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The Planning Premises for A Tuberculosis Centre

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Abstract:

Background Significance: The aim of this study is to plan the premises for the establishment of a Tuberculosis Centre. The objectives include studying the layout of an existing Tuberculosis Centre, investigating available Guidelines, and developing the planning premises for a Tuberculosis Centre with a specific focus on the Waiting area, Out-patient Unit, Ward, Isolation room, and the inclusion of a Respiratory Rehabilitation Unit.

Materials and Methods: A Cross-sectional Observational study was conducted for a period of 8 weeks, Document reviews, On-site Observations and Stakeholder interviews were done to form planning premises of a TB Centre. Various research Articles were also taken into consideration.

Results: The TB Centre's design and ventilation strategies, informed by IPHS Guidelines 2022 and WHO Reports, emphasize natural ventilation methods like Cross-Flow, Wind Towers, Stack (flue), and Stack (atriums), alongside Mixed Mode Ventilation for optimal airflow and pollutant removal. OPD areas prioritize natural ventilation per WHO recommendations, and Isolation Rooms are designed with Mixed-Mode Ventilation based on Anuraghava et al.'s CFD study. In-Patient Units adopt natural ventilation, as shown in studies by Qian et al. and Littler et al., and emphasize mixed-mode ventilation for good IAQ, highlighted by Ijaz et al. The Respiratory Rehabilitation Unit follows Physiotherapy guidelines, and corridors ensure proper air exchange rates, reflecting the TB Centre's commitment to effective ventilation and infection control.

Conclusion: This study explored planning principles for a Tuberculosis (TB) center. The World Health Organization (WHO) prioritizes Natural Ventilation for TB care, particularly in resource-limited areas with suitable climates. (1) However, mixed-mode ventilation, combining natural and mechanical systems, is the next preferred option (1). While natural ventilation can achieve the recommended air exchange rates (ACH) under certain conditions, (2,3) it might require additional support like fans or stack ventilation during low-wind periods. (4) Additionally, single-bed rooms might be preferable for better airflow control and infection risk reduction. (5)

Keywords: Air Change per Hour (ACH), Decentralized and Centralized Model of TB Care, Natural Ventilation, Mixed-mode Ventilation, Upper-room Ultraviolet Germicidal Irradiation

Introduction:

In 2022, India represented 27% of the global TB cases among the 30 highest TB burden countries. (6) A 2020 systematic review found that 7-32% of Drug-Sensitive TB (DS-TB) patients and 68% of Drug-Resistant TB (DR-TB) patients faced Catastrophic Costs related to TB care. (7)

As Model of Care for Tuberculosis, WHO prioritizes a decentralized model, including DR-TB, with treatment delivered by local Healthcare Centres and Community workers for better access. However, for high-risk cases like poor adherence, severe illness, or limited outpatient care, a centralized approach with specialists may be considered. (1) The CDC guidelines mentions TB patients meeting required criteria; starting TB Drug Regimen and DOT can be discharged home if there are no high-risk household members (PLHIV, Children < 4 year), limited travel is ensured, and local TB program is involved. (8)

Although many hospitals in developing countries lack scientific designs, leading to overcrowded and inadequate facilities. A hospital's physical design is vital for infection control, addressing issues to minimize infection transmission. (9) The imbalance in the classical epidemiological triad triggers the disease process, emphasizing the role of hospitals in managing the environment to reduce Hospital-Acquired Infections. (10)

Materials and Methods

Study Design: A Cross-sectional Observational study was conducted from October 2023 to January 2024. This Study included the following forms as its Data Sources:

1. Document Review: Various documents were reviewed, including:

(a) WHO Consolidated Guidelines on TB (Modules 1,2,3),
(b) Guidelines on Airborne Infection and its Prevention in Healthcare Facilities, 2010,
(c) National Strategic Plan (NSP) for Tuberculosis Control, 2017-2025,
(d) Indian Public Health Standards (IPHS) Guidelines,
(e) Indian Health Facility Guidelines,
(f) Global Tuberculosis Report 2023,
(g) India Tuberculosis Report 2023, and, various Published articles were taken into consideration

2. Unstructured Interviews: Stakeholders were interviewed to gather data regarding processes of patient flow from admission to discharge and follow up.

