Studying the association between structural factors and tuberculosis in the resettlement colonies in M-East ward, Mumbai

Final Report

Doctors For You

Contents

Executive Summary

The building architecture and site planning seems to play a big role in creating a healthy atmosphere in the urban resettlement colonies as is projected by the various reports on research carried out in different countries (1-14). High burden of TB results in sizeable economic and social costs making it a critical issue to address. Hence, it is worthwhile to study if the urban resettlement colonies in M-East ward also show similar trends. Further, it is important to consider if the Development Control Regulations (DCRs) for resettlement buildings need to be changed in order to ensure that the health of the families residing in these buildings is not compromised due to any design and layout faults. Through this study, *we aimed to investigate and establish the strength of association between structural factors of slums resettlement colonies buildings and the incidence pattern of tuberculosis.* For this, we performed a cross sectional study using household survey to find architectural and socioeconomic details of the household, computational modelling of sunlight and ventilation access based on house design and layout of the Lallubhai compound, Natwar Parekh compound and PMG colony and validation of these models by actual measurements of air velocity and daylight.

Results: Computation modelling has shown that lower floors do not have access to sufficient light (Fig. ES1) and ventilation in the living area. These results were compared to the results obtained from statistical analysis of household survey data and both were found to be in sync. The survey brought out the following correlations:

<u>Floor</u> – Low floor have more number of cases probably because they have poor ventilation and sunshine access.

<u>Window design and usage</u> – Households not having openable windows and/or using the closed windows as storage spaces have high likelihood of having a TB patient.

<u>Exhaust fans</u> – Lack of exhaust fans are strongly correlated to TB prevalence, indicating towards lack of mechanical ventilation, one of the risk factors for TB prevalence and transmission.

<u>Sky view factor, daylight autonomy, ventilation</u> – All colonies show poor sky view factors, daylight autonomy and ventilation which may be likely cause of high TB in this area. Low daylight autonomy and ventilation may be because of poor design of the houses and compact stacking of the building next to each other.

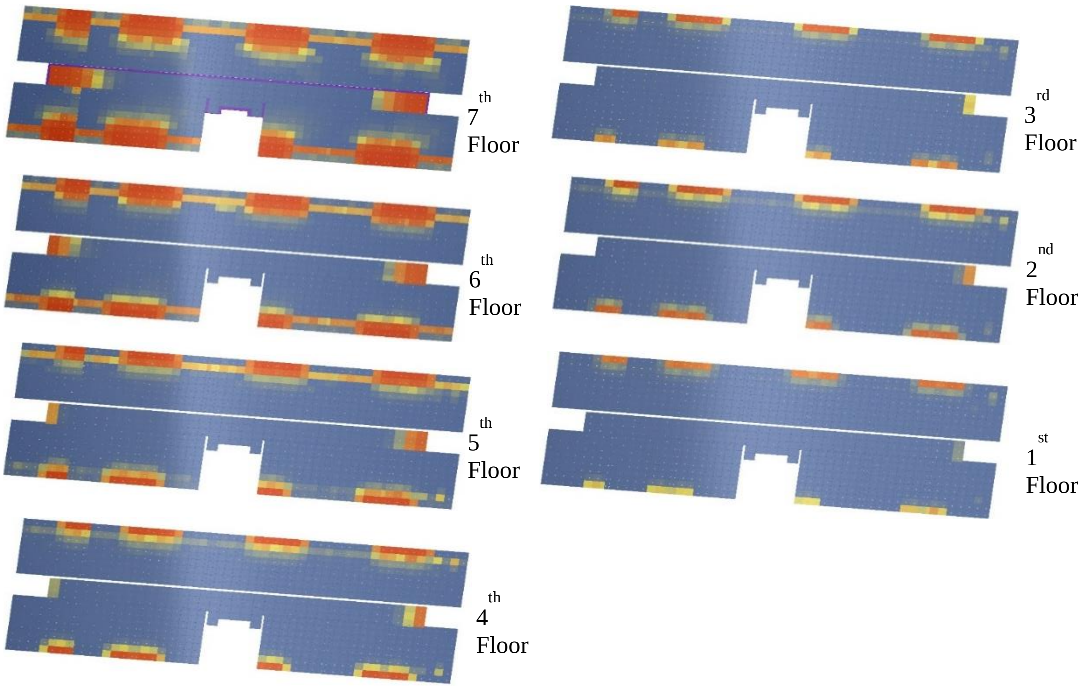


Fig. ES1. Simulation of floor-wise Daylight Autonomy due to impact of nearby buildings in Lallubhai colony

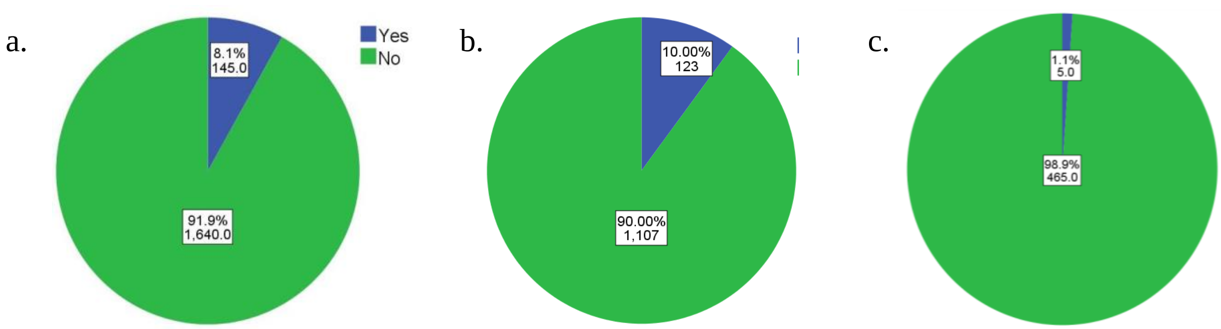


Fig ES2. Households having at least a TB patient in the three colonies: a). Lallubhai colony, b) Natwar Parekh colony, c) PMG colony

Conclusion and Recommendations: The results show that the occurrence of TB in Natwar Parekh and Lallubhai compounds is strongly associated with the built environment of the houses and the layout of the buildings in both the colonies. In contrast, occurrence of tuberculosis is least in PMG colony which is associated with better built environment and the layout characteristics. This explains that, efficient provision of daylight and natural ventilation strategies within a particular space may act as a factor in improving human health condition, whereas poor sunlight access and natural ventilation may be major risk factors for the deadly TB disease.

Table ES2. Statistical analysis of Household survey data to find correlation between TB and house design

At least one member of the household is suffering from TB		B	Std. Error	t statistics	Sig.
Yes	Intercept	-5.523	0.605	-9.130	0.000
	House hold size	0.152	0.021	7.364	**0.000**
	Number of the floors in the building in which the respondent is residing	-0.056	0.028	-2.005	**0.045**
	Number of exhaust fans	-0.222	0.132	-1.686	**0.092**
	Not openable Window	2.823	0.583	4.846	**0.000**

Planners have long known the relationship between the city's built form and public health. A detailed study of the layout of these resettlement colonies and the Development Control Regulations (DCRs) reveal that there is huge disparity between the housing provided by the government and that built by the private firms. This study strongly suggests that the SRA and PAP project developers must follow the National Building Codes for the resettlement colonies without any dilution of the strict norms. Also, there should be no separate rules and regulations for public and private housing, in order to maintain a healthy locality and a hence, healthy country. It is imperative to roll back on the norms that are detrimental to the health of the public.

In the era of climate change, climatically sensitive design is necessity for survival of the lower income classes that cannot depend on costly mechanical solutions for air conditioning and ventilation. Public housing that is being built is expected to last at least for the next 30 years and should be built after due deliberation of built form and livability standards. The city government must take necessary actions bring improvements in built from, livability and avert a public health crisis.

In the areas where the population has already been affected by poor access to natural ventilation and sunlight, structural and social interventions can be made retrospectively, in order to increase the air flow in the houses and help the residents avail of the clean air and open surroundings. In populations that are particularly vulnerable to certain diseases like TB, special measures need to be taken to prevent the occurrence of disease in them.

Introduction

Tuberculosis (TB) is the leading cause of deaths due to infectious diseases. *Mycobacterium tuberculosis*, the causative agent of TB remains viable in damp and cool environment and is transmitted through aerosols generated by coughing and sneezing. According to WHO estimates, there were 1.4 million deaths due to TB and 10.4 million new cases reported in 2015 (1). India has the highest burden of TB with more than 25% of the cases worldwide (1). Tuberculosis has been named as the disease of poverty. Lack of hygiene, large family size, crowding, unhealthy food leading to low immunity, non-compliance of dose regimen, HIV co-infection are among the major factors contributing to the spread of TB.

With rapid urbanization taking place, people from rural and poor areas are migrating towards metro cities in search of livelihoods. Mumbai being the commercial capital of the country, has become a hub of slums populated with migrant workers. These slums are temporary dwellings which lack in hygiene and sanitation facilities. Municipal Corporation of Greater Mumbai (MCGM) has tried to accommodate the slum dwellers in concrete settlements with the amenities of electricity, water and attached lavatories. However, the problems of access to sunshine and ventilation persist.

The building architecture and site planning seems to play a big role in creating a healthy atmosphere in the urban resettlement colonies as is projected by the various reports on research carried out in different countries. In the urban quarters of Hong Kong, it was found that there is a positive correlation between height of the building and tuberculosis. The lower floors had more TB cases as they had less access to sunlight and fresh air (2)(3). In an ecological study carried out in Birmingham, it was established that TB spread more during winter season when there was less exposure to sunlight as compared to that in summer season (4). A similar study in Peru associated TB incidence with the potential risk factors like crowding of the houses, hours of sunlight exposure and vitamin D deficiency (5). Also, in Bern, Switzerland, a study found a positive correlation between TB mortality and crowding and lack of sunlight. TB mortality decreased with the introduction of improved housing conditions and public health measures, over many years (6).

Among Mumbai's 24 wards, M-East ward has reported high TB prevalence. Chembur area of Mumbai had 3452 total TB cases whereas Govandi area had 4642 total TB cases in 2016 (7). This amounts to a prevalence of 758 cases per lakh persons in Chembur and 1055 cases per lakh persons in Govandi, about 3-5 times higher than the national average. Both these areas fall under M-East ward. This high burden and mortality results in sizeable economic and social costs making it a critical issue to address. With the established correlation of TB morbidity and mortality with building architecture and housing conditions, as discussed above, it is worthwhile to study if the urban resettlement colonies in M-East ward also show similar trends. Further, it is important to consider if the Development Control Regulations (DCRs) for resettlement buildings need to be changed in order to ensure that the health of the families residing in these buildings is not compromised due to any design and layout faults. It is interesting to note that the DCRs for private buildings and those for public housing schemes may differ so as to allow more crowding which could prove to be a health risk. With these principles in mind, the current study was undertaken.

Aim

"To investigate and establish the strength of association between structural factors of slums resettlement colonies buildings and the incidence pattern of tuberculosis"

The study would try to understand the epidemiology of TB in these resettlement colonies and investigate if structural factors of the buildings have a role to play in the profile of TB cases.

Objectives

Primary objective:

To compare the architectural parameters like building height, distance between two buildings, sky view factors, air exchange rates of the three colonies and draw their correlation to the number of TB cases in the residents of these resettlement colonies

Secondary objectives:

To determine the health parameters and socioeconomic status of the population residing in resettlement colonies

To find good architectural and structural parameters for resettlement colonies which are cost effective but at the same time do not compromise the health of the residents.

Researchers associated in the Project

Sr No	Researchers Associated	Qualification	Affiliation
1	Dr Ravikant Singh	MBBS & MD Public Health KEM Hospital Mumbai	Doctors For You
2	Dr Peehu Pardeshi	M.Sc Microbiology PhD IIT Bombay	Doctors For You
3	Dr Narendra Sutar	MBBS, Mumbai University	DTO, RNTCP
4	Prof. Ronita Bardhan	B.Arch, MCP, PhD	Centre for Urban Science & Engineering, IIT Bombay
5	Ms Namrata Kapoor	M. Arch., M City Planning, UC Berkeley	KRVIA, Mumbai
6	Dr Balram Jadhav	BAMS,MPH KLE	Doctors For You
7	Mr Siddharth David	MSW TISS Mumbai	Doctors For You
8	Dr Nabhojit Roy	MBBS, MS, MPH John Hopkins University USA	BARC & NHSRC Govt. of India
9	Dr Daksha Shah	MBBS, MD Public Health	City TB Officer, RNTCP
10	Dr Arnab Jana	B.Tech, PhD	Centre for Urban Science & Engineering, IIT Bombay

Methodology

A. Study area-

Households in two resettlement colonies in which Doctors For You provides health services along with the MMRDA, in the M East Ward (A and B) (Fig. 1a and 1b) and households from another resettlement colony with better ventilation and spacious building design (C) (Fig. 1c) were selected for the house hold survey. The sample was approximately 12,000 households with a population of about 70,000. The approximate number of households in the three colonies are given below.

A. Lallu Bhai Compound, Govandi West: 36 Buildings; 4,890 occupied rooms
B. Natwar Parekh Compound, Shivaji Nagar, Govandi West: 59 Buildings; 4,800 occupied rooms
C. PMG colony (Ambedkar Nagar, MHADA), Mankhurd: 16 buildings; 2,100 occupied rooms

a. b. c.

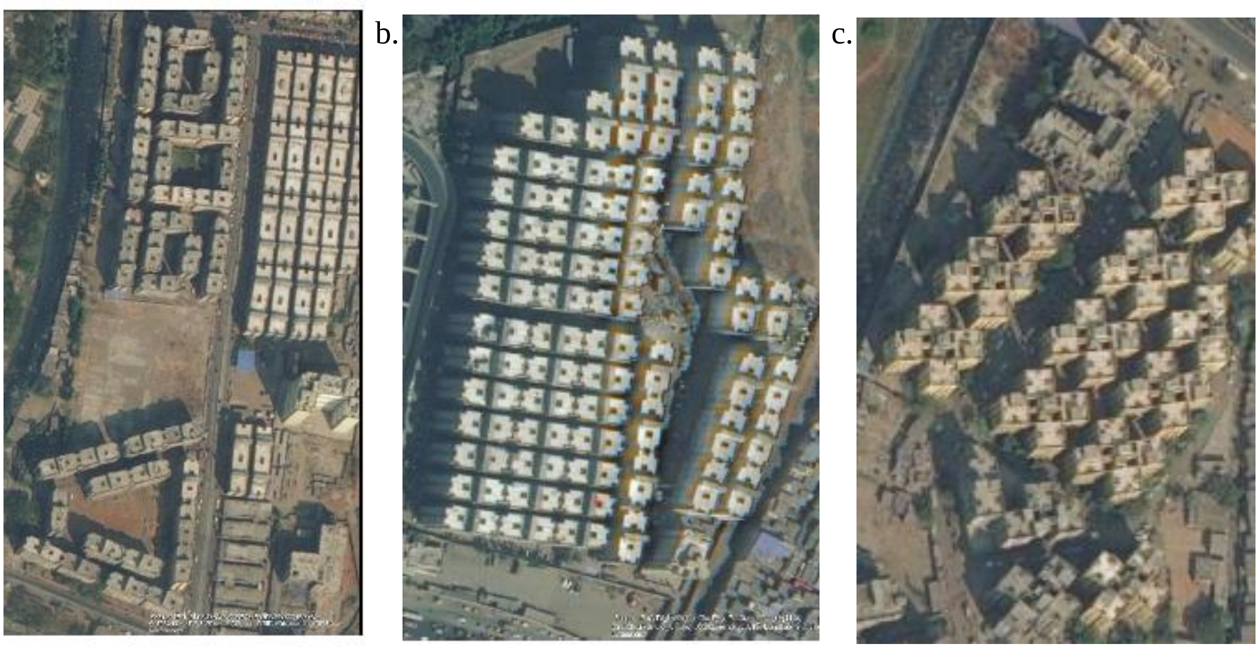


Fig. 1 Snapshots of top view of: a. Lallubhai compound, b. Natwar Parekh compound, and c. PMG colony

B. Study population-

Persons residing in the houses in the three resettlement colonies (Natwar Parekh, Lallubhai Compound and PMG colony) were considered for the data collection and questionnaire based interviews.

C. Study Design-

The study design consisted of a household survey in the three colonies to gather information on various indicators of TB as well as housing conditions, followed by computational modelling and simulations to study the architecture houses and layout of the buildings. The computational models were further validated by actual measurements in the households. The detailed design and method of the study is given below:

i) Household survey

This is a cross-sectional study based on **house-to-house survey**. (Questionnaire attached in Annexure I). Sampling technique used was systematic random sampling, using which at least $1/3^{rd}$ of the households on each floor of every building were interviewed. Further, detailed field visits and informal open-ended interviews of the residents of all the colonies were taken, in order to understand the reasons behind some of the habits and patterns observed in the colonies.

For conducting this survey, a team was formed as given below:

Research team: Research officer, field supervisor, data entry operator and data collectors

Recruitment and training of data collectors:

For the household survey, data collectors who belonged to Lallubhai compound and Natwar-Parekh compound were recruited. The recruitment was based on personal interview conducted by the Research officer. The candidates who had a prior experience of working in healthcare settings and survey area were selected. A total of 8 data collectors were appointed. Workshop for explaining the questionnaire and consent forms was conducted at the Doctors For You office. Also, intermittent training and revision was conducted every week to understand the problems faced during survey and to reiterate the important points to be considered during the interview. A pilot study for the survey was conducted with 40 households over two days, in order to ensure the robustness of the questionnaire. Fig. 2 shows some data collectors starting on their first visit to houses for survey at Natwar-Parekh compound.

Fig. 2. Six of the eight data collectors along with the research officer, at the Doctors For You office on their first day of survey

For the survey, the questionnaire in English and Hindi formats (Annexure I) was given to the data collectors along with the consent forms (Annexure II). Participants were approached personally at their residence and were explained about the nature of study and tool. The consent form was explained to them and their signature was sought. Data collectors interviewed the participants and filled the forms according to the information provided (Fig 3).

In total, about 10,000 households were considered for the study out of which more than 40% were sampled for the survey. The survey started at 10.30 am and ended at 5pm with a lunch break from 1-2 pm, on all working days.

The parameters monitored in the survey were as follows:

a. Socioeconomic and demographic details – Name, age, gender, house number, building number, number of occupants in the house, time since occupying the house, occupation of the respondent, family income

b. Morbidity details – Whether any family member suffered TB in the past or present, any other disease or disorder

c. Housing conditions and practices – windows and doors opening habits, electricity consumption, layout of windows in the house, using windows as storage space, time spent in the house.

However, data pertaining to life style, food habits and other dietary habits were not inquired. No blood samples or any physical measurements were undertaken during the survey.

The information in the questionnaires filled by the data collectors was compiled by the data entry operator in the form of Microsoft excel sheets which were further subjected to statistical analysis.

A total of 4,080 households were surveyed. Number of households surveyed in each colony are mentioned below:

Name of the colonies	Number of Households Surveyed
Natwar Parekh Compound	1797
Lallubhai Compound	1785
PMG colony (Ambedkar Nagar)	498

Data analysis has been performed using SPSS software, on the household survey data and the secondary data. The main areas of analysis and comparison were: age group affected, floors wise distribution of TB patients in each colony, gender wise distribution, type of infection and time of incidence of TB after shifting into the colony. For further statistical analysis, all the samples were pooled and incomplete samples with missing data were deleted. Post data cleaning, the sample size reduced to 4,019 (Table 2).

Fig. 3. Snapshots of a dark corridor in one of the buildings of Lallubhai compound (a) and data collectors interviewing various households (b, c, d).

ii) Computational Models using building drawings

Computational modelling and simulations were used to prepare models of age of air in the house, daylight autonomy and sky view factor for the three colonies. These models are based on the floor plans and section maps of the buildings in the three colonies (Attached in Annexure III), procured from MMRDA and MHADA by Ms. Namrata Kapoor, Urban Planner, KRVIA. The computation facility at IIT Bombay was used for this purpose under the guidance of Dr. Ronita Bardhan and Dr. Arnab Jana, C-USE, IIT Bombay. The software used for these experiments were: ESRI 2011. ArcGIS Desktop: Release 10.5. Redlands, CA: Environmental Systems Research Institute. Autodesk® Revit® 2017 Autodesk, Inc., Autodesk® AutoCAD® 2017 Autodesk, Inc.,Rhinoceros 5 Rhinoceros. Inc. and DIVA 4.0.2.9 for Rhino Sustainable Design (G(SD)2) research group Solemma LLC.

The factors studied through modelling are explained below:

Sky view Factor

Theoretically, 'the sky view factor (SVF) is a geometrical concept that describes the fraction of the overlying hemisphere occupied by the sky'. The SVK is a dimensionless parameterisation of the quantity of visible sky at a given point. It is a graded value between zero and one. Increasing the height of flanking objects obstructs the vision of the sky, which leads to a decreasing SVF value, reaching the value of zero at its lowest. In contrast, by decreasing the height of flanking objects to when the entire hemisphere is clearly visible, the SVF value will equal one. (Fig. 17, 18, 24, 25, 31 and 32)

Daylight Factor

Daylight factor (DF) is the most common metric used in actual practice and/or guidelines, which is the ratio of internal illuminance to external horizontal illuminance under an overcast sky defined by the CIE (International Commission on Illumination) luminance distribution.

1. The CIE standard overcast sky is merely an idealist sky model: Overcast sky type is not unique. The CIE overcast sky is applicable when the complete sky canopy is covered with uniform dark clouds representing heavy overcast sky only.
2. DF is assessed under overcast conditions, no account is made of illuminance from sun and non-overcast skies, and so the daylight factor is invariant to building orientation and the location of the room.

Daylight autonomy was preferred over Daylight factor.

Daylight Autonomy

Daylight autonomy (DA), on the other hand, is a climate-based Daylight performance metric which factors in the daylight climate of the building site and facade orientation. DA is represented as a percentage of annual daytime hours that a given point in space is above a specified illumination level. It is a major innovation since it encompasses specific weather conditions of the geographic location on an annual basis. DA uses work plane illuminance as an indicator of whether sufficient daylight is rendered in a space so that an occupant can work by daylight alone.

Natural Ventilation

Exchange of air between indoor and outdoor environment without reliance on mechanical support like fans and other cooling sources is known as natural ventilation. Natural ventilation not only improves thermal comfort but also provide healthier indoor environment by boosting indoor air quality within a particular space. Efficient provision of natural ventilation strategies into building spaces can significantly reduce energy consumption as well as monetary concerns due to its negligible cost and low energy consumption in comparison to mechanical modes of ventilation. This strategy can be more useful in the hot and humid or subtropical climate dominant countries where air conditioners are major elements for energy consumption. Therefore, it is essential to study natural ventilation in residential buildings in order to increase benefits.

The LIG settlements, particularly in Mumbai, are characterized by lack of airflow path in the living spaces leading to poor indoor air quality, higher indoor temperature and lack of sanitation and hygiene. The relationship between health and built environment majorly focuses on Household Air pollution (HAP).

The interior layouts of tenement units for each of the colonies were studied. A mixed mode research methodology was involved in this study which included i) Measurement of temperature and air velocity for 10 minutes in 60 households and ii) and airflow in each of the tenement units were computed using Computational Fluid Dynamics(CFD) simulations. The recorded values of air velocity from field survey were taken as input boundary conditions for CFD simulations.

CFD simulation

The 2015 version of the CFD software ANSYS coupled with FLUENT interface, was used to carry out the simulations. This is well known and well-established tool for simulating and analyzing fluid flow, air velocity and has been used worldwide by researchers to predict airflow characteristics in different ventilation scenarios.

The airflow in the tenement units was assumed to enter through window (inlet) and escape through door (outlet). Only unidirectional flows were considered in the simulation. The window was assumed as velocity inlet while the door as pressure outlet. The middle of the window and door was assumed at a constant atmospheric temperature of 305 K (21 deg C). Pressure was considered constant across inside and outside boundaries of the tenement unit. Therefore, ventilation was assumed to be completely wind driven. The details of boundary conditions are shown in Table 1. The monitoring point was taken at the mid bed position at a height of 0.7 m from the ground level.

