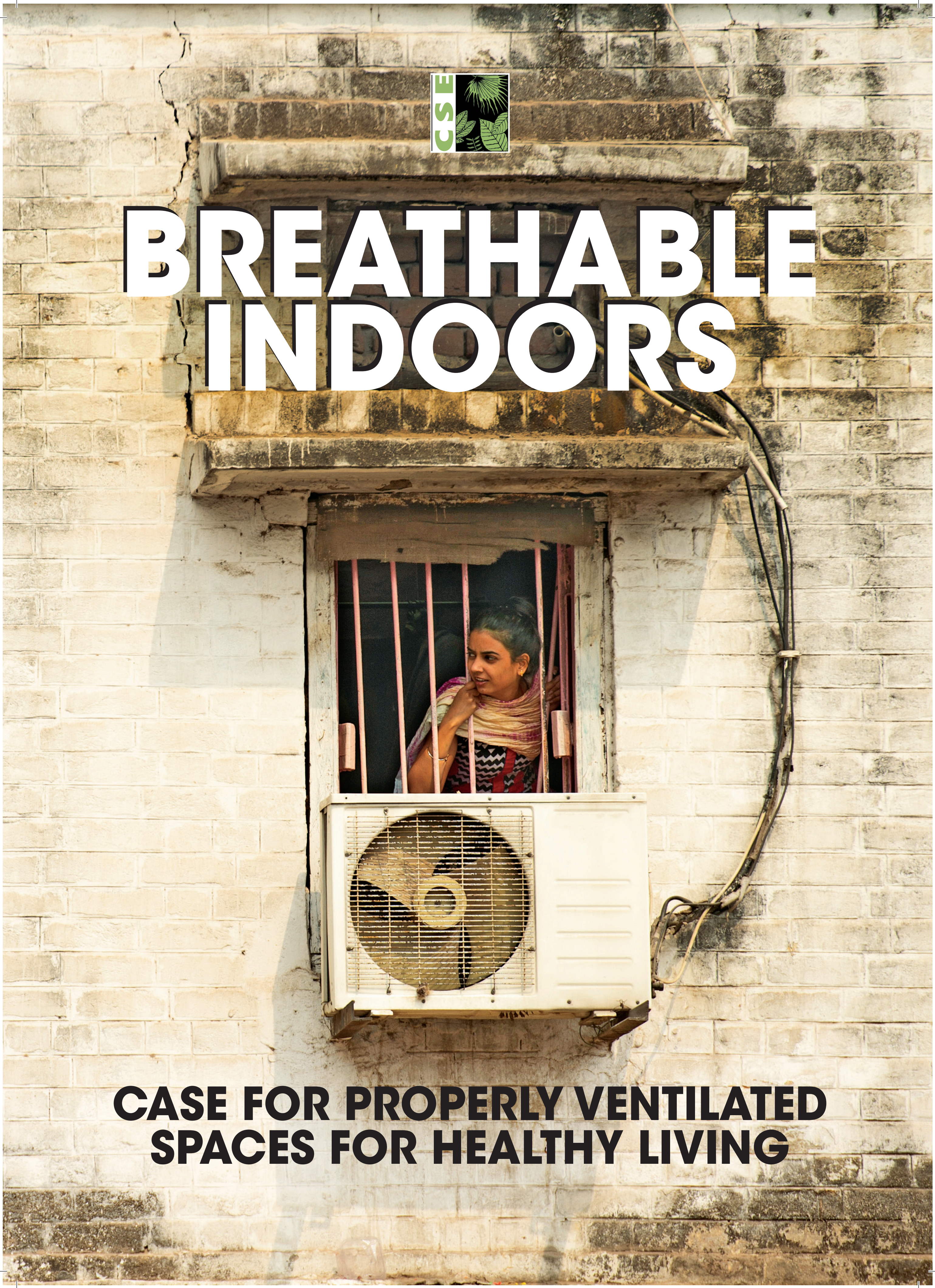
BREATHABLE INDOORS



CASE FOR PROPERLY VENTILATED SPACES FOR HEALTHY LIVING

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Why this study?

As the novel coronavirus COVID-19 pandemic grips the world, scientists are continuously tracking the medium of transmission of the deadly virus and alerting citizens about it to minimize risk of spread. Many advisories have been issued since the onset of the pandemic about the transmission risk from surface contamination, direct contact with an infected person, and exposure through breathing in proximity of an infected person. Newer evidence is deepening the insight into the nature of the risk of transmission and informing the mitigation strategy that may have a profound influence on the way we design our homes, offices, and retail and built environments.

The latest shocker is the evidence that SARS-CoV-2—the pathogen responsible for the ongoing pandemic—can remain airborne for a considerable length of time. A number of studies, such as the one published in the *Lancet* journal,[1] have produced evidence demonstrating that the virus causing acute respiratory distress is transmitted through air. This has led the global health monitoring and regulatory institutions such as World Health Organization (WHO) to sound the alarm and to state that the current safety measures like physical distancing, wearing masks, restriction on public gathering, washing hands, maintaining respiratory hygiene, isolation, quarantine, contact tracing, testing and other Infection Prevention Control (IPC) need to be enhanced to limit the spread of the virus. This has also shifted the focus towards strategies to prevent build-up of virus load inside buildings.

It has been known for some time that SARS-CoV-2 spreads through a person's mouth or nose—when an infected person talks, sings, coughs, sneezes or breathes heavily, the virus is released from their body in the form of heavier droplets which fall on the ground and other surfaces. But now it is better understood that the virus is also spread in the form of aerosols that can also float freely in the air and remain active for hours. When a person inhales these aerosols, or touches a surface that contains droplets or comes into contact with an infected person, they can catch the infection.[2]

In light of this new evidence, the Centre for Disease Control and Prevention (CDC), in its *Scientific Brief: SARS-CoV-2 Transmission* of May 2021, has advised that transmission of SARS-CoV-2 from inhalation of virus in the air farther than six feet from an infectious source can occur and that the role of inhalation in spreading of the diseases is significant. The presence of an infected person for an extended time indoors leads to virus concentration in the air. This transmits infection to people more than six feet away. CDC has identified enclosed spaces with inadequate ventilation and prolonged exposure as a serious risk.[3]

The World Health Organization (WHO) has stated that particle concentration is much higher indoors due to poor ventilation that doesn't match the occupancy rate of the space. Ensuring proper ventilation, shortening the duration of encounters between people and reducing the number of occupants in buildings are some of the measures that need to be added to safety protocols, according to WHO. This need stems from the fact that the spread of viruses takes place more aggressively indoors.[4] Both WHO and the US Environment Protection Agency (EPA) have recommended ventilation of indoor spaces with outdoor air and filtering the air in the best possible way, as an important strategy to mitigate the spread of SARS-CoV-2.[5]

This new science has once again underscored and reinforced the importance of proper ventilation in buildings for healthy living. This strategy was in any case needed to improve thermal comfort in buildings but now has received a thumbs up from the perspective of safe and healthy living. This is a reminder and a learning from the times of the Spanish flue pandemic during the early 20th century, when fresh air was prescribed as cure to the patients.

Modern buildings and health risks: Yet this fundamental principle of architecture has been deeply compromised in ill-designed modern buildings and in buildings with active cooling systems. As the trend towards closing and confining air for active cooling is gaining ground, ventilation strategies are falling out of favour. This is not only compromising the thermal comfort of buildings and increasing the need for air conditioned hours but also turning buildings into petri-dishes in which viruses thrive. In non-residential buildings, air conditioning penetration data suggests that these buildings are dominated by mechanical ventilation—either partially or completely.

The new conversation has exposed concerns around the viral load building up in air conditioned buildings, especially air conditioned offices. Trapped air in air ducts and spaces without air exchange with fresh air has increased the risk of infection. Air conditioned homes and high occupancy public buildings like offices, educational institutions, shopping malls and cinemas have centralized closed systems for climate control and ventilation. These systems need to be maintained well and the duct system needs to be cleaned properly to prevent virus transmission through recirculation of contaminated air.

All new advisories, therefore, are calling for ventilation strategies to reduce concentration of airborne viruses indoors. It is said that the higher the number of people inside a building, the greater is the need for ventilation. USEPA states that ventilation rate is based on the number of people that occupy an indoor space. Proper ventilation requires opening windows and doors, using fans and vents to increase outdoor ventilation rate.[6]

High occupancy buildings, especially schools, office and commercial buildings with central air conditioning systems, are of special concern. Their maintenance will require conformation with new guidelines on ventilation. Occupancy of rooms also needs to be reduced to reduce the risks from SARS CoV-2.

There will be an energy penalty if air exchange is allowed through open windows when air conditioning systems are on. This will have to be understood to address energy-saving settings for demand-controlled ventilation in central air conditioning systems. It is necessary to understand how the heating and cooling set points and even humidification set points of heating, ventilation, and air conditioning (HVAC) systems need to be operated to reduce potential risk from SARS-CoV-2 transmission. Direct air flow should be diverted away from people indoors. Maximum effort is needed to avoid the use of air recirculation. This requires strong guidance to inform audit and implementation.

Houses of the poor and health risk: While air conditioned modern buildings are facing increased risk of virus transmission, there is an added challenge in crowded houses of lower-income groups. The current gap and deficit in housing supply is largely reflected in the congestion or overcrowding in houses (constituting 80 per cent of the housing shortage) and obsolescence (constituting 12 per cent of the housing shortage). There is a huge problem of sub-standard housing stock. According to the Technical Group on Urban Housing Shortage (TG-12), India had a housing shortage of 18.78 million houses in 2012. More recently, India's housing demand was placed at nearly 47.3 million in 2018 according to an independent assessment.[7] To address this gap, India has paced up building construction, especially for low-income groups under the Pradhan Mantri Awas Yojana–Urban (PMAY-U) scheme and plans to add at least 11.2 million housing units by 2022.

Overcrowded dwellings in unplanned areas or informal settlements present a special challenge. For instance, about 42 per cent of Greater Mumbai's population lives in slums according to the Slum Compendium of India. Linkages between these unplanned areas and disease risks are now becoming more pronounced. A study on seroprevalence of COVID-19 in Mumbai places it at 55.61 per cent in slums and

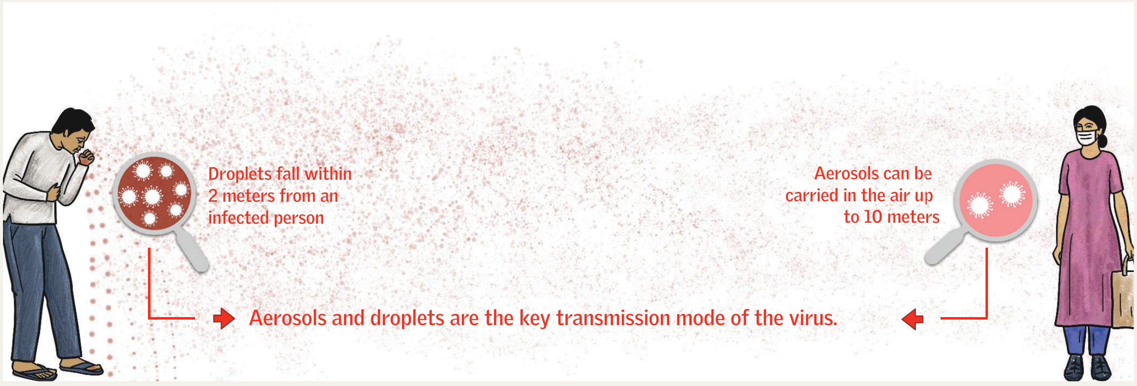
LATEST EVIDENCE ON COVID-19 TRANSMISSION

On 7 May 2021, Centre for Disease Control and Prevention came up with an updated science brief to reflect the latest knowledge on the COVID-19 virus. According to this brief, 'Inhalation of very fine respiratory droplets and aerosol particles' is one of the principal ways in which the virus spreads.

How does this affect our understanding of transmission of the virus?

- While the largest droplets settle down within minutes, the smallest droplets and aerosol particles that come into existence as the droplets dry out can remain suspended in air for hours.
- The risk of transmission remains greatest from three–six feet of an infected person; however, the virus can be transmitted beyond six feet as well.
- As the infected person exhales the virus indoors for extended periods of time (more than 15 minutes), the virus gets concentrated in the air and may infect people present beyond six feet in distance.
- This virus concentration can become diluted due to the streams of air that they come in contact with. Hence improper ventilation can build up the exhaled respiratory fluids in the air, increasing the likelihood of transmission.
- Even a light wind can rapidly reduce concentration of COVID-19 particles, hence the virus spreads more readily in indoor conditions. (See *https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html*)
- The WHO guidelines of April 2021 *Roadmap to improve and ensure good indoor ventilation in the context of COVID-19*, mention that the proper use of natural ventilation can reduce the spread in indoor spaces by diluting the concentration of potentially infectious aerosols.

