of four major objectives:

1. To provide thermal comfort
2. To control indoor air quality
3. To save energy
4. To prevent and control airborne infection

Converting an existing building or designing a new building to use natural ventilation for preventing and controlling airborne infection would ideally include the presence of single-patient AIIRs with operable windows and ensuite toilets.

Unlike other types of building, when the prevailing wind direction and average air velocity may be used, the design of natural ventilation for AIIRs should consider the worst situation — that is, when the wind is absent, and where supplementary mechanical ventilation and/or air disinfection may be needed.

7.2 Developing the Design

Developing the design concept for a naturally ventilated building which incorporates airborne infection prevention and control involves three basic steps:

1. Specify the desired airflow pattern from the inlet openings, through the wards and other hospital spaces such as corridors, to the outlet openings.

This is associated with the four designs (cross flow, wind tower, chimney and atrium), location and organisation (relative location of the nursing station, offices, storage, etc.) of the building, which in turn depends on its intended use and site conditions, such as sun direction and prevailing winds.

2. Identify the main available driving forces which enable the desired airflow pattern to be achieved.
   The effective strategies for airborne infection prevention and control tend to be mostly wind- driven, although the stack-driven strategy may also work if designed properly. A combined wind-driven and stack-driven flow needs to be considered where necessary and feasible. In some cases, hybrid (mixed-mode) ventilation may be used with supplementary fans. In a good design, the available dominating driving forces are in synergy with the intended flow pattern.
3. Size and locate the openings so that the required ventilation rates can be delivered under all operating conditions.
   This is in itself a three-step process. 1. The ventilation rates need to be determined based on the risk of transmission. 2. The openings need to be sized and located to deliver these airflow rates under design conditions. 3. A control system needs to be designed to maintain the required airflow rates under varying weather and occupancy conditions.

A general procedure for natural ventilation design includes several components:

- **Architectural design:** Architects, engineers and facility staff must initially set the global geometric configuration of the system (e.g. siting of the building and landscape configuration, overall building form, and approximate positions of fresh air inlets and air exhausts), considering both dominant and prevailing wind conditions.
- **System layout and component selection:** The designer will then lay out the airflow paths from inlet to outlet which will achieve the desired airflow objective (e.g. for the purpose of infection control, indoor air quality and thermal comfort) and then select the types (e.g. cross- flow, wind tower, chimneys and solar atriums) which will provide the desired control of airflow.
- **Opening (door, window, vent etc) size:** The designer will then size the components selected considering the ventilation standards and

relevant climatic conditions. Both, the indoor and outdoor design conditions (or design criteria) need to be considered.

- **Design control strategy**: The designer must then develop a strategy for keeping ventilation in line with the design objectives when the operating conditions vary. At this stage, both hardware and software controls may need to be chosen to implement the control strategy if a high-tech natural ventilation strategy is used.
- **Detailed design drawing:** Finally, the designer must develop detailed drawings. After consultation with the facility staff and seeking their agreement on the detailed drawings as end-users, the systems can then be built.

Vent sizing: refers to the process of estimating the area of openings needed to achieve the required ventilation rates based on certain geometry, climate and other data of the building design. The sizing of openings is also a function of the opening distribution, which is a part of the ventilation strategy.

There are two methods for estimating the size of the vents required:

- Direct methods are derived for simple buildings where the ventilation rate is a simple function of the governing parameters
- Indirect methods use network models to try different opening size combinations and identify the best one. One promising design method is the loop pressure equation-based method.

After the required ventilation rates in each zone of a building have been estimated, these methods can be used to design the main flow paths and the size of ventilation openings to satisfy ventilation standards in each zone. When designing large buildings, designers might also need to know different design options, how natural ventilation compares with mechanical systems, etc.

When a building is designed and operated with a configuration of openings and flow paths, the ventilation rate will mostly be determined by the available natural driving forces. At the design stage, it is important to harness the prevailing winds and to enhance and control buoyancy forces in the building. This can be done by carefully positioning and sizing the openings, and by the use of wind towers, chimneys and solar atriums.

Designing natural ventilation requires more than just estimating vent and window sizes - it also requires innovative design by paying significant attention to the three layers of the design process related to natural ventilation design:

- Site design: building location, layout, building orientation, landscaping
- Building design: building type, function, form, envelope, natural ventilation strategy, internal distribution of spaces and functions, thermal mass, and a heating, ventilation and air conditioning (HVAC) system, if present
- Vent opening design: position of openings, types of openings, sizing of openings, control strategy.

Site design

Site design involves integrating the buildings with the surrounding topography and buildings. For some situations, minor changes to the local site may be allowed, within the limits of environment, surrounding community and wildlife protection. For natural ventilation, it is best to use the natural airflow patterns of the site to increase the potential of natural ventilation.

When several buildings are being built on one site, make sure each of the buildings is exposed to natural airflow. Vegetation also affects air movement around the buildings through wind sheltering, wind deflection, funnelling and air acceleration. Air quality and conditions are also changed when travelling beneath canopies of vegetation (e.g. trees).

Building design

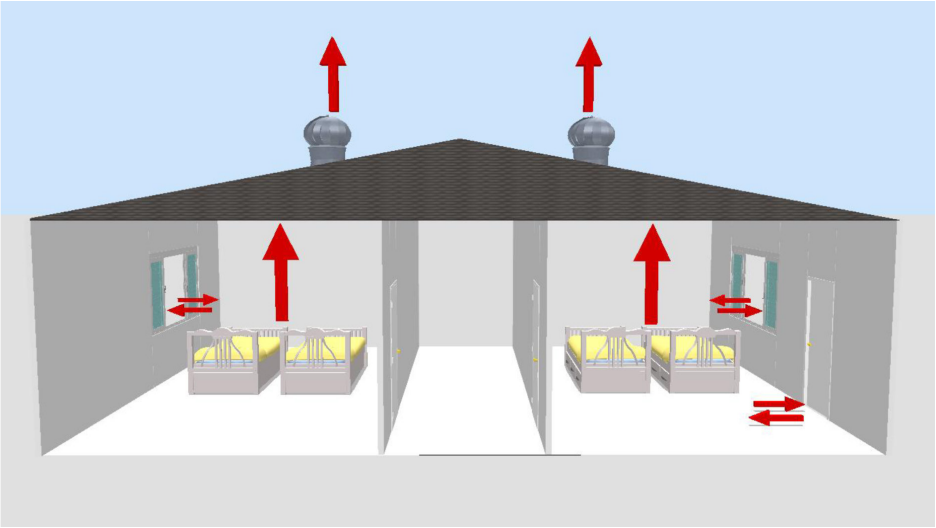
For simple buildings, use roof design, aspects ratios and the use of overhangs, wind walls and recessed spaces. For large and complex buildings, use computational fluid dynamics (e.g. Fluent 6.1, 2003, @ Fluent Inc.) to investigate various design options for improving the natural ventilation potentials, and to avoid cold draughts.

Internal space distribution is also important. For example, relatively “dirty” spaces should be located on the leeward side to avoid the back flow of contaminated and polluted air and odours into other spaces. Large windows for other living spaces on the windward side, such as the wards, can create a funnel effect to allow more incoming air. Interior partitions and furniture should

not block the airflow.

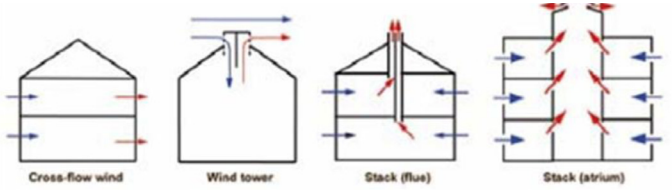
For airborne infection prevention and control, a single-row ward layout works better than a double-row layout with a central corridor, in terms of natural ventilation and daylight. For an existing central corridor layout, natural ventilation may be improved by combining cross-ventilation with stack ventilation through wind towers, wind-driven roof turbines, corridor vents or through shafts in multi-story buildings.

Figure 12: Use of Wind-driven Roof Turbines in case of central corridor type building



For multi-story hospitals, stairwells, wind towers, solar atriums and shafts can work as exhaust ventilation systems avoiding warm air entering the upper-level floors. The outlet openings of the shafts should be located on the leeward side of the building, above the top floor level, with the inlet openings on the windward side of the building.

Figure 13: Use of cross flow, wind tower, chimney and atrium in multi-story building



As the penetration depth of wind-driven natural ventilation is limited, the maximum width of the building is also limited. However, the use of wind towers and wind-driven roof turbines may permit deeper buildings.

Vent Opening Design

In any design, the smallest opening area (the bottleneck) controls the natural ventilation flow rate. Inlet and outlet openings should (as near as possible) have equal dimensions to maximise the airflow rate.

The position of openings needs to be considered with care, because of the possible conflict between cross- and stack (or buoyancy) ventilation, cold draughts or thermal mass cooling, etc.