Table 1 Summary of boundary conditions used for natural ventilation simulation

Part of Computational Domain	**Boundary Conditions**	
Door	Pressure outlet	Gauge pressure = 0; T = 300 K, Hydraulic diameter= 1.26 (authors' computation) ; Turbulence intensity = 10%
Window	Velocity inlet	Gauge pressure = 0; T = 300 K, Hydraulic diameter= 1.09 (authors' computation); Turbulence intensity = 10%, Velocity (authors' computation)
Wall- room	Wall	Stationary wall; No slip

These models were validated by actual measurement of daylight, air velocity and sky view factor of the three colonies these factors using luxmeter (Fig 4a), anemometer (Fig 4b) and Fish eye lens camera, respectively, in the colony premises.

Further, a detailed study of DCRs governing the built form of resettlement and rehabilitation colonies like PMG Colony, Lallubhai Colony and Natwar Parekh Compound was performed.

a.

b.

Fig. 4. Representative images of a Luxmeter (a) and an Anemometer (b)

Results

Simulations and calculations

Using the building maps, models of the three building designs were built and simulated for air velocity, sky view factor and daylight autonomy.

Sky View Factor

SVF simulations for Lallubhai and Natwar Parekh compounds showed that these colonies have poor sky view between the buildings indicating crowding which could be detrimental to the well-being of their residents. PMG colony was found to be a better colony with open corridors and better sky view (Fig 5, 6, 13, 14, 21, 22). Actual measurements show that an open corridor in PMG colony has a SVF of 0.3, whereas widest spaces in Lallubhai and Natwar Parekh compound could reach only upto a SVF of 0.1 and 0.2. These measurements validated the observations made by simulations and thus indicate that Lallubhai and Natwar Parekh compounds do not provide access to sunshine and open sky in their buildings.

Daylight Auntomy

Lallubhai compound:

Daylight Factor (DF) Analysis: 19% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 26% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 28% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 44% for active occupant behavior. The percentage of sensors with a DA_MAX > 5% is 10% for active occupant behavior

Useful Daylight Illuminance (UDI): The percentage of the space with a UDI<100-2000lux larger than 50% is 45% for active occupant behavior. (Fig.7, 8)

A yearly occupancy schedule was used for the simulations in which the occupied hours were considered to be from 8 AM to 6 PM for the months of Jan, Feb, Nov, Dec and 7 AM to 5 PM in rest of the months this was done considering the daylight availability.

Natwar Parekh compound:

Daylight Factor (DF) Analysis: 44% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across ‘all spaces occupied for critical visual tasks’, the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 60% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 65% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 76% for active occupant behavior. The percentage of sensors with a DA_MAX > 5% is 31% for active occupant behavior

Useful Daylight Illuminance (UDI): The percentage of the space with a UDI<100-2000lux larger than 50% is 58% for active occupant behavior. (Fig 15, 16)

PMG colony model type 1:

Daylight Factor (DF) Analysis: 28% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does not qualify for LEED-NC 2.1 daylighting credit 8.1.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 38% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 40% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 51% for active occupant behavior. The percentage of sensors with a DA_MAX > 5% is 22% for active occupant behavior

Useful Daylight Illuminance (UDI): The percentage of the space with a UDI<100-2000lux larger than 50% is 45% for active occupant behavior. (Fig 24, 25)

PMG colony model type 2:

Daylight Factor (DF) Analysis: 25% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 36% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 39% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 48% for active occupant behavior. The percentage of sensors with a DA_MAX > 5% is 20% for active occupant behavior

Useful Daylight Illuminance (UDI): The percentage of the space with a UDI<100-2000lux larger than 50% is 42% for active occupant behavior. (Fig 27, 28)

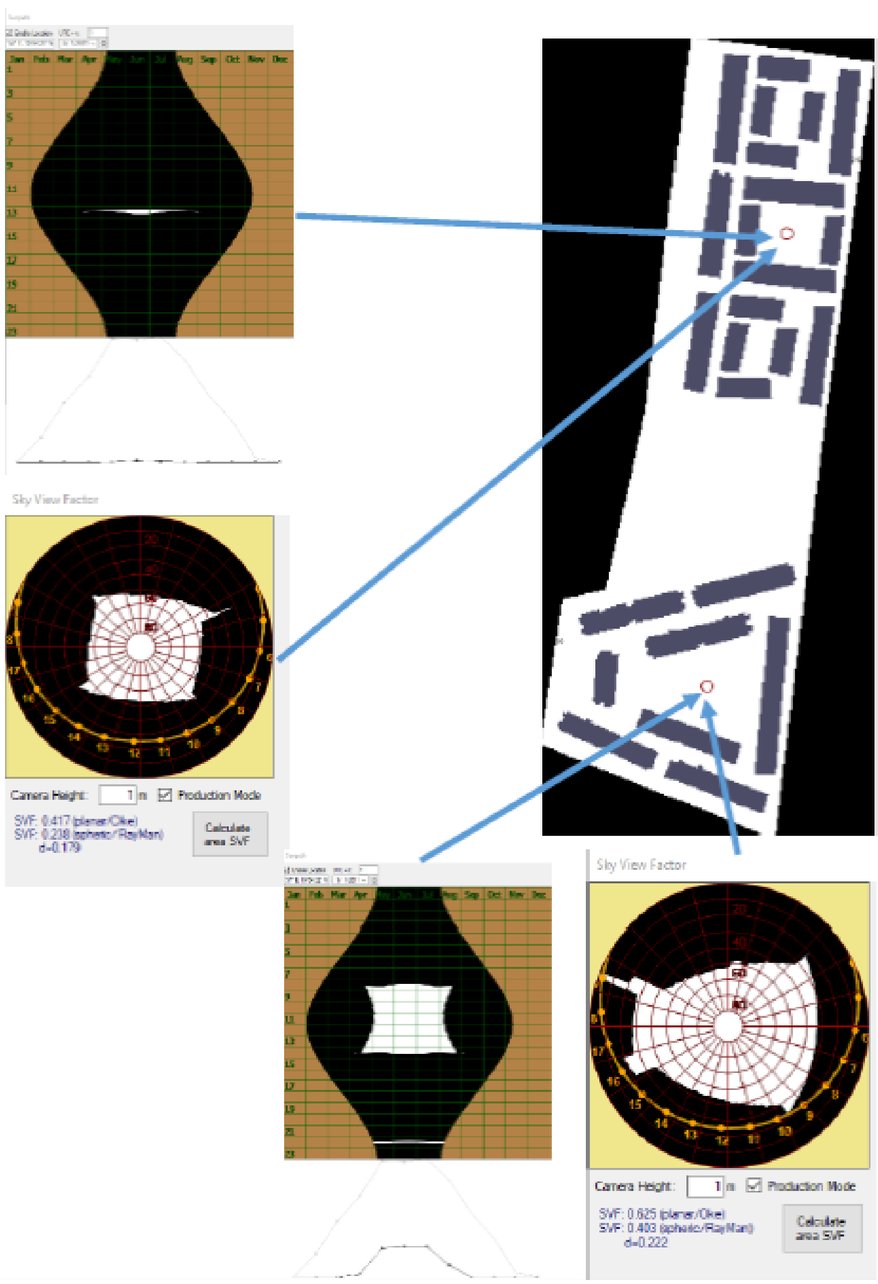


Fig 5. Sky view factor calculation for Lallubhai compound. (Camera height – 1m above ground)

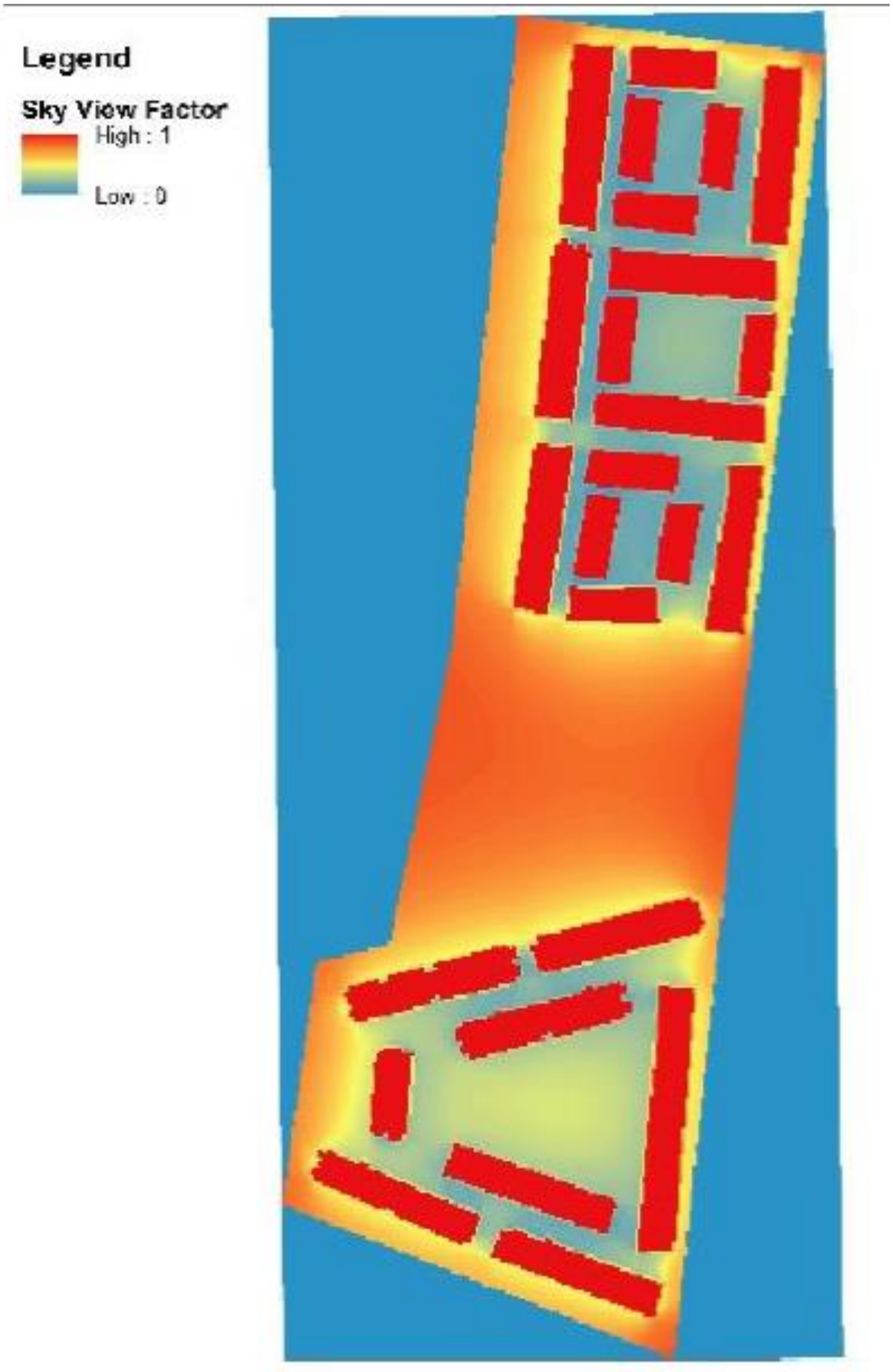


Fig 6. Simulated model for Sky view factor of Lallubhai compound

Table 2. Daylight simulation report for Lallubhai compound

Daylit Area (DA_{300lux}[50%])	28% of floor area
Mean Daylight Factor	1.4%
Occupancy	3650 hours per year

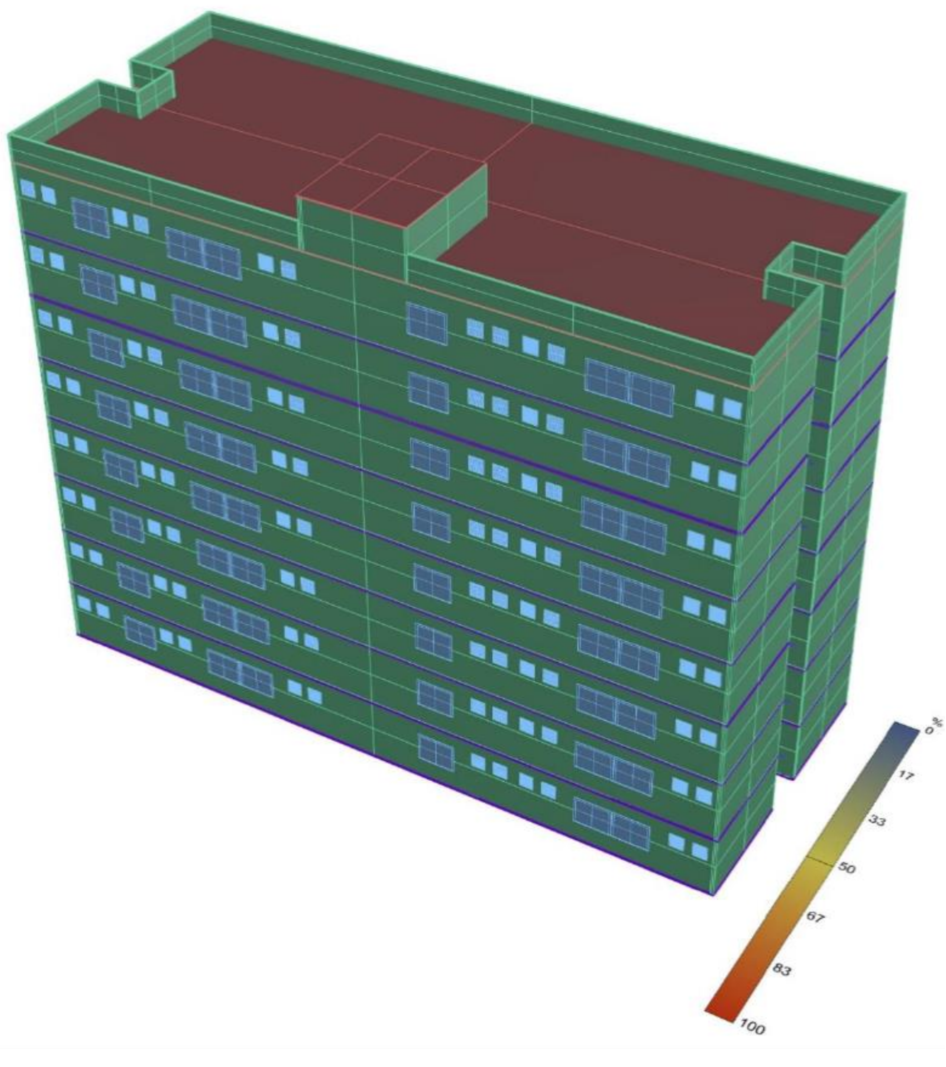


Fig 19. Building model for Lallubhai compound

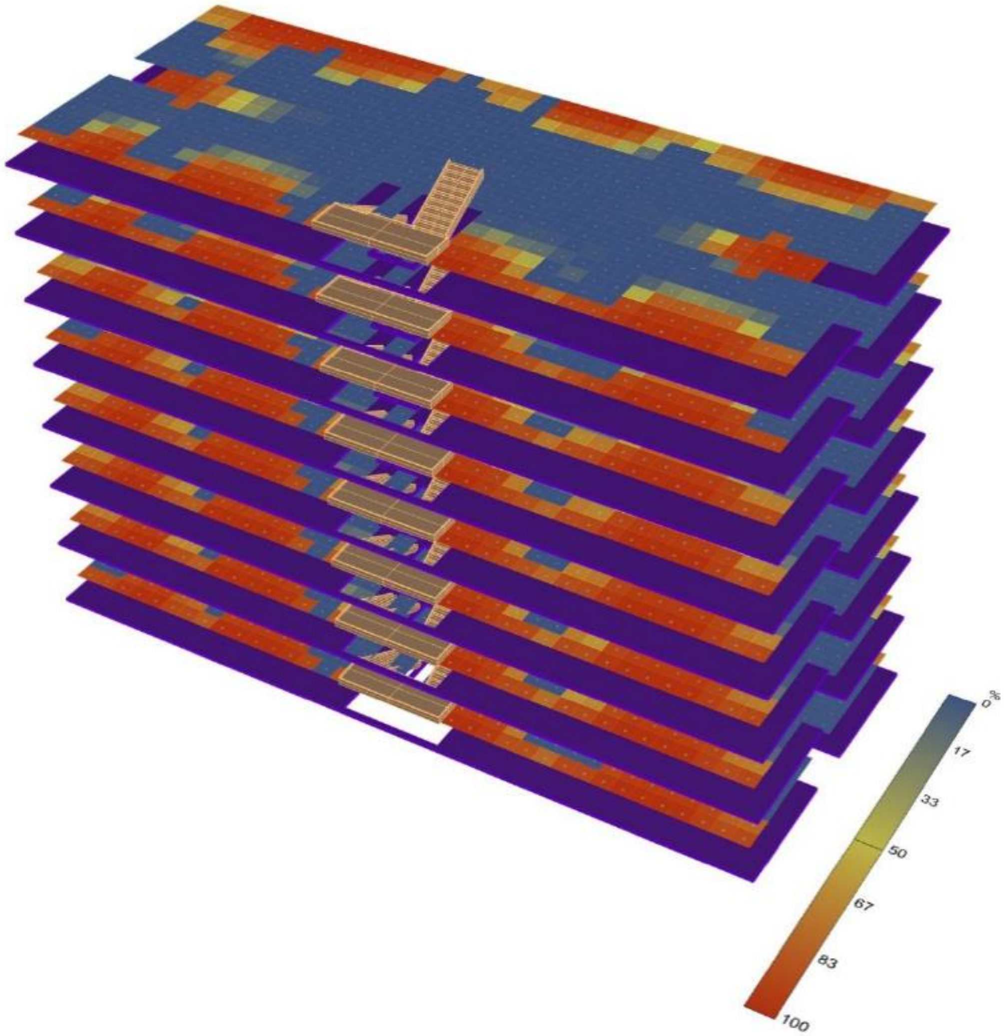


Fig 7. Daylight autonomy of all floors in Lallubhai compound

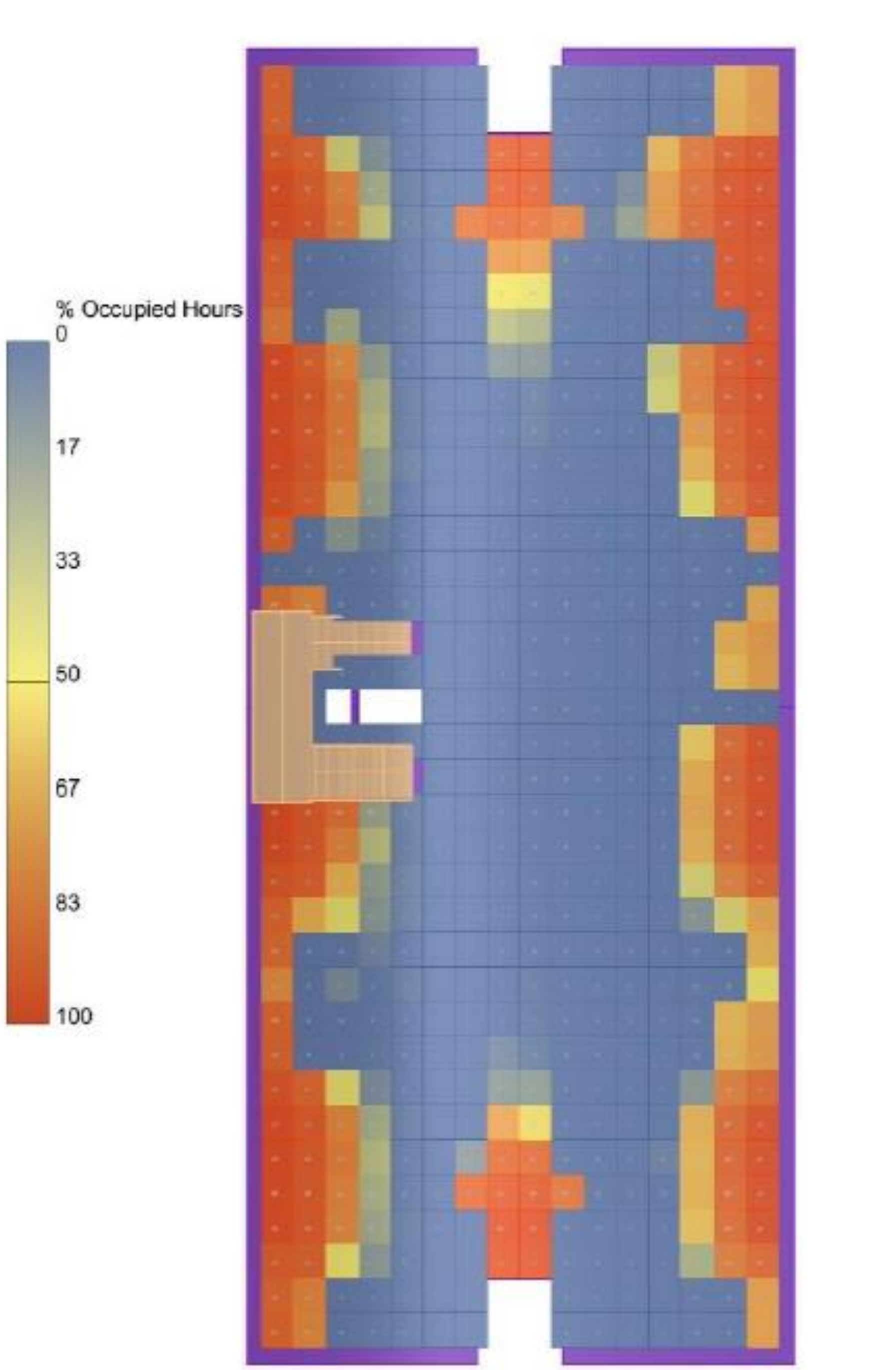


Fig 8. Floor with maximum Daylight autonomy in Lallubhai compound

Daylight autonomy calculation considering impact of nearby buildings.

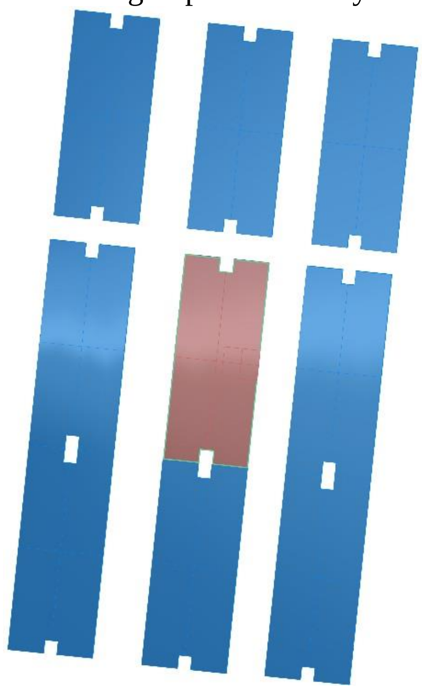


Figure 9 Building used for DA calculation in Lallubhai compound

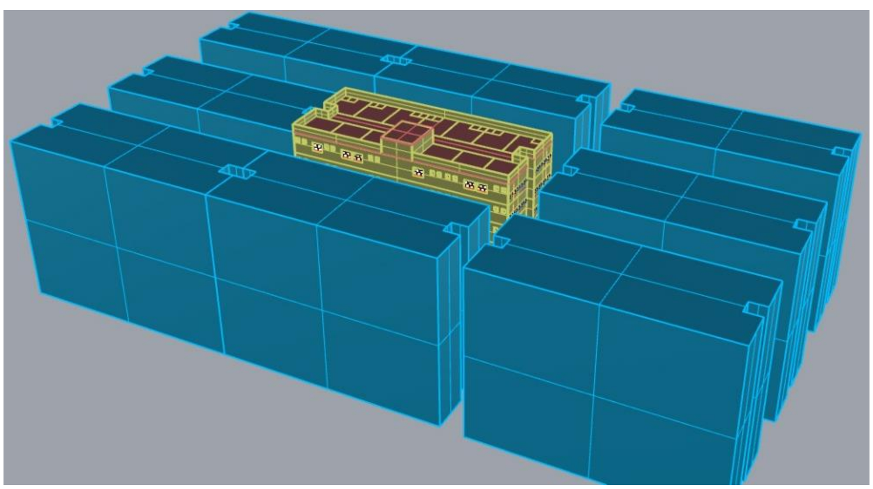


Figure 10 Building model with surrounding building cover in Lallubhai compound

Table 3. Daylight simulation report for Lallubhai compound – impact of stacked buildings

Daysim Simulation Report

Daylit Area (DA_{300lux}[50%])	12% of floor area
Mean Daylight Factor	0.7%
Occupancy	3650 hours per year

<u>Daylight Factor (DF) Analysis:</u> 7% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

<u>Daylight Autonomy (DA) Analysis:</u> The mean daylight autonomy is 12% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 12% for active occupant behavior.