Figure 1: Guidelines on COVID-19 transmission



Source: Principle Scientific Advisor to the Government of India

12–19 per cent in other types of housing.[8] Dharavi in Mumbai, for instance, was one of the earliest COVID-19 hotspots in the country in 2020. This should come as no surprise. Dharavi houses are about 8.4 lakh people in an area of 2.4 sq. km, i.e., roughly 43.75 sq. ft of living space per capita. Other assessments suggest that the habitable space in Dharavi is as low as 29.38 sq. ft per capita.[9]

Crowding, poor housing conditions, community toilets, inadequate drinking water supply, insufficient natural lighting and ventilation in the houses, lack of awareness and scarcity in health care facilities are contributing to the increased risk of pandemic.[10] Informal settlements also face substantial economic stress to meet the costs of electricity consumption to improve indoor environment with artificial lighting and ventilation.

The ground reality in Dharavi holds true for any other Indian city as well. The 76th National Sample Survey (NSS) round reveals that 45.16 per cent of the urban population has less than a room per capita. In rural areas, the per capita room availability is worse as 66.08 per cent do not have even a room. On an average, about 60 per cent of India's population will face challenges in self-isolation or home quarantining in the event of COVID-19 infection in the house.

Moreover, the 69th NSS report has revealed that the poorest households both in urban and rural areas (80 per cent and 60 per cent of the poorest households respectively) have only 94 sq. ft and 93 sq. ft of housing space per person respectively. This is lesser than the 96 sq. ft per capita requirement for prison cells according to the Model Prison Manual, 2016 and way lesser than what the WHO guidelines for healthy housing recommend. According to the guidelines, a habitable space of 12 sq. m or 129.16 sq. ft per capita must be provided in order for all the inhabitants to maintain health and well-being.[11] The Government of India is developing affordable houses with 30 sq. m or 323 sq. ft carpet area. Considering an average family size of four, the new houses for the poor translates into 80 sq. ft of habitable space per capita. This is less than the WHO standard.

To combat this space crunch, disease-proofing by design and by ensuring proper ventilation in buildings becomes the top priority in the wake of the ongoing COVID-19 pandemic.

Thus, India faces a double whammy. At one level, the buildings for higher income groups, offices, commercial and retail buildings, are adopting designs and active cooling methods that discount ventilation and adequate air exchange of the living spaces making them extremely vulnerable. On the other hand, overcrowded spaces of the poor, especially those being built under formal housing, are ill-designed, neglecting design for efficient ventilation. Operational nuances in buildings—comprising of dos and don'ts—and design solutions turn out to be the immediate and long-term strategies to respond to the requirements set by the ongoing COVID-19 pandemic. This two-fold strategy not only places health safeguards but also keeps the building sector in line with larger energy goal of the country.

The rethink

The pandemic and the mounting evidence on the virus being airborne has led to a major regulatory rethink on building design and operations. Ventilation and day lighting that need to be central to designing of buildings for thermal comfort to reduce air conditioned hours under the mandate of India's National Cooling Action Plan also need leveraging to curb the new danger of disease transmission. It is, therefore, necessary to have this conversation to inform new developments and accelerate change and build public awareness.

Therefore, Centre for Science and Environment (CSE) has reviewed several international and national guidelines on ventilation that are relevant from the perspective of improving ventilation and reducing risk from the COVID-19 pandemic. Guidelines and rules related to ventilation are regularly formulated and made part of the existing regulations; for example, the National Building Code, 2016, Energy Conservation Building Code (ECBC)–Commercial, 2018, and ECBC–residential or Eco Samhita. In addition, new guidelines have emerged that have put a spotlight on the linkage between ventilation and COVID-19 risk. These include those from Centre for Disease Control and Prevention, Environment Protection Agency, World Health Organization, National Building Code, and India Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE).

While reviewing these norms, CSE has further applied some of the essential design criteria to different building typologies—residential buildings (affordable housing), and non-residential buildings (commercial and institutional) that are either fully or partially mechanically ventilated.

To check out the adequacy of these guidelines in addressing ventilation, this assessment has combined some of the existing rules to apply them to the emerging building typologies under the affordable housing scheme of PMAY-U. The purpose of this exercise has been to assess how some of the current design approaches in buildings perform when the existing provisions of ventilation are applied and how the variation in layout design of the buildings and the openings of rooms respond to the ventilation requirement under the guidelines.

The diversity of building typologies in the formal sector presents a range of concerns when assessed from the perspective of the ventilation requirements enshrined in the guidelines, standards and standard operating procedures, be it by retrofitting or optimizing operations, to address the virus risk. This has provided strong insight into the design and operations of the buildings.

CSE has conducted ventilation audits for mixed-mode buildings with naturally ventilated spaces as well as mechanically cooled spaces. The current mass affordable housing typologies being built under the PMAY-U have been assessed and simulated to see how they are performing and will perform if the criteria of ventilation are applied.

This review has focused on residential buildings to understand how Indian codes and guidelines such as National Building Code, Eco-Niwas and Eco-Samhita have provided for ventilation in regular buildings and whether they adequate to be adapted for addressing COVID-19 requirements, especially in isolation rooms for quarantine etc., in the current as well as future designs. How will these buildings perform against the following key indicators of ventilation?

- Openable window-to-floor area ratio: This is needed to ensure that the size of the window with relation to the space is adequate for ventilation
- Placement of windows to enhance ventilation
- Avoiding obstruction by other elements
- Habitable rooms opening to open spaces for proper cross-ventilation
- Building orientation to be able to respond to local wind direction
- Are buildings adhering to minimum air exchange rates?

Using these indicators and COVID-19 requirements, CSE has assessed the performance of the current mass affordable housing typologies being built under the PMAY-U. This brings out the current ground situation and throws up lessons for long-term design solutions to meet the requirement of ventilation, especially in isolation rooms and quarantine areas for infection management in houses, strategies for cross-ventilation and enhanced air exchanges.

The assessment has revealed that high occupancy non-residential buildings with increased penetration of mechanical ventilation need to optimize their operations and enhance the quality of ventilation to curb the spread of SARS-CoV-2 infection. For these typologies, the latest guidelines on mechanical ventilation were overlaid over the mechanically ventilated buildings to draw operational nuances for these typologies. To enable this, scenario-wise, chronological assessments are needed, starting from audits of on-ground operations. A few such solutions are summarized in this assessment for easy understanding and application in non-residential buildings.

The focus on ventilation has also put the spotlight on the quality of outside air and the importance of mitigating air pollution on an urgent scale.

Summary of key findings

This analysis has provided clear insight into ways to de-risk indoor air during pandemic times while contributing towards improving overall thermal comfort inside and reducing energy-intensive air conditioned hours. The pandemic, despite being a humanitarian crisis, is an opportunity to push for these co-benefits.

Evaluate housing templates and adopt operational do's and don'ts in the existing housing stock: The current guidelines and their applications are inadequate to address the ventilation requirements to reduce infection risk. This assessment has provided the evidence on the kind of rooms that can be used or not used for isolation for home quarantining. Room designs with windows opening to external open spaces are needed; room designs with windows or doors opening to exchange spaces such as corridors must be avoided. An assessment of state housing templates can bear out specific guidelines focusing on operational do's and don'ts in residential buildings based on what can be done immediately in the houses to contain the spread of SARS-CoV-2. To enable this, more and more housing typologies need to be studied for their repercussions on health. State authorities have always worked with fixed templates for affordable housing. These templates need to be assessed and compared with the latest COVID-19 related guidelines—both national and international—to draw on how these templates perform on the spread of infection risk.

Mainstream design strategies for natural ventilation in future building stock and improve thermal comfort for healthy living while reducing air conditioned hours: Ventilation strategies need to improve not only to reduce infection risk but also to improve thermal comfort in buildings. This assessment has provided evidence through simulations of existing building design and building form, clustering, height of the buildings and overall layout that either enable or constrict ventilation in buildings. Future housing designs should maximize access to open spaces through positioning, size and openability of windows. Similarly, more assessments are needed to build a knowledge bank comprising different typologies of buildings and how they behave in certain climatic conditions and to identify remedies to regulate the flow of air inside and around buildings. This is needed for disease-proofing future building stock. Nearly 80 per cent of buildings in India are naturally ventilated or of mixed-mode typology. It will take much time for mechanically ventilated buildings to dominate the built environment, especially after the implementation of National Cooling Action Plan in 2019. This makes a strong case for the government to promote mixed-mode buildings with more naturally ventilated spaces, especially for affordable housing; at the same time, codes must be set to incorporate ventilation strategies in new construction and retrofits.

Rooms with windows opening to external open spaces are crucial for isolation rooms and quarantine areas: The assessment has revealed that a COVID-19 patient must not be isolated or quarantined in rooms with windows not opening to external open spaces as well as rooms with windows or doors opening to poorly ventilated common spaces. For instance, assessment of some of the housing typologies showed that their living rooms open to doubly loaded corridors which are often misunderstood as open space. This results in spread of the air-borne diseases as such corridors are common spaces that often have limited ventilation. Isolation or quarantining in a room with windows opening to such corridors will risk the spread of infection to people using the corridor as well as those living in other dwelling units accessed by that corridor as contaminated air will keep on exchanging.

Maximize access to open spaces to enable cross-ventilation: Simulation analysis on different housing typologies has given evidence for the fact that a habitable room opening to external open spaces performs better in terms of cross ventilation than rooms with windows opening to common spaces such as closed corridors. Keeping in mind the isolation and ventilation requirements, future housing designs should go for building typologies that maximize access to open spaces through positioning, size and openability of windows. CSIR-CBRI has come up with a tool which can calculate the window opening size based on the size of the room for the desired air change rates. The tool takes into account the average wind speed in the city, wind direction (coefficient value changes if wind hits the window perpendicularly or obliquely) and the placement and number of windows (coefficient value changes if there is a single window in the room). The tool can also be used to determine the preferred direction and size of windows to achieve thermal comfort for its occupants. This can be a useful instrument for building designers to get a rough idea of the sizes of windows required.

Wind hydraulics need to be studied and integrated with site planning to enhance air change rates inside buildings: A regression analysis has revealed a positive co-relation between outdoor wind speed and indoor air changes per hour. When placed in the predominant wind direction, dwelling units demonstrated an R^2 value of above 0.83, representing a strong correlation between indoor ventilation (air changes per hour) and outdoor wind speed. Further, factors such as building form, clustering, positioning of blocks, height of the buildings and overall layout also play a vital role in enabling or constricting ventilation in buildings. Therefore, wind hydraulics need to be studied well and integrated with site planning to ensure desirable air change rates in buildings.

Reform building design and operation codes: There are codes that target energy conservation such as Eco Niwas Samhita and those guiding thermal comfort and health through appropriate design like the National Building Code. However, the ongoing pandemic has shown that these codes now need to converge for a better informed practice that comprehensively addresses adaptive thermal comfort, energy penalty and disease-proofing. There is a need for detailed and merged design codes that guide and ensure appropriate building typology combined with existing guidelines for cross-ventilation, mid-rise height of the buildings, adequate spaces between blocks, staggered arrangement, windows opening to open space, etc. This will enable code-vetted practices in the long-term. The enhanced codes need to improve health performance and also consider energy penalty through adaptive thermal comfort standards. The ventilation audit has to ensure ventilation effectiveness. To achieve this, strategies like use of fans to dilute the air and exhaust air effectively and prevent contamination of air ducts of mechanically cooled buildings will be needed.

Need ventilation audits and operation protocols for different building typologies: There is an immense need to develop and disseminate what could be done immediately in existing buildings to contain the spread of SARS-CoV-2. However, there is a dearth of studies and data on ventilation performance in different building typologies that range from partially mechanically ventilated, fully mechanically ventilated, equipped with centralized air conditioning or standalone air conditioning, among others. In order to optimize ventilation in these buildings, it is crucial to get audits conducted by HVAC experts. Based on these audits, operational guidelines are needed to enhance air changes and prevent the spread of COVID-19 infection.