Proper selection and design of openings such as windows, screens, louvres, wind towers, chimneys solar atriums and passive stacks, is also important. Proper sizing may be done using the vent sizing methods discussed earlier.

7.3 Design Considerations

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

Design considerations should include:

- Fire safety and smoke control
- Noise and air pollution
- Climate
- Location of TB settings
- Number of occupants
- Unwanted intruders

Fire safety and smoke control

High air-change rates are needed when airborne infection prevention and control is the main objective of the building design. The impact of high air-change rates on the overall indoor environmental conditions should be considered. As mentioned before, these include thermal comfort, indoor air quality and also fire safety.

Designing a naturally ventilated building may conflict with fire safety and smoke control standards. Ventilation openings may need to be closed during a fire. Fortunately, naturally ventilated buildings can be designed to be in line with the compartmentalisation requirement for smoke control. The fire escape route needs special attention, because natural ventilation designs also have an impact on smoke flow patterns.

Noise and air pollution

Other unfavourable ambient environmental factors such as noise and air pollution, and their impact on indoor environmental quality have to be assessed before building design begins.

Climate

When a ventilation type is evaluated against a climate type, thermal comfort, air quality and infection prevention and control should be considered, but not energy-saving performance.

Table 3: Comparison of types of natural ventilation systems in the four major climates

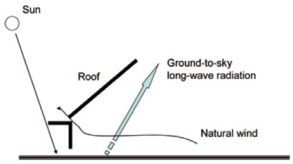
Climate type	Natural ventilation design type			
	Cross-flow	Wind tower	Chimney	Atrium
Hot and humid	+	-	-	-
Hot and dry	++	++	-	-
Moderate	++	++	++	++
Cold	-	-	+	+

Climatic extremes may require some adjustments to ensure that minimum ventilation standards are achieved. When the ambient air temperature stays above 30 °C, the thermal conditions in a naturally ventilated room may become intolerable.

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 the ground to sky to occur (see Figure 14).

The semi-opening should be on the shaded side of a building to avoid direct solar irradiation — this is how a sunshade works. Solar heat gain should be minimised by using proper external shading or 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, which fortunately is in line with the desired airflow patterns for airborne infection prevention and control.

Figure 14: Semi-open design allowing ground-to-sky thermal radiation



The following design considerations should also be made in designing for warm to hot climates:

- Minimise solar heat gain through proper use of sunshades, external shading or verandas.
- Use outdoor shaded waiting areas to the greatest possible extent.
- Where augmentation of ventilation is required, use of air supply fans may help improve thermal comfort, compared to exhaust fans.
- The use of evaporative coolers (“desert coolers”) may be an effective solution to achieve both comfort and adequate ventilation, as these tend to have powerful fans. However, proper preventive maintenance, is essential.
- Air conditioners are to be avoided or used with caution in patient care

areas. If air conditioners are used, it must be acknowledged that the need to maintain adequate ventilation for airborne infection prevention and control may compromise the comfort of room occupants and the efficiency of the air conditioner.

- Planting trees to encourage thermal comfort and also to serve as buffer for extreme conditions.
- Use construction materials which reflect light and heat.
- The installation of whirlybirds (also known as whirligigs) which do not use electricity and provide a roof exhaust system, can greatly increase both ventilation and comfort.

In cold climates, the need for warmth inside the building can be at odds with the high air-change rate needed for airborne infection prevention and control. 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 minimise conduction loss through the wall. Proper insulation of walls and the use of double glazing are desirable.

Where augmentation of ventilation is required, the use of air exhaust fans may help maintain adequate ventilation, even where windows or doors are closed.

When considering active heating strategies, targeted radiant or direct near-body heating methods are more effective, and are preferred for two reasons:

1. Due to buoyancy effects, the warm air from the common convective radiators tends to float to the upper part of a space.
2. At a high air-change rate, heat loss is excessive.

Modern, electric radiant heaters are readily available, and are a better option than other commonly used electric radiators.

Patients and attendants should be encouraged to wear more clothes and extra blankets should be provided especially when the weather is very cold, so that adequate natural ventilation can be achieved by opening windows.

In transient seasons of hot and humid climates, moisture condensation in the room interior can lead to wet bedding, floors and ceilings, and mould and mildew growth.

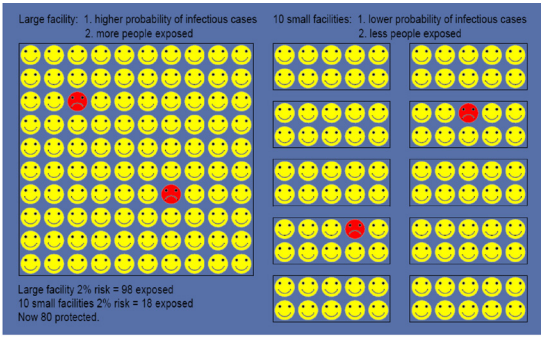
Location of TB settings

Locating respiratory wards on the top floors may be desirable in high-rise buildings as this minimises 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. If space is available, a separate block for TB and DR-TB patients may be a better option than keeping patients on the top floor of a multi-story building as patients may move around and come into contact with vulnerable patients.

Number of occupants

Smaller areas with less occupants reduce the risk of transmission by an infectious patient as illustrated in figure 15.

Figure 15: Transmission risk in large areas with many occupants exposed versus risk in separated small areas with few occupants exposed



Unwanted intruders

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, large openings in the building envelope make it easier for insects, wild animals and other unwanted intruders, and may cause problems relating to security and vector-borne infectious disease control. Purpose-designed barred windows (particularly on ground floors) and semi-transparent mosquito meshes can be used in these situations.

Chapter 8 Ultraviolet Germicidal Irradiation

8.1 The UV Spectrum

For convenience the UV spectrum is described in three different wavelength bands: UVA (long wave lengths, range: 320–400 nanometres [nm]), UVB (midrange wavelengths, range: 290–320 nm) and UVC (short wave lengths, range: 100–290 nm).

Figure 16: The UV Spectrum

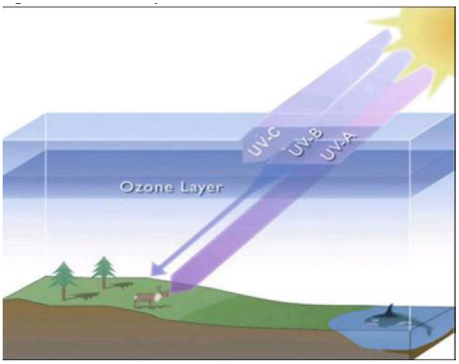
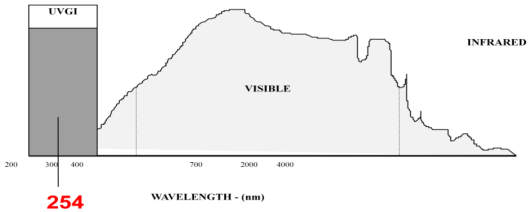


Figure 17: Wavelength ranges



UVC is unlike UVA and UVB, as it has extremely low penetrating ability. Ultraviolet germicidal irradiation (UVGI) is a form of electromagnetic radiation with wavelengths between the blue region of the visible spectrum and the radiograph region, and is not visible (the blue glow from a UV lamp is not the germicidal wavelength). UVC radiation can be produced by various artificial sources. The majority of commercially available UV lamps used for germicidal purposes are low-pressure

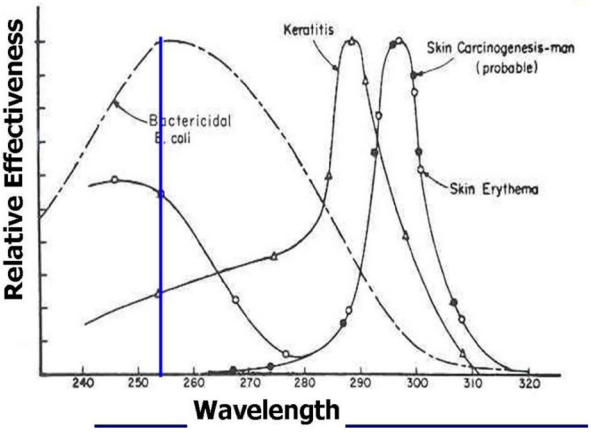
mercury vapour lamps which emit radiant energy in the UVC range, predominantly at a wavelength of 254 nm.

8.2 Potential Health Hazards of Ultraviolet Radiation Exposure

UVC is nearly completely absorbed by the outer layer of the skin, where little or no harm is caused. Although listed as a potential carcinogen, UVC is unlikely to be carcinogenic or to cause skin or eye irritation if applied correctly within exposure limits as set out by the International Radiation Protection Agency and other international health bodies.

Various biological effects have been established in humans and laboratory animals. The skin, immune system and eyes are target organs for UV. The potential hazard to the skin and eyes varies with wavelength and is indicated by an action spectrum.