<u>Continuous Daylight Autonomy (DA) Analysis:</u> The mean continuous daylight autonomy is 24% for active occupant behavior. The percentage of sensors with a DA_MAX > 5% is 7% for active occupant behavior

<u>Useful Daylight Illuminance (UDI):</u> The percentage of the space with a $UDI_{<100-2000lux}$ larger than 50% is 18% for active occupant behavior.

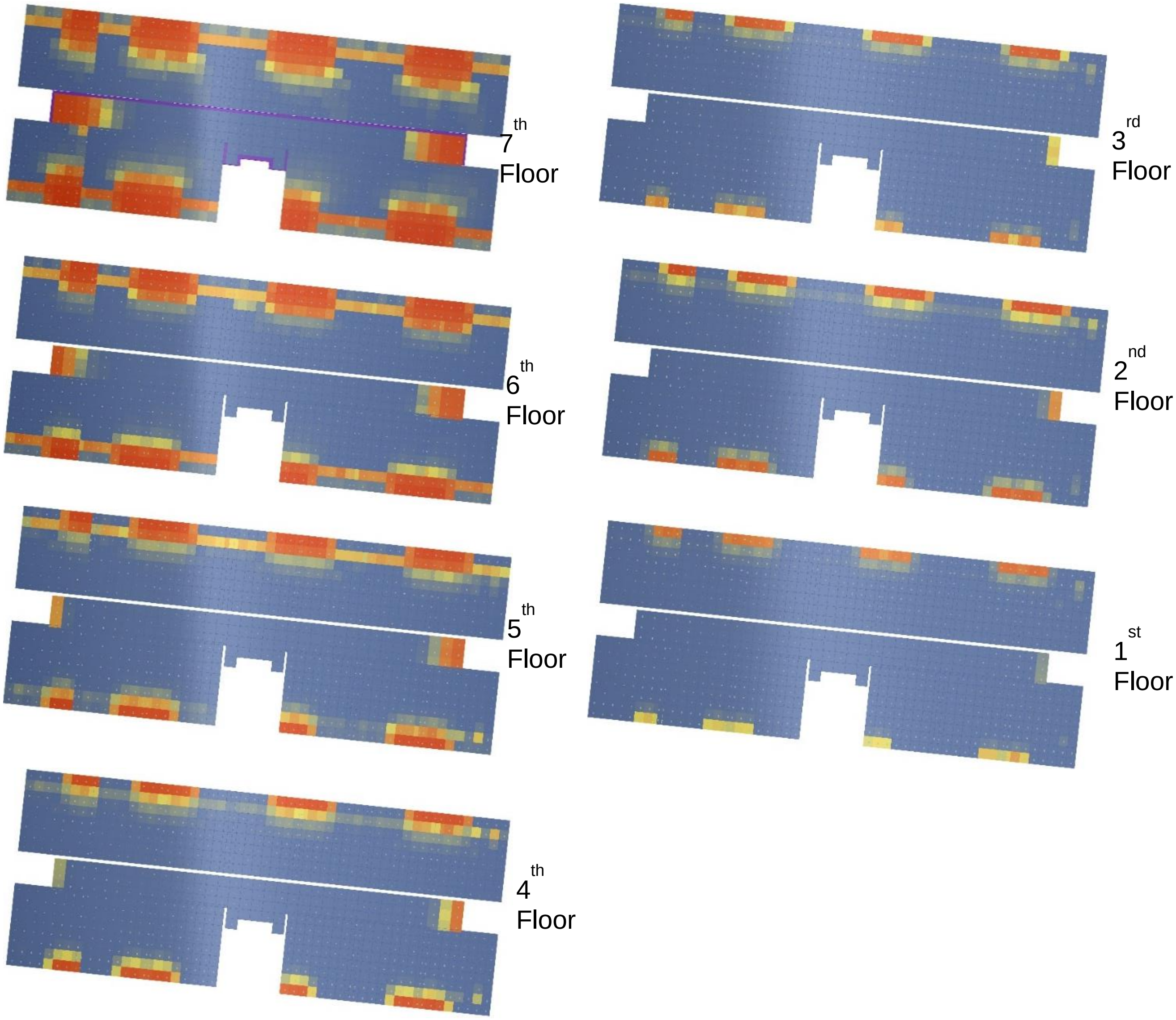


Figure 11 Floor wise DA results in Lallubhai Compound

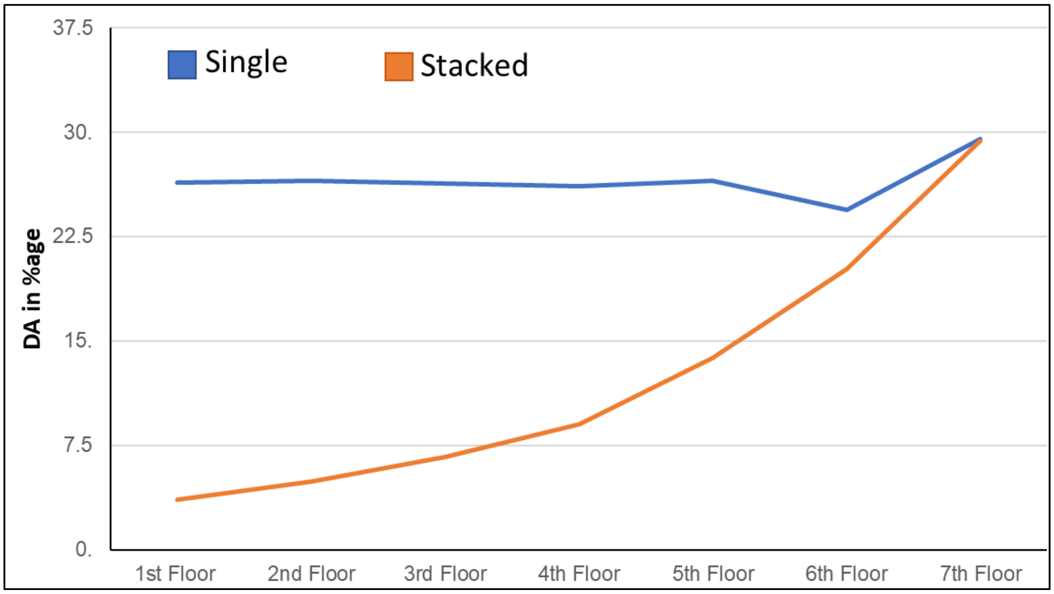


Figure 12 Change in DA of building with and without surrounding buildings in Lallubhai compound

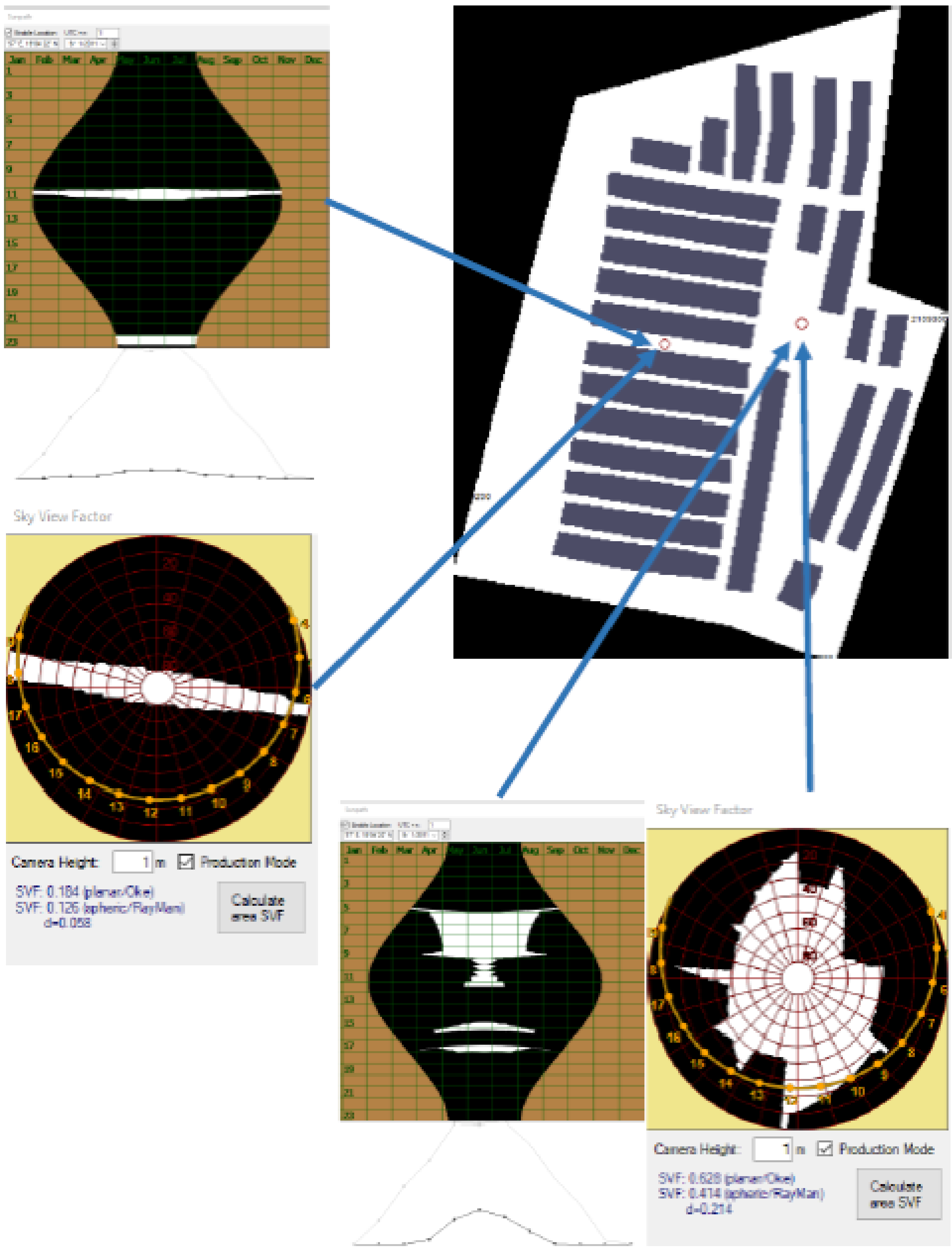


Fig 13. Sky view factor calculation for Natwar Parekh compound

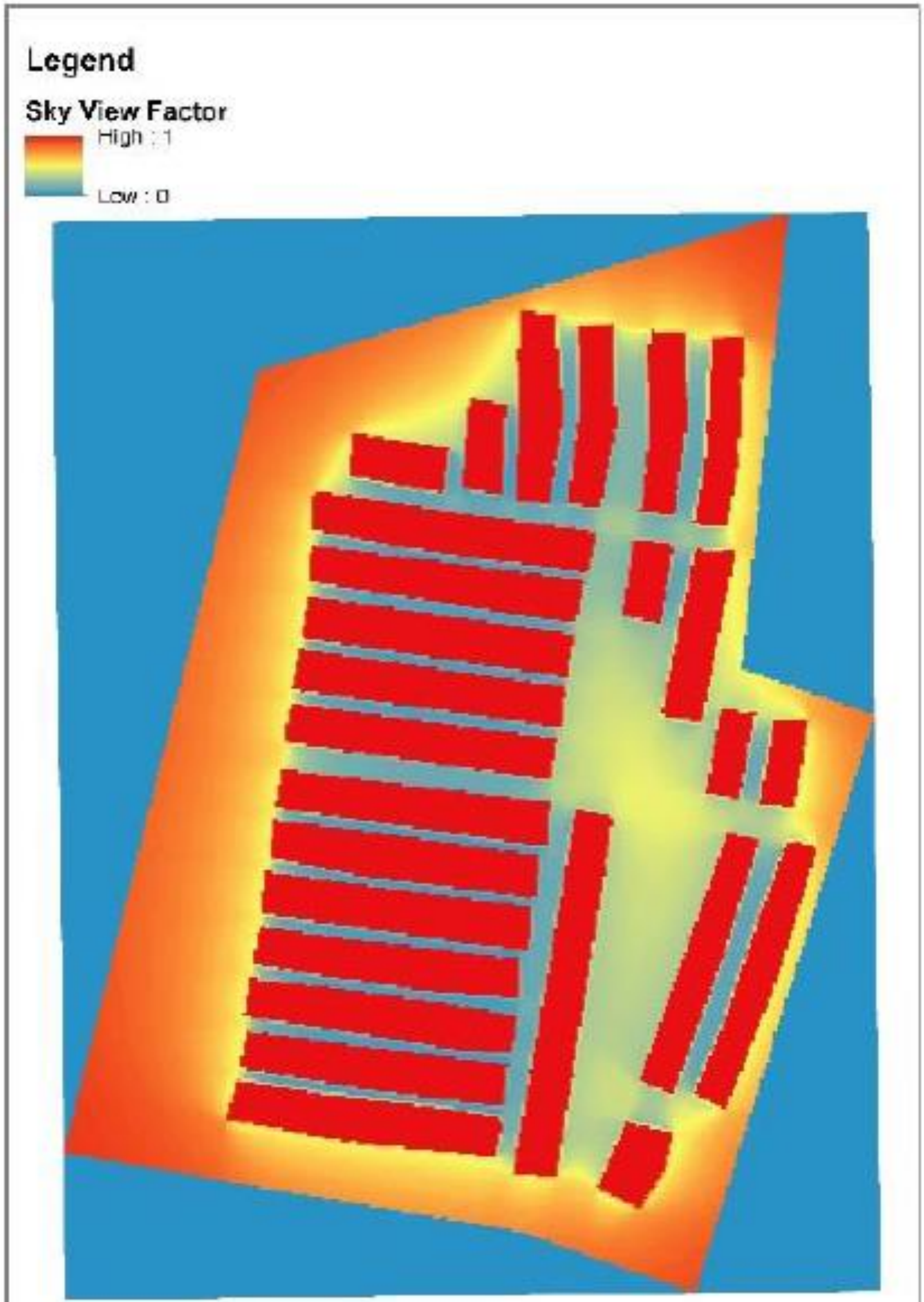


Fig 14. Simulated Sky view factor for Natwar Parekh compound

Table 4. Daylight simulation report for Natwar Parekh compound

Day lit Area (DA_{300lux}[50%])	65% of floor area
Mean Daylight Factor	6.3%
Occupancy	3650 hours per year

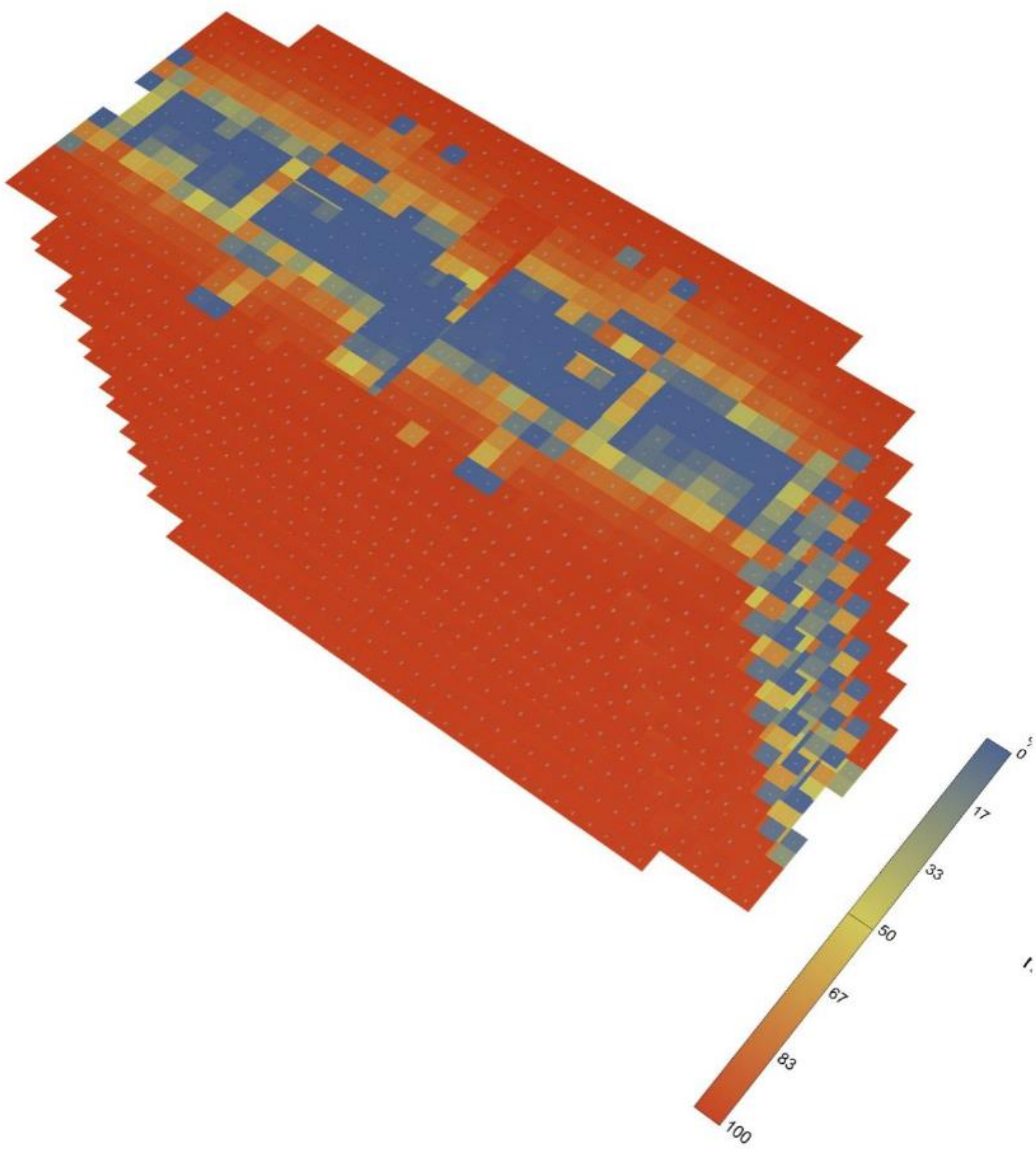


Fig 15. Daylight autonomy of all floors in Natwar Parekh compound

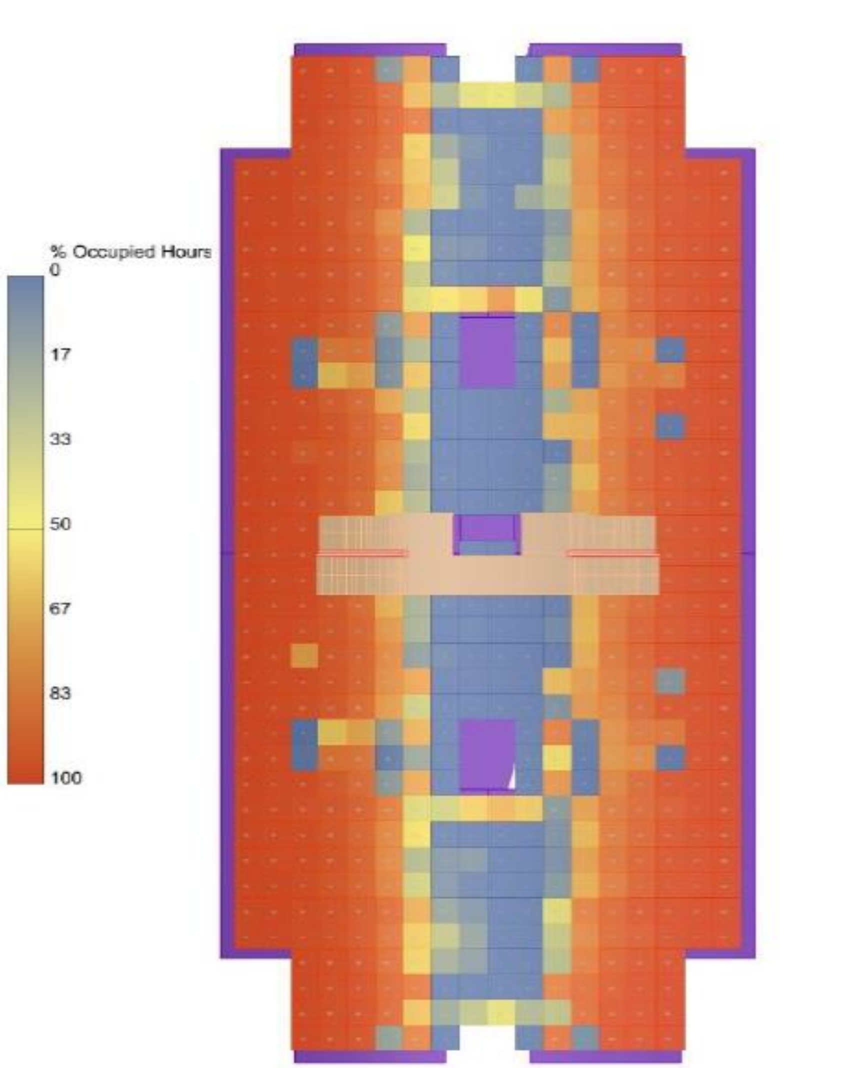


Fig 16. Floor with maximum Daylight autonomy in Natwar Parekh compound

Daylight Autonomy calculation considering impacts of nearby buildings

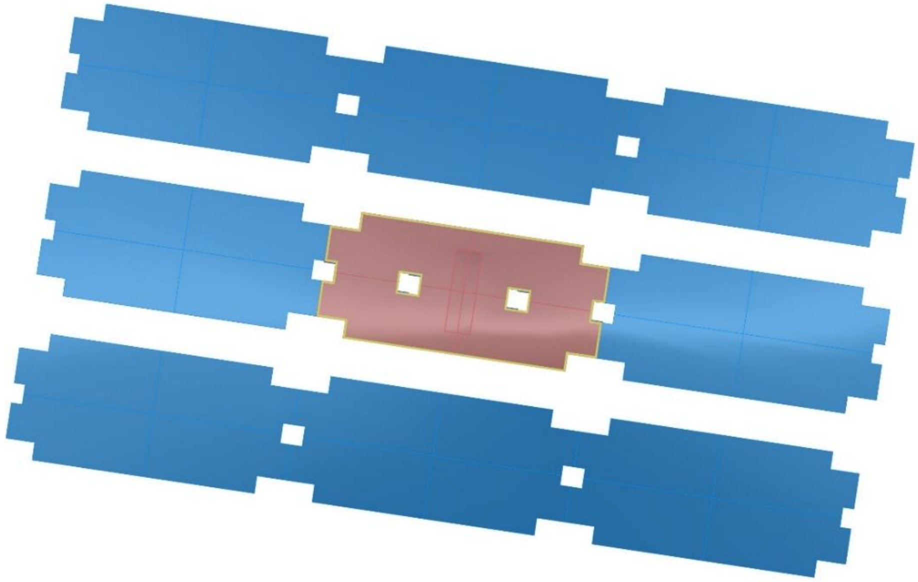


Figure 2 Building used for DA calculation

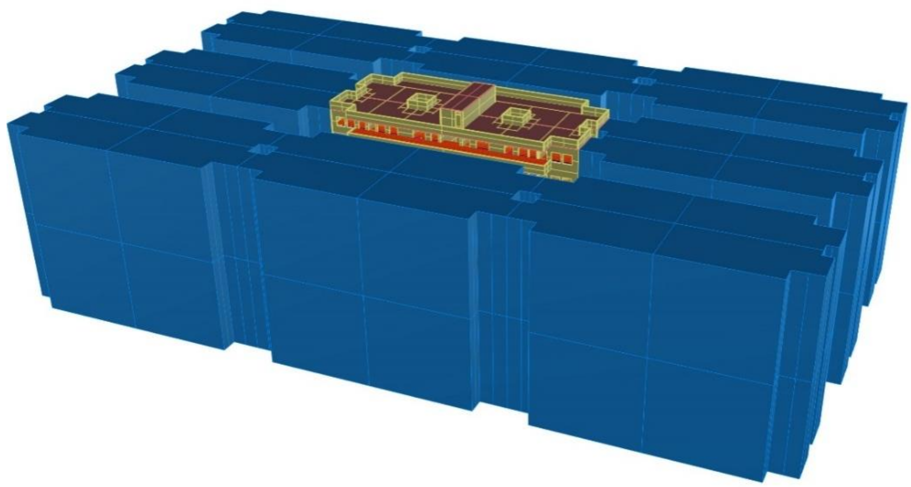


Figure 3 Building plan with surrounding building cover.