COVID-19-related operational guidelines for mechanically ventilated spaces must address the associated energy penalty: In a COVID-19 scenario, a number of guidelines for mechanically ventilated spaces stress on introducing more fresh air by keeping the windows open even when the ventilation is running. Keeping windows open in centrally air conditioned buildings as well as houses amidst the emerging COVID-19 requirement is going to have a tremendous impact on energy consumption. While it is too early to estimate energy consumption based on this new requirement, it is certain that air conditioners will not work on part load with their compressors continuously active in open windows. In this unavoidable scenario, considering the health emergency, set point temperature can be an effective tool. Setting air conditioning temperature close to the outside ambient temperature can help mitigate some of the energy spike caused by this new requirement.

Further, according to ISHRAE,[12] instead of increasing fresh air intake into a mechanically conditioned space to achieve the desired air change rates, equivalent air changes per hour must be focused upon. ISHRAE is proposing a combination of fresh air intake and a right form of filtration system for effective infection control. This is expected to save energy by decreasing the need to bring outside air and condition it. Several institutional and educational buildings have started to adopt this strategy.[13] These strategies need to be assessed from the perspective of disease control. Architects point out that there is a need to pre-cool air and prevent cross contamination of indoor and outdoor air. Overall, heat ingress must be reduced.[14]

Mandatory protocols in leased commercial spaces: Leased commercial spaces have limited control and less possibility of re-capitalization for infrastructure retrofits. With these limitations, the building users might not be able to operate the building in response to the updated health requirements, hence these spaces need to be brought under mandatory operation protocols.

While a summary of this emerging trend is presented for public information and awareness, it has also highlighted the status of overall regulatory approach to integrating ventilation requirements in the design and layout of buildings. This builds the case for stronger action.

Review regulations and guidelines on ventilation to improve ventilation effectiveness: Consultations on this matter carried out as part of this study has brought out the need for further reforms to improve ventilation requirements in our existing regulations. The CSIR-Central Building Research Institute (CBRI), which is also a part of the framing of the new COVID-19 guidelines by the office of the Principle Scientific Advisor, said at a CSE webinar held on 20 July 2021[15] that WHO and EN-16798 have recommended a ventilation rate of 10 litre per second per person (which is 36m^3 per hour per person) for the COVID-19 situation. In fact, the air change per hour requirement—in terms of the ratio of the volume of outside air allowed into a room in one hour to the volume of the room—of the National Building Code (NBC) are not sufficient to achieve these ventilation rates in different settings. In most buildings, the acceptable level of air change per hour and indoor air quality are determined by coupling the provisions of ISHRAE standard or NBC, 2016. Now, CSIR guidelines are available on ventilation for residential and office buildings version that recommend increased requirements for air change per hour. For instance, if under NBC 2016, a living room and a bedroom require air change per hour of three–six and two–four respectively, the new recommendations have increased the corresponding requirements to four–seven and three–five respectively.

What is ventilation and how is it regulated?

To put it simply, ventilation is the flow of air into and out of a space for the physical comfort of an occupant. Architecturally, ventilation is defined as, 'The process in which clean air (normally outdoor air) is intentionally provided to a space and stale air is removed, either by natural or mechanical means.'[16] The absence of adequate ventilation creates a condition in which the occupant feels both physically and mentally ill, wherein an individual could observe health problems like tiredness, dizziness, headache, nausea, increased heart rate, difficulty in breathing etc., while occupying the space. This is also termed as "Sick Building Syndrome".[17]

The health problems associated with the Sick Building Syndrome are, however, short-term and diminish when the person leaves that space, i.e., the syndrome is tethered to the space or the building. But that does not diminish their danger. The ongoing COVID-19 pandemic has amply demonstrated the serious health risk posed by ill-ventilated buildings.

Ventilation and SARS-CoV-2: USEPA and WHO have recommended ventilation of indoor spaces with outdoor air and filtering of air as the best possible ways to mitigate the spread of SARS-CoV-2.[18] According to WHO's roadmap to improve and ensure good indoor ventilation in the context of COVID-19, natural ventilation can be enhanced when used in combination with ceiling or standalone pedestal fans. However, care should be taken that these fans are placed in a proper position. For instance, pedestal fans should be placed close to open window so that the virus is expelled as quickly as possible before it is distributed or circulated throughout the room.[19] This is the most economical and effective way of improving the health conditions within an indoor space without making any major changes to the existing setting of the room.

Centre for Disease Control and Prevention (CDC) has published guidelines for examining workplaces for ventilation before reopening them.[20] Firstly, it is required to identify the places which are poorly ventilated. This can be easily done; by identifying spaces with bad smell; examining if the present ventilation system is working efficiently; if the mechanically ventilated space is just recirculating the air, or it provides outdoor air into the space; identifying places where people are working but there is no provision of natural or mechanical ventilation such as windows, vents, etc.[21] Subsequently, after identification of poorly ventilated spaces one needs to resolve the issue by adequately ventilating them, using various ventilation methods, following minimum recommendations of ventilating different occupancy space as per the national codes and guidelines.

In India, many regulations and guidelines related to ventilation in building exist. But the ongoing scenario demands that these guidelines evolve to address the disease risk in buildings. The National Building Code, 2016 is the key guideline for ventilation in buildings by both natural and mechanical means (see *Figure 2: Timeline of codes and guidelines on ventilation*). The guidelines recommend improving ventilation through orientation of the building, open spaces around the buildings, window openings and number of air changes based on the building occupancy. In 2017, Energy Conservation Building Code (ECBC) for commercial buildings was launched to address three types of ventilation—natural, mechanical and mixed-mode. Eco Niwas Samhita (ENS) was launched in 2018 for residential buildings and brought an indicator—openable window-to-floor area ratio—as a guide to ventilation. But adequacy of these guidelines from the perspective of disease-free environment and thermal comfort requirements is doubtful.

More specific to the context of the SARS-CoV-2, Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE) has recently released COVID-19 guidance documents for air conditioning and ventilation in April 2020. NBC guidelines have also been updated to enable increase in air changes for residential and commercial buildings in the wake COVID-19. The most recent intervention is the guidelines released by the Office of Principal Scientific Adviser to the Government of India to prevent the spread of SARS-CoV-2 through ventilation. Moreover, the Council for Scientific and Industrial Research (CSIR) under the Central Ministry of Science and Technology has further issued guidelines on *Ventilation of Residential and Office for SARS-CoV-2 Virus* which stress on modifying the NBC, 2016 for the ongoing pandemic. The guidelines recommend air change rates for different rooms in a building and for different building uses.

Applying ventilation criteria to building typologies

As part of this assessment, CSE has reviewed several existing regulations in India, including NBC and ECBC, and national and international guidelines on ventilation that have now emerged due to the ongoing COVID-19 scenario. This includes guidelines brought out by Centre for Disease Control and Prevention, Environment Protection Agency and World Health Organization, among others (see *Figure 3: Methodology adopted for this assessment*).

Figure 2: Timeline of codes and guidelines on ventilation

Timeline of updated codes/guidelines and their association with ventilation

Pre COVID - 19

2016
National Building Code of India
- Recommends open space standards to be kept around the buildings for the purpose of Ventilation
- Openings to floor area ratio
- Suggests that buildings are oriented keeping climatic factors in consideration
- Defines number of air changes based on occupancy type

2017
Energy Conservation Building Code – Commercial
- Addresses three medium of Ventilation (Natural, Mechanical and Mixed Mode)
- Air Changes per hour as per recommendation by National Building Code (NBC) 2016

2018
Eco Niwas Samhita (ECBC-R)
- Introduction of the openable window to floor area ratio (mandatory criterion)

During COVID - 19 Pandemic

DECEMBER 2019
- World Health Organisation was informed of cases of pneumonia of unknown cause in Wuhan City, China

JANUARY 2020

7 January 2020 - A novel coronavirus was identified as the cause by Chinese authorities and was temporarily named "2019-nCoV"

27 January 2020 - The first case of COVID-19 infection reported in Kerala, India

29 MARCH 2020
The World Health Organisation (WHO) said airborne transmission of the virus is possible only after medical procedures that produce aerosols, or droplets smaller than 5 microns

APRIL 2020

13 April 2020 - The Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE) releases COVID- 19 Guidance Document for Air Conditioning and Ventilation, it mentions ways of ventilating and creating a isolating enclosure.

17 April 2020 - The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) releases a document covering Potential route of Airborne transmission recognized as COVID- 19 spread

09 JULY 2020
- World Health Organisation (WHO) said airborne transmission of the virus can occur in health care settings where Aerosols Generating procedures are performed.
- Increasing evidences and reports on outbreak suggest that the virus can also spread in indoor spaces through aerosol transmission.

06 JANUARY 2021
The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) releases Core recommendations for Reducing Airborne Infectious through Aerosol Exposure

01 MARCH 2021
World Health Organisation releases a roadmap to improve and ensure good indoor ventilation in context of COVID- 19 which recommends the rapid identification and **isolation of COVID- 19 cases** and also mentions **enabling cross ventilation rather** than single sided ventilation.

15 APRIL 2021
The Lancet Journal mentions Ten Scientific reasons in support of Airborne Transmission of SARS-CoV-2

MAY 2021

07 May 2021 - Centre for Disease Control and Prevention (CDC) states transmission of SARS-CoV-2 can occurs through inhalation of virus through air even at a distance farther than 6ft. from the infectious source

The Council for Scientific and Industrial Research (CSIR) issues guidelines on Ventilation of Residential and Office for SARS-CoV-2 virus by **modifying number of air changes** in existing National Building Code, 2016

Office of Principal Scientific Adviser to the Government of India issued guidelines to prevent the spread of virus through Ventilation, which **recommends cross ventilation** to reduce the viral load in a space

Source: CSE compilation

This review has identified four emerging requirements in relation to the COVID-19 scenario:

Isolation rooms: An isolated room is needed for quarantining and should have a ventilation system in which the contaminated aerosols are exhausted from the space and do not infect other individuals in the surrounding.

Cross-ventilation: Lack of proper ventilation creates an excessive viral load and increases the chances of infection inside poorly ventilated spaces. Cross-ventilation is a preferred strategy to dilute air and mitigate this viral load.

Increased air change rates: Under the current circumstances, the air change rate requirements have been modified to ensure that there is no build-up of aerosols in indoor spaces.

Enhanced filtration: If other preventive measures like improving fresh air intake are not possible in buildings, installation of high quality filters are suggested under the new guidelines.

This review has attempted to understand how Indian codes and guidelines such as National Building Code and Eco-Niwas Samhita are dealing with ventilation. As these codes and guidelines do not address the infection risks due to SARS-CoV-2 virus, their potential to incorporate the four identified COVID-19 requirements is assessed in this study based on the following indicators:

- Openable window-to-floor area ratio
- Placement of windows
- Orientation in response to wind direction
- Avoiding obstruction by other elements
- Habitable rooms opening to open spaces

By combining these indicators with the emerging COVID-19 requirements, CSE has conducted ventilation audits for mixed-mode buildings that are a combination of naturally ventilated buildings with some cooling devices like ceiling fans. The current mass affordable housing typologies being built under PMAY-U have been assessed to see how they are performing and will perform should such layouts and designs continue to be implemented.

For non-residential typologies, firstly, penetration of mechanically ventilated buildings was understood and the latest guidelines on mechanical ventilation were overlaid to draw operational nuances for these typologies.

This assessment has reinforced the need for a two-fold strategy to improve ventilation and curb the spread of SARS-CoV-2 in buildings. Operational aspects of the buildings, comprising of the list of do's and don'ts, and design solutions needed for immediate and long-term strategies to respond to the new concerns around the COVID-19 pandemic have been taken into consideration. This is not only expected to improve health safeguards but also enable the building sector to meet the larger energy goals in the country.