Figure 18: Germicidal and Hazardous wavelengths



Ultraviolet radiation exposure could result in acute and chronic effects, such as erythema (diffuse skin redness) and photosensitisation. Erythema follows a dose-dependent latency period of 2–10 hours. Photosensitivity involves an abnormal skin reaction to ultraviolet radiation in the presence of certain chemical agents, for example coal tar, colognes, lipsticks, cosmetics, hair preparations, psoralens and sunscreens. Photosensitivity reactions are characterised by

eruptions on exposed parts of the body, for example the face, arms and hands. Photosensitivity reactions are either phototoxic or photo-allergic. The former is more common than the latter and can be of either an acute or a chronic nature.

UVC and UVB wavelengths of less than 300 nm are highly absorbed by the corneal tissues of the eye. As the UV wavelengths increase beyond 300 nm, they are increasingly absorbed by the lens of the eye. Photokeratitis and conjunctivitis are dose-dependent inflammations of the tissues of the cornea and conjunctiva, respectively. Typically, the onset of signs and symptoms follows overexposure by about 6–12 hours although they have been observed in as little as 2 hours and as long as 24 hours. Signs and symptoms include: pain, twitching of the eyelids, tearing, congestion of the conjunctiva, photophobia, visual haze and a scratchy feeling in the eyes. In addition, erythema may develop on the eyelids and the skin around the eyes. These effects may be incapacitating for up to two days. Permanent effects however, are rare.

Due to the health effects of UV radiation exposure, the American Conference of Governmental Hygienists (ACGIH), the National Institute of Occupational Safety and Health (NIOSH, 1972) and the International Radiation Protection Association (IRPA, 1985), have recommended occupational exposure limits which apply to wavelengths between 180 and 400 nm.

The occupational exposure limits of the ACGIH are called threshold limit values. All of the exposure limits are for acute effects to the skin and eyes. They are given as a measure of irradiance and radiant exposure. The UVC–irradiance at eye level must be <0.2 microwatt/cm2. The maximum radiant exposure is 6000 microjoule/cm2 over an 8-hour limit.

8.3 Upper-room UVGI

A dose of 10,000 microjoule/cm2 inactivates 99% of the TB bacilli. UVGI can be equivalent to 10-20 ACH, but air disinfection is decreased if air mixing is incomplete, therefore only well-designed and well-characterised UVGI systems should be used.

There are two commercially available types of UVGI fixtures:

- Open fixtures with upward facing metal flanges called shields: The base of the lamp is shielded to direct the radiation upward and outward to create an intense zone of UVGI in the upper room while minimising the level of UVGI in the lower (occupied) portion of the room. Shielded UVGI fixtures may be used in rooms with ceilings as low as 3.20m.
- Fixtures with louvers: The louvers provide a horizontal irradiation beam which prevents reflection from the ceiling, but these units are (up to four times) less efficient than shielded units because of the louvres. Louvered UVGI fixtures may be used in rooms with ceilings as low as 2.80m.

UVGI fixtures are generally suspended from the ceiling or installed on walls. Ceiling mounted units function well in square or oblong rooms with moderate width/length dimensions. These units provide a 360 degree irradiation radius. If the rooms are too small, reflection from the walls might be a problem. Ceiling mounted units are heavy, normally more than twice the weight of wall mounted units, so the load bearing capacity of the ceiling/roof structure must be investigated before a decision is made. The correct position of the unit may interfere with existing services in existing buildings.

Photo 5: Ceiling pendant shielded (A) and louvered (B) fixtures (Courtesy: J ter Stege)

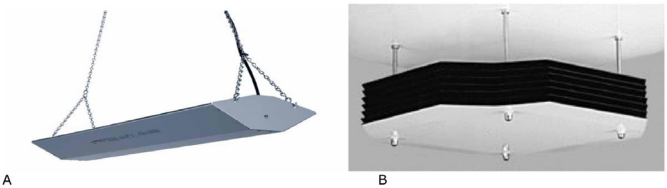
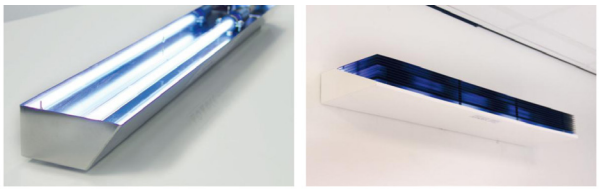


Photo 6: Wall mounted shielded (C) and louvered (D) fixtures (Courtesy: J. ter Stege)



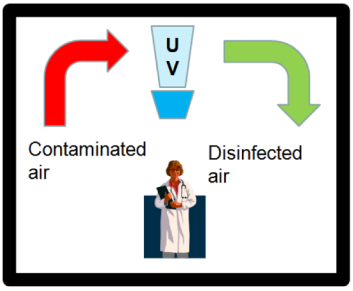
Upp used in high-risk ar-

eas where ventilation standards cannot be met at all times. Upper-room UVGI systems are considered supplemental to ventilation systems especially in larger rooms. Also, as an adjunct to ventilation systems, upperroom UVGI can be used in AIIRs where presumptive or confirmed DR-TB patients are isolated or in service areas where high-risk procedures are performed (e.g., bronchoscopy, sputum induction).

The most common way to generate germicidal UV radiation in the lamps used in UVGI systems is to pass an electrical charge through low-pressure mercury vapour enclosed in glass tubes which only transmit certain UV wavelengths. Low-pressure mercury lamps should be rated for 'low' or 'no' ozone generation. Since all lamps must eventually be discarded, each lamp should only contain a relatively small quantity of mercury (i.e., 5mg or less). Care must be used when selecting the correct UVGI lamp for use in upper-room UVGI systems. Typically, the optimal wavelength for UVGI is 254 nanometres (nm) in the UVC range. UVC measurements will ensure that the lamps are truly UVGI lamps, emitting radiation at 254 nm.

UV lamps are made for a variety of purposes which may have a negligible consequence in killing airborne microorganisms. These lamps are available on the market but are not capable of inactivating TB bacteria. Some UV lamps (such as those used for tanning) radiate energy in the UVA and/or UVB range and over extended periods may have adverse health consequences for exposed persons. Other UV lamps are designed to emit radiation at 184.9nm and produce ozone, which is hazardous to humans even at low concentrations.

Figure 19: Contaminated air passing through the upper-room for disinfection



8.4 Installation of upper-room UVGI

Before the procurement and installation of a UVGI system, a professional who is knowledgeable in upper-room UVGI systems design and installation should be consulted. Only (qualified) service technicians who have received training on the installation and placement of UVGI lamp fixtures should install the systems, however the number of persons properly trained in the design of upper-room UVGI systems is currently limited..Following installation, UV lamps require on-going performance testing, maintenance and replacement by suitably skilled technicians. This consideration may be a limiting factor in the use of the devices.

Preparing for the installation of an upper-room UVGI system:

- Find a suitable consultant: specialised expertise and equipment are required to establish effective upper-air UVGI.
- Only a qualified contractor, working closely with a UVGI system's supplier and UV lamp manufacturer's representative, should attempt the design, installation, and testing of an upper-room UVGI system.
- Contact a number of UVGI lamp manufacturers. Ask each of them for the names and addresses of experienced consultants and contractors.
- Interview suggested consultant companies or individuals about their experiences with previous installations.
- Ask the consultant to arrange a visit to a successful installation site.
- Talk to the contractor about the possibility of arranging a service contract for system monitoring and replacement of the lamps after the installation.
- In the installation contract, include measurements of radiation levels after installation.

Instructions for the installation of an upper-room UVGI system:

Qualified Contractor:

- Locate UVGI fixtures so that radiation in the upper-room is uniform, continuous and complete.
- The on/off switch for the UV lamps should only be accessible to designated members of staff; not to patients, who may turn off the fixtures.

- Take radiation measurements following the 'Extensive Efficacy Test' (see section 8.6). Submit a written report to the facility management.
- If meter readings indicate excessive radiation in the occupied area, the ceiling may need to be painted with non-reflective paint. This should be included in the budget for the planned installation. Paint containing titanium dioxide is recommended to reduce reflections.

Facility Staff:

- Post warning signs, in all appropriate languages, on the UVGI fixtures and on the walls.
- Staff and/or patients may have concerns regarding health hazards from UVGI. To address these concerns, provide education on the purpose, benefits and risks associated with upper-room UVGI.
- Also, consider posting an information sheet on the wall of the room.

8.5 Effectiveness of UVGI systems

Factors influencing effectiveness of upper-room UVGI systems include:

- Irradiance and dose
- Ventilation rates
- Level of air mixing
- Relative humidity, and to a lesser extent,
- Temperature

Irradiance and dose: A well-designed upper-room UVGI system is effective in inactivating most airborne droplet nuclei containing TB bacilli if designed to provide an average UV fluence rate in the upper room. When using fixtures with louvers, an average intensity of greater than 10 microwatts/cm2 in the irradiated zone is recommended, however variance within the test-points is also of great importance (GLA, Germicidal Lamps & Applications: manufacturer's product specifications).