Table 5. Daylight simulation report for Natwar Parekh compound – impact of stacked buildings

Daysim Simulation Report	
Daylit Area ($DA_{300lux}[50\%]$)	31% of floor area
Mean Daylight Factor	2.8%
Occupancy	3650 hours per year

Daylight Factor (DF) Analysis: 21% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 31% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 31% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 43% for active occupant behavior. The percentage of sensors with a DA_MAX > 5% is 18% for active occupant behavior

Useful Daylight Illuminance (UDI): The percentage of the space with a $UDI_{<100-2000lux}$ larger than 50% is 30% for active occupant behavior.

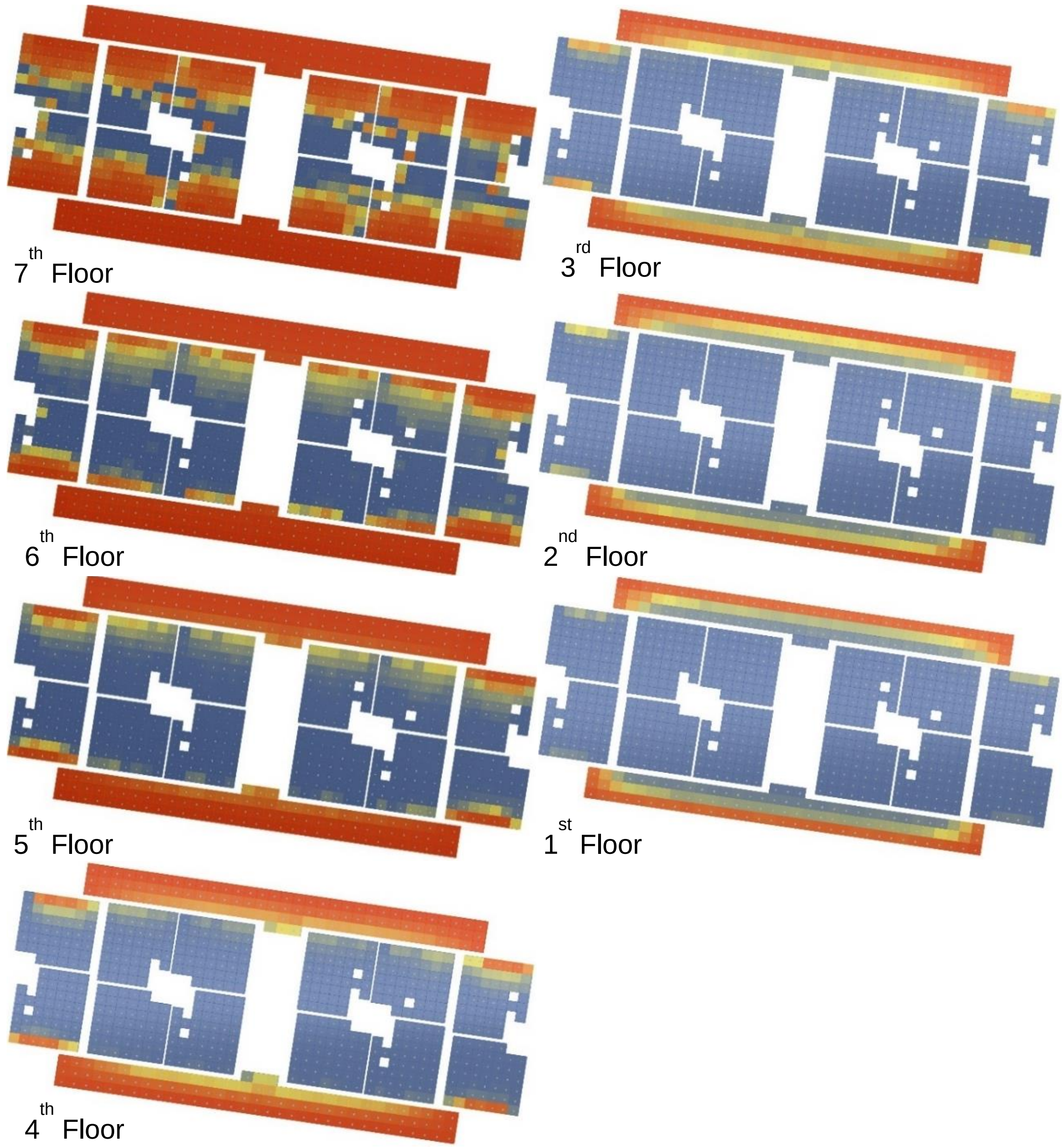


Figure 4 Floor wise DA of Natwar Parekh compound

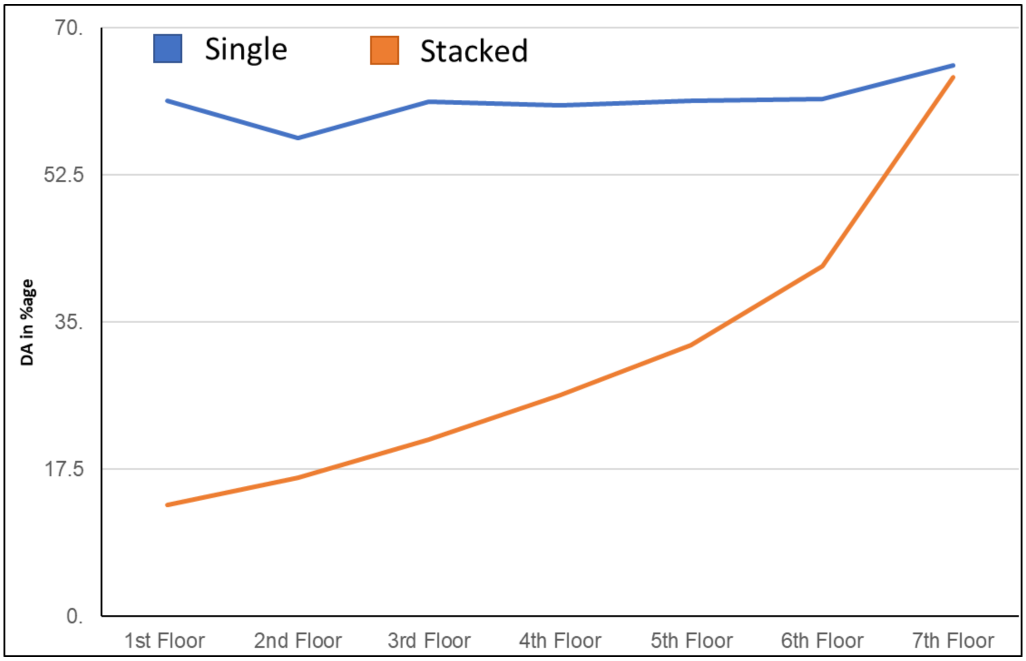


Figure 5 Change in DA of building with and without surrounding buildings.

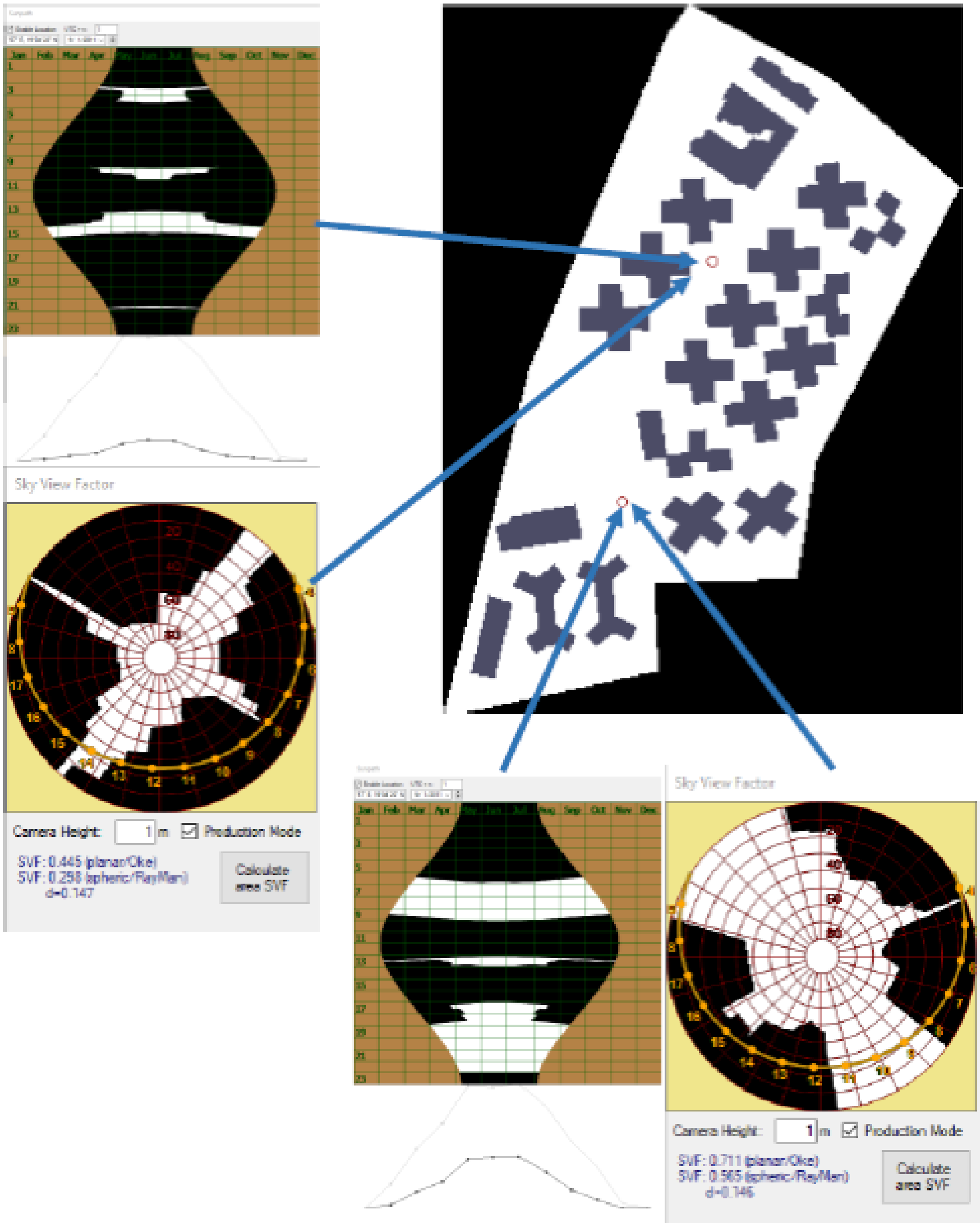


Fig 21. Sky view factor calculation for PMG colony

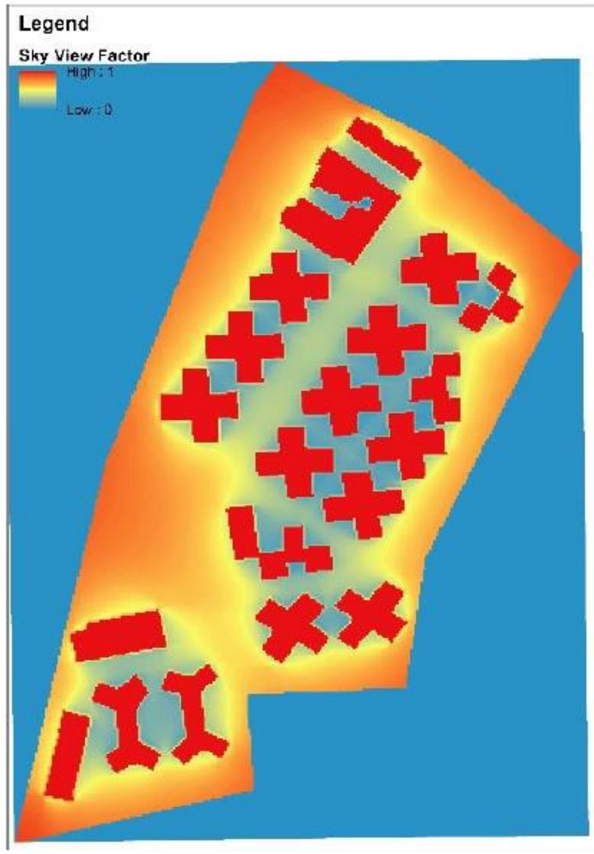


Fig 22. Simulated Sky view factor for PMG colony

Table 6. Daylight Simulation report for PMG colony type I

Daylit Area (DA_{300lux}[50%])	40% of floor area
Mean Daylight Factor	2.4%
Occupancy	3650 hours per year

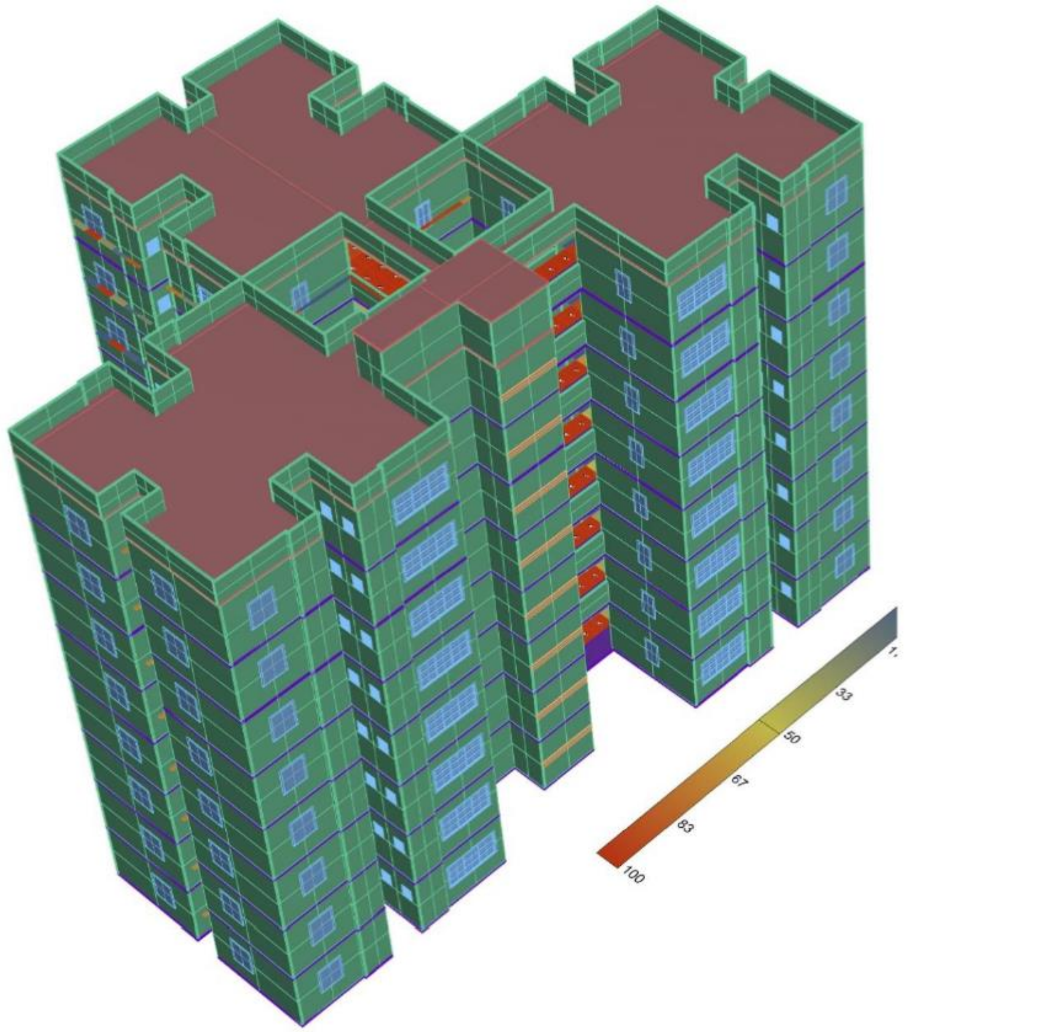


Fig 23. Type 1 Building model type 1for PMG colony

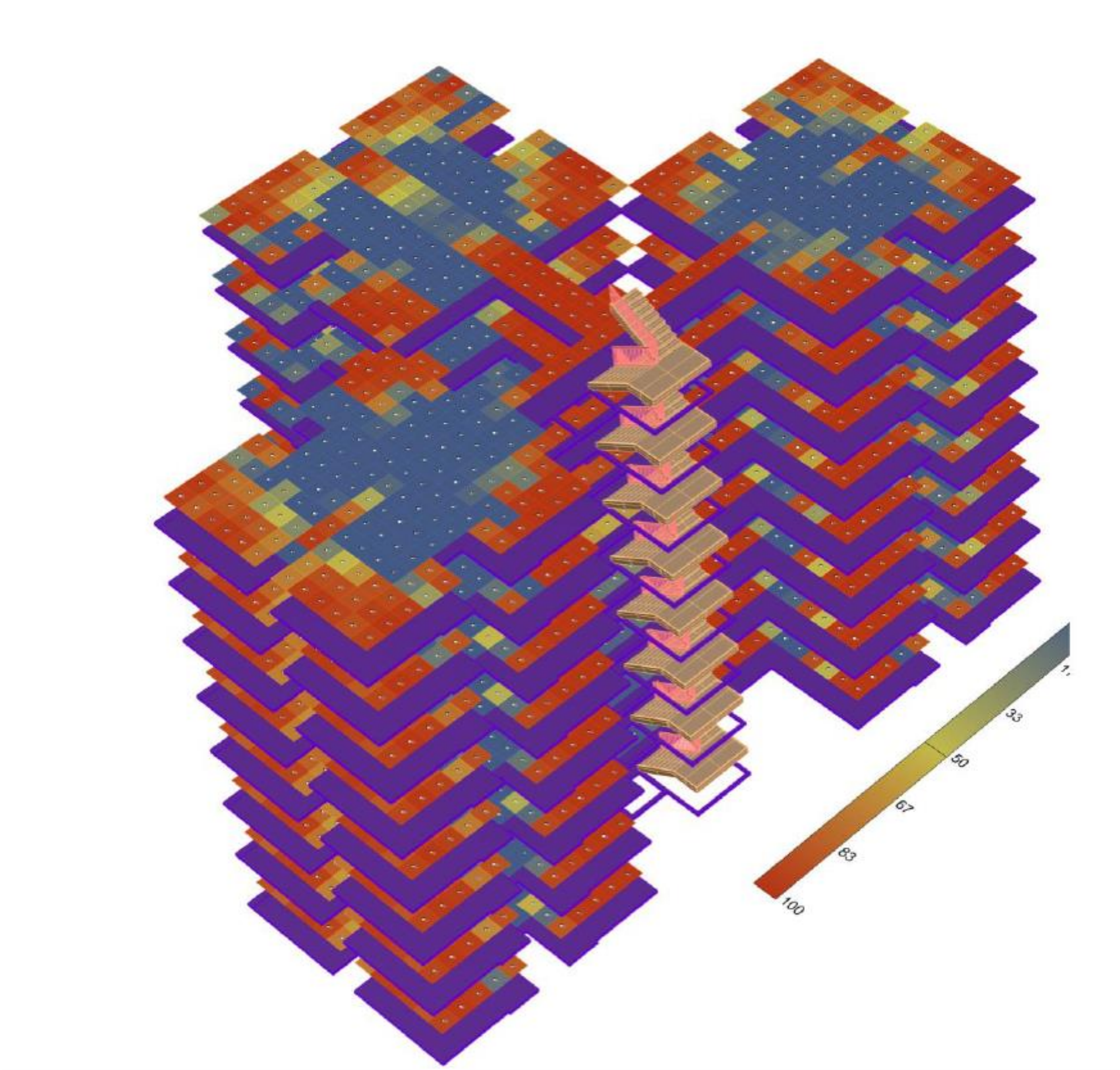


Fig 24. Daylight autonomy of all floors in PMG colony type 1

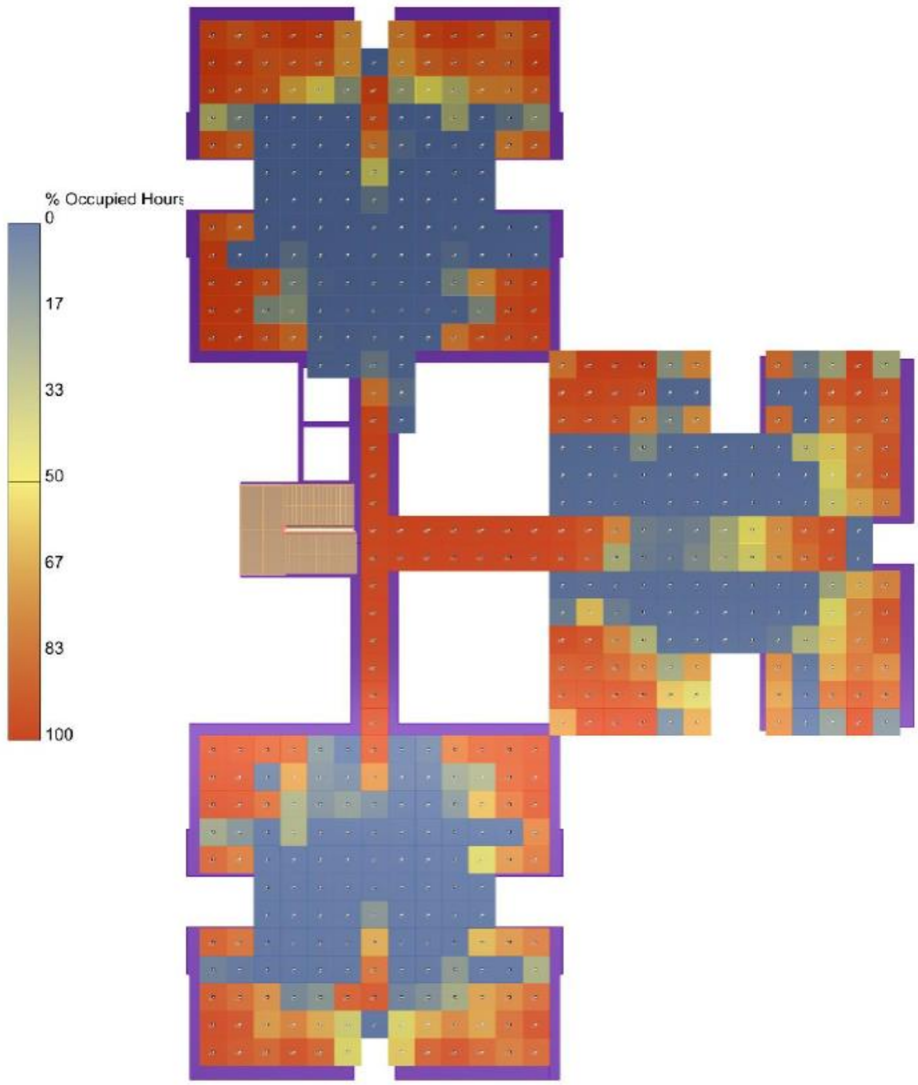


Fig 25. Floor with highest Daylight autonomy in PMG colony type 1

Table 7. Daylight simulation report for PMG colony type 2

Daylit Area (DA_{300lux}[50%])	39% of floor area
Mean Daylight Factor	2.2%
Occupancy	3650 hours per year