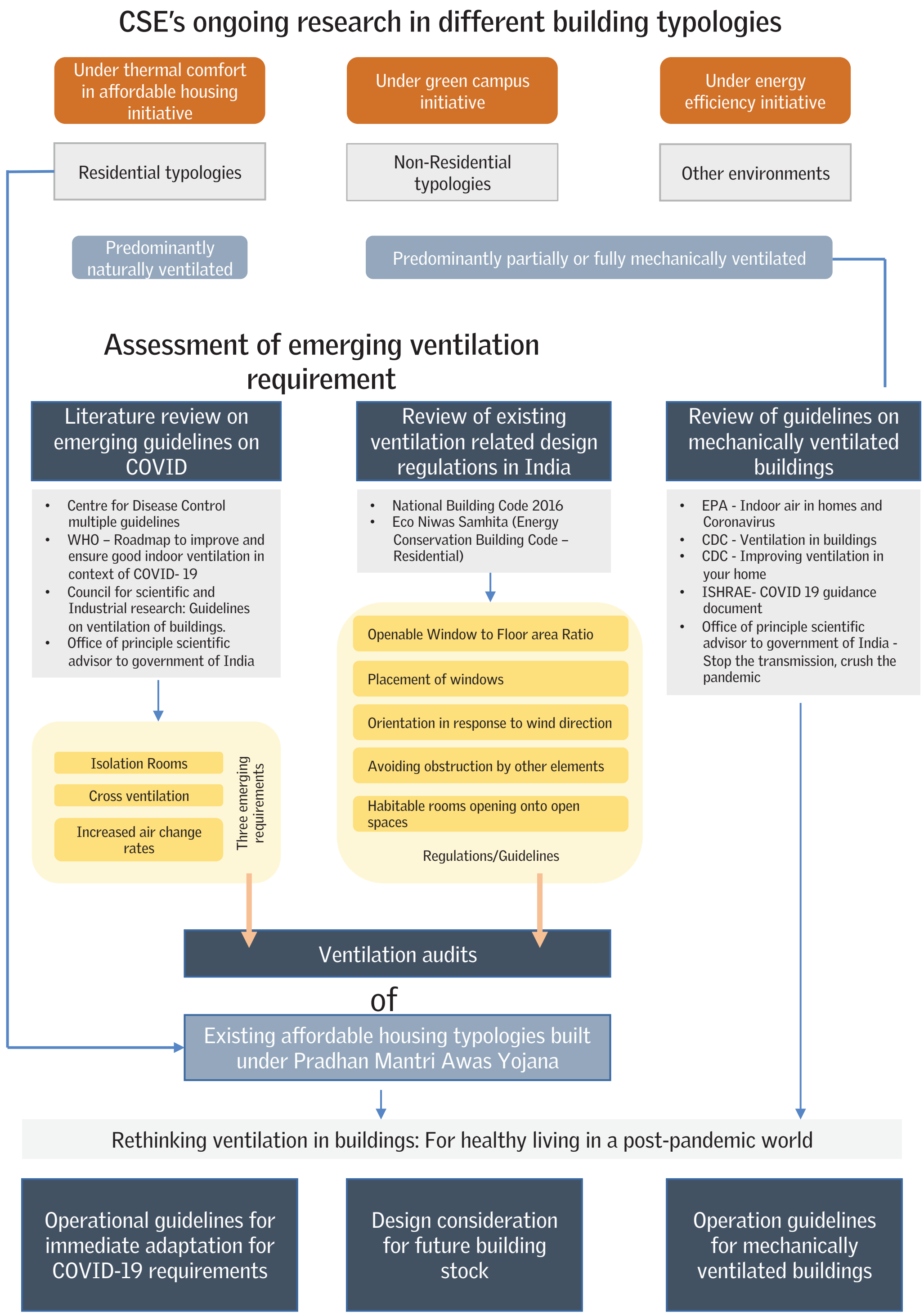
Buildings and inadequate ventilation

The new guidelines brought out by WHO and CDC as well as the ones recommended by CSIR, focus on increasing air changes in residential and commercial buildings to improve the ventilation rate. WHO guidelines suggest strategies such as use of fans or fan coils or split units to dilute the contaminant, opening of windows before and after occupancy, use of exhaust fans in the isolation area and ensuring cross-ventilation by keeping doors open to reduce the risk of infection. Similarly, the other guidelines also aim to neutralize the impact of the ongoing pandemic indoors and contain the spread of the infection.

NBC, 2016 so far addresses ventilation to provide health comfort to the occupant by balancing body temperature (thermal comfort), nullify the odours, and removing hazardous gases, contaminants and any combustible gases from the space. The code suggests various measures for proper ventilation, including air change rates for maintenance of required oxygen, carbon dioxide and other air quality levels and for the control of body odours when no products of combustion or other contaminants are present in the air. This leaves NBC inadequate amidst the prevailing COVID-19 circumstances. NBC now needs to evolve and factor in the infection risk in different types of buildings in its recommendations for ventilation rates. Similarly, ECBC 2017 and Eco Niwas Samhita, among other codes that provide guidance on ventilation, also need to take into account the infection risk in buildings.

WHO recommends minimum ventilation rates in buildings as 10litres per second per person (36 cu. m per hour per person) considering the ongoing COVID-19 scenario. The air change rates currently prescribed in NBC are not sufficient to achieve this ventilation rate in different outdoor settings. CSIR guidelines on ventilation of residences and office buildings for SARS-CoV-2 virus recommend improvements in NBC standards for air changes (see *Table 1: Ventilation rate recommended by CSIR for a SARS-CoV-2 scenario*).This recommendation by CSIR will have an impact on the window sizes in buildings.

Figure 3: Methodology adopted for this assessment



Source: CSE compilation

Table 1: Ventilation rate recommended by CSIR for a SARS-CoV-2 scenario

Application	Air changes per pour (ACH) as per NBC, 2016	Recommended ACH in a SARS-CoV-2 virus scenario
Living room	3–6	4–7
Bedroom	2–4	3–5
Changing room or bathroom	6–10	8–12
Corridor	5–10	6–12
Entrance hall	3–5	4–6
Garage	6–8	8–10
Kitchen or gymnasium	> 6	> 10
Basement or cellar	3–10	4–12
Laundry room	10–30	12–36
Lavatory	6–15	8–18
Toilet	6–10	8–12
Isolation (quarantine) room	-	> 10
Assembly room and banks	4–8	8–10
Bakery or dye work	20–30	24–36
Billiard rooms or hospital wards	6–8	10–12
Café or coffee bar or compressor room or recording studio	10–12	12–15
Canteen, restaurant, dairies and conference room	8–12	10–15
Church	1–3	10–15
Cinemas, theatres, hair dressing saloon, photo room and X-ray dark rooms	10–15	12–18
Club room or dance hall or public house bar	> 12	> 15
Hospital (sterilizing)	15–25	18–30
Hospital (domestic)	15–20	18–24
Laboratory	6–15	8–18
Lecture theatre	5–8	> 12
Library	3–5	> 12
Lift car	> 20	> 24
Office	6–10	> 12
Paint shop (not cellulose)	10–20	12–30
Recording control room	15–25	18–30
School room	5–7	> 12
Shop or supermarket	8–15	10–18
Shower bath	15–20	18–24
Store or warehouse	3–6	4–8
Squash court	> 4	> 6
Underground vehicle parking	> 6	> 8
Utility room	15–30	18–36

Source: Council of Scientific and Industrial Research (CSIR), 2021, CSIR Guidelines for ventilation of Residential and Office Buildings for SARS-CoV-2 Virus

Table 2: Window areas to achieve minimum air change rates as per NBC and CSIR guidelines

	Minimum window areas as per NBC recommended ACH rates	Minimum window areas as per CSIR recommended ACH rates
Area of window perpendicular to prevalent wind direction (for each window on opposite side)	450 sq. cm	600 sq. cm
Area of window oblique to prevalent wind direction (for each window on opposite side)	900 sq. cm	1200 sq. cm

Source: Ashok Kumar, Head, Architecture and Planning, CBRI, Roorkee, 2021

For instance, when window sizes in a living room in Delhi (size 4m x 3m x 3m) are calculated considering the air change rates according to NBC vs the CSIR guidelines, the latter yields an increase in size by over 30 per cent (see *Table 2: Window areas to achieve minimum air change rates as per NBC and CSIR guidelines*). NBC recommends three–six air changes per hour (ACH) for a living room, whereas CSIR recommends four–seven ACH, keeping in mind the COVID-19 scenario.

Further, to achieve the minimum air change rates, orientation of windows with respect to the prevalent air flow also has a role to play. Calculation of window sizes to enable the minimum recommended ACH as per NBC and CSIR resulted in different areas when the window was perpendicular to the prevalent wind direction vs when it was oblique to the prevalent wind direction. Therefore, achieving the desired air change rates is a function of both the sizing of the window as well as the way the window is oriented in relation to the prevailing wind.

It is now clear that the size of the windows has an impact on the air change rates. This study establishes the link between outdoor wind speed and indoor air change rates. This link is described in subsequent sections.

CSIR–CBRI METHOD OF ESTIMATING AIR CHANGE HOUR RATES

In order to guide the calculation of window sizes for desired ACH rates, CSIR–CBRI has come up with a tool. The tool takes into account the average wind speed in the city, wind direction (coefficient value changes if wind hits the window perpendicularly or obliquely) and the placement and number of windows (coefficient value changes if there is a single window in the room). The tool can also be used to determine the preferred direction and size of windows to achieve thermal comfort for occupants of a room. This can be a useful instrument for building designers to get a rough idea of the sizes of windows required, especially to curb the spread of SARS-CoV-2.

To map the transmission of the virus and how fresh air can help in cutting down the transmission, CSIR conducted a study. A scenario of a bus carrying 45 passengers with one COVID-19 infected person was taken, the calculations revealed that up to 19 people in the bus can get infected if there is no intake of fresh air into the bus, this value is reduced to four people when there is a 30 per cent fresh air intake and reaches the value of two people with 100per cent fresh air intake. The infection can be further cut down if solutions like UV-C are employed. CSIR has also developed a test bed facility at its office at CSIR–CBRI, wherein the system is adjusted to take care of the viral load.

Optimization of natural ventilation in residential buildings in the wake of COVID-19

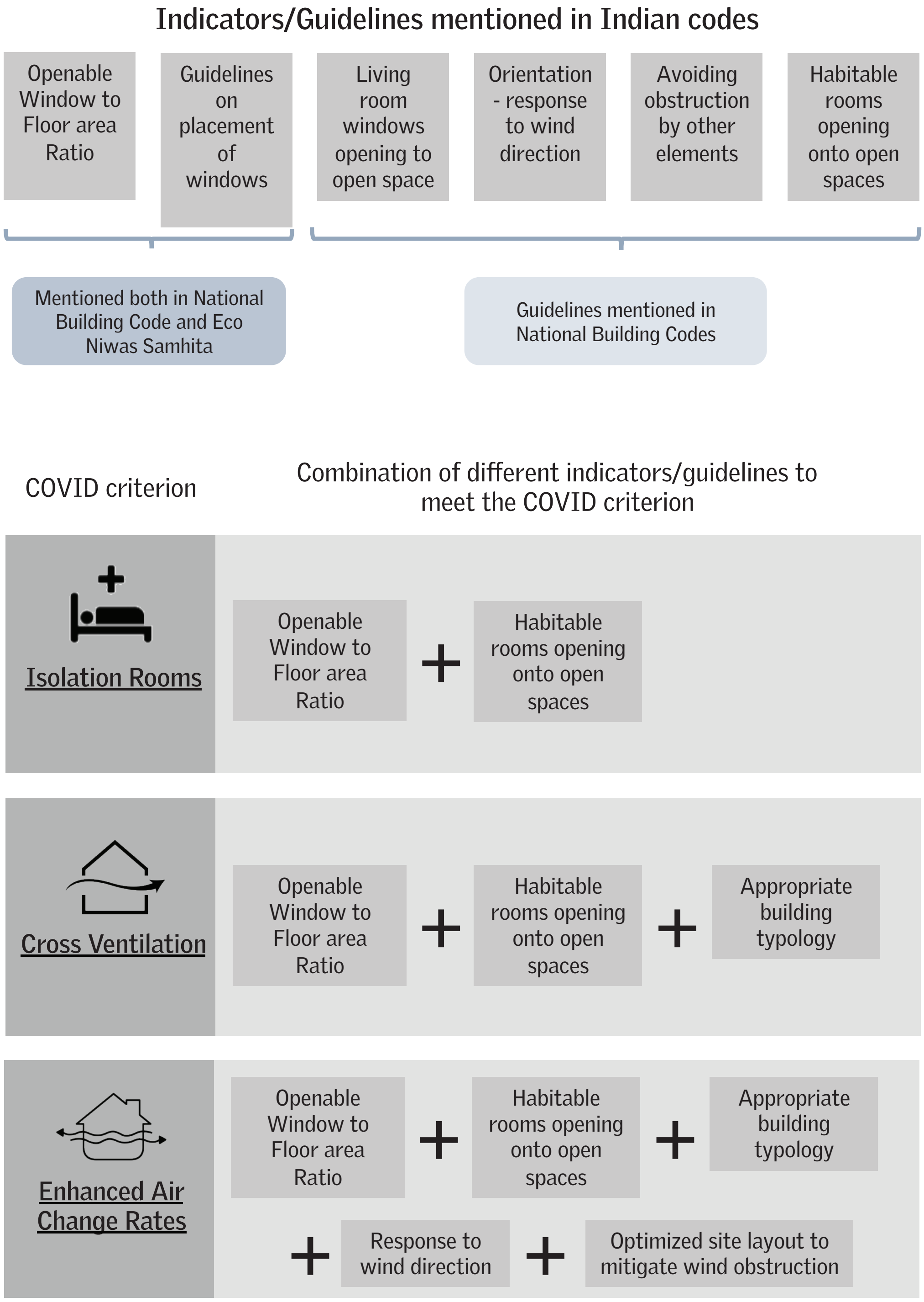
CSE has analyzed an array of regulatory and guidance frameworks, both national and global, to draw key requisites for proper ventilation in future building stock. The following minimum qualifiers have been identified.