Ventilation rates: As the mechanical ventilation rate in a room is increased, the total number of microorganisms removed from the room via this system also increases. However, when mechanical ventilation is increased in a room where an upper-room UVGI system has been deployed, the effectiveness of the UVGI system may be reduced when it exceeds 6 ACH because the

residence time of the bacteria in the irradiated zone decreases.

Level of air mixing: Upper-room UVGI systems rely on air movement between the lower portion of the room where droplet nuclei are generated and the upper irradiated portion of the room. Once in the upper portion, droplet nuclei containing TB particles may be exposed to a sufficient dose of UVGI to kill or inactivate them. When upper-room UVGI systems are installed, general ventilation systems should be designed to provide optimal airflow patterns within rooms and to prevent air stagnation or short circuiting of air from the supply diffusers to the exhaust grills. Also, hot and cold seasons should be considered and the system should be designed to provide for optimal convective air movement. Consideration of the drop and throw parameters of selected ventilation air terminals is critical to ensuring good mixing under all seasonal conditions. Most rooms or areas with properly installed supply diffusers and exhaust grills should have adequate mixing. If areas of air stagnation are present, air mixing should be improved by the addition of fans or the repositioning of the supply diffusers and/or exhaust grills. If there is any doubt about vertical air mixing between the lower and upper portions of the room due to environmental or other factors, fans should be used to continually mix the air. In a room without adequate air mixing under experimental
laboratory conditions, the UVGI system effectiveness increased by up to 72% when a mixing fan was used.

Relative humidity: A number of studies have indicated that the effectiveness of upper-room UVGI systems decreases as humidity increases. The reason for the decrease in UVGI effectiveness is not clearly understood, but the effect needs to be considered in the general context of upper-room UVGI systems.

For optimal efficiency, relative humidity (RH) should be controlled to between 25% and 60% where upper-room UVGI systems are installed. This is consistent with the American Institute of Architects (AIA) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommendations that the RH affecting patient care areas in hospitals and outpatient facilities range from 30% to 60% RH. If high humidity conditions are normal, it may be necessary to install a system with greater than normal upper-room irradiance levels.

Temperature: Recommendations developed by the ASHRAE and AIA stipulate that the temperature for most areas affecting patient care in hospitals and outpatient facilities range from 20 to 24 °C. This temperature range is consistent with the optimal use of low pressure mercury lamps which are used in upper-room UVGI systems.

8.6 Assessing UVGI systems

An extensive efficacy test should be performed before installation and should preferably be included in the bid specifications.

A performance monitoring test should be done on each lamp every 6 months. The performance monitoring test should be compared with the extensive efficacy test. Based on the outcome of the performance monitoring test, the interval can be shifted to annual testing.

After the installation of a fixture and after changing bulbs, a safety test should be done.

The efficacy, performance monitoring, safety tests and checklists are described in detail on the following pages.

Extensive Efficacy Test (Source: G.L.A. Germicidal Lamps & Applications The Netherlands)

h_c = ceiling height relative to floor

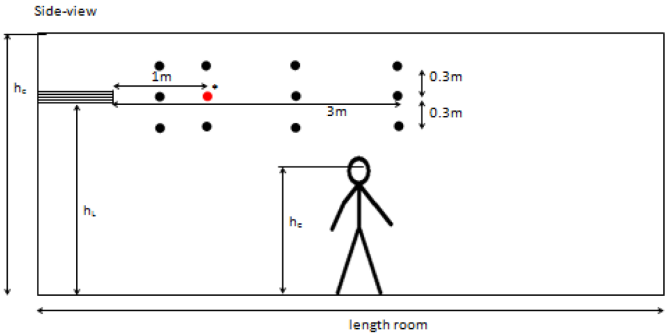
h_L = height lower side lamp relative to floor

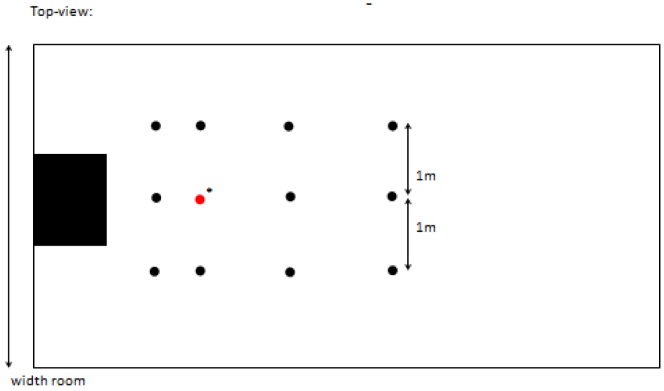
h_e = average height of eyes is 170cm, relative to floor.

$H_c - h_L$ = 50cm or more

$h_L - h_e$ = 60cm

* = measuring point used for performance monitoring test





CHECKLIST Extensive Efficacy Test – UVC-irradiance

DATE:
Location:
Name and position of person which performed the test:
Temperature ± 25°C, RH <60%: (if not mention otherwise)
Ceiling white plaster +50cm higher then bottom of fixture: (if not mention otherwise)
Brand and type bulb:
Measuring device IL1400 (if not mention otherwise)

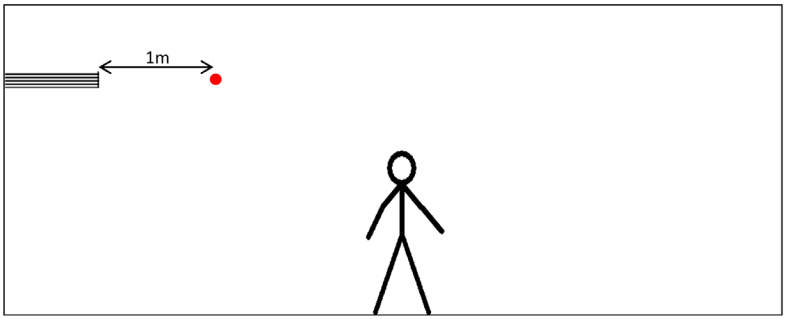
Position in regard to fixture	Distance from fixture	Irradiance
	[cm]	[microwatt/cm2]
Straight in front, height-level with centre	50 cm	
Straight in front, height-level with centre	100 cm	
Straight in front, height-level with centre	200 cm	
Straight in front, height-level with centre	300 cm	
1 metre left, height-level with centre	50 cm	
1 metre left, height-level with centre	100 cm	
1 metre left, height-level with centre	200 cm	
1 metre left, height-level with centre	300 cm	
1 metre right, height-level with centre	50 cm	
1 metre right, height-level with centre	100 cm	
1 metre right, height-level with centre	200 cm	
1 metre right, height-level with centre	300 cm	
Straight in front, +30 cm from level	50 cm	
Straight in front, +30 cm from level	100 cm	
Straight in front, +30 cm from level	200 cm	
Straight in front, +30 cm from level	300 cm	
1 metre left, +30cm from level	50 cm	

1 metre left, +30cm from level	100 cm	
1 metre left, +30cm from level	200 cm	
1 metre left, +30cm from level	300 cm	
1 metre right, +30cm from level	50 cm	
1 metre right, +30cm from leve	100 cm	
1 metre right, +30cm from leve	200 cm	
1 metre right, +30cm from leve	300 cm	
Straight in front, -30 cm from level	50 cm	
Straight in front, -30 cm from level	100 cm	
Straight in front, -30 cm from level	200 cm	
Straight in front, -30 cm from level	300 cm	
1 metre left, -30cm from level	50 cm	
1 metre left, -30cm from level	100 cm	
1 metre left, -30cm from level	200 cm	
1 metre left, -30cm from level	300 cm	
1 metre right, -30cm from level	50 cm	
1 metre right, -30cm from level	100 cm	
1 metre right, -30cm from level	200 cm	
1 metre right, -30cm from level	300 cm	

Performance Monitoring Test (Source: G.L.A. Germicidal Lamps & Applications The Netherlands)

Performance monitoring should be done on each lamp every 6 months. Based on the outcome of the performance monitoring test, the interval can be shifted to annual testing.

Measuring point: 1 metre in front of the UV-lamp, height level centre of fixture



Compare the outcome to the output of the same measuring point of the extensive efficacy test.