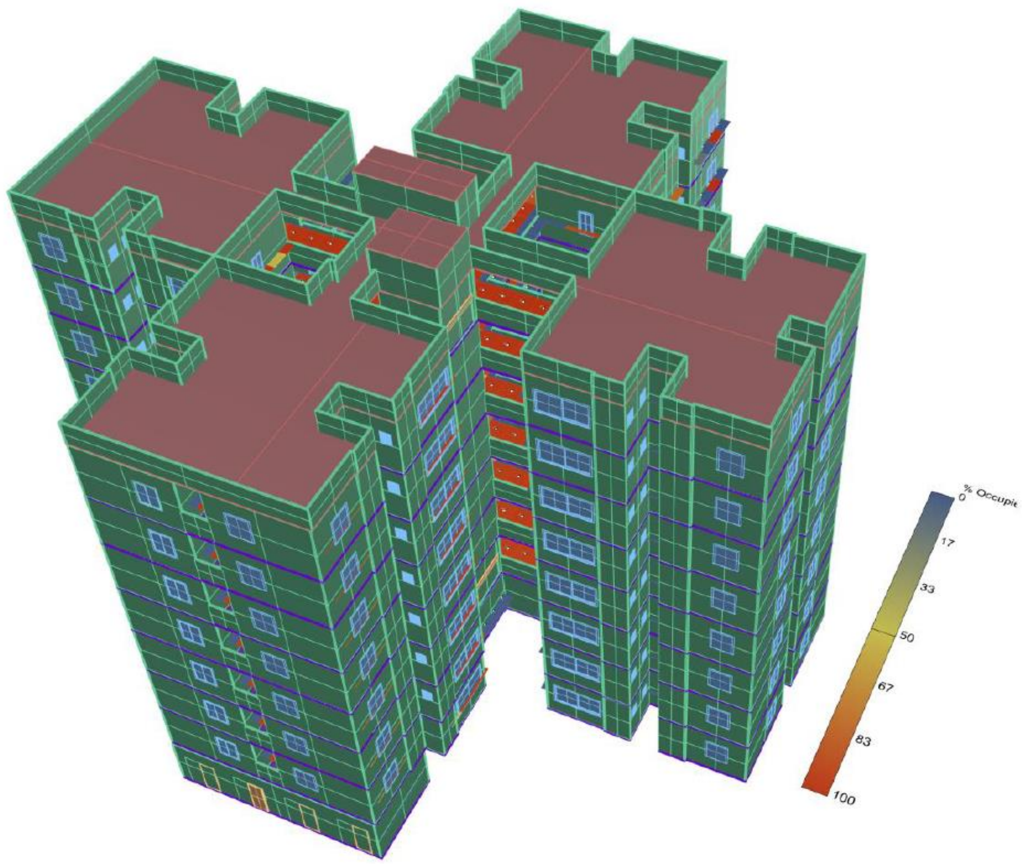


Fig 26. Type 2 Building model type 1for PMG colony

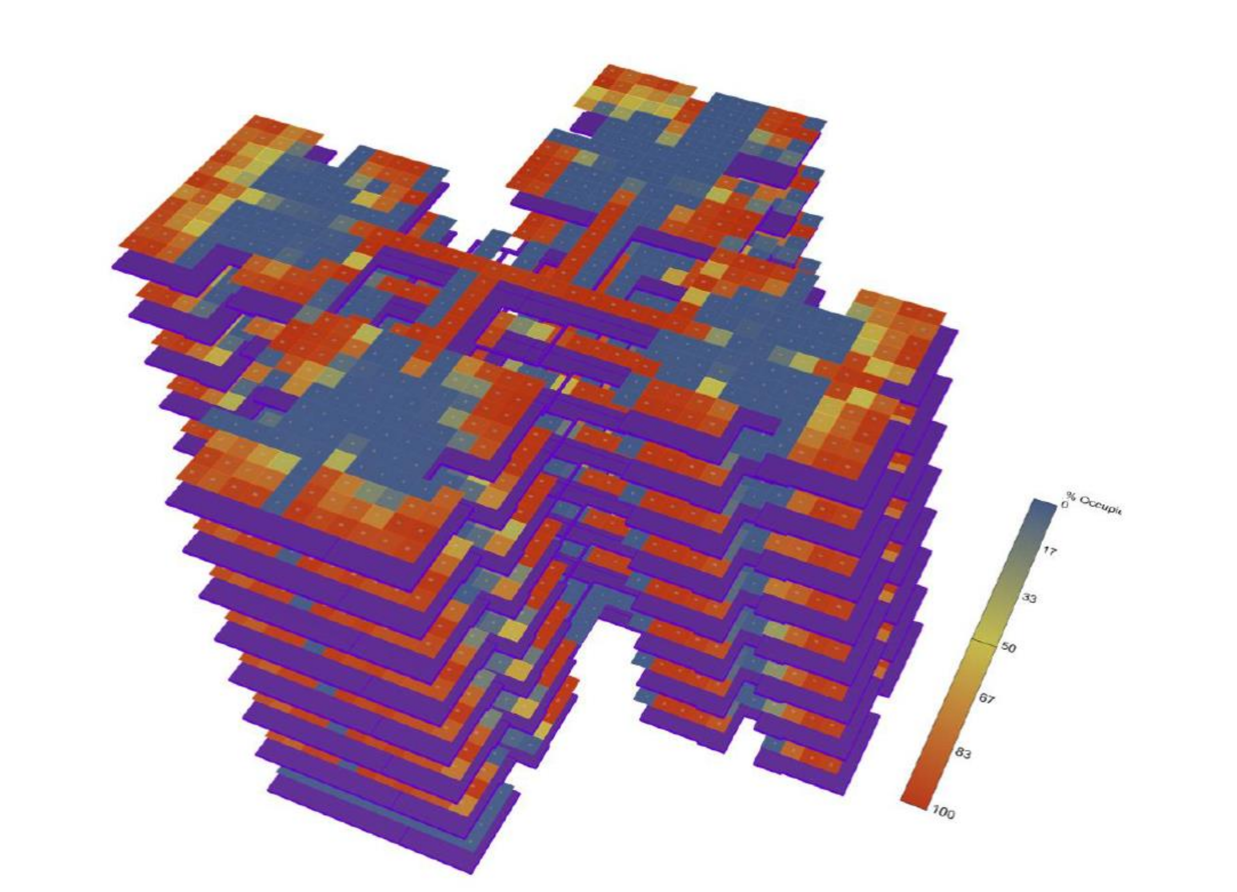


Fig 27. Daylight autonomy of all floors in PMG colony type 2

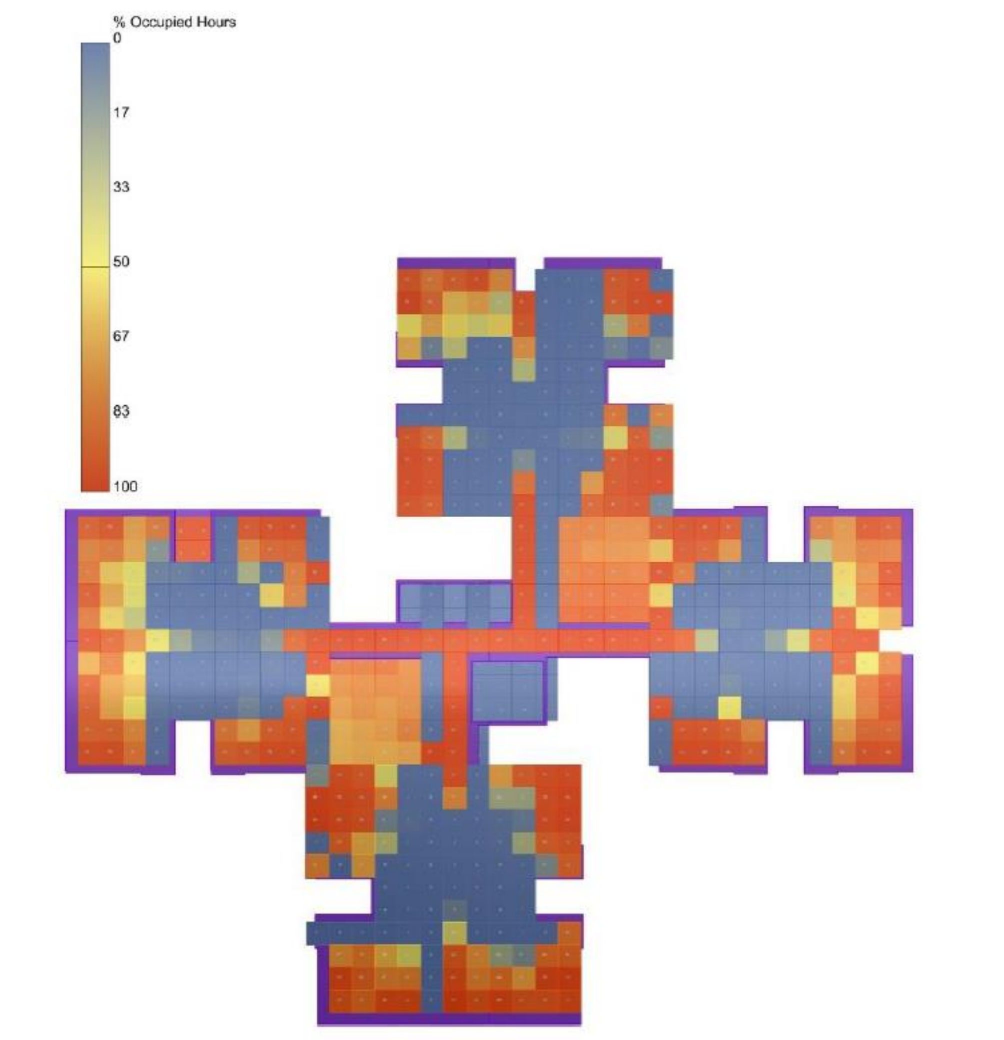


Fig 28. Floor with highest Daylight autonomy in PMG colony type 1

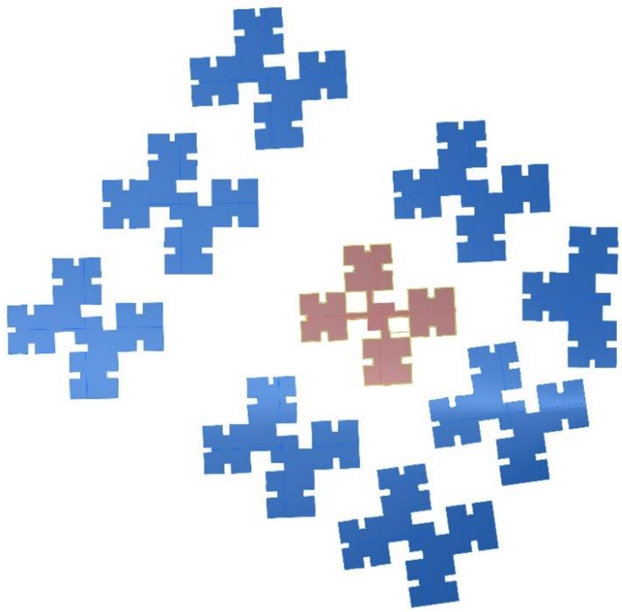


Figure 29 Building used for DA calculation

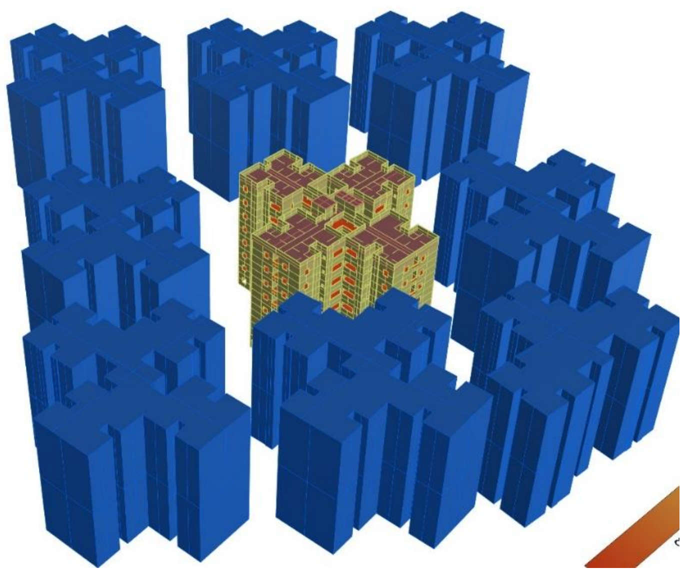


Figure 30 Building plan with surrounding building cover.

Table 8. Daylight simulation report for PMG colony – impact of stacked buildings

Daysim Simulation Report

Daylit Area (DA_{300lux}[50%])	36% of floor area
Mean Daylight Factor	2.0%
Occupancy	3650 hours per year

Daylight Factor (DF) Analysis: 23% of all illuminance sensors have a daylight factor of 2% or higher. Assuming that the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone does **not** qualify for LEED-NC 2.1 daylighting credit 8.1.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 34% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 36% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 48% for active occupant behavior. The percentage of sensors with a DA_MAX > 5% is 19% for active occupant behavior

Useful Daylight Illuminance (UDI): The percentage of the space with a $UDI_{<100\text{-}2000lux}$ larger than 50% is 42% for active occupant behavior.

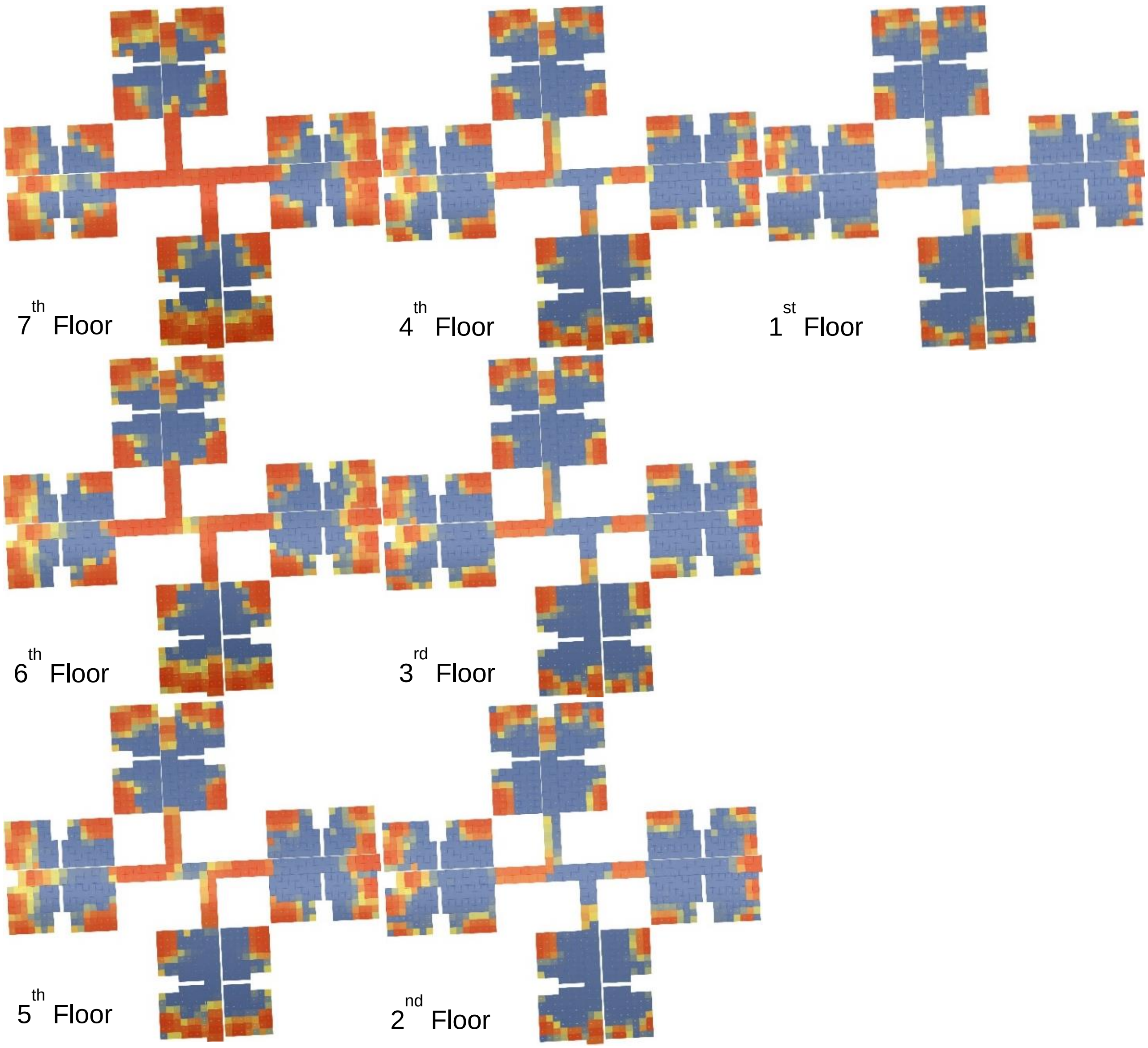


Figure 31 Change in DA of floors.

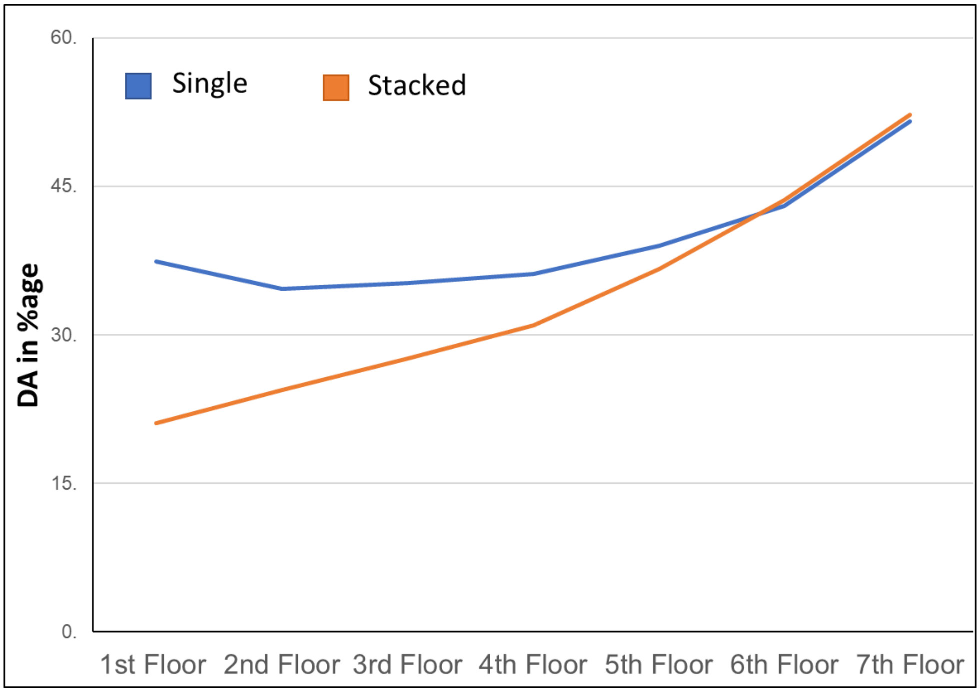


Figure 32 Change in mean DA of Building with and without surrounding buildings

Natural ventilation

This study has focused on the performance of single sided naturally ventilated multifunctional tenement units of three different housing typologies. It was observed that in Lallubhai compound, due to the presence of window and door on the opposite faces, cross ventilation occurs which generates an airflow path with a velocity of 0.8m/sec. However, there is no airflow in the living zone. The velocity in other parts ranges from 0 to 0.1 m/sec (Fig 35, 36).

In Natwar Parekh compound, the corner plot has better airflow within the room than that of the apartments beside the staircase. The air velocity near the windows is 0.9m/sec. However, there is no airflow in the living space (0 to 0.3m/sec). This simulation has been performed when windows are fully open. This velocity can be even reduced on manual controlling of window opening schedule (Fig. 37, 38, 39). In PMG colony, due to the presence of three windows on different wall surfaces which are acting as air inlets, there is airflow with a velocity of 0.8-1m/sec in the living and sleeping area. However, there is no natural ventilation in the kitchen (Fig. 40, 41).

Hence, from the CFD simulations it is observed that Natwar Parekh and Lallubhai compound lack sufficient airflow within the room due to lack of cross ventilation design facilities.

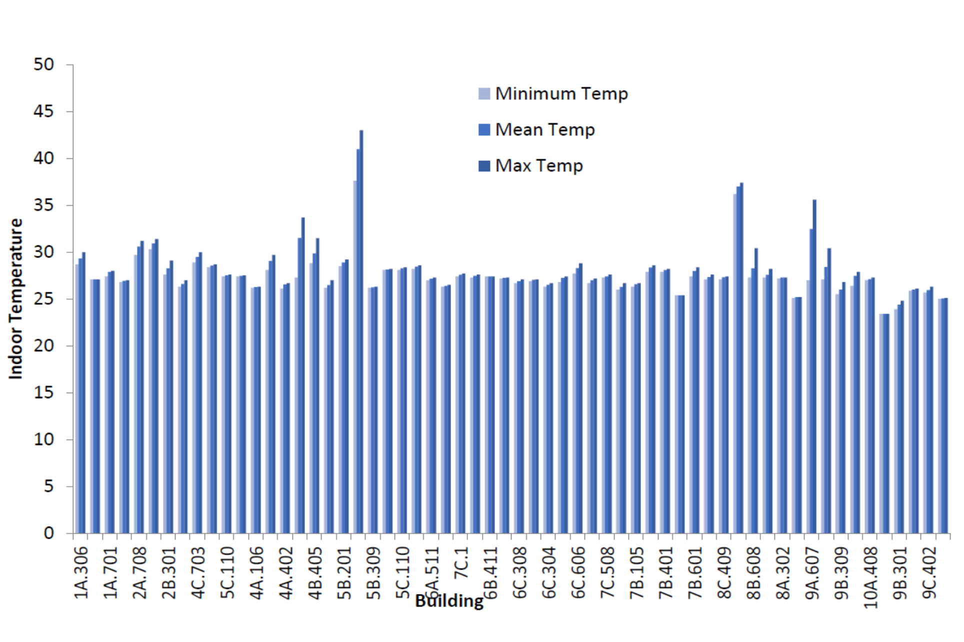


Fig 33. Temperature profile of tenements in Natwar Parekh compound

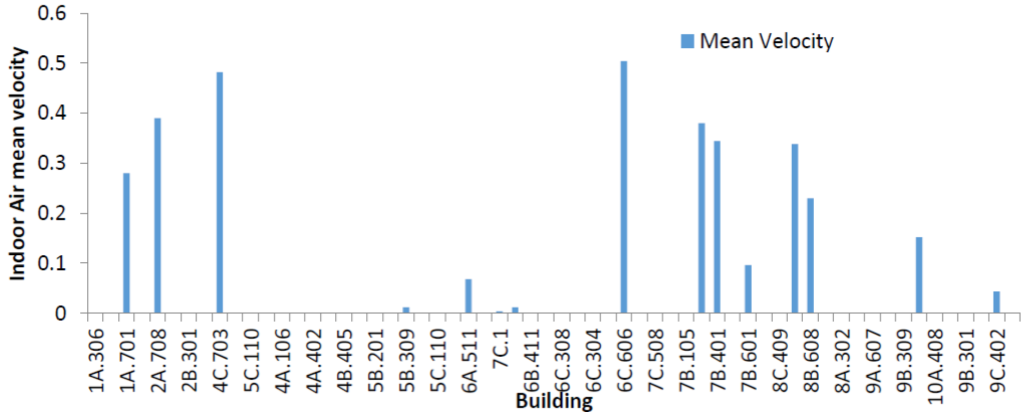


Fig 34. Air velocity profile of tenements in Natwar Parekh compound

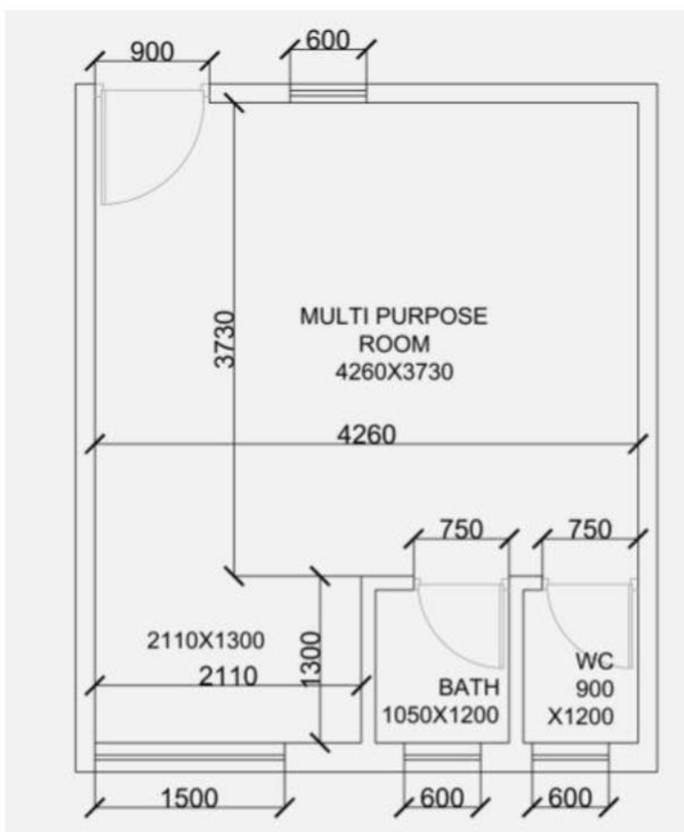


Fig 35. Floor plan of a house in Lallubhai compound

a. b.