Openable window-to-floor area ratio (WFRop): Windows provide multiple functions in a building. While daylighting may be achieved with a fixed window, openability of a window is critical for natural ventilation. The openable window-to-floor area ratio (WFRop) is an indicator of the dwelling unit's potential to use external air for ventilation. This indicator is suggested both in the NBC,2016 and ECBC-R 2018 and takes into account the size of the openable window in comparison with the floor area of the dwelling unit. Considering the COVID-19 circumstances, this requisite ensures appropriate 'hardware' is in place but does not guarantee performance, i.e., appropriate ventilation.

Windows opening to the exterior: Windows are necessary for ventilation and daylighting. The amount of daylighting and ventilation that the window provides is dependent on the space to which the window open. To ensure ventilation, the NBC suggests that the windows in all habitable rooms should open to an exterior area. If the habitable rooms do not abut any exterior open areas, NBC suggests providing interior open spaces such as an inner or outer courtyard and ventilation shafts for the spaces like toilets and bathrooms for proper daylight ingress and ventilation. In both cases, i.e., when the window is opening to an external open space or a courtyard, COVID-19-related requirements for isolation as well as ventilation can be met. The analysis of sample dwelling units has given a third possibility in which the windows are opening to a doubly loaded corridor. Such a design may not necessarily provide both ventilation and isolation.

Building typology and window placement: Placement of windows is important to ensure good ventilation. The purpose of windows is not just to ventilate the dwelling unit but also to ventilate at the height at which the room is occupied. The surfaces

Figure 4: Guidance on ventilation as given in Indian codes and the COVID-19 criterion



Source: CSE compilation

the building has towards an open space provide options for window placement and also help determine the ventilation potential of the building. NBC provides guidance on placement of air inlets and outlets in a building and the placement of windows with respect to the native wind direction. ECBC-R, 2018 provides an illustrated set of guidelines on how to design for natural ventilation and describes extensively how a window in a dwelling unit should be placed.

Site layout in response to wind direction: Orienting the window to respond to the predominant wind direction enhances or diminishes the ventilation effect in a given space. But the arrangement of buildings on a site can affect the wind movement. Therefore, it is necessary to plan the layout in a way that the placement of a building must not hamper ventilation in the adjacent buildings. According to NBC, 2016, inlet opening should not as far as possible be obstructed by adjoining buildings, trees, sign boards or other obstructions or by partitions inside in the path of air flow. The NBC also guides the angles at which the wind may hit the window without losing any beneficial aspect of the breeze. Further, CSE simulated a sample housing project using computational flow dynamics (CFD) and found that there is a strong correlation between outdoor and indoor ventilation. The rate of air changes and the correlation is better when the building is oriented in a direction or a manner that enhances the wind flow.

The combination of how the various indicators and guidelines can be combined to meet COVID-19 criterion are discussed further.

COVID-19 criterion: Isolation rooms

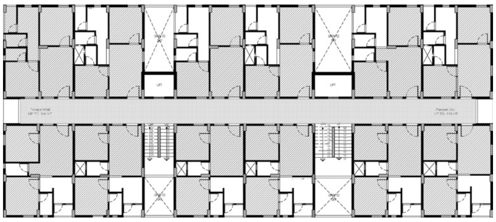
Indicator and guideline investigated: Openable window-to-floor area ratio

The first indicator that has been investigated is the WFRop. An analysis was conducted on the current WFRop compliance of a few affordable housing schemes in the country. The WFRop value of four buildings of different forms were found to be compliant and identical(see *Figure 5: Comparative analysis of different typologies of blocks*).

This analysis has also investigated whether compliance with the WFRop indicator ensures that the requirement of isolation rooms is met. An isolation room should have the air flow direction from clean to the less clean zone such that the contaminated aerosols are exhausted from the space and do not infect other households. The isolation room should have a separate ventilation system and mixing of the air with fans or split units should be done carefully such that it does not contaminate the rest of the air in the house. Looking at this requirement, it becomes important that a potential isolation room has good ventilation and the exhaust air does not end up in another dwelling unit.

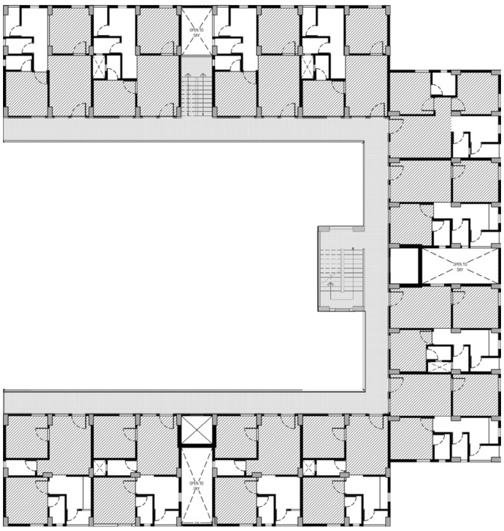
This analysis has brought to light that even if the dwelling unit is WFRop-compliant, it might not ensure that all habitable rooms of the dwelling unit can be used as isolation rooms(see *Figure 6: Assessment of possibility of an isolation room in a WFRop-compliant unit* and *Annexure*). While WFRop does indicate a basic possibility of ventilation, the quality of the ventilation by itself cannot be ensured by compliance with the indicator.

Figure 5: Comparative analysis of different typologies of blocks

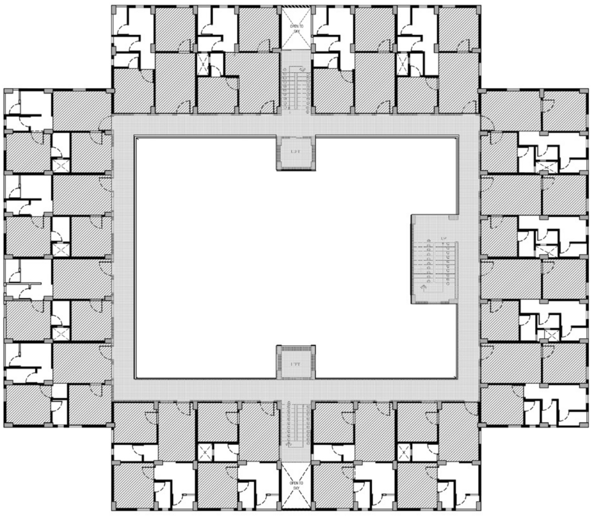


Openable Window to Floor area Ratio: 16%

Openable Window to Floor area Ratio: 17%



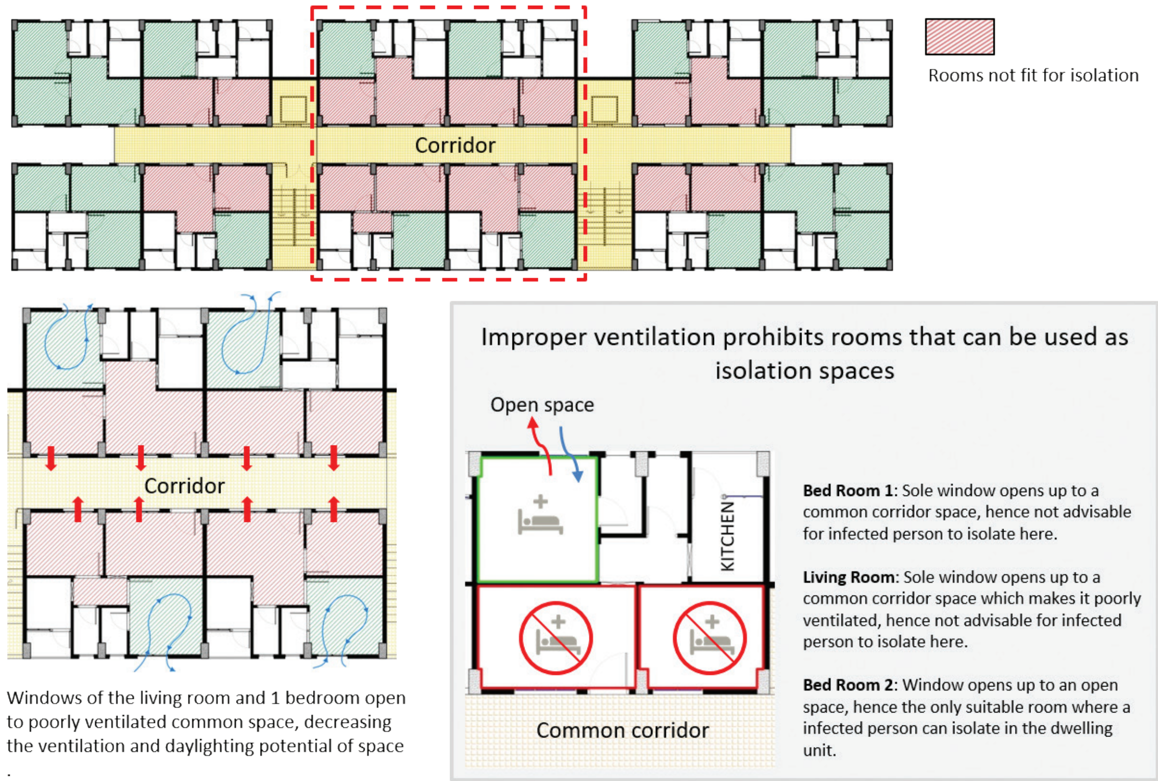
Openable Window to Floor area Ratio: 17%



Openable Window to Floor area Ratio: : 16%

Source: CSE analysis

Figure 6: Assessment of the possibility of an isolation room in a WFRop-compliant unit (window opening towards common poorly-ventilated space)



Source: CSE analysis

Figure 7: Compliance with WFRop does not ensure that all requirements of isolation room get fulfilled

Requirement for isolation rooms

Ventilation Indicator	Possibility of Isolation room	Cross Ventilation	Air change rate
Openable window to Floor area ratio(WFRop)		-	-

Compliance to the WFRop does not ensure the possibility of converting habitable rooms into isolation spaces if need be.

Source: CSE analysis

COVID-19 criterion: Isolation rooms

Indicators and guidelines investigated: Openable window-to-floor area ratio + Habitable rooms opening onto open areas

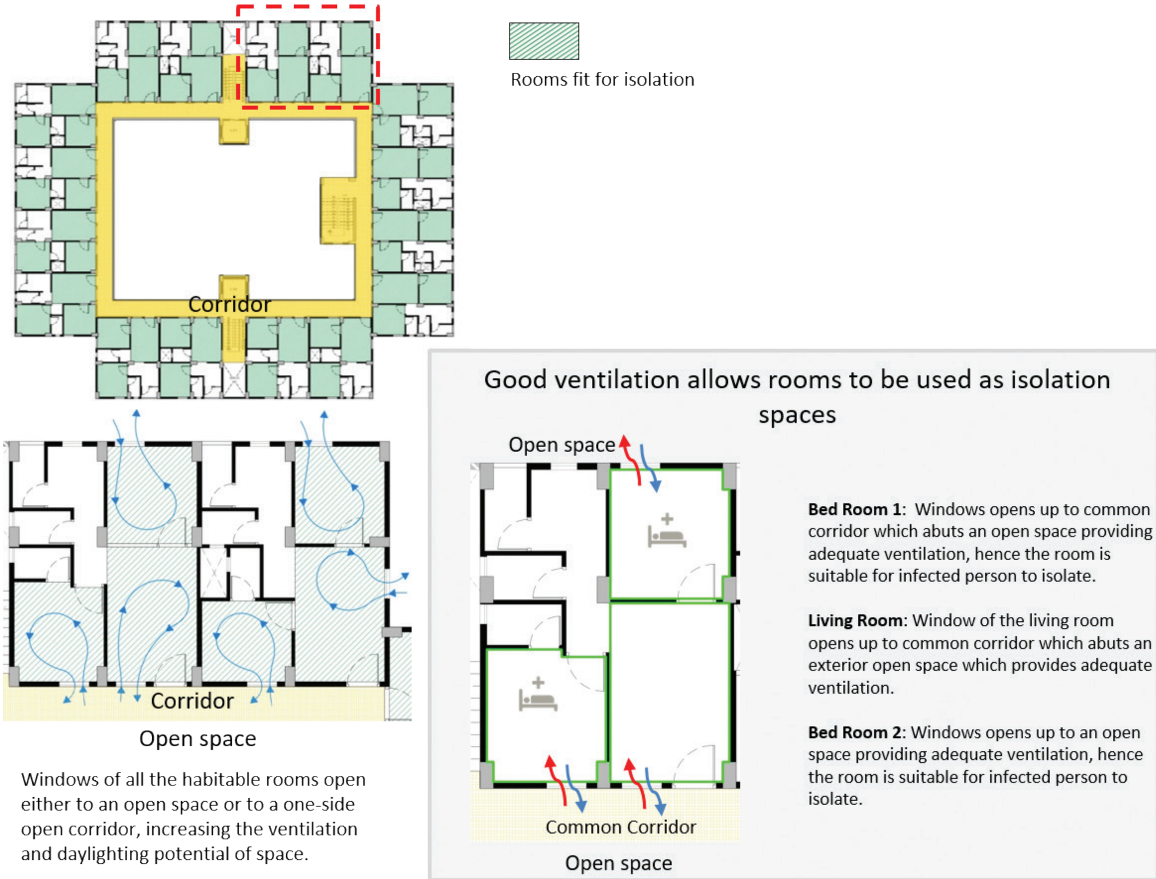
The WFRop indicator was juxtaposed with another recommendation of the NBC, 'the windows in all habitable rooms should open to an exterior area'. An analysis was carried out to check if these two guidelines can ensure meeting the needs of isolation rooms.