CHECKLIST Performance monitoring test – UVC irradiance

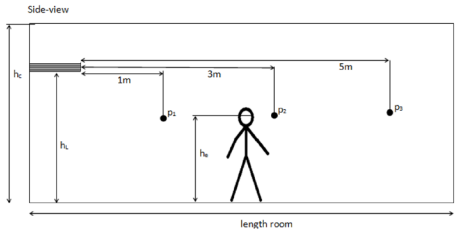
DATE:
Location:
Room Number:
Name and position of person which performed the test:
Temperature ± 25°C, RH <60%: (if not mention otherwise)
Ceiling white plaster +50cm higher then bottom of fixture: (if not mention otherwise)
Brand and type of bulb:
Measuring device IL1400 (if not mention otherwise)
Date of next bulb replacement:
Date of next performance monitoring test:

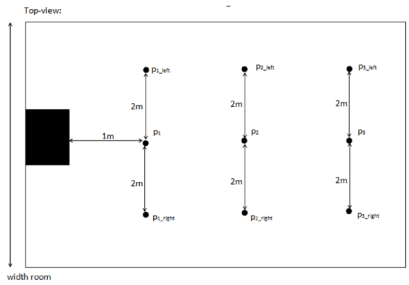
Location	Lamp Number (if required)	Irradiance
		[microwatt/cm^2]
	nr.1	
	nr.2	
	nr.3	

Safety Test (Source: G.L.A. Germicidal Lamps & Applications The Netherlands)

Always perform after installation fixture and after changing bulbs. Set-up for safety test: standard white plastered ceiling.

H_c = ceiling height relative to the floor
h_L = height lower side lamp relative to the floor
h_e = average height of eyes is 170cm, relative to the floor.
H_c – hL = 50cm
h_L – he = 60cm





CHECKLIST Safety-Test – UVC-irradiance

DATE:
Location:
Name and position of person which performed the test:
Temperature ± 25°C, RH <60%: (if not mention otherwise)
Ceiling white plaster +50cm higher then bottom of fixture:
Brand and type of bulb:
Measuring device IL1400 (if not mention otherwise)

Test set-up:	Distance [cm]
length room	
Width room	
	Height [cm]
h_c	
h_L	
h_e	

Location: Room nr: Date of next bulb replacement: Date of next safety test:	

Maximum value, move the sensor in the direction of the lamp and find the maximum value.

Measure points:	Irradiation [microwatts/cm^2]	Comments (near window or when abnormal values are measured)
p1		
p2		
p3		
p1_left		
p2_left		
p3_left		
p1_right		
p2_right		
p3_right		

Chapter 9 Planning, Use and Preventive Maintenance

9.1 Project Planning & Design Stages

It is critical that engineers and architects are involved in the early stages of a project's initial planning, studies, investigations and assessments. Exclusion or late inclusion of an engineering team from the planning stages of a construction project presents a considerable risk of unnecessary expenditure and design delays which ultimately compromise the functional and build quality of the product. The added value of the early inclusion of building service professionals is frequently underestimated.

Table 4: Design stages and deliverables

Stages	Deliverables
Need identification	Request from end users
Inception	Assessment, project brief and team established
Project definition	Preliminary design, cost estimates and approval from all stakeholders
Design and specification development	Finalised design, drawings and financial plan
Procurement	Bid document, tender process, selection of contractor and signing of contract agreement
Construction work	Site handover to winning contractor, scheduled inspections, evaluations and supervision
Provisional acceptance	Completion and preliminary handover
Evaluation	Final inspection, validation and operations & maintenance manual
Final acceptance	Redressing construction shortcomings (up to one year for major renovations)

The performance of a ventilation and UVGI system depends entirely on the design, operation and preventive maintenance — collectively known as commissioning. These factors determine the performance and reliability of the system and are important whatever the level of technology used.

Proper construction and commissioning are needed to ensure the recommended building design and environmental engineering standards and

requirements are achieved under different (climatic) circumstances, while proper operation and preventive maintenance are needed to ensure these requirements throughout the system's lifetime.

The successful commissioning of the installed ventilation or UVGI system depends on the successful completion of the following steps:

- Defining performance and functional building design and engineering requirements as identified during the project definition stage
- Ensuring that the performance and functional building design and engineering requirements are met by the design and specification
- Validating that the system performs and functions as intended. An independent authority should validate the performance and functioning of the system.

In the design development stage and as part of the financial plan, the engineer/architect must assist in developing the facility lifecycle cost by giving input into the lifecycle cost estimates.

9.2 Operations and Maintenance Manual

Even for a very low-tech system (e.g., using grilles and vents), it is important that the documentation describing the reasons for the design, how it works and how it should be maintained be handed over to the building manager or operator. For example, design and maintenance documentation describing why vents are of a certain size and in certain places will enhance the understanding of the system and help to ensure it is maintained properly.

The designers need to provide documentation to the personnel managing the building and its ventilation and UVGI system, if applicable:

- About the design strategy and expected operation of the natural or hybrid (mixed- mode) ventilation system
- On the operation of the natural or hybrid (mixed-mode) system during the day or night, in different seasons, in extreme weather conditions, and when adapted for emergency conditions
- Explaining to the patients and personnel how the building works, is

operated, and who has the right to open windows, etc
- Describing the operation and preventive maintenance of the ventilation system, developed jointly with the personnel (i.e., an operations and maintenance manual) and
- Explaining all the above (i.e., commissioning documentation).

It is desirable that the personnel using the systems have the opportunity to provide feedback to the designers, however simple the system. Feedback and fine-tuning are essential to iron out potential problems in the systems, and should continue for the first year of operation.

The commissioning process acts as a checking procedure to ensure that:

- The systems are installed and operated as designed
- The systems can be operated correctly and safely
- The systems may be adjusted to satisfy the building design and engineering requirements at different climatic conditions
- Ventilation rates under different weather conditions are appropriate.

The personnel should understand how the systems for airborne infection prevention and control operate. Instruction should be given to these personnel based upon the operation manual.

Assigned personnel need to be trained in the procedures to follow. Patients are generally not permitted to operate the systems unless instructed to do so (this includes opening windows).

Natural ventilation or hybrid (mixed-mode) ventilation usually have many distributed components, such as windows and fans. Detecting faults in these components can be time consuming.

It is crucial for any health-care facility designed for airborne infection prevention and control to be reconsidered in terms of ventilation system design when the occupancy patterns are changed.

9.3 Preventive Maintenance

Maintenance failures within the building services of the health-care environment have the potential for severe consequences, so services should be designed with this in mind. The design should consider the financial and environmental impact of disposable and reusable components within the planned maintenance regime.

Reporting on the financial aspects of the lifecycle is required within the design project plan.

In the development of health-care building engineering services, the designer should consider the following preventive maintenance challenges when designing systems and planning preventive maintenance regimes:

- Where highly specialised services are installed in remote areas, it becomes difficult to source the requisite level of technical skills and as a result, either preventive maintenance costs rise or the serviceable life of these systems decreases.
- The availability of spares and contracted technical services becomes problematic in remote locations and this leads to difficulties with un-scheduled maintenance and extended callout response times.
- Routine and unscheduled maintenance may need to be performed with a system in operation or with minimal downtime. This should be considered when planning levels of redundancy.
- Routine and unscheduled maintenance should not have a negative impact on health-care service levels. Where infection and cross-infection risks are high, systems should be designed such that the maintenance staff can (complete) work without affecting staff or patient safety.

Preventive maintenance of a health-care facility's ventilation or UVGI system differs from almost all other types of building component maintenance. Maintenance personnel must be assigned to each health-care facility to conduct these activities. Preventive maintenance activities include periodic inspection, cleaning, calibration and routine services of the systems. The nature of preventive maintenance varies depends on the type of systems employed in the health-care facility.

9.4 Maintenance of Ventilation systems

Compared to mechanical ventilation, natural ventilation systems require less maintenance. However, the functionality of the systems, needs to be inspected periodically. Calibrating door and window openings, lubricating hinges, fixing broken glass, stays and handles, checking for blockages in insect screens, removing barriers on the wind- and leeward side of openings and general cleaning of the ventilation route (wind tower, atrium opening etc) are a few of the routine maintenance activities required.

Mechanical ventilation systems require routine maintenance for blocked or plugged air intakes and exhausts, loose belts, bearings in need of lubrication, motors in need of attention, corroded duct work, and/or minor component failures. Filters should be replaced periodically in certain types of ventilation systems, such as electrostatic precipitators and cyclones for dust collection. Installing monitoring devices in ventilation systems is recommended to keep the maintenance personnel aware of any malfunctions.

Maintenance of a hybrid ventilation system combines the maintenance activities for both natural and mechanical ventilation systems. Instructions for the provision of fresh outside air:

- Keep doors, windows and skylights open as much as possible.
- Add fans to increase air mixing and directional airflow.
- Keep fans running as much as possible when the space is occupied.
- Place fans so that air movement can be felt in all the occupied parts of the room.
- Room fans should be placed in locations where they will add to natural ventilation currents.
- Place fans so that air flows from clean to less clean areas. Place staff near fresh air sources.

Instructions for use:

- Check that all occupied rooms have a source of natural ventilation.
- Check that windows and doors are easy to open and to keep open.
- Check air mixing and determine the directional air movement in all parts of occupied rooms.