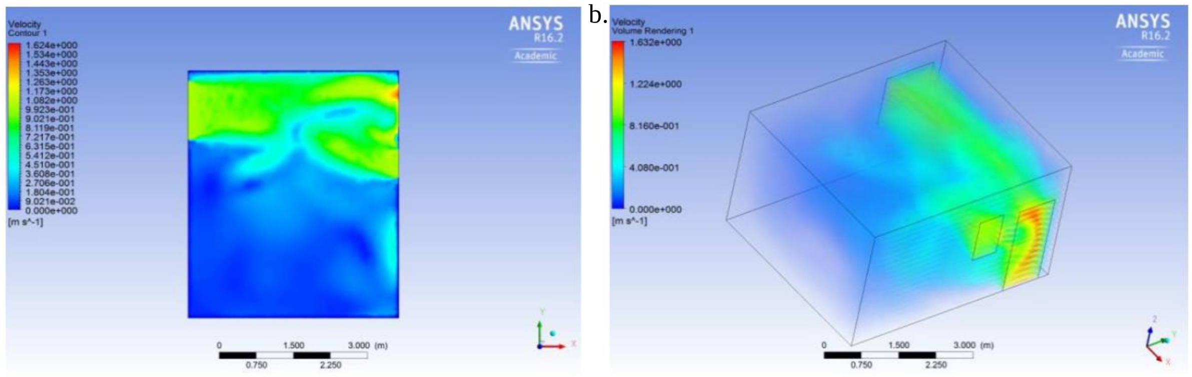
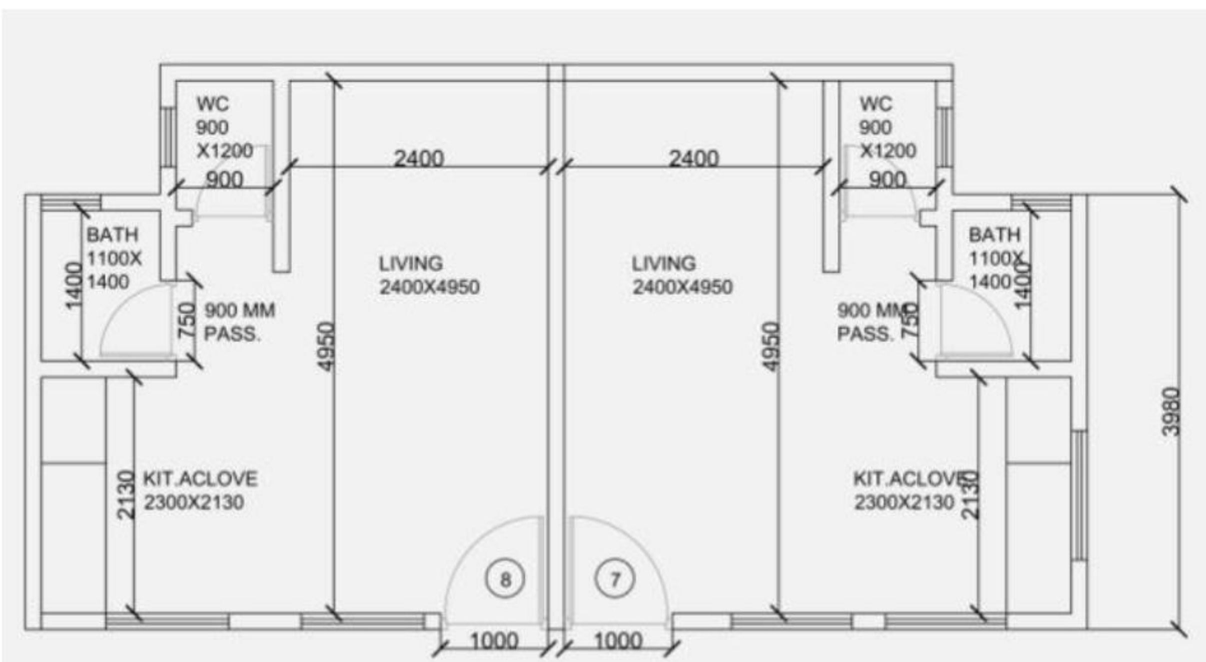


Fig 36. Velocity contour (a) and Volume rendering (b) of air velocity within the room in Lallubhai compound



House near the stairwell

House at the corner

Fig 37. Floor Plan of tenement in Natwar Parekh compound

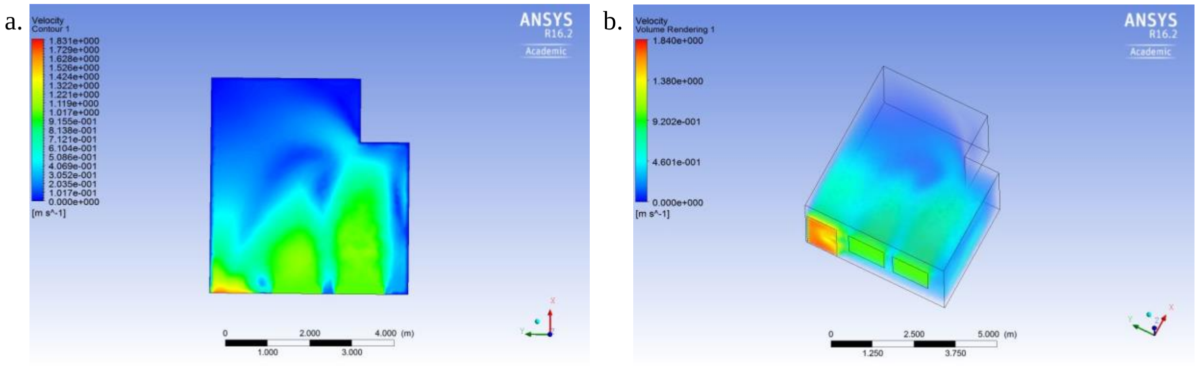


Fig 38. Velocity contour (a) and Volume rendering (b) of air velocity within the apartment beside the stairwell in Natwar Parekh compound

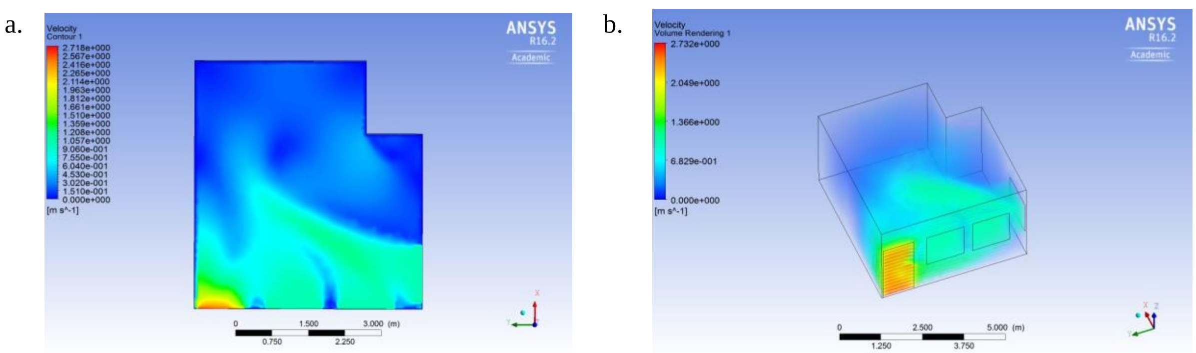


Fig 39. Velocity contour (a) and Volume rendering (b) of air velocity within the corner apartment in Natwar Parekh compound

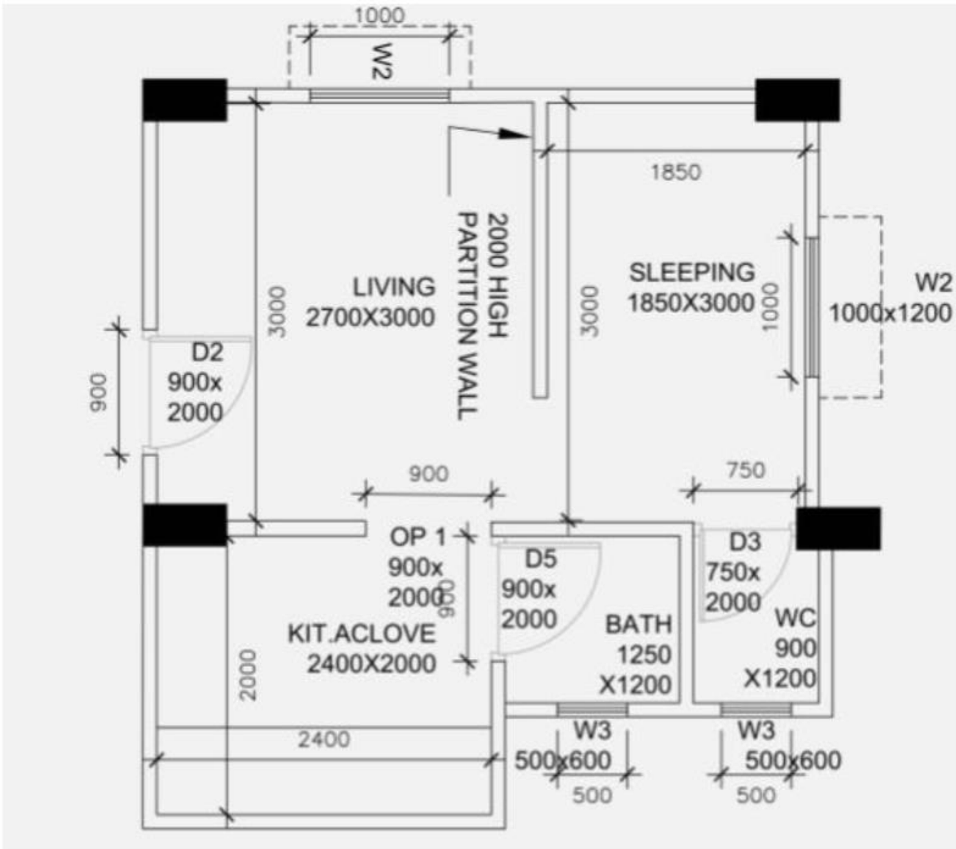


Fig 40. Floor Plan of a tenement of PMG colony

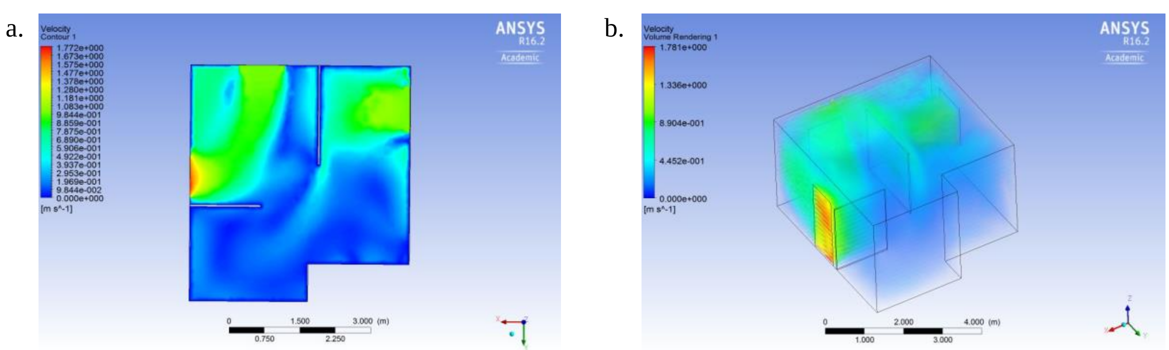


Fig 41. Velocity contour (A) and Volume rendering of air velocity within the room in PMG colony

Household survey

According to TB India 2017 report, the incidence of TB in India was 217 per 100,000 persons. However, in some pockets of Mumbai like the resettlement colonies of M-East ward, the incidence is remarkably higher than the national average as indicated by our records (Fig. 42). These facts make M-East ward in general and Lallubhai and Natwar Parekh compounds in particular, interesting cases for studying TB burden and its association with various housing conditions.

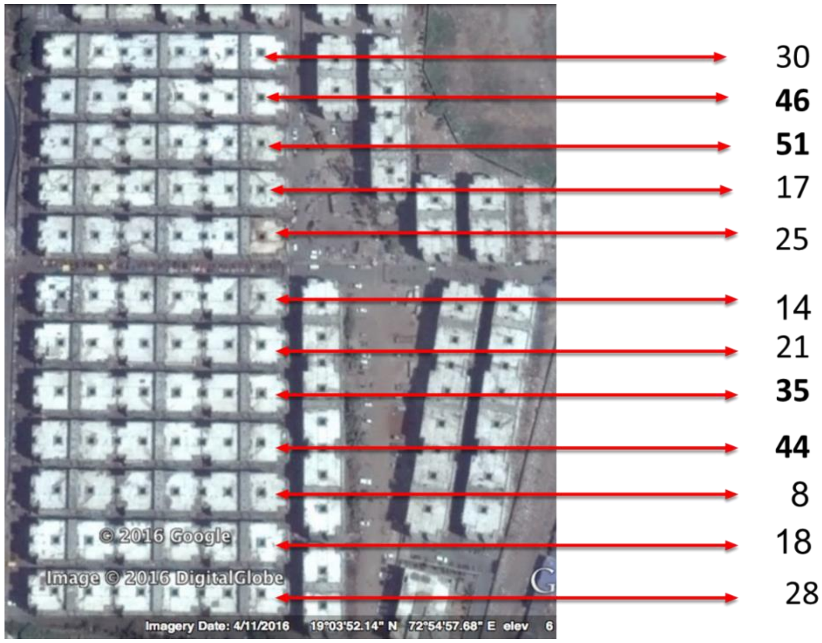
The household survey has brought to attention a variety of problems affecting the residents of Lallubhai and Natwar Parekh colonies. The field visits and informal interviews revealed that Natwar Parekh and Lallubhai compounds were very filthy and were almost always waterlogged during heavy rains. Due to these, there was dirty water around the buildings giving out foul smell which forced the residents to keep their windows closed. This was aggravated by the fact that large amount of garbage was thrown off the balconies and windows by the people staying on the upper floors which accumulated on the open spaces between the buildings. Important quantitative findings from the related to tuberculosis patient distribution are as follows:

- In Lallubhai and Natwar Parekh colonies, about 8-10% of the households have reported at least one TB patient. In contrast, in PMG colony 1% of the households reported a TB patient (Fig. 43). This indicates that Lallubhai and Natwar Parekh compounds have been rich breeding grounds for TB bacterium. This rate of TB prevalence is much higher than the national average.
- In Lallubhai and Natwar Parekh colonies, most of the TB patients got their infection after they started living in the colony, indicating that the infection hotspot may be lying inside the colony itself (Fig. 44).
- The percentage of families having TB patients was greater where there were more members in the household (Fig. 45), indicating that overcrowding of the houses may be associated with prevalence and spread of TB. Even in PMG colony the families with higher number of members had higher incidence of TB (Fig. 45c).

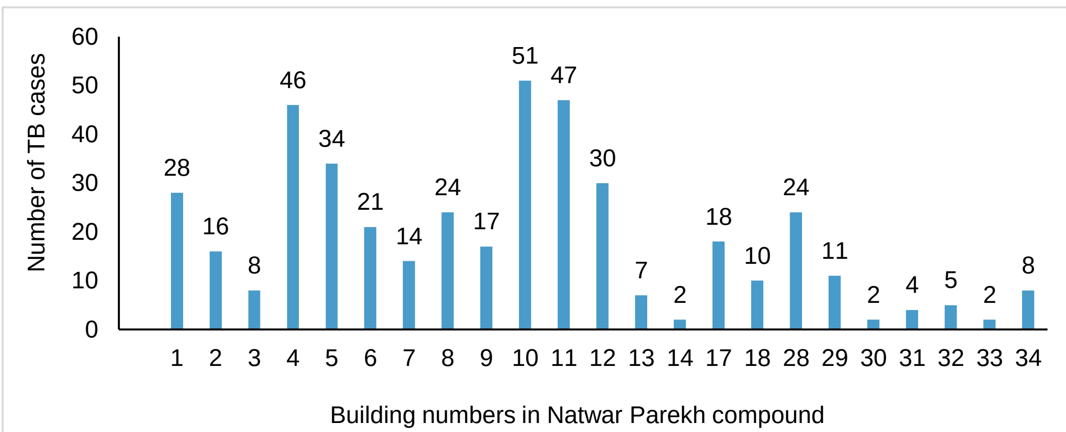
Further, the analysis of pooled and cleaned data was done to find the possible association between household factors and TB morbidity. Of 4019 respondents, 74.5% were female. Only around 12.2% of the respondents have shifted to these residents in last one year. However, 60% of the residents have been living in these tenements for more than five years.

The households: The average family size in these tenements was found to be 5.27, which is higher than Mumbai (4.56 as per census 2011). In 40.1% households there is at least one child below five years of age. The mean house hold income was found to be INR 11500/- approximately, whereas the median income was found to be less than INR 10,000/- (Fig. 47).

a.



b.



c.

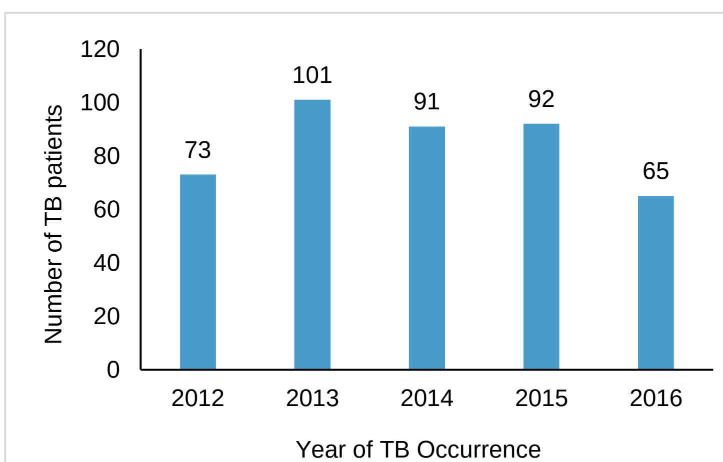


Fig 42. TB cases in densely clustered buildings in Natwar Parekh compound from 2011 to 2016 (5 years data), as recorded by the DOTS center run by Doctors For You (a and b); Year-wise distribution of TB cases in Natwar Parekh compound (c).

Occurrence of TB (the analysis is based on the direct reported patients): Analysis revealed that around 60% of the respondents who reported TB are between age group 20 to 40 (Fig. 46), while 65% of the affected respondents belonged to lower income group (household income less than INR 10,000). Importantly, most of the people suffering from TB are under medication. Most of the patients suffering from TB talked about lack of cleanliness and unhealthy environment.
In order to determine probable factors that might be affecting the occurrence of TB and with respect to the type of survey data collected, we estimated two models, based on the responses on the occurrence of TB. In the following sections, results of two binary logistic regression are presented:

Model A: Only for the patients who reported TB directly. (Table 10, 11)

Model B: At least one of the household member is suffering from TB. (Table 12, 13)

For both models the correlation between occurrence of TB and the existence of one of the possible risk factors was calculated statistically. The B value indicates the strength of the correlation. Higher the magnitude stronger the correlation. Negative B values indicate that there is negative correlation between the two variables tested. The values in the extreme right column (Sig.) indicate whether the correlation is statistically significant or not. Values below 0.1 indicate that there are chances of 10% error in the correlation with the current sample size, i.e. there is at least 90% confidence that the correlation is true. If the value is below 0.05, it means that there are chances of 5% error, i.e. there is 95% confidence that the correlation is significant. The regression analyses thus performed, showed the following correlations:

Model A states that the occurrence of TB is more likely in crowded spaces, occupied by more number of household members. Households having exhaust fans and openable windows are less likely to be affected.

Model B states that as the occurrence of TB is more likely in crowded spaces, occupied by more number of household members. The likelihood decreases as one goes higher up in the upper floors. Households having exhaust fans and openable windows are less likely to be affected (Table 13).

a. b. c.

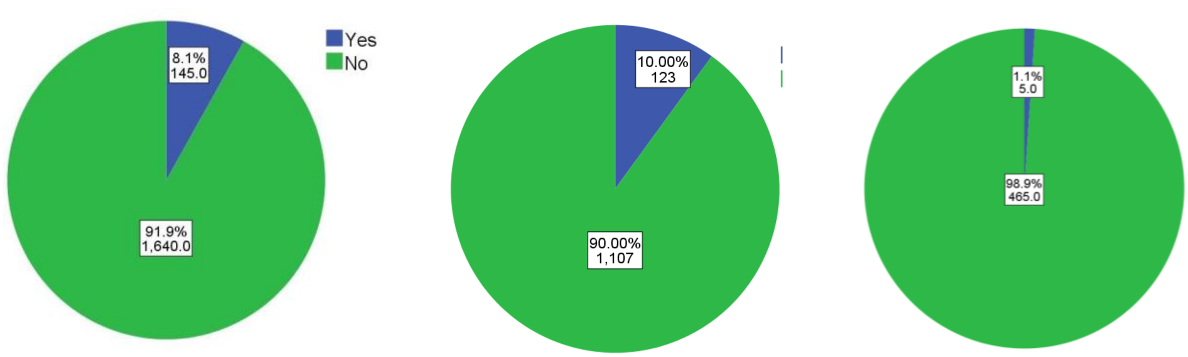
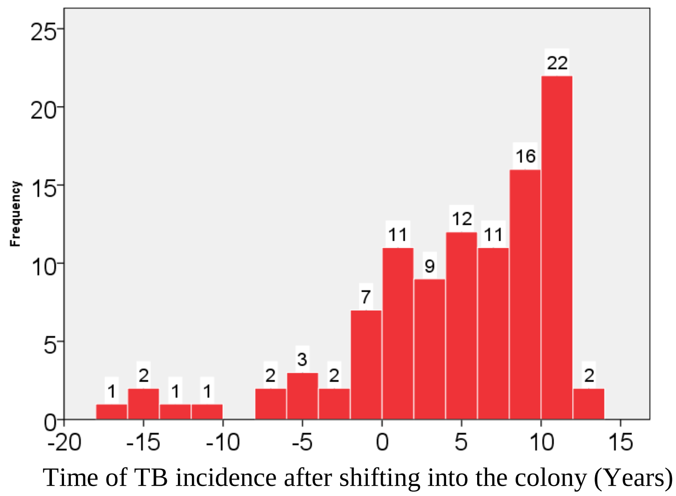
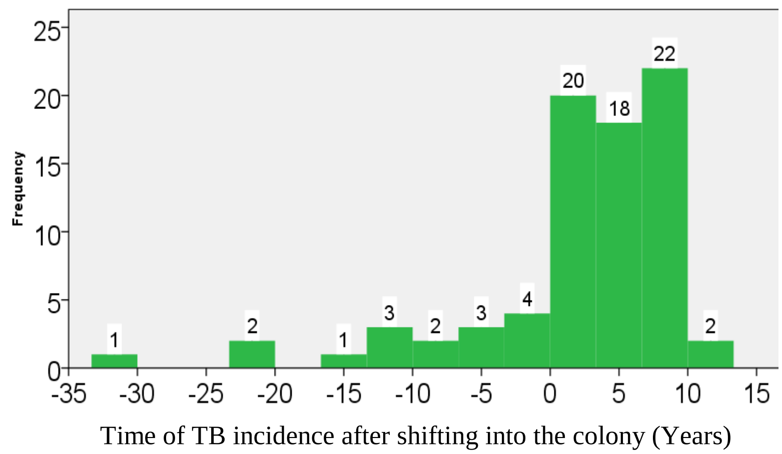


Fig 43. Households having at least a TB patient in the three colonies: a). Lallubhai colony, b) Natwar Parekh colony, c) PMG colony

a.



b.



c.