3. On-ground Observations, of an existing Tuberculosis Centre.

Findings

On-ground Observations

The building design of the TB Centre followed a Courtyard type of building design, characterized by combined wind and buoyancy-driven Natural Ventilation with outermost Wards, inner Corridor and Innermost Courtyard. (4) The TB Centre's dimensions include Nursing Stations (2.9m x 4.5m x 2.9m), 03 x General Ward (9.1m x 19.4m x 3.6m) with 18 beds, and 02 x MDR TB Ward (9.1*19.4*3.6) with 10 beds. "The distance between beds in the MDR TB ward was more than twice that of the General TB ward. Additionally, the MDR TB ward included Upper Room Ultraviolet Germicidal Irradiation (UVGI), one per bed. (1) The available statistics of the TB Centre revealed an increase in General TB cases by 35.6% for OPD visits and 13.3% for IPD admissions from 2021 to 2022. Conversely, MDR TB cases showed a 5.2% decline in OPD visits and a 0.2% decrease in IPD admissions during the same period. These figures underscore the evolving landscape of TB care within the TB Centre, reflecting the challenges and advancements in managing both General TB and MDR TB cases.

Discussion

Structure

The planning premises for this study will encompass key areas including the Outpatient Department (OPD), Wards, Isolation Rooms, and Respiratory Rehabilitation Unit. These are established with considerations drawn from various sources, including IPHS Guidelines 2022, WHO Consolidated Report on Tuberculosis, Guidelines on Airborne Infection Control in Healthcare and Other Settings, and, various published articles.

Ventilation Strategies

Building ventilation looks at four key areas: supplying enough fresh air, maintaining clean-to-dirty air flow, distributing fresh air efficiently, and removing pollutants effectively. Two key metrics are air exchange efficiency (fresh air distribution) and ventilation effectiveness (pollutant removal).

Natural Ventilation (4) - Buildings can achieve natural ventilation through four methods as shown in **Fig 1**: Cross-Flow (wind-driven air movement through open windows), Wind Towers (using wind pressure to draw air), Stack (flue) (utilizing buoyancy from air density differences for air movement), and Stack (atriums) (heated atriums inducing airflow).

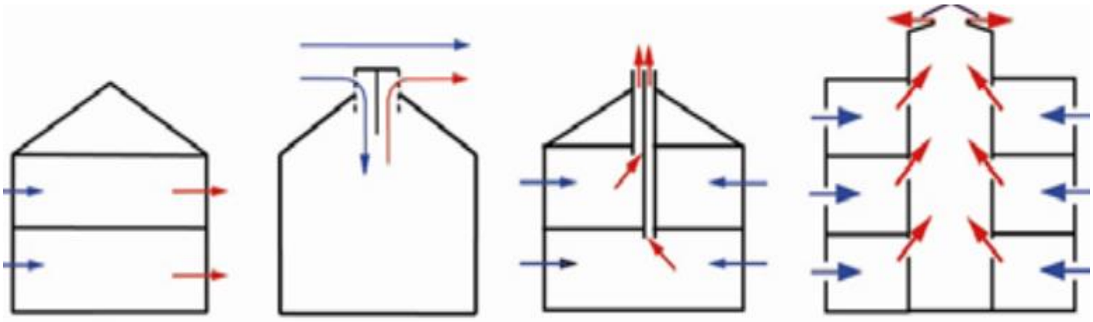

Fig 1: Cross-flow Wind Tower Stack (flue) Stack (Atriums)

Mixed Mode Ventilation (4) - Hybrid ventilation blends natural and mechanical methods. Fan-assisted stacks use fans to boost air removal during low sun periods, while top-down ventilation adds wind towers for natural air supply, as shown in **Fig 2.**