An inexpensive way to visualise air movement is to use incense sticks:

- Hold two incense sticks together and light them.
- As soon as the incense starts to burn, blow out the flame. Now the incense should produce a continuous stream of smoke.
- Observe the direction of the smoke.
- Observe how quickly the smoke dissipates. This is a subjective test which may require some practice. It does not give a definite result but is useful in comparing rooms to each other.
- Repeat smoke tests for different common conditions at the facility. For example, if doors are kept open during the day but closed at night, the tests should be done under both conditions.

- Check that all room fans are working and clean.
- To check exhaust fans with a grille, hold a tissue or a piece of paper against the grille. If the fan is working, the tissue or paper should be pulled against the grille.

Instructions for Routine Upkeep:

- Routine upkeep should be preferably done when patients are not in the room.
- Clean exhaust fan outlets and fans about once a month with a vacuum cleaner.
- Use a damp cloth or vacuum cleaner to remove dust and lint from fans, grilles and ducts.
- Clean ducts behind grilles as far back as the vacuum cleaner can reach.
- Assess ACH of naturally ventilated areas at least once a year or whenever disruption/alteration is suspected.
- Keep records of all routine upkeep activities and dates.

9.5 Maintenance of UVGI systems

Preventive maintenance of UVGI systems is crucial, because the intensity of lamps fades over time and dust reduces the output of the lamps considerably.

Instructions for radiation (UVC) measurements:

- Protective equipment is required to take these readings without overexposing the skin or eyes to the radiation.
- If lamps are working, they emit a visible violet blue glow which can be seen from below.
- Check that the radiation level at each fixture meets the lamp manufacturer's recommendations. Check radiation levels according to the checklists provided in chapter 8.
- If radiation levels are too high in any location, turn off any lamp(s) causing the high radiation levels. To correct the problem, it may be necessary to add non-reflective paint to the ceiling and/or wall and/or to relocate or replace the fixtures.
- Lamps should be replaced with new ones if the radiation levels are below the manufacturer's recommended minimum levels.

Instructions for Routine Upkeep:

- Designate a member of staff from the engineering department to be the in-house monitor of the UVGI fixtures. This person should be trained in the basic principles of UVGI operation and safety and should be responsible for cleaning, maintaining, testing and replacing the lamps.
- Check and clean lamps and fixtures every three to twelve months.
- Turn off the lamps and let the lamps cool before they are cleaned.
- Open the unit in accordance with the manufacturer's directions.
- Remove the lamps from the fixture for cleaning. Only handle the lamps while wearing gloves to prevent oil deposits from accumulating on the lamps and decreasing their emission efficiency.
- Use a cloth dampened with alcohol (e.g. 91% isopropyl) to clean the lamps and reflectors - do not use water.
- Whilst wearing gloves, dry the lamps and reflectors with a soft cotton cloth to remove any residue.
- Lamps should be changed according to a fixed schedule based on the lamp manufacturer's recommendations. If feasible, group relamping should be done on a yearly basis.
- The lamp or ballast should also be replaced if the lamp is burnt, broken, stops glowing or flickers. Note: the violet blue glow emitted by a lamp is

not an indicator of the lamp's effectiveness.

- When the lamp has been replaced, turn on (re-energise) the system and verify (visually) lamp operation and that all louvers (if present) are in the correct position.
- Take the radiometer readings of each new lamp after replacement to ensure that radiation levels meet the manufacturer's recommendations.
- Dispose of used lamps following the lamp manufacturer's recommendations.
- Keep a record of all maintenance and monitoring, including radiometer readings and dates (This will help determine the average lifespan of the lamps).
- New lamps should be purchased close to the planned time of replacement, as prolonged storage may result in a loss of radiation intensity.

Chapter 10 Building Design and Engineering Requirements

10.1 FMHACA Standards

In 2011, the Food Medicine and Health Care Administration and Control Authority (FMHACA) released minimum standards for all levels of health-care facilities in Ethiopia. These minimum standards uphold general provisions, licensure, governance, patient rights and responsibilities, human resource management, service standards and physical design standards.

In the paragraphs below, the relevant FMHACA standards and additional recommended building design and environmental engineering requirements for airborne infection prevention and control are summarised.

10.2 Requirements to Prevent and Control Airborne Infections

A. Site requirements

1. The site should be landscaped and well-kept with green areas and trees to provide clean external environment with improved air quality for the provision of natural ventilation. Existing trees should be saved as much as possible.
2. Health-care facilities should preferably be away from the following conditions: undue noises, smoke, dust or foul odours, and not be located adjacent to railroads, bus stations, freight yards, grinding mills, chemical industries, gas depot and waste disposal sites.
3. Health-care facilities should preferably be located on plateaus or open fields with a gentle slope and unobstructed wind flow to optimise natural ventilation.
4. The total area of the health-care facility premises must comply with the minimum requirements specified in the FMHACA Minimum Standard.

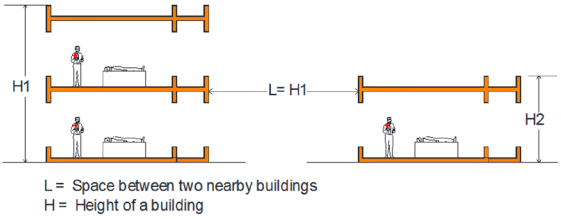
B. Physical design requirements

1. Health-care facilities must be designed, constructed, and maintained in a manner which is safe, clean, and functional for the prevention and control of airborne diseases.
2. The location of a facility, climatic conditions, prevailing wind, land, actual

and foreseen population volume, the types of services provided, patient flow and specimen movement, furniture arrangements, capital investment and preventive maintenance budgets and contracting regulations, all need to be considered prior to any renovation or new construction.

3. The building design must comply with all other relevant national codes and standards.
4. Architects and engineers must include basic airborne infection prevention and control design concepts and considerations into new constructions and renovations by making the best use of available spaces to implement infection prevention and control interventions.
5. The appropriate organ/body should be consulted to ensure conformity with the building design and environmental engineering standards and requirements.
6. The construction should be regularly supervised to ensure conformity with the provided design documents.
7. Upon completion of construction, the appropriate organ/body must inspect and issue a license for operation of the health-care facility if all the findings conform to the building design and environmental engineering standards and requirements.
8. Different health-care facility blocks must be arranged with ample spaces in between to allow optimum natural ventilation. The space between two nearby buildings or the distance to general traffic should be equal to the height of the tallest building (with a minimum of 4 metres distance).

Figure 20: Preferred Gap between adjacent buildings; L cannot be less than 4.00m



9. To support the most important administrative controls – the FAST strategy – for the prevention and control of airborne infections, the building design should facilitate triage and the temporary separation of patients

with presumptive or diagnosed (DR-) TB of the lungs, especially those who have not yet started effective treatment.

10. For environmental controls to be implemented, managerial activities and administrative controls should also be in place to ensure the proper use and preventive maintenance of equipment.

C. Access and circulation requirements

1. Blocks or spaces dedicated to airborne diseases must be arranged in such a way that the patients and clients will have minimal interactions with the other clinical blocks, especially those occupied by vulnerable patients e.g. HIV care, child and oncology blocks.
2. Blocks or spaces dedicated to airborne diseases should preferably be accessed separately.
3. Entrances and exits for blocks dedicated to airborne diseases must be clearly labelled with warning signs.
4. Fences and gates to control access to blocks dedicated to airborne diseases should be considered.
5. All horizontal and vertical circulation areas which include stairs, corridors, exits and entrances of health-care facilities must be kept clear and free of obstructions, and must not be used for other functional purposes which include storage or waiting-, recreation- or visiting areas.
6. In multi-story buildings separate elevators should preferably be installed, a dedicated patient elevator and another elevator for use by staff and visitors.
7. TB culture laboratories where high-risk procedures are performed (i.e. biosafety level 3) must only be accessible to authorised staff, preferably with a fence around the building.
8. Entrance doors of TB laboratories must be clearly labelled with warning signs.

D. Specified areas requirements

1. Airborne Infection Isolation Room: For patients with presumptive or diagnosed lung TB, an airborne infection isolation room (AIIR) is preferred; an AIIR should be a single-patient room with hybrid or mechanical ventilation providing unidirectional airflow. An anteroom and bathroom are recommended (see Figure 21).
2. Multiple patient airborne precaution ward: a multi-patient airborne

precaution ward must accommodate a maximum of four patients (see Figure 22).