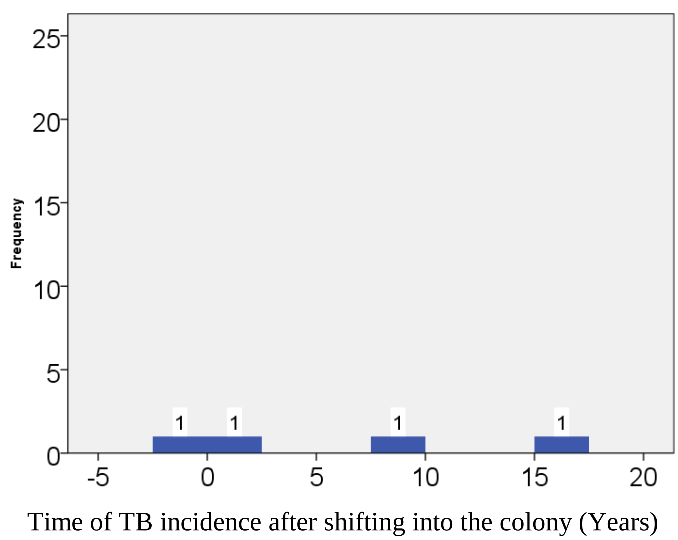
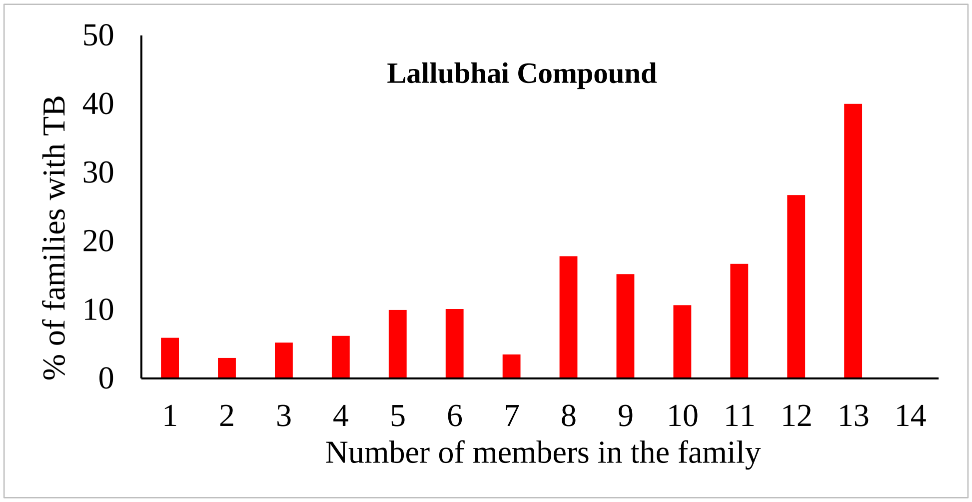
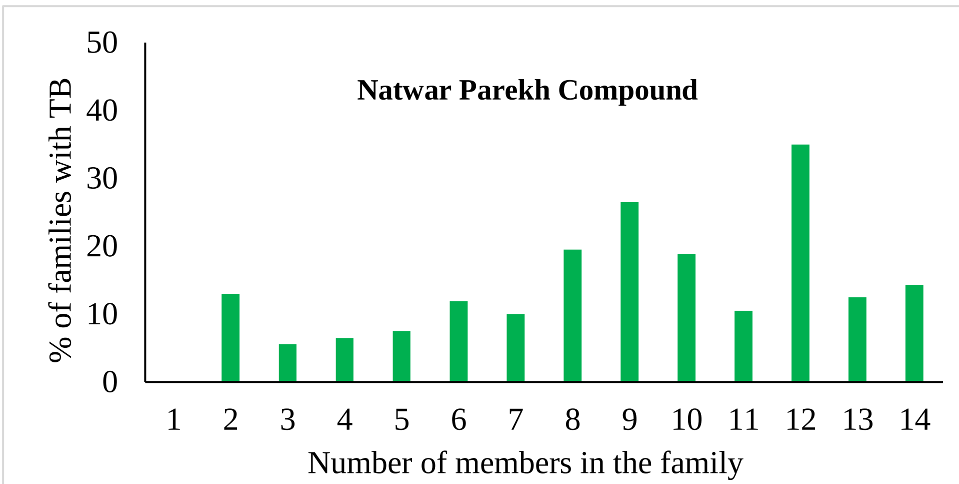


Fig. 44 Distribution of TB patients according to time of infection after shifting into Lallubhai colony (a), Natwar Parekh colony (b) and PMG colony (c)

a.



b.



c.

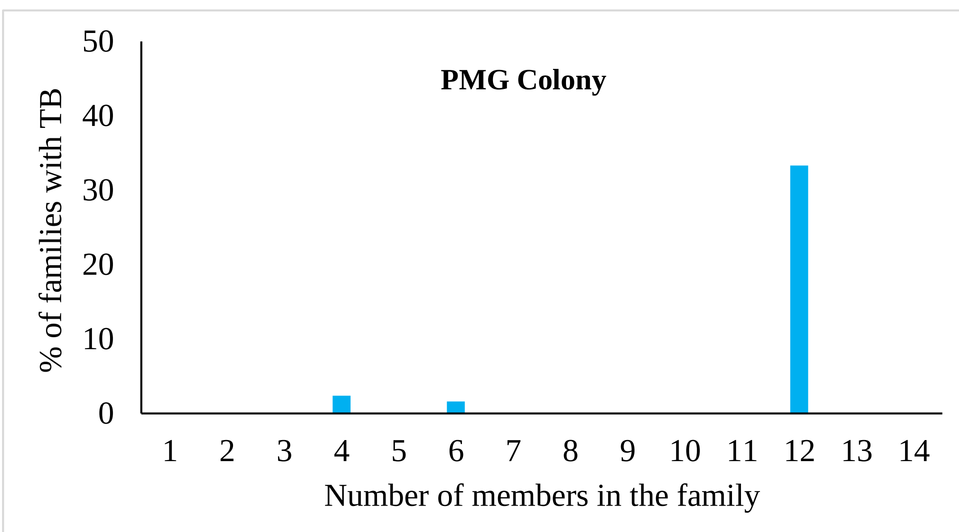


Fig. 45. Distribution of TB affected households in Lallubhai compound (a), Natwar Parekh compound (b), PMG colony (c). The graphs show that larger families had more chances of having a TB patient in the family.

Table 9. Survey data used for correlation analysis

Name of the location	Total Sample collected	%age	Samples analyzed	%age
PMG Colony	498	12.2	471	11.7
Lalu Bhai	1,785	43.8	1,770	44.0
N P Compound	1,797	44.0	1,778	44.2
Total	4,080		**4,019**	

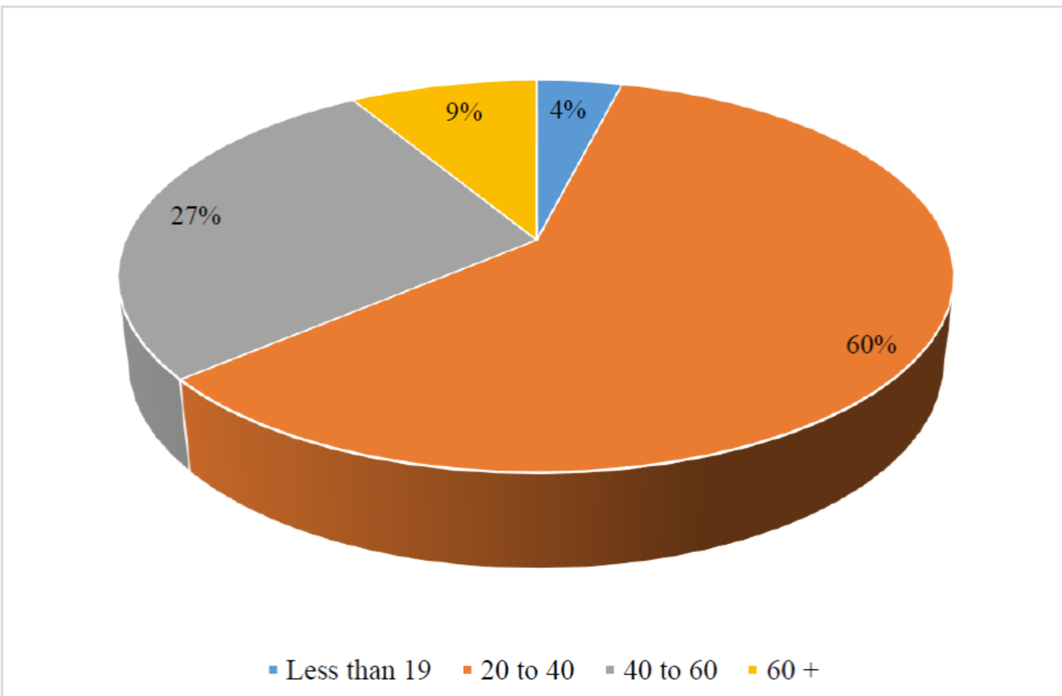


Fig 46. Age of TB patients (based on direct reported patients)

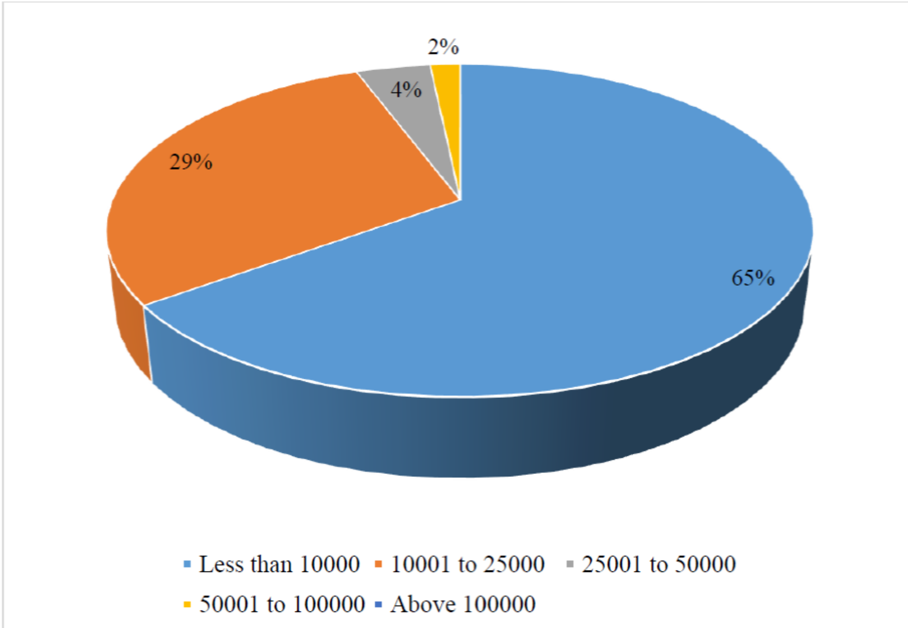


Fig 47. Income distribution of the reported TB patient households

Table 10 Statistical analysis of Model A

		N	Percentage
If the respondent is suffering from TB	No	3,890	97.0%
	Yes	122	3.0%
Does the windows have openable shutter?	No	3,562	88.8%
	Yes	450	11.2%

If the respondent is suffering from TB		B	Std. Error	t statistics	Sig.
Yes	Intercept	-6.291	1.090	-5.769	0.000
	House hold size	0.083	0.036	2.308	**0.021**
	Number of exhaust fans	-0.573	0.255	-2.249	**0.025**
	Duration of stay in the current residence (in months)	0.003	0.002	1.471	0.141
	Not openable Window	2.917	1.013	2.881	**0.004**
	Openable	0^b			
a. The reference category is: Not suffering from TB					
b. This parameter is set to zero because it is redundant.					

Table 11. Segmented models for 2 colonies in Model A

Model A1 – Natwar Parekh compound - reported TB directly

If the respondent is suffering from TB	B	Std. Error	t statistics	Sig.
Intercept	-3.261	0.145	-22.489	0.000
Number of exhaust fans	-0.750	0.381	1.969	**0.049**

Model A2 – Lallubhai compound - reported TB directly

If the respondent is suffering from TB		B	Std. Error	t statistics	Sig.
	Intercept	-3.963	0.326	-12.156	0.000
	House hold size	0.126	0.054	2.333	**0.020**

Table 12. Statistical analysis of Model B parameters

		N	Percentage
At least one member of the household is suffering from TB	No	3,638	90.5%
	Yes	381	9.5%
Does the windows have sliding shutter or openable shutter?	No	3,568	88.8%
	Yes	451	11.2%

At least one member of the household is suffering from TB		B	Std. Error	t statistics	Sig.
Yes	Intercept	-5.523	0.605	-9.130	0.000
	House hold size	0.152	0.021	7.364	**0.000**
	Number of the storey in the building in which the respondent is residing	-0.056	0.028	-2.005	**0.045**
	Number of exhaust fans	-0.222	0.132	-1.686	**0.092**
	Not openable Window	2.823	0.583	4.846	**0.000**
	Openable	0^{b}			

Table 13. Segmented models for 2 colonies in Model B

Model B1 – Natwar Parekh compound – at least 1 TB patient

At least one member of the household is suffering from TB		B	Std. Error	t statistics	Sig.
	Intercept	-2.704	0.270	-10.015	0.000
	House hold size	0.151	0.027	5.593	**0.000**
	Storey of the apartment	-0.097	0.039	-2.487	**0.012**
	Duration of stay at the current apartment (in months)	0.003	0.002	1.500	0.138

Model B2 – Lallubhai compound – at least 1 TB patient

At least one member of the household is suffering from TB		B	Std. Error	t statistics	Sig.
	Intercept	-3.170	0.246	-12.886	0.000
	House hold size	0.134	0.035	3.829	**0.000**
	Duration of stay at the current apartment (in months)	0.003	0.002	1.500	**0.085**

Study of Development Control Regulations

This section of the report takes detailed look at the DCRs governing the built form of resettlement and rehabilitation colonies like PMG Colony, Lallubhai Colony and Natwar Parekh Compound.

Table 14 given below compares the DCRs for Rehabilitation & Slum Redevelopment buildings with the norms for general residential development and National Building Codes. The comparison shows a relaxation of norms related to unit density, open space, distance between buildings for rehabilitation and resettlement (R & R) and slum redevelopment buildings and a lack of regulations on window design for light and ventilation. Further comparison of rehabilitation and redevelopment DCRs since 1991 shows that the over the years, norms have been modified to increase the size of individual units and the FAR that can be consumed on site. To build larger units and consume the FAR on site the SRA, R&R/slum redevelopment buildings go taller. However, the minimum distance required between the buildings (3 m) has not increased. This further leads to poor light and ventilation conditions. Moreover, in order to accommodate a larger group of people further concessions in setbacks and distances maybe granted for a rehabilitation or slum redevelopment project. These concessions can exacerbate the already poor quality of light and ventilation in these projects.

These DCR changes are reflected in the three buildings that we have studied. PMG colony is the oldest among the three. Its blue prints were approved in December 1997. Lallubhai Compound was built next. A part of Lallubhai compound was approved on August 2003 and another part in

2005. Natwar Parekh Compound's plans were sanctioned by the SRA cell in MMRDA in March 2008. Table 15 provides details on the built form of these buildings.

Table 14. Comparison of DCR for SRA and general buildings

DCR Categories	Resettlement & Rehabilitation of PAP 33(13)	Slum Redevelopment 33(10)	General Residential Development	National Building Codes	Proposed DCRs for Slum Redevelopment 33(10)	Proposed DCRs for General Residential Development
Permissible FSI	2.5 FSI for plots that are not being redeveloped DCR 33(10) applies for the plots where rehabilitation is happening using redevelopment	Proportion of Rehab: Incentive FSI Island city- 1 : 0.75 Suburbs- 1 : 1 Difficult Areas- 1 : 1.33	Island city = Total 1.8 (1.33 Base FSI x 0.35 Premium) + 1.33 Base FSI Suburbs = Total 2.7 (1 Base FSI + 1 max TDR) + (1 Base FSI + 1 max TDR) 0.35 Premium FSI = 2. 7	Prescribes an FAR of 2 Consumption of FAR subject to other restrictions on height and setbacks	For Slum Redevelopment: Proportion of Rehab: Incentive FSI Island city- 1 : 0.75 Suburbs- 1 : 1 Difficult Areas- 1 : 1.33 Additional BUA for free sale ranging from 5% to 20 % will be admissible for plots 5acre to 40 acre	Island city = Total 2 1 Base FSI + 0.34 Premium + 0.33 TDR Suburbs = Total 2 1 Base FSI + 0.5 Premium + 0.5 TDR
Insitu FSI Consumption & TDR	For plots not under redevelopment - 2.5 FSI rehabilitation in situ 2.5 TDR	Insitu FSI may exceed 3 if existing DU on site between 500 DU/Ha -	Insitu consumption for general plots: Island city = May exceed 1.8	Not prescribed	May exceed 4	Island city = May exceed 2 Suburbs = May exceed 2 TDR floating

	as compensation to developer of Rehab DCR 33(10) applies for the plots where rehabilitation is happening using redevelopment	650 DU/ha Insitu may exceed 4 if existing DU/ha more than 650 Du/ha Rest floated as TDR	Suburbs = May exceed 2.7 TDR floating permitted for some conditions			permitted for some conditions
Density DU-Min	500 DU/Net Ha	500 DU/Net Ha for regular slum redevelopment 650 DU/net ha for Dharavi Redevelopment Plan	For plots 1 ha and above 267 Du/Net Ha/FSI 200Du/Net Ha/FSI	Not prescribed	325 DU/Ha/FSI for rehabilitation/ Affordable housing Min 650 DU/ha could be reduced by chief fire officer by 25%	200 DU/Ha/FSI (1 ha and above)
Density DU-Max	No limit mentioned		600 DU/Net Ha/FSI Island City 450 Du/Net Ha/FSI Suburbs	For low income housing - 15sqm in size in 4 storied walkups, without possibility of incremental growth- 500 DU/ha is maximum density prescribed	No limit mentioned	450 DU/Ha/FSI

			Otherwise 125 - 150 DU/gross ha for metropolitan housing		
Height	No limit (But until now the buildings have not been taller than 24mt i.e. G+7 However there are plans to increase building heights for future)	The height of a building shall not exceed one and half times the total of the width of the street on which it abuts and the required front open space. Unless high rise permitted by Commissioner in accordance with min street widths mentioned in DCR (min street width 9m for building 32 mts in height.. onwards)	15 mts for low income housing i.e G+4	No limit mentioned	The height of a building shall not exceed two times the total of the existing or prescribed width of the street on which it abuts and the required front open space. Unless high rise permitted by Commissioner in accordance with min street widths mentioned in DCR (min street width 9m for building 32 mts in height.. onwards)

Setbacks and Step backs	Front and side setback: 1.5mt. for building up to 24mt height 6mt. for buildings above 24mt. 3mt where plot abuts DP road 18.3mt wide No separate regulations for Stepbacks	Front: Varies from 7.5 to 3 mts depending on street width Side and Rear: Width between internal buildings not less than a third of the height of that building above the ground level, rounded to the nearest decimeter subject to a maximum of 20 m. Minimum being 3.6 m. Differnt for detached buildings and row houses Step Backs allowed on upper floors for taller buildings	Front - 1.5 m to 6 mt depending on street width Side Open Space: For buildings above 10 mt in height = Height/3 till the height of 30 mts then +1 mt for every 5 mt height increase subject to a maximum of 20 m. Rear open space: Average width of 3.0 m and at no place measuring less than 1.8 m Step backs allowed on the upper floors for taller buildings	Front for building upto 32mts is 3 min side and rear marginal open spaces may be reduced to 3.0 m. for a building with height more than 32 m but up to 70 m the side and rear marginal open spaces shall not be less than 6 m and for a building with height more than 70 m the side and rear marginal open spaces shall not be less than 9 m and 12 m beyond 120 m subject to fulfillment of fire safety requirement as specified in these Regulations.	Front varies from 6 - 3 depending on the Road Marginal and side open space for ht upto 32mts is 3.6 mt Beyond that: For plots under 1000 sqm is Height/5 subject to max 12 mts For plots over 1000 sqm is Height/4 subject to max 12 mts Different for semi detached row houses etc Step Backs allowed on upper floors for taller buildings

Area between buildings	3 mts min	Width between internal buildings not less than a third of the height of that building above the ground level, rounded to the nearest decimeter subject to a maximum of 20 m.	H/3 till the height of 30 mts then +1 mt for every 5 mts subject to a maximum of 20 m. Sizes also provided for ventillation shafts for kitchens and toilets	Distance between two rehab buildings upto 32 mts 6 mts	Marginal and side open space for ht upto 32mts is 3.6 mt Beyond that: For plots under 1000 sqm is Height/5 subject to max 12 mts For plots over 1000 sqm is Height/4 subject to max 12 mts
Rehab Unit Size/ Unit Size	Used to be 20.9sqm changed to 25sqm in 2008 A multi purpose room shall be allowed with size upto 12.5 sq.mt. with a minimum width of 2.4 mt. Each house abuts common passages 2 mts min Kitchen can be an alcove no size restrictions- no direct ventilation requirement/ mechanical is fine Bathroom no size restrictions - Artificial light ventilation is fine	No limit to unit size Min habitable room size 9.5 sqm - min width 2.4 mts	Min habitable room size 9.5 sqm - min width 2.4 mts Multipurpose single room should be at least 12.5 m2 with minimum width of 2.5 m	25 sqm A multi purpose room shall be allowed with size upto 12.5 sq.mt. with a minimum width of 2.4 mt. Each house abuts common passages 2 mts min Kitchen can be an alcove no size restrictions- no direct ventilation	No limit to unit size Min habitable room size 9.5 sqm - min width 2.4 mts

				requirement/ mechanical is fine Bathroom no size restrictions - Artificial light ventilation is fine	
Windows size and design	Habitable Room: At least a window not less than 1 sq.m. in area, opening directly on to an interior or exterior open space, but not into a shaft Kitchen Window: No Window / direct ventilation requirement - mechanical light an ventilation is fine Bathroom Window: No Window / direct ventilation requirement - mechanical light an ventilation is fine	At least a window not less than 1 sq.m. in area, opening directly on to an interior or exterior open space, but not into a shaft For towers external windows on a floor shall be not less than 2 1/2 per cent of the floor area Bathroom openings (windows, ventilators, louvers) not less than 0.3 sq. m in area or 0.3 m in width.	1/6th of the area of room should be window area for warm and humid - 25% higher window area for kitchen If a window is partly fixed, only the openable area shall be counted. No portion of a room shall be assumed to be lighted, if it is 7.5 mt away from building	Habitable Room: Every Habitable room shall have window at least 1sqm in size For towers external windows on a floor shall be not less than 2 1/2 per cent of the floor area Bathroom openings (windows, ventilators, louvers) not less than 0.3 sq. m in area or 0.3 m in width.	