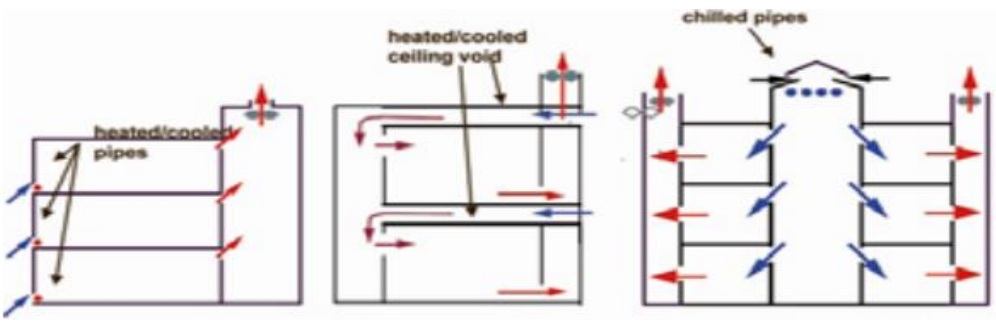

Fig 2 Fan Assisted, Stack, and Top down Ventilation

Waiting Area

The IHFG guidelines mentions Waiting Area spanning 25 m^2 with occupancy up to 20 occupants, for visitors and patients, with separate areas for males and females. (11) Mustafa and Colleague (12) conducted a study analysing the impact of outpatient clinic layout typologies on social distancing, particularly within waiting areas, using space syntax methodology. The study identified decentralized-sectoral outpatient clinics (as shown in **Fig 3**) as optimal for social distancing. Space syntax analysis revealed these layouts promote privacy and lower density while accessibility remains adequate. This balanced approach minimizes crowding and disease spread in waiting areas.

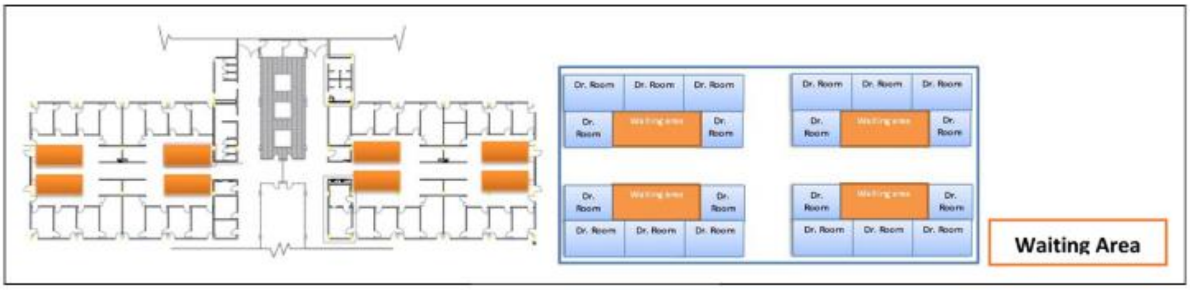

Fig 3: (12) showing Decentralized outpatient typology–sectoral waiting area

OPD

For high-risk TB settings, WHO (1) prioritizes natural ventilation, especially in resource-limited areas with suitable climates. Mixed-mode ventilation combining natural and mechanical systems is the next option. Mechanical and HEPA-filtered recirculated air, while possible, require substantial resources and upkeep.

The Guidelines on Airborne Infection Control (13) mention maintaining "controlled" Natural Ventilation with fixed and unrestricted openings that are not affected by weather conditions.

The Wells-Riley equation (4), $P = \frac{D}{S} = I - \exp\left(-\frac{Ipqt}{Q}\right)$, where;

P = probability of infection for susceptible
D = number of disease cases
S = number of susceptible
I = number of infectors
p = breathing rate per person (m^3/s)
q = quantum generation rate by an infected person (quanta/s)
t = total exposure time (s)
Q = outdoor air supply rate (m^3/s), is a valuable tool for assessing the risk of airborne infection in various enclosed spaces. It takes into account factors like ventilation rate, exposure time, and the number of infectious particles released by an infected individual (quantum generation rate - q). A study by Ko et al. (14) investigated the risk of Multidrug-resistant Tuberculosis (MDR-TB) transmission during an airplane flight using the Wells-Riley framework. They varied the estimated q value within the equation. Interestingly, the study found that even with relatively low q values, the calculated probability of infection (P) was still a concern.