All habitable rooms that were WFRop-compliant and opening onto external spaces or towards a one-side-open corridor were found to be fit for use as isolation rooms (see *Figure 8: Assessment of possibility of an isolation room in a WFRop-compliant unit*).

Observations and recommendation for the COVID-19 criterion of isolation spaces:

- Habitable rooms with windows opening only towards common poorly ventilated spaces (such as closed corridors) are unfit to be used as isolation spaces. Being a common space, it would be in the best interest of other users in the building that an infected patient is not quarantined in these rooms (see *Figure 9a: Isolation room and aerosol transmittance behavior*).
- Habitable rooms with windows opening towards open spaces, balconies or single side open corridors maybe used as isolation spaces if need arises. Such rooms provide a basic level of ventilation which may be further enhanced by using correct placement of fans (see *Figure 9b:Isolation room and aerosol transmittance behavior*)
- Exhaust fans in bathrooms, kitchens and toilets should be operated continuously within the isolation area.[22]
- The use of a pedestal fan placed close to an open window could enable ventilation. A fan facing towards the window (i.e., facing outside) serves to pull the room and exhaust air outwards from the room. This may be used such that as soon as the virus is expelled from the source, it is quickly eradicated from the space without distributing or circulating it throughout the room.[23]

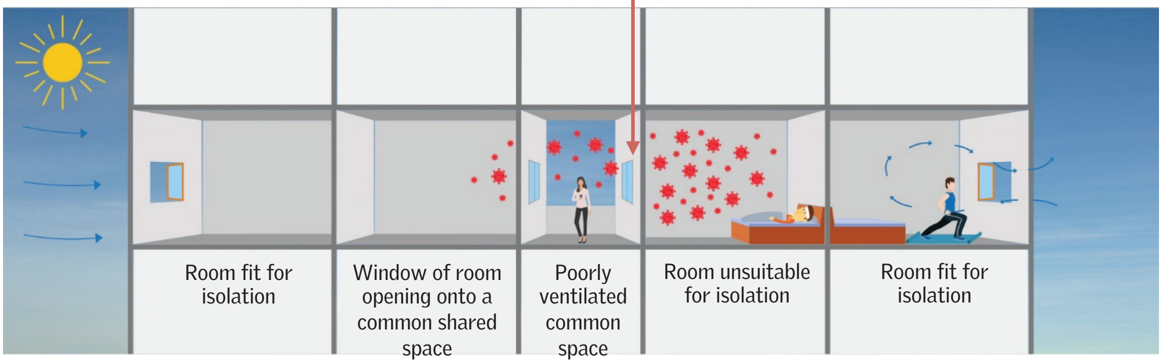
Figure 8: Assessment of possibility of an isolation room in a WFRop-compliant unit (window opening towards well-ventilated space)



Source: CSE compilation

Figure 9a: Isolation room and aerosol transmittance behavior in a dwelling unit with window opening towards common (poorly-ventilated) space

The window opens onto a poorly ventilated common space which has a potential to trap the infection particles for a long duration and the dilution from fresh air will be low.



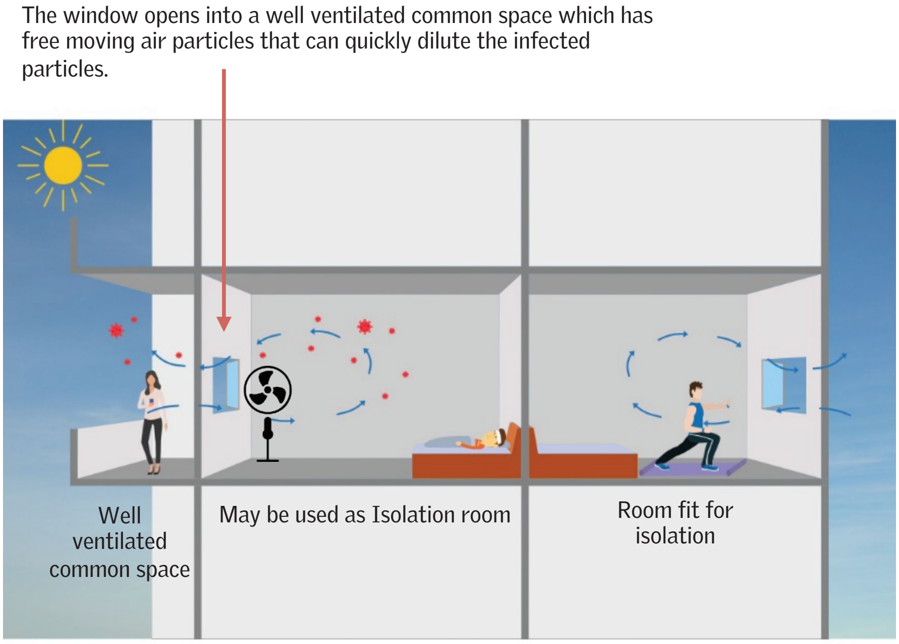
TYPOLOGY
Side 1: Window of a habitable room opening onto a poorly ventilated common space.

Side 2: Window of the dwelling unit opening onto open space.

WHO recommends the use of a pedestal fan as an exhaust, in an isolation room.

In this scenario, the fan will hurl the air with infection particles into the common shared space and further to the other dwelling unit. The room opening onto common space is an unsuitable typology for isolation room.

Figure 9b: Isolation room and aerosol transmittance behavior in a dwelling unit with window opening towards well-ventilated space



Source: CSE analysis

Figure 10: A proper combination of guidelines can ensure all requirements of an isolation room get fulfilled

Requirement for isolation rooms

Ventilation Indicator	Possibility of Isolation room	Cross Ventilation	Air change rate
Openable window to Floor area ratio + Habitable rooms opening onto open space			-
WFRop compliant dwelling unit is combined with the condition that the habitable rooms should abut an open space, the isolation room requirement is met but might not ensure quality of cross ventilation			

Source: CSE analysis

COVID-19 criterion: Cross-ventilation

Indicators and guidelines investigated: Openable window-to-floor area ratio + Habitable rooms opening onto open area + Building design typology

WHO guidelines, released in April 2021, lay emphasis on cross-ventilation in residential and non-residential settings.[24] Cross-ventilation takes place when there are openable fenestrations on both sides of the enclosure, allowing wind to enter from one side and exit from the other side. It is an effective strategy to dilute viruses that might be present in the air by bringing in fresh air from outside to flush out the contaminated air in indoor spaces.

According to NBC, 'Windows located diagonally opposite to each other with the windward window near the upstream corner give better performance than other window arrangements for most of the building orientations.'

CSE has conducted a wind simulation analysis to assess how cross-ventilation takes place in different building typologies (see *Figure 11: Wind simulation analysis*). For this, two typologies were identified:

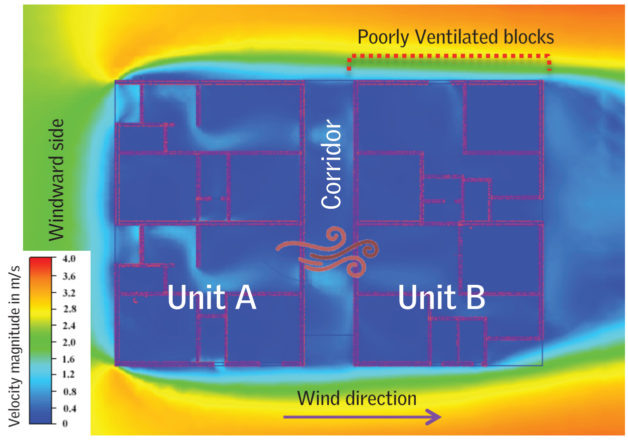
- ➢ Doubly loaded corridor typology: One side of the building has an entrance to open air while the other side has an entrance into a closed corridor facing another dwelling unit.
- ➢ Singly loaded corridor typology: One side of the building has an entrance to open air while the other side opens up onto a one-side-open corridor.

Observations and recommendations for the COVID-19 criterion of cross-ventilation in spaces

- While both the typologies identified for analysis have windows at opposite ends of the dwelling units, the results in the doubly loaded corridor typology are different from the ones in singly loaded corridor typology.

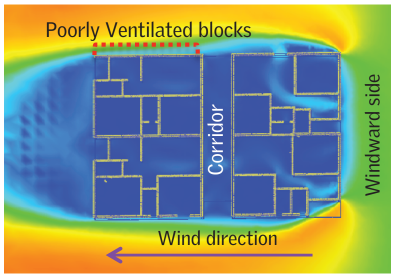
- The singly loaded corridor performed better than doubly loaded corridor in terms of cross-ventilation, the situation was re-simulated by reversing the wind direction and the same observation was repeated (see *Figure 11: Wind simulation analysis*)

Figure 11: Wind simulation analysis



Case 1: Doubly loaded corridor

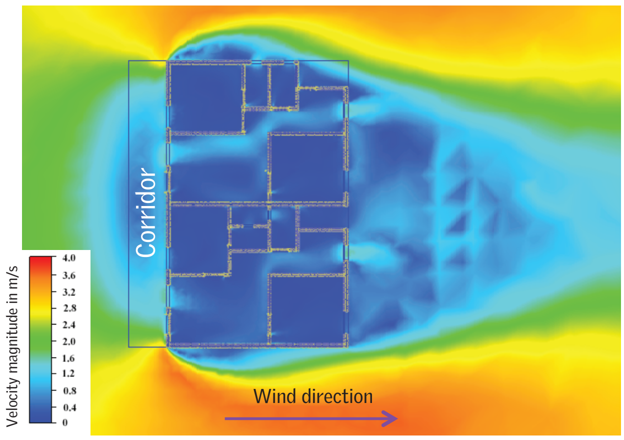
Case 1: Doubly loaded corridor
Poor ventilation in the non-windward side of doubly loaded corridor, this reduces thermal comfort, livability and increases chances of air-contamination which may cause spread of infectious diseases.



Wind direction reversed

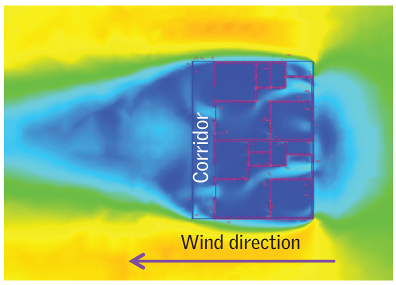
1. The units facing the non-windward side of the building are poorly ventilated.

2. Wind is flowing from Unit A to Unit B, however the wind entering the unit B shall be considered stale since it has already passed through Kitchen and Living room of unit A and a common corridor. This increases the chances of transmission of airborne diseases. Similar observations can be made even if we reverse the wind direction.



Case 2: Singly loaded corridor

Case 2: Singly Loaded Corridor
Good Cross-ventilation in singly loaded corridor units, this improves thermal comfort, livability and reduces chances of air-contamination.



Wind direction reversed

1. Good cross ventilation in units as they are abutting open spaces on both the sides.

2. The stale air from both the units is exhausted into open space which improves the livability and reduces air contamination. Similar observation can be made even if we reverse the wind direction.