Open Space Requirement	8% min on ground level	For plots over 1001 sqm depending on area of Plot 15% - 25% of open space shall be reserved	Layout/plot measuring 0.3 ha or more for recreational purposes which shall as far as possible 15 percent of the area of the layout, or b) 0.3 to 0.4 ha/1 000 persons; for low income housing	8% min on ground level	For plots over 1001 sqm depending on area of Plot 15% -25% of open space shall be reserved

Table 15. Comparison of three colonies under current study

DCRs	PMG Colony	Lallubhai Compound	Natwar Parekh
Year of approval	1997	2003 and 2007	2008
Plot Area	15.14 ha	14.4 ha	16.13 ha
FSI	2.5	2.5	2.5 consumed 2.44
Study Area*	2.7 ha	6.1 ha	5.16ha
Study Area - Roads and built up amenity area	2.57 ha	6.1 ha	4.46 ha
Number of Units in Study Area (including shops)	1632 DU	Total built total units = 5184 Occupied total units = 4896 DU Residential at least: 4332 DU	Total built total units 5856 occupied total units 4800 aprox Residential at least: 5124 Du total occupied 4200 at least

Density DU/ ha in Study Area	635 units/net ha Residential at least:	Built for 850 units/Net ha	Built for 1313 units/net ha
Height	G+7 = 24 m	G+5 to G+7 = 18m to 24m	G+8 = 24 m
Distance between buildings	Mediated through 15x15 m courts Each building has 4 light wells measuring 5x5m	3 m min distance	3 m min distance
Open Space Requirement	15%	15%	15%
Room Size	21 sqm	21 sqm	21sqm
Area of window	Type 1: (1 x 1.2 m) x 2 = 2.4 + Bathroom ventilators 11.4% of room area Type 2: (2.4 x 1.2) + (0.6 X 1.2) = 3.6 + Bathroom Windows 17% of room area	1.2 x 1.5 = 1.8 + Bathroom ventilators 8.5% of room area	(1.2 x 1.2) + (0.9 x 1.2) = 2.52 + Bathroom Ventilators 12% of room area
Cross Ventillation	Yes	No	No
*The Study Area is different from total plot area mentioned on the blue prints. Permissible built up area of each colony is calculated on the basis of the total plot area (Plot area X FSI). Refer to Fig. 48. Study area is the area of the residential cluster where the BUA is constructed and study for TB was conducted			

a.

PMG colony | Lallubhai colony | Natwar Parekh Compound

Study Area = 2.7 ha | Study Area = 6.1 ha | Study Area = 5.16 ha

635 units/net ha | Built for 850 units/net | Built for total 1313 units/net ha

b.

PMG COLONY | LALLUBHAI COMPOUND | NATWAR PAREKH COMPOUND

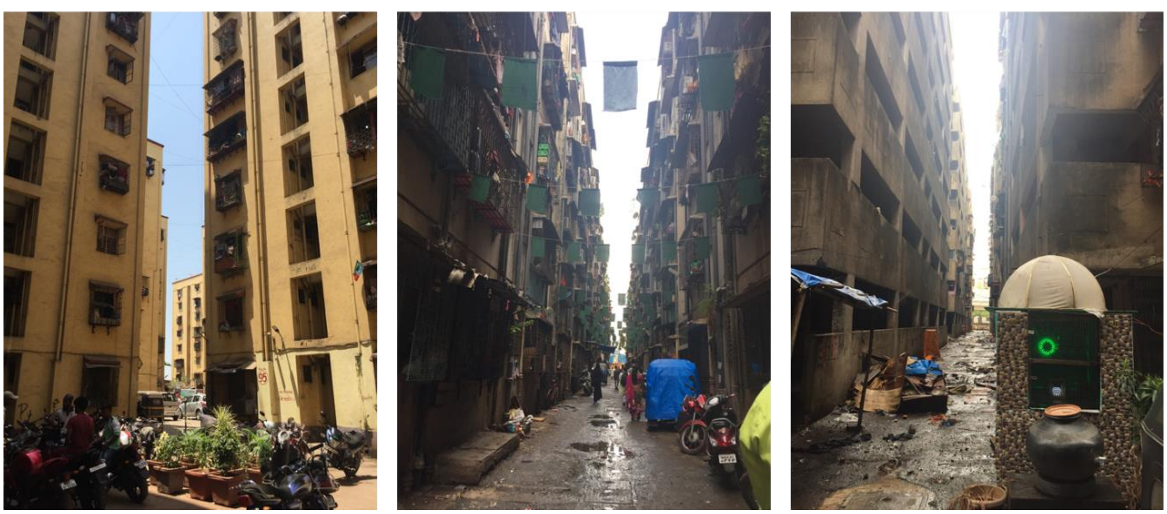
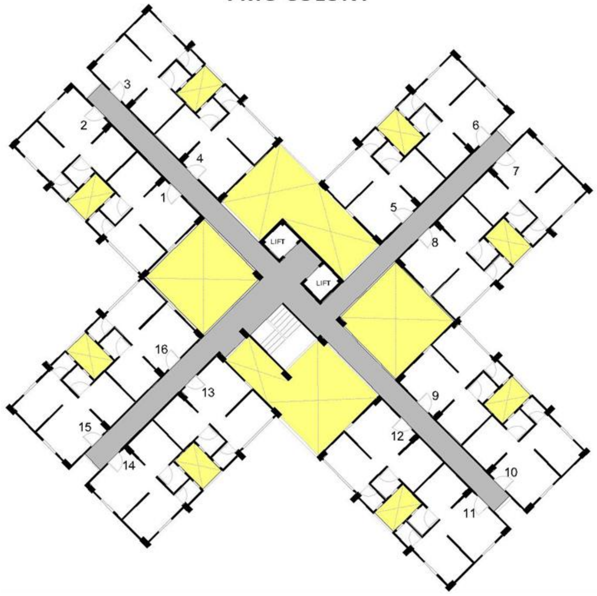


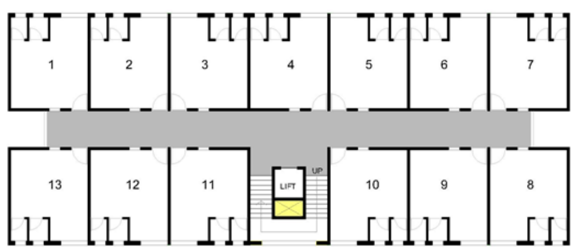
Fig. 48 Study area of the three resettlement colonies (a) and photographs of the open spaces between buildings in the three colonies.

PMG COLONY



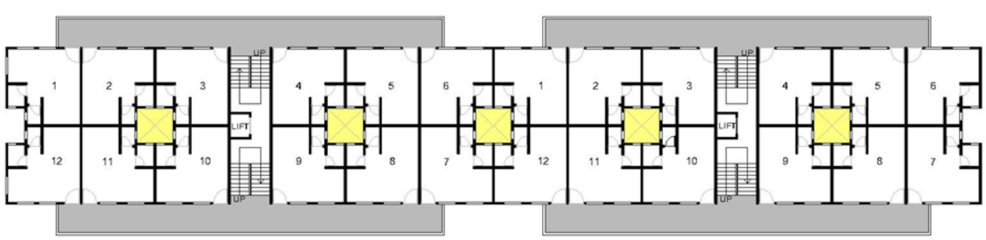
Windows open to both external and internal courtyards

LALLUBHAI COMPOUND



Windows on external walls

NATWAR PAREKH COMPOUND



Windows open to passages and ducts

Fig. 49 Floor plans of the three colonies

Analysis of DCR and Site conditions

- **FSI:** In order to accommodate a higher number of formal dwelling units the in situ consumption of FSI on a plot has been increased since 1991 to 2015 years from 2.5 to 4. All three buildings studied are utilizing an FSI of 2.5.

- **Distance in between buildings:** In order to accommodate for higher densities the distances between buildings has been relaxed from building height/3 to 3 m no matter the height of the building. This means that as per general building regulations the distance between buildings 24 m in height should be 8 m. This is relaxed to 3 m in the case of redevelopment buildings. This has affected the light and ventilation conditions in rehab colonies. Although some of the problems of light and ventilation can be improved using the step back norms for tall buildings, R & R and Slum rehabilitation buildings have not made use of these norms. Perhaps because the uniformity in units stacked over each other makes it difficult to make use of these norms structurally. The proposed DCRs have recommended that the distance between buildings be increased from 3 m to 6 m for buildings upto 32 m in height. If adopted this norm will provide some relief to the congestion in the buildings.
  A stark difference in the quality of light and ventilation can be seen in PMG colony vs Lallubhai and Natwar Parekh colony. In PMG colony, the distance in between buildings is mediated through courts measuring 15mt x 15 m. Each building also has internal light courts measuring 5x5 m. This provides for cross ventilation in the colony and interiors of buildings.

- **Density:** The NBC suggests a **max** dwelling unit (DU) density of 500 DU/ gross ha in the case of low-income housing that cannot be expanded. The DCRs require for a **min** density of 500 Dwelling Units (DU)/net ha for redevelopment buildings. However, the net density of DU/ha far exceeds this number. It is also important to note that the average number of people living in these households is larger (5.27 persons per unit) than the city (4.56 persons per unit). This leads to even higher population density and hence crowding in these areas.

  The DU/ha in the study area of Natwar Parekh Compound is 1076 units/net ha. Lallubhai Colony has a density of 803 du/net ha.As a result of larger distances between buildings, there is a lower ground coverage and hence lower density of homes per net hectare in PMG colony. Density in study area of PMG colony is 635 Du/net ha. This is not below the minimum required density of 500 DU/net ha in the DCR.

- **Windows:** The national building code prescribes that buildings in hot and humid area should have open window area as $1/6^{th}$ the size of the room (17%).
  In Natwar Parekh Compound the windows are 12% of room area reduces to 6% after accounting for shut pane of sliding window. These windows also open to a common 2mt wide corridor and many homes like to keep their windows closed or covered with curtains to

maintain privacy. In Lallubhai colony the windows are 8.5% of room area reduces to 4.25% after accounting for shut pane of sliding window. In PMG colony the windows are 11.4% to 17% of room area. This reduces to 5.7% to 8.5% after accounting for shut pane of sliding window. Rooms in PMG colony are also cross ventilated. TB cases in this colony are negligible.

Owing to better livability conditions, many residents from Lallubhai Compound and Natwar Parekh want to shift to PMG colony.

Discussion

Building indoor environment plays a significant role in modifying health of occupants. Efficient provision of daylight acts a contributing factor in maintaining health and hygiene of occupants. Similarly, in naturally ventilated multifunctional tenement units, airflow network depends on building parameters like windows. Literature has established that windows or openings have a sincere effect on daylight and natural ventilation strategies in compact high-rise apartments. This helps in refreshing the indoor environment by easier and faster removal of household air pollution. Also, it has been reported that sunlight and natural ventilation help in controlling airborne infections like TB. Natural ventilation has been preferred over mechanical ventilation for a better exchange of gases and dilution of infectious agents (8).

Further, direct sunlight is involved in killing of mycobacteria, whereas diffused light has not been found as efficient. Also, direct sunlight exposure leads to production of Vitamin D in the body which is important for prevention as well as cure of TB (8)(9)(10)(11). A study in a district in Indonesia has reported that risk of TB disease is high at lower floor of residential buildings as well as under conditions of overcrowding, lack of sunlight and/or natural ventilation (12). Similar studies have been reported for public housing colonies in Hong Kong (3). Even in school settings with lack of ventilation, the school children have been found to be at high risk of being infected with TB (13). In hospital-like settings, it has been reported that the treatment of spaces with UV radiation and the air with ionizer could prevent air-borne transmission of TB (14). Sky view factor has been defined by personnel working in the field of building design, in order to compare the sunshine access and distance between any group of buildings. The values of SVF can range from 0 to 1. According to the literature, any value below 0.6 is a potential risk for TB prevalence and transmission (2). Thus, poor building design and layout pose many health risks to its residents, risk of airborne infection being major one of them. Access to natural ventilation and sunlight may, then, prove to be important public health measures in controlling drug resistant TB where the antibiotics have failed to cure the disease.

The M-East Ward of Mumbai has been found to be one of the hotspots for incidence and spread of drug resistant TB, worldwide (7). This area contains mainly slums, SRA colonies and PAP resettlement colonies. The low income high-rise urban settlements under current study (eg. Natwar Parekh compound, Lallubhai compound and PMG colony) have developed many health risks for PAP families. Increased risk or incidence of tuberculosis due to lack of efficient daylight and natural ventilation is one of the leading examples. In this study, sky view factor, daylight autonomy and natural cross ventilation were investigated extensively using various computational simulation models, physical household survey as well as real time measurements of these parameters inside the tenements.

Under the simulated conditions, PMG colony performed better in comparison to Natwar Parekh and Lallubhai compounds from the perspective of provision of daylight, because of enough space available between two buildings of PMG colony. In all the three cases, the living areas within the units lacked enough natural ventilation. However, due to the presence of windows on opposite external walls, PMG colony performed better than Natwar Parekh and Lallubhai compound as far as natural ventilation is considered. These findings corroborate with the observations from the field studies using different experimental tools and setups.

For comparison of simulated results to the real-life scenario in the resettlement colonies, the analysis of the survey data was performed using binary logistical regression for different cases such as 'if the respondent reported of having TB' or 'at least one of the member of the household was affected with TB'. Household and individual characteristics, together with built-up characteristics were included in the analysis. Segmented models were estimated for different study areas separately. Statistical analysis of the survey data revealed that the occurrence of TB is more likely in crowded spaces, occupied by more number of household members. Households having exhaust fans and openable windows are less likely to be affected. Moreover, the likelihood decreases as one goes higher up in the upper floors. Detailed field visits and informal interviews revealed that even the fully openable windows were kept closed in many houses in order to keep out the foul smell from the surroundings. Also, the windows were kept closed to maintain privacy and avoid theft. Further, the portion of the sliding windows that was permanently closed was used as a storage space thus blocking any entry of light from that area.

Thus, the results derived from the simulations are found in sync with the household survey results, which show that the occurrence of TB in Natwar Parekh and Lallubhai compounds is strongly associated with the built environment of the houses and the layout of the buildings in both the colonies. In contrast, occurrence of tuberculosis is least in PMG colony which is associated with better built environment and the layout characteristics. Also, PMG colony was found to be much cleaner than the other two colonies, which helped the residents to keep their windows open. This explains that, efficient provision of daylight and natural ventilation strategies within a particular space may act as a factor in improving human health condition, whereas poor sunlight access and natural ventilation may be major risk factors for the deadly TB disease.

A detailed study of the layout of these resettlement colonies and the Development Control Regulations (DCRs) reveal that there is huge disparity between the housing provided by the government and that built by the private firms. The people displaced from slums are allotted tenements in the resettlement colonies mostly based on a lottery system and often have no choice in selecting the location of their house. Thus, these families are doomed to suffer various health risks which are present in these colonies by design, as has been shown in the current study and supported by the reports in the literature.

This study strongly suggests that the SRA and PAP project developers must follow the National Building Codes for the resettlement colonies without any dilution of the DCR norms. Also, there should be no separate rules and regulations for public and private housing, in order to maintain a healthy locality and hence, a healthy country. In the areas where the population has already been affected by poor access to natural ventilation and sunlight, structural and social interventions can be made retrospectively, in order to increase the air flow in the houses and help the residents avail of the clean air and open surroundings. In areas where ventilation is a problem, fully openable windows should be installed, instead of sliding windows. In populations that are particularly vulnerable to certain diseases like TB, special measures need to be taken to prevent the occurrence of disease in them. As shown, in the current study, females of productive age group are specifically affected by TB. Hence, it is essential to provide possible interventions structurally and socially, so as to maintain the health of the society as a whole.

Recommendations

The existing built form and the relaxations in the DCRs that allow for its construction are detrimental to public health. We recommend a two-pronged approach to control the spread of TB in existing and future SRA and rehabilitation colonies.

Retrofitting existing rehabilitation and SRA buildings that are built after 1997. These are buildings that have been built at a distance of 3m from each other. In order to provide some relief to the people residing in the already existing resettlement colonies, some constructive interventions can be made. For example:

1. Change the sliding windows to openable windows
2. Install exhaust fans in the living area/kitchen area
3. Ventilators on the wall/door

One of the scenarios – an extra window in the living area of a tenement of Natwar Parekh compound- was modelled and simulation experiments were performed in order to see the possible impact of the intervention on the natural ventilation in the house (Fig 50 a-c). It was observed that by addition of this extra window, the air velocity in the living area increased considerably because of the cross ventilation. Since, none of the houses in this colony have any windows for cross ventilation, this intervention may help in maintaining a healthier atmosphere in the house. Further it is essential that the sliding windows in these colonies are changed to fully openable as there is already a lack of ventilation between the buildings.

Revert relaxations in standards for slum redevelopment:

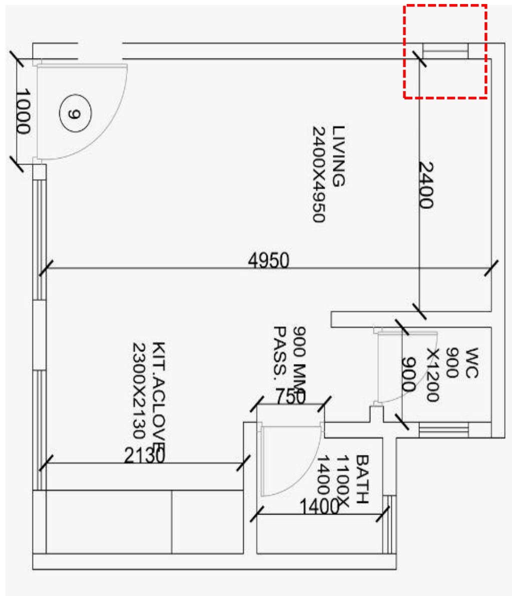
Our findings suggest that relaxation in building standards for slum rehabilitation and redevelopment are detrimental to the health of the poor who inhabit these homes and must be amended. It is imperative to revert the relaxations in standards on setback and dwelling unit density.

The general DCRs for Mumbai should be followed for adequate light, ventilation and density. Further modeling studies, similar to the ones carried out in this report, could be conducted to see the effect of light and ventilation in the rooms using the step back methods of building and different building and open space layouts.

Window design can also be studied. We suggest that shutter windows instead of sliding windows are provided in rehabilitation homes to increase the size of openings

Do not allow authorities to provide further concession: Concessions that lead to overcrowding or compromise the light ventilation of homes in redevelopment/ rehabilitation homes must not be allowed

a.



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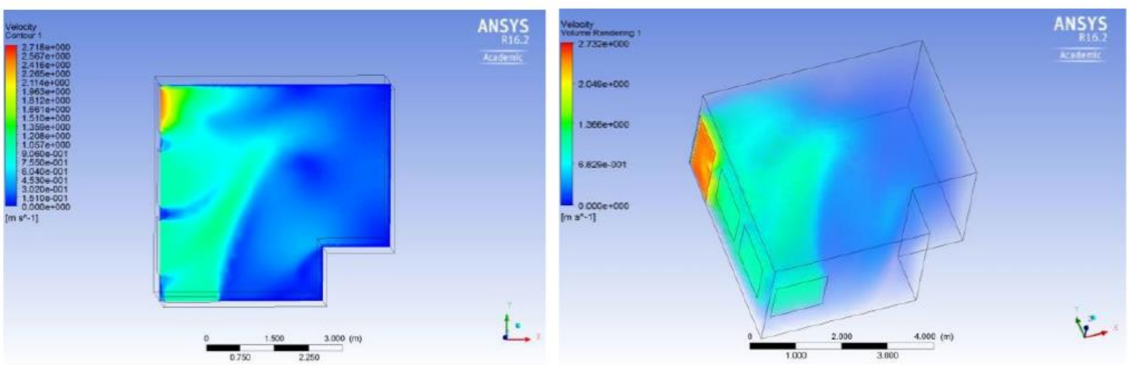

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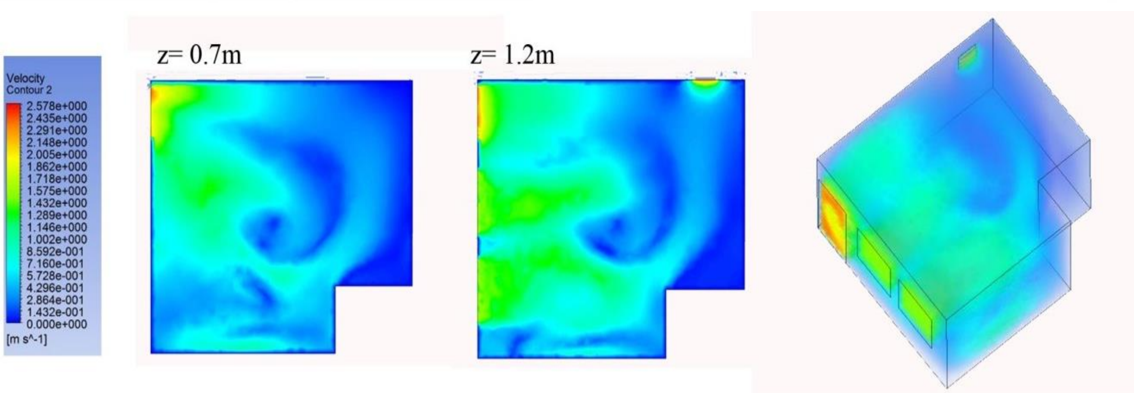

Fig. 50 Simulation studies for a model with an extra window introduced in a house in Natwar Parekh compound. a. The design of the simulated house. Red box shows where the window was introduced, b. Velocity contour and volume rendering of the house before introducing the extra window, c. Contour and Volume rendering of the air velocity in the modelled house with the new window.

Conclusions and Future Prospects

Planners have long known the relationship between the city's built form and public health. The first planning interventions and regulations were implemented by the Bombay Improvement Trust in the aftermath of the plague of 1896. However, over time, in a bid to provide formal housing for maximum number of people on high value land, the DCRs have compromised on the basic standards for livability for the poor. Our planning norms are now aiding a public health disaster. It is imperative to roll back on the norms that are detrimental to the health of the public.

In the era of climate change, climatically sensitive design is necessity for survival, especially for those who cannot depend on costly mechanical solutions for air conditioning and ventilation. Public housing that is being built is expected to last at least for the next 30 years and should be built for these future needs. The city government must take necessary actions to bring improvements in housing and avert a public health crisis.

<u>Summary of the findings</u>

Design and layout of the house/colony:

Floor – Almost all floors are equally affected. Top floors have lesser number of cases probably because all the other floors have poor ventilation and sunshine access.

Window design and usage – Households not having openable windows and/or using the closed windows as storage spaces have high likelihood of having a TB patient.

Exhaust fans – Lack of exhaust fans are strongly correlated to TB prevalence, indicating towards lack of mechanical ventilation one of the risk factors for TB prevalence and transmission.

Sky view factor, daylight autonomy, ventilation – All colonies show poor sky view factors, daylight autonomy and ventilation which may be likely cause of high TB in this area. In literature, Sky view factor less than 0.6 has been associated with TB prevalence. PMG colony has the highest SVF among these colonies, although all the three colonies show SVF from 0-0.4 indicating that Lallubhai and Natwar Parekh colonies are acting like culture medium/breeding ground for the TB bacteria. Low daylight autonomy and ventilation may be because of poor design of the houses and compact stacking to the building next to each other.

Thus, this study suggests that the architectural factors and layout of the colony is an important risk factor for TB prevalence and transmission. Thus, the parameters followed for the building of the new resettlement colonies in the future must conform to the National Building code without any dilution. No separate DCRs should be made specifically or SRA and PAP colonies.

In the already existing buildings, installing ventilators and exhaust fans might reduce the risk of occurrence of TB, while decongesting the living spaces might aid in reducing the risks. This is substantiated by the observations that lesser number of people are affected by TB residing in the higher floors of these high-rise low income urban habitats. It can be concluded from the study that window position plays a very important role in modifying natural ventilation strategies within the room. A detailed study needs to be conducted to frame effective design guidelines for constructing high rise housing for low income groups incorporating better air circulation and ventilation to improve air exchange rate.

Socio economic indicators:

Age – 20-40 years – productive age group
Gender – Female – maybe because of being bound to house and
Income – Low income groups more affected
Family size – Bigger the family higher are the chances of finding a TB patient in that household.

These factors indicate that for the well-being of the population residing in the resettlement colonies, urgent measures and a targeted approach to ascertain the health of the particularly vulnerable population i.e. females of productive age group, need to be taken.

Further, to ascertain that TB is being transmitted within the colony and households and to track the path of transmission, genetic identification of the strain of the bacteria infecting various individuals is needed. Also, a detailed qualitative analysis along with patient and family interviews are needed to understand and address the problems faced by the TB patients and their family members. Further, quality of external atmosphere needs to be tested and efforts to improve the quality of air in the locality need to be taken.

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