The ACH using formula (15), $\frac{\left(0.65 * wind\ speed\ \left(\frac{m}{s}\right) * Opening\ Area\ (sq\ m) * 3600\right)}{Volume\ of\ the\ room\ (cu\ m)}$, (0.65, C^d, being the Discharge Coefficient, Opening Area, being the smallest opening in the room (4)), A minimum ACH of 12 (preferable >15) will require 23 minutes and 35 minutes for 99% and 99.9% removal of airborne contaminants, respectively. (16) Considering smallest opening being the Door (4) which according to iHFG guidelines (17) is 1.4 m wide and 2.03 m high, Ceiling Height of 2.7m (18) window is 20% of floor space. (13)

Ijaz et al highlights the importance of mixed-mode ventilation in achieving good Indoor Air Quality (IAQ) and mitigating the spread of airborne diseases. This approach combines natural ventilation with mechanical systems, offering an energy-efficient solution while maintaining good IAQ. (19)

In-Patient Unit

Qian et al. investigated the effectiveness of natural ventilation for controlling airborne infections in a tuberculosis (TB) hospital ward located in a warm and humid climate. (2) A study by Littler et al. found natural ventilation in hospital wards can be effective with moderate winds (1-4 m/s), it achieved good air exchange (3.4-6.5 ACH), diluting airborne pathogens. The study also concluded that open wards spread infection risk more evenly, while partitions protected some patients but trapped pockets of pathogens. (3) Mingotti et al. found that high-frequency ventilation could decrease residence times of infectious aerosols, despite residual effects of corridor traffic and temperature differences across doorways. They suggest this strategy may enhance safety for vulnerable individuals, reducing cross-infection risk between healthcare workers (HCWs) and patients. (20) Rahman et al. found that natural ventilation alone may be insufficient for achieving thermal comfort in hospital wards of tropical regions as occupant surveys suggested discomfort. (21) Beggs et al. hints that Airborne Infection Control strategies might be more effective in single-bed wards due to less patient density and easier airflow control. (5) As per Adamu et al. compared natural ventilation strategies for hospital wards. A new ceiling-based system with supply ducts showed promise for airflow, comfort, and potentially personalized delivery. Hospitals offer various room configurations for patients. Modern trends favour single or double occupancy for privacy and recovery. Some hospitals can flexibly convert double rooms to singles during low patient volume. (22) When planning inpatient units, various geometric options are considered to optimize space and movement. These include the Linear model with a single corridor (as shown in **Fig 4**), the Racetrack model with patient rooms on the outer edges and support rooms in the centre, and the L-shaped and T-shaped models, which are variations of the linear layout. The Hybrid T model combines aspects of the Racetrack and T models, while the + shaped model features two intersecting wings. (22) The Wards can have Upper-room Ultraviolet Germicidal Irradiation (UVGI) set up, which produces UV-C energy to kill pathogens, this set up is recommended as part of Standard of Care by WHO (1), with due consideration that the patients in the treated area are protected from excessive exposure of the GUV System, by fixtures such as louvres or bafflers in order to block radiation below the horizontal plane of the fixtures. (1)

Fig 4: Linear (Single Corridor) Model, (22)