Source: CSE analysis

- The units facing the non-windward side of the singly loaded corridor building were poorly ventilated.
- The wind entered unit B after having passed the kitchen and living room of unit A as well as the common corridor. This can be an unwanted situation in the presence of airborne infections as according to WHO guidelines, 'The direction of the air flow should be from the clean to the less clean zone".[25]
- The same situation was detected even when the wind direction was reversed.
- Cross-ventilation is much better in singly loaded corridors as they open onto an open area.
- Exhaust air from units of singly loaded corridor leaves through the open area without entering other dwelling units.

• The air should flow from the clean to the less clean zone, hence a scenario where the wind is entering a dwelling after having passed through another dwelling unit (less clean zone) should be avoided. The occupant should close certain fenestrations if the wind is passing through another adjacent dwelling unit.

Figure 12: A proper combination of multiple guidelines is needed to ensure cross-ventilation

Requirement for cross ventilation

Ventilation Indicator	Possibility of Isolation room	Cross Ventilation	Air change rate
Openable window to Floor area ratio + Habitable rooms opening onto open space + Appropriate design typology			-

An analysis is done where different building typologies are studied and some perform better than the others in providing cross ventilation hence emphasizing the role of building design in itself in enhancing or diminishing cross ventilation potential in a building.

Source: CSE analysis

COVID-19 criterion: Enhanced air change rates

Indicators and guidelines investigated: Openable window-to-floor area ratio + Habitable rooms opening onto open area + Building design typology + Optimized site layout to mitigate obstruction of wind + Orientation according to wind

Air change rate for a COVID-19 scenario

WHO recommends a minimum ventilation rate of 10 litre per second per person or 36 cu. m per hour per person. The Council for Scientific and Industrial Research (CSIR) under the Ministry of Science and Technology (Government of India) has issued guidelines on *Ventilation of Residential and Office for SARS-CoV-2 Virus* by modifying existing NBC, 2016 for the ongoing pandemic. These guidelines recommend air change rates for different rooms in a building and different building uses (see *Table 3: Recommended air change rates as per CSIR in the wake of COVID-19*). These air changes rates have been increased over the previous values to enable better ventilation.[26]

Table 3: Recommended air change rates as per CSIR in the wake of COVID-19

Application	Recommended ACH in SARS-CoV-2 virus scenario	Air changes per hour (ACH) as per NBC, 2016
Living room	4–7	3–6
Bedroom	3–5	2–4
Changing room and bathroom	8–12	6–10
Corridor	6–12	5–10
Entrance hall	4–6	3–5
Garage	8–10	6–8
Kitchen and gymnasium	> 10	> 6
Basement and cellar	4–12	3–10
Laundry	12–36	10–30
Lavatory	8–18	6–15
Toilet	8–12	6–10
Isolation (quarantine) room	> 10	-

Source: Council of Scientific and Industrial Research (CSIR), 2021, CSIR Guidelines for ventilation of Residential and Office Buildings for SARS-CoV-2 Virus

Strong correlation between outdoor wind speed and indoor air changes

An analysis was conducted by CSE for a housing project in Hyderabad to study if the velocity of external wind was related to the air change rates inside the dwelling units. A regression analysis revealed a positive correlation between outdoor wind speed and indoor air changes per hour. The correlation between indoor ventilation and wind speed is very strong for west-facing units as the R^2 value is above 0.83. However, for north-facing units, the correlation is lesser with the R^2 value being 0.73. This is due to the fact that the predominant wind direction in Hyderabad is from the west. This underscores that orientation can play a dominant role in enhancing or diminishing the ventilation potential of a building.

Optimizing site layout principles to avoid obstruction of wind

CSE has further simulated a sample project located in Hyderabad to understand the impact of wind flow on under-construction high-rise buildings. This analysis has been done using IES-VE Macroflo software for outdoor wind flow around the building. Climatic data for predominant wind direction and wind speed are used in the CFD analysis.

The predominant wind directions in Hyderabad are west, east and southeast. The wind rose diagram created using the weather file for Hyderabad is shown in *Figure 13: Wind rose diagram for Hyderabad*. The annual average wind speed in Hyderabad is approximately 2.5 m/s (see *Figure 14: Annual average wind speed in Hyderabad*).

Observation and recommendations for the COVID-19 criterion of air change rates

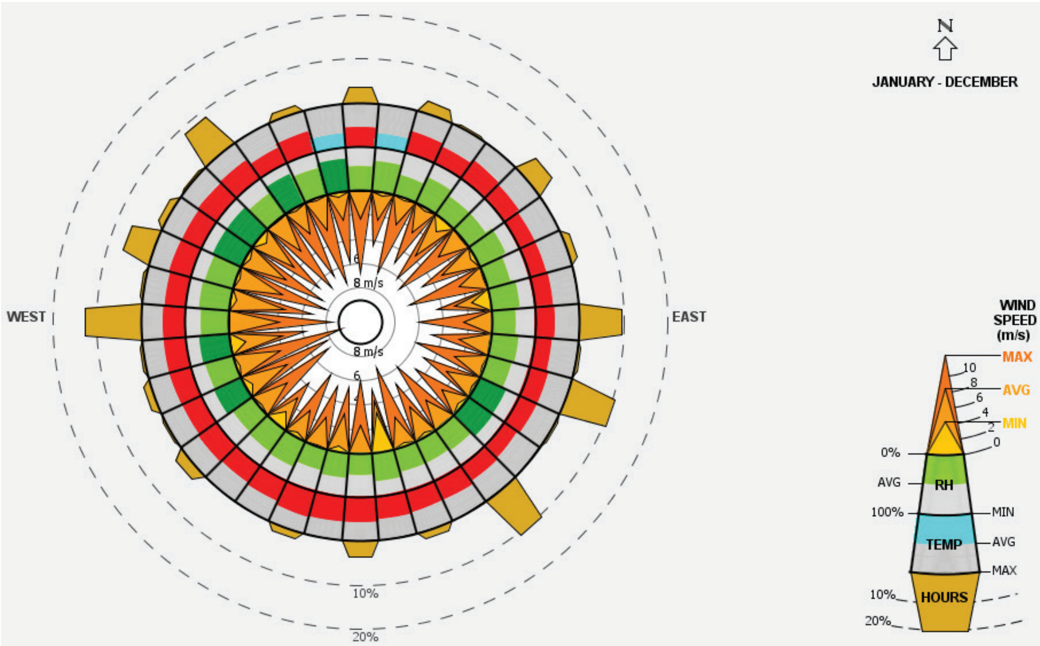
Unsuitable wind flow due to 'tunnel effect'

The impact of clustering of blocks on the site is shown in *Figure 15: Impact of clustering on wind flow across the site*. When the wind is flowing from the west and perpendicular to the buildings, several cases of venturi effect or tunnel effect were observed on the site. In these cases, the wind velocity was higher but only on the outside, without much of it getting into the buildings.

Stagger buildings to negate tunnel effect

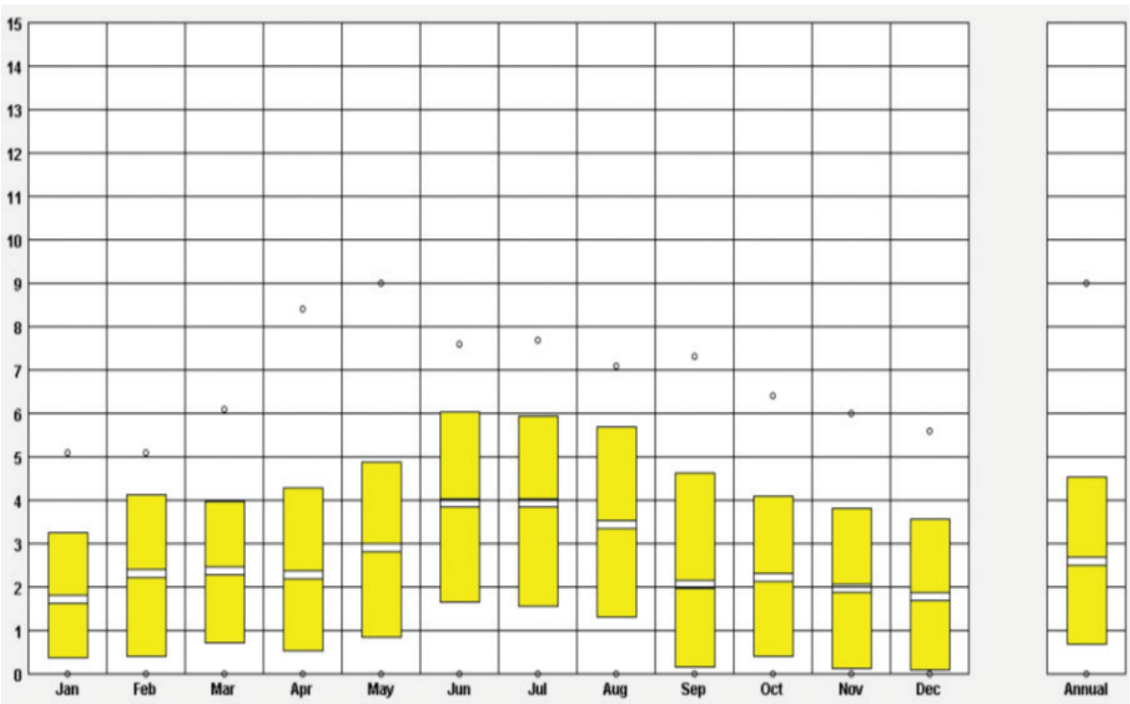
The unsuitable tunnel effect is mitigated in buildings constructed in a staggered manner (see *Figure 16: Wind behaviour due to staggering of buildings*). Due to staggering, the wind shadows (low or least velocity zones) do not fall on adjacent buildings, instead they occupy the void between buildings.

Figure 13: Wind rose diagram for Hyderabad



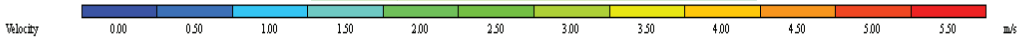
Source: Hyderabad weather file

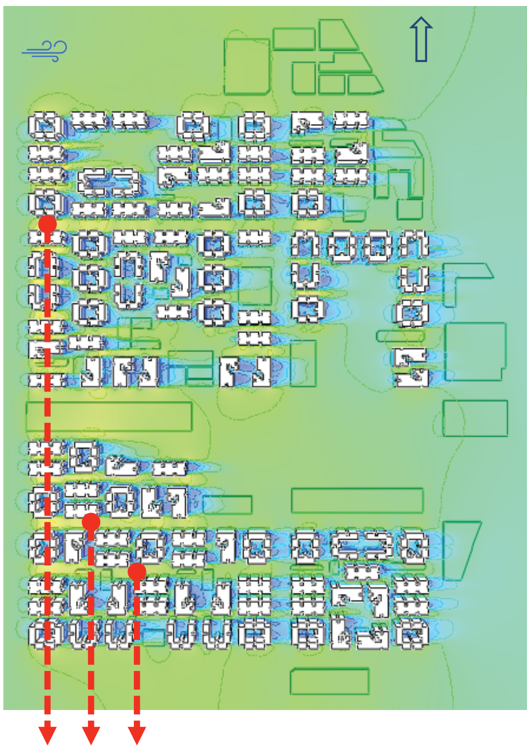
Figure 14: Annual average wind speed in Hyderabad



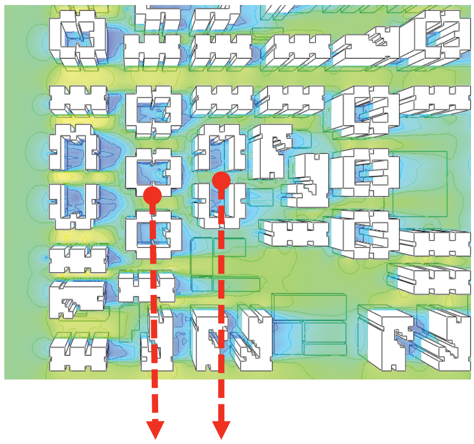
Source: Hyderabad weather file

Figure 15: Impact of clustering on wind flow across the site





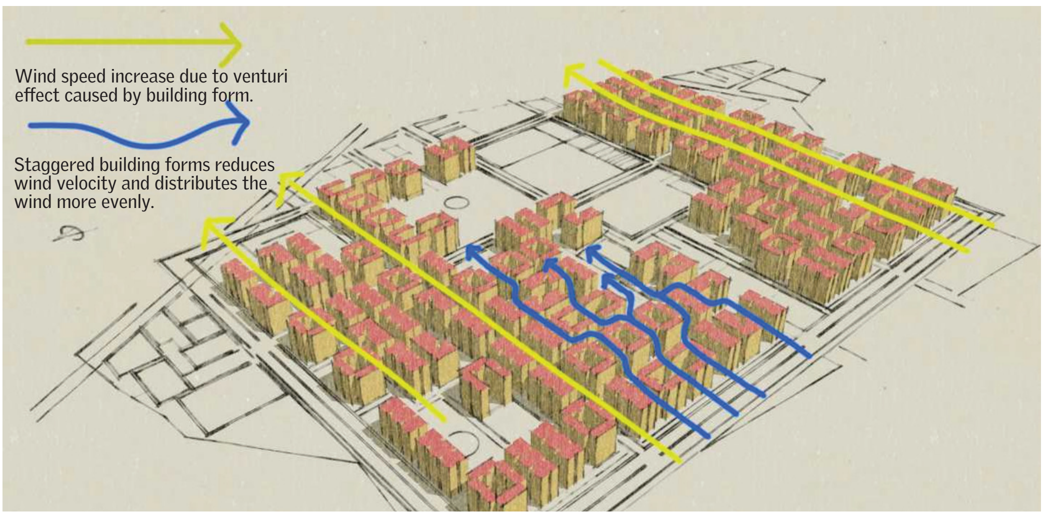
Venturi effect takes place in between buildings, increasing wind velocity. The wind flows like it would in a tunnel without getting inside the buildings.



