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Natural Ventilation as a Key Airborne Infection Control Measure for Tuberculosis Care Facilities: A Review

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ABSTRACT

Tuberculosis (TB) is an airborne disease which has a risk of being nosocomial (hospital acquired) by the patients, visitors and the healthcare workers. Healthcare guidelines should highlight the role of architects and engineers in better infection control especially through Natural Ventilation. Research on TB may also be applicable to Measles, SARS-2003 and other air-borne diseases. Hospitals provide valuable information for other public assembly buildings with possible community spread of infection like prisons, homeless shelters, schools, etc. Natural ventilation leading to increased air changes per hour creates Dilutional Ventilation which reduces infection spread as shown in prominent Thai and Peruvian studies. Our under-standing of the transmission of airborne diseases and the behaviour of micro-organisms is still an area of active research. As the Indian built environment is getting increasingly air-conditioned, hermetically sealed and energy efficient, there is scope in this lead study to create awareness among architects on this multi-disciplinary issue.

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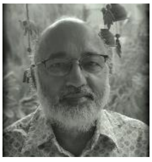

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Introduction

There have been an estimated 2.8 million new Tuberculosis cases in the world. India accounts for 1/4th of these cases (Pai, Kalantri, Aggarwal, Menzies, & Blumberg, 2006). This disease is spread through the airborne route and it is very important to prevent the infection using Airborne Infection Control measures. Healthcare-associated outbreaks in many parts of the world have warranted attention for Tuberculosis infection controls especially in HIV and TB care facilities which go hand in hand as HIV patients are immunosuppressed and are most likely to catch the infection, especially when the possibility of getting the infection from the community is high in the developing countries. This possibility of getting infected is even higher when a person goes to a TB care facility. Healthcare workers are at the greatest risk of getting nosocomial infection (hospital acquired) from their workplace.

Along with TB, there have been other diseases which have been linked to airborne infection spread (Hobday & Dancer, 2013). This had led to an active interest of researchers worldwide in airborne infection control which is achieved through administrative measures, engineering/environmental measures and personal protective measures (Parmar, et al., 2015). The scope of the architects and other healthcare infrastructure professionals is limited to the engineering/environmental control measures. This paper will portray airborne infection control as an Indoor Air Quality issue linked to natural ventilation as a trained architect would perceive it.

Architectural Design for Healthcare

Hospital Design comprises of the indoor environment, interior design and the configuration of the built spaces. The configuration is about design of the relative locations and the adjacencies of the spaces. Interior design is about the furniture, fixtures and the materials used. The indoor environment in a hospital deals with noise, lighting, psychological comfort, the air quality, etc. (Joseph & Rashid, 2007).

According to the National Airborne Infection Control Guidelines, architects play a key role in the Health Infrastructure Design. It highlights their role in the reduction of nosocomial infection not only by the means of optimized patient flow patterns but also by finding other affordable solutions to improve the organization of existing and new facilities. This opens us the area of evidence-based design which evaluates the design of healthcare facilities by relying on post-construction design flaws. This can be done by mock-up studies or by simulations (Birnbach, Nevo, et al., 2010). Evidence-based design prescribes design decisions to be based on strong research footing. Testing of proposed architectural designs before construction allows for the improvement of designs leading to the development of safer hospitals (Birnbach, Nevo, et al., 2010).

An analysis by an army hospital administrator states that 'most hospitals in the developing countries are not scientifically designed'. He not only mentions about the configuration issues but also talks about another key issue – that of the air conditioning and ventilation in hospitals. He mentions that these requirements, not being properly met, increase the risk of infection transmission (Rao, 2004). With respect to the modern practice of designing healthcare buildings, some researchers believe that the inclination towards providing comfort to the patients favours pathological persistence, increasing the chances of spread of infection within the hospital (Hobday & Dancer, 2013). TB even made resurge in New York, USA (Cole & Cook, 1998). This is an example of a developed country where nosocomial (hospital acquired) infections are among the leading causes of death (Kembel, et al., 2012) and there has been awareness about the health related benefits of judiciously done architecture design.