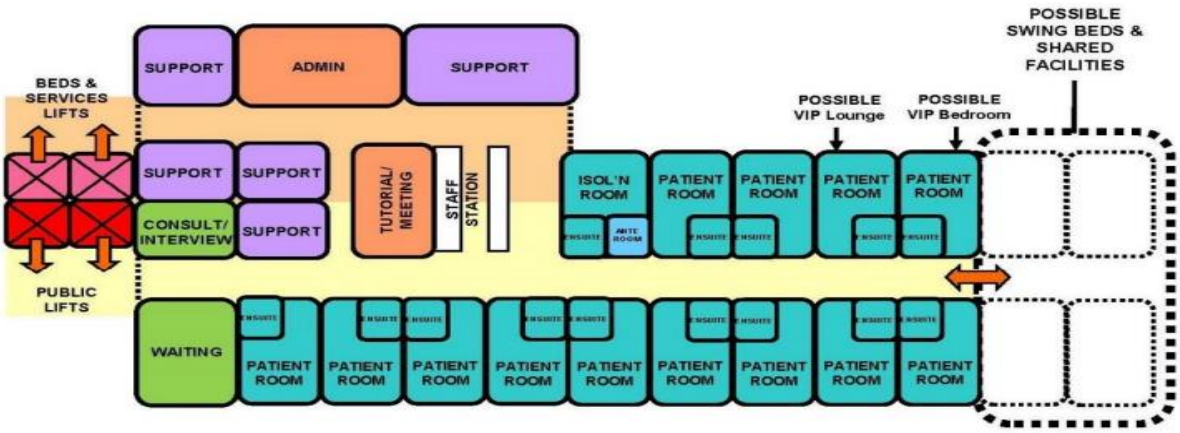

Fig 4: Linear (Single Corridor) Model, (22)

Airborne Infection Isolation Room

WHO recommends an individual risk assessment for usage of an Isolation Room, balancing potential risks and benefit.(1) Anuraghava et al. (23) used Computational Fluid Dynamics (CFD) to show Mixed-Mode Ventilation system might be more effective in managing airborne droplet dispersion in negative-pressure isolation rooms. The Anuraghava et al. study (23) created an Isolation Room with 02 beds maintaining the Internal Environment of the Isolation room as per the Airborne Precaution Room requirement (13), bearing in mind this CFD Model was based on the movement of virus diffusion characteristics in a Negative Pressure Room with Mixed Mode Ventilation. (23) The CFD simulation (23) was conducted in a 20x9x9ft (6.1x2.7x2.7m), with a partition in middle creating a space of 810 sq ft (44.5 sq m) per patient. The per patient space for a Ward for a 02 patient unit is suggested to be 6.4x4.2m, (22) which is an area of 26.88 sq m as compared to 16.47 sq m in the Anuraghava et al. (23) Isolation Room Model. This Isolation Room should have rectangular inlet to introduce air, while circular outlets positioned above patients' heads to remove it. This angled (45°) natural airflow at inlet, coupled with negative pressure at outlet, aims to capture airborne particles and direct them towards HEPA filters for removal. The HEPA should maintain the Outdoor ACH to 2. (24)

Respiratory Rehabilitation Unit

A study by Aeni & Murniati (25) showed that chest physiotherapy improved airway clearance in children with tuberculosis, while research by Selvia & colleague (26) suggests similar benefits for adult TB patients.

Wang et al. studied how to reduce infection risk for HCWs in negative-pressure isolation wards. They examined how coughing, speaking, and breathing affect droplet movement in the ward. Their findings show faster-moving aerosols from coughing and speaking are also removed quicker. (27)

As per the Physiotherapy Handbook, Curriculum & Rules and Regulations, Bachelor of Physiotherapy and Master of Physiotherapy (National Commission for Allied and Healthcare Professions), the Department of Cardio-Respiratory Physiotherapy should span over a space of 1200 sq ft (111.48 sq m). The Instrument requirement for the Department of Cardio-Respiratory Physiotherapy is also as per the above manual.

Corridors

Corridor ventilation rates in healthcare facilities depend on use. Typically, corridors require a minimum of 2.5 liters per second per cubic meter (l/s/m³). However, if patient care is provided (e.g., Emergencies), Airborne Precaution Room (160 l/s/patient ideal, 80 l/s/patient minimum) or General Ward (60 l/s/patient) ventilation rates apply. (4)

Conclusion

This study explored planning principles for a Tuberculosis (TB) center. The World Health Organization (WHO) prioritizes Natural Ventilation for TB care, particularly in resource-limited areas with suitable climates. (1) However, mixed-mode ventilation, combining natural and mechanical systems, is the next preferred option (1). While natural ventilation can achieve the recommended air exchange rates (ACH) under certain conditions, (2,3) it might require additional support like fans or stack ventilation during low-wind periods. (4) Additionally, single-bed rooms might be preferable for better airflow control and infection risk reduction. (5)

Conflict of Interest: None

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