Figure 21: Typical AIIR with anteroom, Negative Pressure

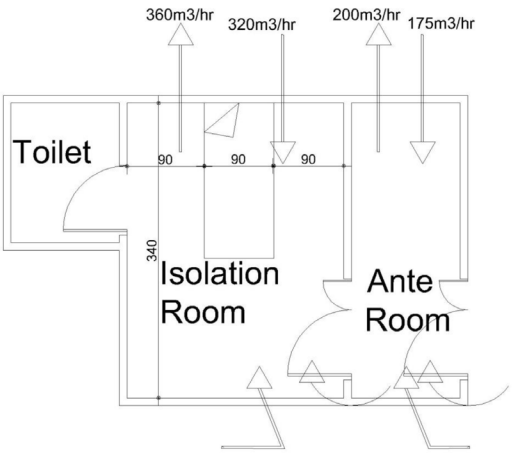
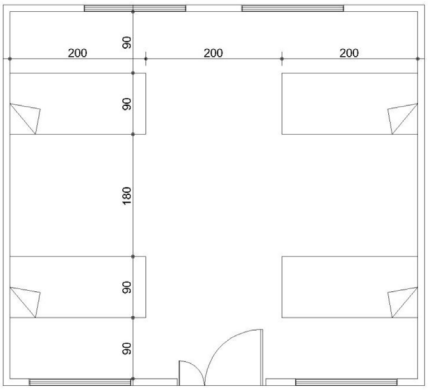


Figure 22: Typical four-patient airborne precaution ward



Four Bed Wards

3. Floor area: The recommended floor area of single-patient airborne infection isolation rooms (AIIRs) and multi-patient airborne precaution wards is 9.20m2 per bed.
4. Ceiling height: The minimum usable height of the ceiling of patient rooms and wards is 2.80m. To reduce the transmission of airborne infections a minimum usable height of 3.20m is recommended.
5. Bed distances: The recommended space between beds is 1.20m for general wards and 1.80m for TB wards. The recommended space between the bed and a wall is 90 cm.
6. Staff room: Separate staff and support areas from patient areas with additional doors in passages as needed. Staff and support areas must be restricted for unauthorized persons.
7. Triage area: A triage area should preferably be provided at the main entrance to identify coughing patients which should be directed to the designated waiting area.
8. Sputum collection area: sputum collection points should be situated outside whenever possible. If the situation allows, sputum should preferably be collected inside purpose built structures which allow free movement of air and are provided with sinks. Inpatients can produce a sputum sample on the balconies of rooms/wards.

Photo 7: Outside sputum collection area with sink (Courtesy: M. Meis)

9. Waiting area: Roof covered outside waiting areas, verandas and passages represent a very cost-effective and well-ventilated approach to

minimise the risk of transmission of airborne diseases (see Figure 23). A roof protects patients against rain and provides shade.

10. Multiple smaller waiting areas are recommended because the risk of transmission is reduced if smaller groups of patients are exposed to an infectious patient.

Figure 23: Roof covered outside Waiting area

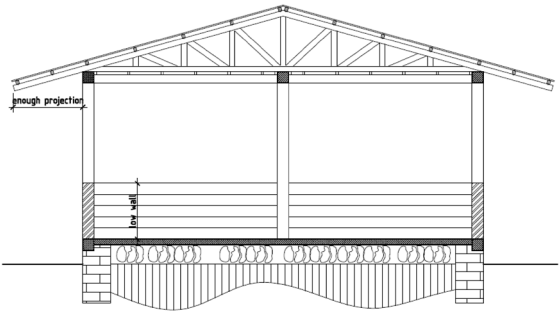
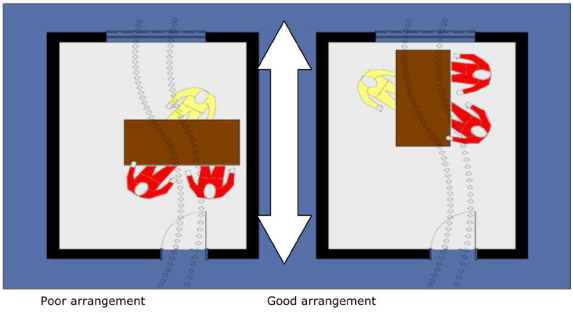


Figure 24: Seating Arrangement

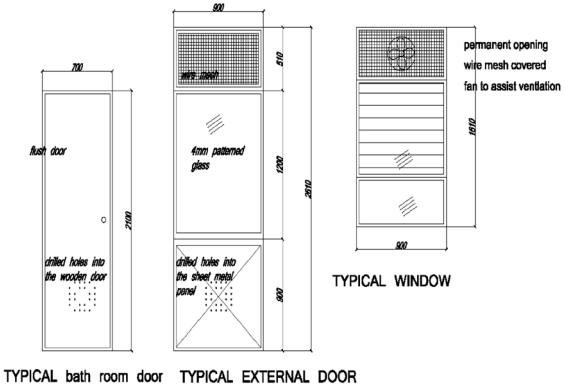


11. Consultation room: Furniture and seating should be placed such that staff-patient interactions occur with airflow passing between the patient and staff, rather than from patient to staff (see figure 24).

E. Door and window requirements

1. All doors must be able to open and close easily. If possible, doors should be kept open to maximise cross-ventilation.
2. To improve cross-ventilation, provide permanent openings (louvres, drilled holes or door cuts) in or above doors when they cannot be left open.

Figure 25: Typical permanent openings in Doors and Window for improved ventilation



3. Use mosquito screens as needed for permanent openings and windows which are frequently left open for the purpose of ventilation. At least the top portion of a window should be permanently left open.
4. Mosquito screens need to be made of materials which are corrosion resistant.
4. The openable area of a window should not be less than 75% of the total window area.
5. Openings must not have any obstruction to air circulation.

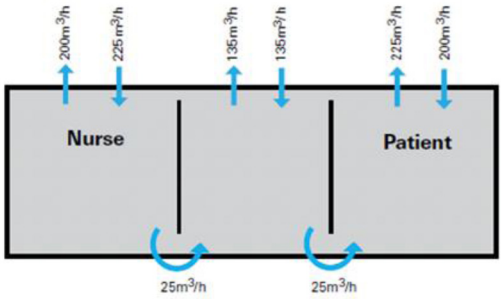
F. Ventilation requirements

1. Where the air quality, quantity and consistency within a space can be maintained to a satisfactory degree, natural ventilation should always be the preferred solution.
2. Where natural ventilation alone cannot achieve the required air quality, quantity and consistency, mixed-mode (hybrid) ventilation should be

considered as a solution preferred over full mechanical ventilation.

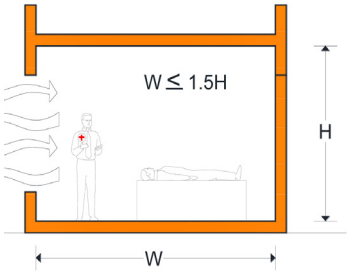
3. Where mixed-mode (hybrid) ventilation cannot achieve the required air quality, quantity and consistency, supply and exhaust mechanical ventilation, negative pressure, single-pass or re-circulation systems should be installed.

Figure 26: Supply and Exhaust mechanical ventilation, Negative Pressure



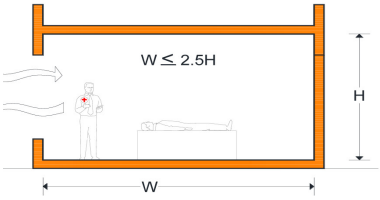
4. Existing renovated buildings should achieve at least 6 ACH in high-risk areas; New constructed buildings should achieve at least 12 ACH in high-risk areas.
5. Occupancy-based ventilation standards account for the fact that each person in a space should have a certain supply of fresh air. The following occupancy-based ventilation standards are recommended: 160 litre/second/patient for airborne precaution rooms in new and a minimum of 80 litre/second/patient in renovated health care facilities; 60 litre/second/patient for general wards and outpatient departments; 2.5 litre/second/m3 (Note: not per occupant as the other occupancy-based standards) for corridors and other transient spaces without a fixed number of patients.
6. For natural ventilation systems, the openable window area should preferably constitute >20% of the floor area: 10% located on opposite walls.
7. For natural ventilation systems, the maximum depth of a patient room should not be more than 5 times the height.
8. In single-sided, single opening patient rooms, the maximum depth should not be more than 1.5 times the height. Note: this option is least preferred, as cross-flow should be attempted at all times, even in renovations.

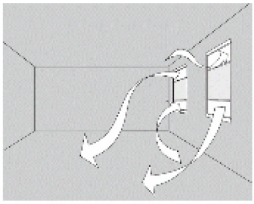
Figure 27: Single sided, single opening



9. In single-sided, multiple opening patient rooms, the maximum depth should not be more than 2.5 times the height..

Figure 28: Single sided, multiple openings



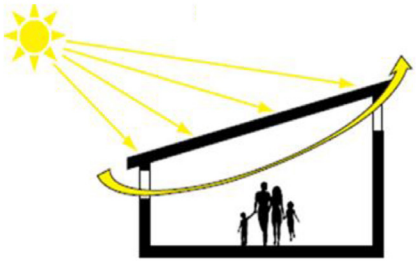


10. Where appropriate for the ventilation system, permanent openings in walls or windows should be installed and covered with mosquito screens and doors should have louvers or 5cm door cuts.