Energy Efficient Buildings and Nosocomial TB

Natural ventilation was believed to be effective in the disinfection of air (Hobday & Dancer, 2013) and TB patients in the past were resorted to a sanatorium (Yuko, 2018). These places had a serene environment with stress on natural ventilation and sunlight. With time, there was an improvement of anti-infective strategies and improvement in living which then led to lesser attention being paid to ventilation as an airborne infection control tool (Hobday & Dancer, 2013). The objective was shifted to creating indoor spaces which had more comfort and which would remove odours.

The priority given to comfort factor came under a question mark due to the 1973 Oil Embargo which led to an energy crisis. Now comfort provided had to be cost-effective and hence, energy-efficient which was possible by using recirculated air and reducing air change rates. Buildings were made tighter and were sealed to trap thermal energy in the spaces. The highly researched 'sick building syndrome' (Menzies & Bourbeau, 1997) was most likely an outcome of these practices mentioned. Studies have also linked increased patient risk to building smaller rooms which are cheaper to build and are air-conditioned, leading to overcrowding and 'becoming stuffy' leading to an upward trend of infection caused by airborne micro-organisms (Escombe, et al., 2007). People may argue that an energy-efficient building with a properly designed HVAC system may be good enough to dilute the concentration of micro-organisms, but the study done in Peru contradicts this and goes on to state that tightly air-sealed, mechanically ventilated rooms has a high chance of infection spread even though they had followed the ventilation rate guidelines (Escombe, et al., 2007). Simulation techniques are useful in the design process to ascertain the probable natural ventilation possible in the spaces.

Infection Spread due to Mechanical Ventilation

Ventilation systems in hospitals have a likeliness of being ill-designed, poorly constructed and not being maintained properly. This has led to occurrences of TB outbreaks (Hobday & Dancer, 2013). To give an example of other diseases, the source of Serratia Marcescens microbes were tracked to the duct of the air conditioning system in a childrens' hospital in the United Arab Emirates (Udaman, Farrukh, & Nath, 2002). MRSA has also been known to spread due to faulty and/or contaminated air conditioning systems. In 1991, during the Operation Desert Shield, there was a higher infection of respiratory tract in air-conditioned barracks than in the open-air tents where the members of the armed forces were observed (Richards, Hyams, et al., 1993).

Another study links mechanically ventilated patient rooms to the presence of microbes which are distinct by their taxonomical identity than the ones found in the outdoor air. This was due to the low phylogenetical diversity of the bacteria found indoors and their closest relatives are the human pathogenic bacteria. The fact that there has been a reduction in the contact with the outdoor environment to make the building more sterile may actually do its opposite. This isolation of the indoor environment is argued as being probably not the best solution for creating bacteria safe spaces. This has led to a rekindling of our interest in the natural disinfection characteristics of outdoor air which were ignored in the past (Kembel, et al., 2012).

Natural Ventilation and its role in Airborne Infection Control

In the context of this paper, natural ventilation means buoyancy and diffusion-driven movement of air. This should not be made synonymous to speedy air movement due to windows which are open or closed and dependent only upon the velocity of the air. In studies, the diffusion of air took place even when there was no wind and the window was partly closed (Escombe, et al., 2007). It has been observed that natural ventilation for dilutional ventilation was achievable when the wind velocities were not high (Escombe, et al., 2007).

Fresh air was correlated in 1894 to reduce the spread of the tuberculosis bacteria. The bacteria were seen to retain their ‘infectivity’ when there was no fresh air. During 1918 influenza pandemic, patients which were placed in the open-air beds had a higher survival rate than those who were placed inside the wards (Hobday & Dancer, 2013). A keystone study was performed by researchers in Lima, Peru in 5 Hospital’s 70 rooms in which they conducted 368 experiments. They established that the naturally ventilated rooms (due to open windows) which were made pre-1950s and the ones made during the times of ‘modernism’ in the 1980s were way more efficient in reducing the risk of tuberculosis transmission than the rooms of the hospital developed in the year 2000 with mechanical ventilation and smaller (tighter) rooms. For all naturally ventilated facilities, opening windows and doors provided median absolute ventilation of 2,477 m3 /h, more than six times the 402 m3 /h calculated for mechanically ventilated rooms at 12 ACH (Escombe, et al., 2007).

The link between natural ventilation and higher air changes per hour has been established in other studies as well. Work done in China showed a positive correlation between cross ventilation and the control of airborne spread of SARS. When the proportion of operable windows increased in the isolation ward, there was an increased prevention rate of SARS seen in healthcare workers (Jiang, Zhao, et al., 2009). A study performed in Thailand also reaffirmed naturally ventilated rooms of the hospital has higher air changes per hour as per the standards. Ventilation rates were found out to be inadequate in work areas having air conditioning and they found that these were the areas with the highest nosocomial tuberculosis infection risk namely the radiology and emergency departments (Jiamjarasrangsi, Bualert, et al., 2009).

Natural Ventilation is best suited for the limited resource settings and tropical climates, which also coincidentally have the highest institutional TB transmission risk and the maximum TB burden. In India, the hospitals, especially the public-owned facilities have reported to being crowded and poorly ventilated (Pai, Kalantri, et al., 2006). In such cases and elsewhere, ventilation is a strategy in the hands of the architects to prevent the spread of airborne infection in spaces (Escombe, et al., 2007). It is observed that in the healthcare facilities, natural ventilation continues to require further research (Escombe, et al., 2007). In the Indian context, it opens up lots of possibilities for an interdisciplinary study driven by people from healthcare, architecture and facilities management.

Role of Microbes for Safety: the counterintuitive study

Microbes are naturally found everywhere. As seen earlier, selected studies on natural ventilation and its impact on Nosocomial TB reduction have been performed. In another such study, it has been hypothesized that 'filtration by mechanical ventilation is a form of dispersal limitation, resulting in indoor microbial communities that represent a subset of outdoor microbes.' However, indoor environments have been found to harbour microbial taxa not commonly found outdoors. These indoor taxa have a common resemblance with human-related DNA and hence they have a likeliness to be from the same subfamily of human pathogens. Hence this study talks not about eliminating bacteria, but in selecting the right bacteria. This opens up the area of architectural probiotics. There is a scope in the exploration of the "good" bacteria that architects can select for their indoor environments (Kembel, et al., 2012). This area requires further study w.r.t. the tuberculosis bacteria and its position in these dynamic spatial system composed of bacteria and other micro-organisms.

Disadvantages of Relying on Natural Ventilation and Possible Solutions

To provide a balanced view, it is important to discuss the possible disadvantages of natural ventilation for a Tuberculosis facility. In places with extreme climates, both hot and cold, sometimes opening up windows for natural ventilation is likely to cause thermal discomfort to the inhabitants. Hence a balance has to be established between thermal comfort, air movement and ventilation for the dilution of the bacterial concentration. A solution to this can be decentralized cooling units in rooms which have operable windows for intentional ventilation whenever required. Non-operable windows should be avoided in almost all cases.

In some cases, windows have shown to be non-operable due to maintenance issues. There may be administrative reasons (like the absence of window opening/closing staff). Sometimes due to poor organization of spaces, windows are concealed by the placement of furniture or closets. In these cases, the design as intended may not perform.

Other issues may be the increased quantity of pollen, particulate matter and gaseous pollutants that may enter through the window openings (Hobday & Dancer, 2013). This can be tackled with the use of innovative filters that can be used in the window assemblies as one that has been developed through research/incubation at the Indian Institute of Technology, New Delhi.

Methodology of Performing Studies

A study in India by Parmar, et al. (2015) involved a baseline assessment of 35 health centres across three Indian states – West Bengal, Gujarat and Andhra Pradesh. It was a very basic risk assessment methodology which involved basic equipment to measure ventilation and air change rates. The equipment used were: 1. incense sticks 2. measuring tape for room volume measurement 3. swing vane anemometer 4. air anemometer and 5. digital cameras. This can be appreciated as an Indian study which has an empirical methodology, but it has certain limitations. It did not perform any surveillance tests on the human subjects, or TB bacterial counts and analysis. It also did not have a CO2 dilution tracer gas test to determine the air changes per hour more accurately.