Photo 8: Door cut (Courtesy: M. Meis)

11. To provide stack ventilation for one-story buildings, a sloped roof with sloped ceiling and permanent openings on the highest part of the room or a flat ceiling with generous room height and clerestory openings are recommended.

Figure 29: Combined Stack- and Cross-ventilation



G. Air disinfection requirements

1. Upper-room UVGI systems may complement ventilation systems in very high-risk areas such as the rooms of patients with presumptive or diagnosed XDR-TB.
2. Upper-room UVGI devices must be properly designed, installed, maintained and operated.
3. UV lamps should not contain more than 5 mg mercury and be rated for zero ozone generation.
4. UV lamps of upper-room UVGI systems must be shielded to direct the radiation upwards and outwards, in order to create an intense zone of UVGI in the upper room while minimising the level of UV-radiance in the lower (occupied) portion of the room.
5. UV lamps which fit the fixture ballast must be effective for at least 1 year (with the selected fixture and the standard ballast-lamp combination).
6. UVGI efficacy, performance monitoring and safety tests, checklists and standard operating procedures for cleaning and lamp replacement must be part of an operations manual.
7. The occupational exposure limit is 6,000 microjoules/cm2 for a daily 8-hour shift which corresponds to a maximum irradiance of 0.4 microwatts/cm2 for 8 hours of exposure.
8. Shielded UVGI fixtures may be used in rooms with ceilings as low as 3.20m.
9. Louvered UVGI fixtures may be used in rooms with ceilings as low as 2.80m.
10. An upper-room shielded UVGI system should provide an average UV fluence rate in the upper room in the range of 30 microwatts/cm2 to 50 microwatts/cm2.

11. Using fixtures with louvers, an average intensity of greater than 10 microwatts/cm2 in the irradiated zone is recommended, however variance between the test-points (as measured in the extensive efficacy test in section 8.6) is also of great importance.
12. UV lamps providing <100 microwatts/cm2 at a distance of 1 metre must be replaced.
13. Group lamp replacement once a year to ensure an effective level of UV irradiation may be cost effective and therefore considered.
14. If there is any doubt about vertical air mixing between the lower and upper portions of the room due to environmental or other factors, slow-moving paddle fan(s) should be used to mix the lower and upper-room air.
15. To reduce reflection, non-reflective surfaces and paint containing tita nium dioxide are recommended.

H. Biosafety requirements:

1. BSL 2 is recommended for TB laboratories with a moderate risk of infection.
2. Recommended building design requirements for BSL 2 laboratories are: Separated from public areas, restricted access and lockable entrance door, impermeable and easily cleaned work surfaces, openable windows, air extraction system without re-circulation, separate areas for smear preparation and microscopy, solid culture. direct DST, BSC, and a minimum size of 22 m2.
3. BSL 3 is recommended for research and regional or national reference TB laboratories.
4. Recommended building design requirements for BSL 3 laboratories are in addition to above BSL 2 requirements: Stand alone building isolated/fenced off from the general traffic patterns, double door entry (anteroom), pass through hatch, shower, emergency exit, surfaces are water and disinfectant resistant, single-pass negative pressure supply and exhaust ventilation system providing 6-12 ACH, air is HEPA filtered before it is exhausted to the environment, separate areas for smear preparation and microscopy, molecular testing, liquid culture, indirect DST, disinfection, and a minimum size of 75 m2.
5. If a laboratory facility does not have all the required BSL 3 features, an acceptable level of safety for conducting routine procedures, including

liquid culture, may be achieved in a BSL 2+ facility where directional inward airflow (negative pressure) by use of extractor fans is maintained and exhaust HEPA filtered air is discharged to the outside (not re-circulated).

I. Operations and preventive maintenance:

1. Maintenance logbooks must be kept at the health-care facility.
2. Allocate 5-10% of the construction costs for preventive yearly maintenance.
3. Regular occupant surveys and checks will help to identify potential operational problems and deal with any complaints.

Annex 1 Definitions of Terms

Terms	Definitions
Aerosol-generating procedures	A procedure which can induce the production of small respiratory droplets (droplet nuclei).
Airborne precaution room	An airborne infection isolation room (AIIR) with ≥12 air changes per hour (ACH). An airborne precaution room can be naturally, hybrid or mechanically ventilated. In addition to the requirement of ≥12 ACH, in a mechanically ventilated airborne precaution room, negative pressure is created and monitored to control the direction of air flow.
Airborne transmission	Transmission of infectious agents which remain infectious over long distances when suspended in the air (e.g., rubeola virus [measles], varicella virus [chickenpox], M. tuberculosis, and possibly SARS-CoV)
Air changes per hour(ACH)	One air change has occurred when the volume of air entering or exiting a room is equal to the volume of the room. Subsequent increases in air change leads to an exponential reduction in droplet nuclei in the room. Under ideal conditions – in which droplet nuclei are evenly distributed and room air is uniformly mixed – the proportion of infectious particles eliminated with each air change or one "equivalent air change" is 63%. A second air change removes 63% of what remains, and so on.
Anteroom	A small room leading from a corridor into another room, often an isolation room.
Balanced mechanical ventilation system	A system where supplies and exhausts have been tested and adjusted to meet particular building engineering specifications.
Clean air	Air which does not contain a considered contaminant.
Considered contaminant	Any actual contaminant, surface or airborne, which may have a certain impact for which measures are taken to avoid.
Droplet nuclei	Airborne particles which carry Mycobacterium tuberculosis; droplet nuclei are generated after people who have pulmonary or laryngeal TB disease cough, sneeze, shout or sing. The particles are approximately 1–5 micrometres; normal air currents can keep them airborne for prolonged periods and spread them throughout a room or building.
Droplets	Inspirable particles larger than 5 micrometres in diameter, which can be deposited on upper respiratory tract levels and mucosa.
Envelope opening	Purpose-built openings in buildings for natural ventilation (e.g. windows, doors, solar chimneys, wind towers, trickle ventilators).
Fresh air	Air drawn from outside air of a building free of contaminants.
High-tech natural ventilation system	A natural ventilation system which uses modern computer control systems, and may be assisted by mechanical ventilation systems.
Hybrid ventilation	Combination of both mechanical and natural ventilation-also called mixed mode ventilation.
Managerial controls	Set of managerial activities to warrant the needed conditions for the application of infection control measures in the health-care setting.
Mixed-mode ventilation	A ventilation system which combines both mechanical and natural ventilation. It provides the opportunity to choose the most appropriate ventilation mode based on the circumstances.

Natural ventilation	Ventilation provided by thermal, wind or diffusion effects through doors, windows or other intentional openings in the building. Control of airflow direction cannot be achieved by simple natural ventilation – it depends on sufficient wind speed or direction, or temperature differential.
Negative pressure mechanical ventilation system	A mechanical ventilation system which generates negative pressure to allow air to flow into the isolation room but not escape from the room, as air will naturally flow from areas with higher pressure to areas with lower pressure, thereby preventing contaminated air from escaping the room. Air is exhausted to the outside or filtered and then (partially) re-circulated.
Negative pressure room	A room which is under negative pressure has a lower pressure than adjacent areas, which keeps air from flowing out of the room and into adjacent rooms or areas.
Positive pressure mechanical ventilation system	A mechanical ventilation system which uses a supply fan through which air is pushed into the room.
Re-circulated airflow rate	The amount of the returned air (for re-circulation). Although re-circulated air can be filtered, its air quality is often worse than the outdoor air for most conventional applications. Therefore, filtered, re-circulated air cannot replace outdoor air for ventilation. Heat, dust and pollution of outside air might be reasons to decide to re-circulate some of the room air
Respiratory droplet	Refers to small particles which can be liberated from the respiratory tract during breathing exercises. Can be either in form of droplets or/and droplet nuclei.
Short-circuiting airflow pattern	The pattern of airflow which occurs when part of the air is stagnant in a ventilated room, and the ventilation air can bypass the stagnant air and move directly to the exhaust outlets, And/or exhausted contaminated room air which flows immediately back into the room through an inlet.
TB containment laboratory	The term refers to a facility which has the minimum design features necessary to safely manipulate TB cultures. This type of facility may or may not meet all of the requirements of a Biosafety Level 3 laboratory. In Ethiopia, these are the regional and national reference and research laboratories.
Transmission-based precautions	A set of practices which apply to patients with specific infections for which precautions beyond the standard precautions are needed to control infection in the health-care setting.
Ventilation	Movement and distribution of air into a room or a building for the purposes of providing fresh air for breathing, diluting contaminants within the building and removing these outside.
Ventilation system	A system which supplies air into a building or a room, distributes air within the building, and removes air from that building.

Annex 2 References

1. WHO, Policy on TB infection control in Health-care facilities, Congregate settings and Households, 2009
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3. WHO, Natural Ventilation for Infection Control in Health-care Settings, 2009
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5. IFIC Basic Concepts of Infection Control, 2011
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7. WHO Tuberculosis Laboratory Biosafety Manual, 2012
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