The study by Escombe et al. (2007) in Lima, Peru used the tracer gas method. It also used a mathematical model called the Wells-Riley Model to establish a correlation between the infection risk assessment and the air changes per hour derived from the above-mentioned CO2 tracer gas technique. It has very effectively given us one of the easiest methods to compare between two cases of naturally ventilated spaces. The comparison between a mechanically ventilated and a naturally ventilated case has also been demonstrated. Combined with the Wells Riley Model, it provides an indication without resorting to actual bacteria samplings, culturing, identification and counting routine. One issue highlighted by some researchers is that Wells Riley is a static model and it may not be an actual indicator of infection caused to humans. The study also does not talk about the proximity of the person to the infection source and it considers the whole space to be homogeneous for this purpose (Escombe, et al., 2007).

Another study performed by researchers in Pakistan (Asif, et al., 2018) took samples of micro-organisms using air samplers, followed by the culturing of bacteria and fungi which were then identified and counted. This was done using microscopic analysis at 1000x magnification, followed by oil immersion and gram staining. The identification was done using Bergey's manual of determinative bacteriology. The counting was done in the unit CFU/m3. Statistical analysis was followed. This gave a quantitative idea of bacteria and fungi population present in the air. The study concluded that the microorganisms were more where the occupancy was more. The study did not compare natural ventilation with a mechanical ventilation case. There was also no study on the air changes in the spaces where the sampling was done (Asif, et al., 2018).

In another study by Kembel et al. (2012), three samples were collected. One was from a mechanically ventilated (duct supplied) room in a hospital. The other was a room where the windows were made operable and were opened with the air conditioning switched off. The third was the outside environment used as a control case. Samples were collected from each of the three cases followed by bacterial cell density estimation, DNA extraction and bacteria 16S gene amplification. This was done in order to very accurately identify the bacteria and fungi for a taxonomically accurate analysis. The goal of which was to find out the phylogenetic diversity of the sampled microorganisms in order to classify and compare their populations and diversity in the different zones (Kembel, et al., 2012).

The tracer CO2 gas dilution analysis method is a suitable method to find the relative rates of diffusion in different spaces. These rates of diffusion provide an idea of the air changes which can be further substituted in the Wells Riley model to check for infection transmission risk. This may seem like a proxy test which can be made more valid by actually performing a sampling of bacteria from the air followed by identifying and counting them.

There is also immense scope in utilizing computational fluid dynamics based simulation modelling software to analyse the movement of air and pathogenic bacteria in the TB care facilities.

The Way Ahead for Infrastructure Designers

It has been established that natural ventilation, with some defects, has a certain advantage over mechanical ventilation for reduction of infection transmission risk. There has been a study in South Africa where the planners have used a wind-driven roof turbine system along with inlet air gratings to enhance the ventilation in a TB facility (Cox, et al., 2011). In places with extreme climates where natural ventilation may not be possible, the use of upper room ultraviolet has also been researched and advocated (Escombe, et al., 2009).

TB is a good starting point (Pai, Kalantri, et al., 2006) as the TB facilities can be used as a model for other diseases caused by airborne infection spread. Addressing the nosocomial infection spread is also particularly helpful for the HIV care centres where the patients are most susceptible to all kinds of airborne infections due to their suppressed immunity. In designing a healthcare facility, an architect has to face many constraints and the choice has to be in consistence with a balanced solution which takes into consideration many factors at once. While providing comfort may be important for a commercial building or a hotel, it may be secondary for a TB facility where infection control is primary and providing comfort may put infection control into jeopardy. There has been an active shift towards performance in architectural design (Negendahl, 2015) and the building needs to perform well on the infection control front too. Hybrid systems where decentralized air conditioning may be provided along with operable windows can be a possible solution where further quantitative research may be done. Other solutions could be more advanced natural ventilation systems which prohibit the entry of dust, pollen and gaseous pollutants into the indoor spaces. The need to address nosocomial transmission should be recognised as it will not only help the patients and visitor to TB facilities but will impact healthcare workers the most. These measures as a whole will contribute towards widening and deepening the scope of the involvement of infrastructure professionals for the common goal of eradication of TB in India by 2025. ■

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