Venturi effect is mitigated between the towers when the buildings are placed in staggered pattern.

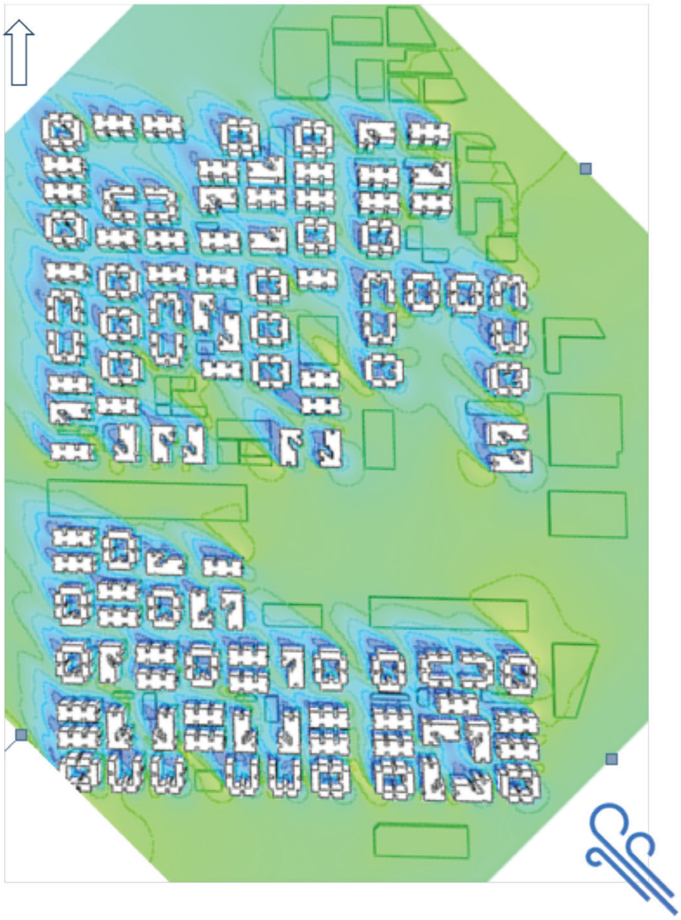
Source: CSE analysis

Figure 16: Wind behaviour due to staggering of buildings



Source: CSE analysis

Figure 17: Wind flow from the southeast direction



Source: CSE analysis

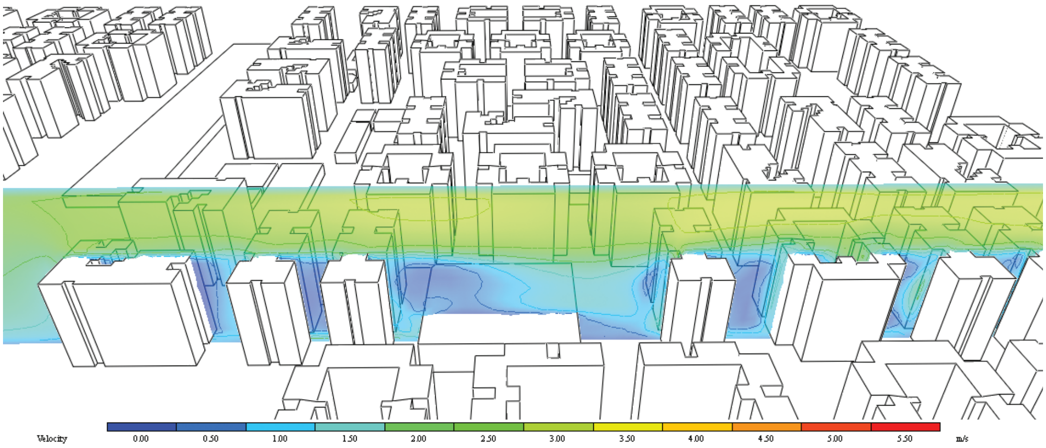
Orienting buildings diagonally to prevalent wind also negates the venturi effect

CFD analysis for wind flow at the intermediate floor (fifth floor) and from southeast direction reveals that the amount of wind shadow area, i.e., the area with very low wind velocity (less than 0.5 m/s), is significantly less than when the wind hits perpendicular to the building (see *Figure 17: Wind flow from the southeast direction*). The spread of wind across the site is better than when the wind flows from the west. This streamlining of wind flow minimizes the tunnel effect as well.

Wind flow improves with adequate spacing between buildings

As the space between buildings increases, the wind velocity also increases for the next buildings in the windward direction as shown in *Figure 18: Wind flow due to spacing between buildings*.

Figure 18: Wind flow due to spacing between buildings

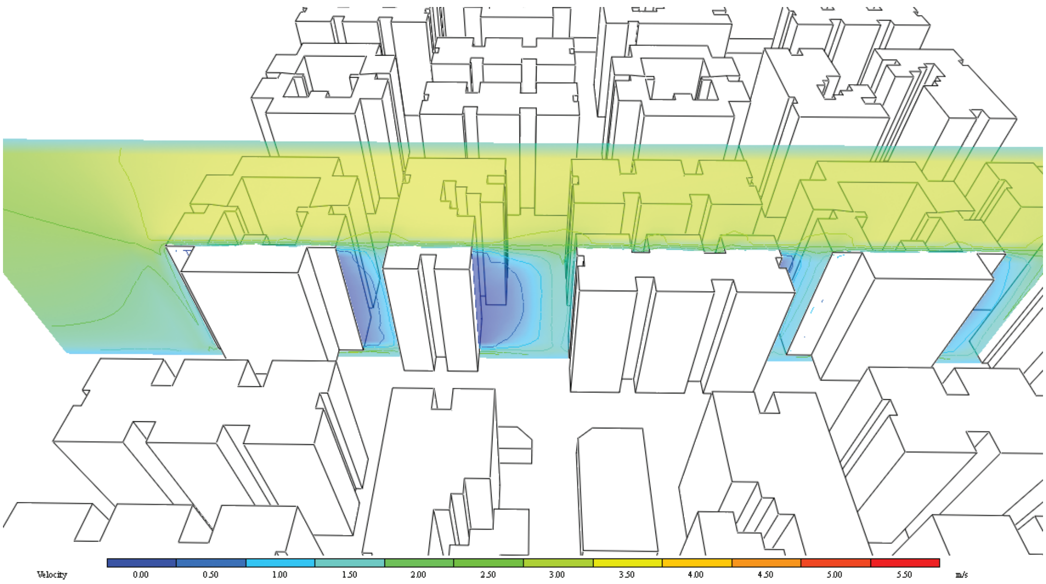


Source: CSE analysis

Wind flow is better in mid-rise developments

A case with mid-rise development (G+6) of the same site plan of the sample project was simulated for wind flow. A significant decrease in wind shadow areas was observed as compared to high-rise development (see *Figure 19: Impact of height on wind flow between buildings*).

Figure 19: Impact of height on wind flow between buildings

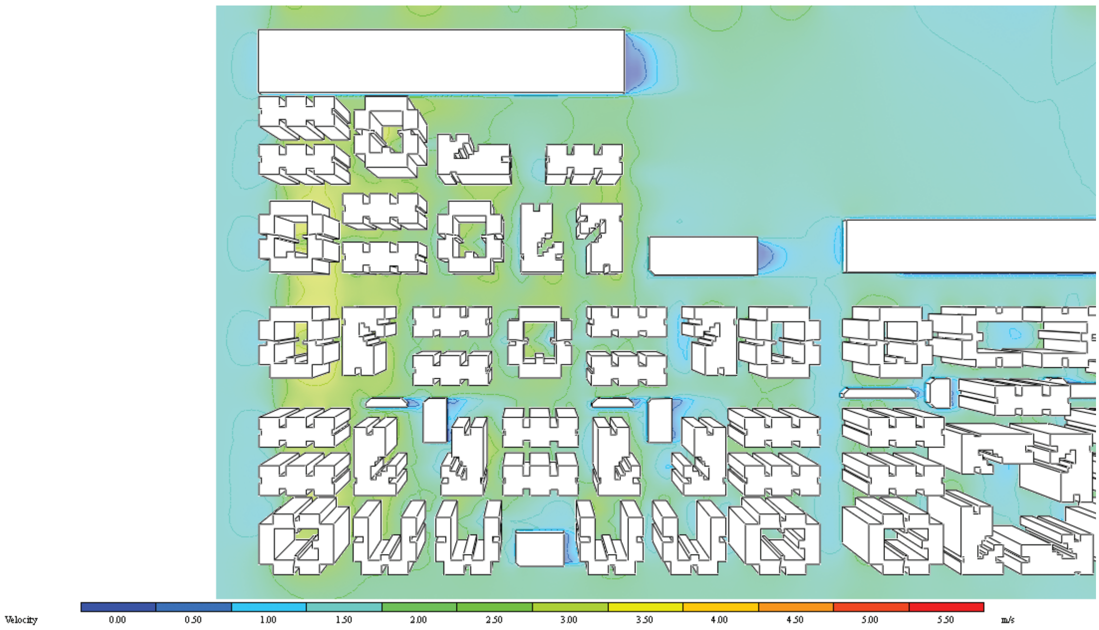


Source: CSE analysis

Stilts increase wind flow at the ground level

CFD analysis at the ground level to see the impact of stilts on wind flow reveals that the wind velocity increases due to stilts and can be attributed to the tunnel effect at the ground level alone. This shows that stilted floors can contribute in dissipation of heat absorbed by paved surfaces and improve pedestrian thermal comfort. Wind shadows were found to be the least in this case (see *Figure 20: Effect of stilts on wind flow at the ground level*).

Figure 20: Effect of stilts on wind flow at the ground level



Source: CSE analysis

Air movement is affected by the form, height, in-between distances, clustering and placement of the blocks on the site. Blocks must be staggered or oriented with respect to the streets in a way that the favourable wind direction hits the buildings diagonally rather than in a perpendicular fashion (see *Figure 21: Wind behaviour due to staggering of buildings*). This reduces wind shadow areas and tunnel effect. According to the NBC, 2016, 'A building need not necessarily be oriented perpendicular to the prevailing outdoor wind; it may be oriented at any convenient angle between 0° and 30° without losing any beneficial aspect of the breeze.' Moreover, the wind direction may also be affected with placement and distances amongst other buildings in the vicinity, therefore, studying the predominant wind direction and the effect of other buildings on the site in detail and determining the appropriate typology of blocks, along with their clustering and layout, is an exercise that should be taken up during the planning stage.

Generally, in mass housing, if the impact of wind flow is not understood and addressed at the planning and design stages, reparative measures will need to be taken up at the cost of the beneficiary. With several incentives for affordable housing construction under government schemes such as extra floor area ratio and floor space index, the typology for affordable housing is shifting towards high rise development in major cities. Ventilation strategies need to be sought in such cases to negate the adversities of high-rise development on micro-climate. Analysis such as CFD simulation helps in understanding the impact of wind and its crucial role in thermal comfort, energy efficiency, and health and safety.

Figure 21: A proper combination of multiple guidelines is needed to enhance air change rates

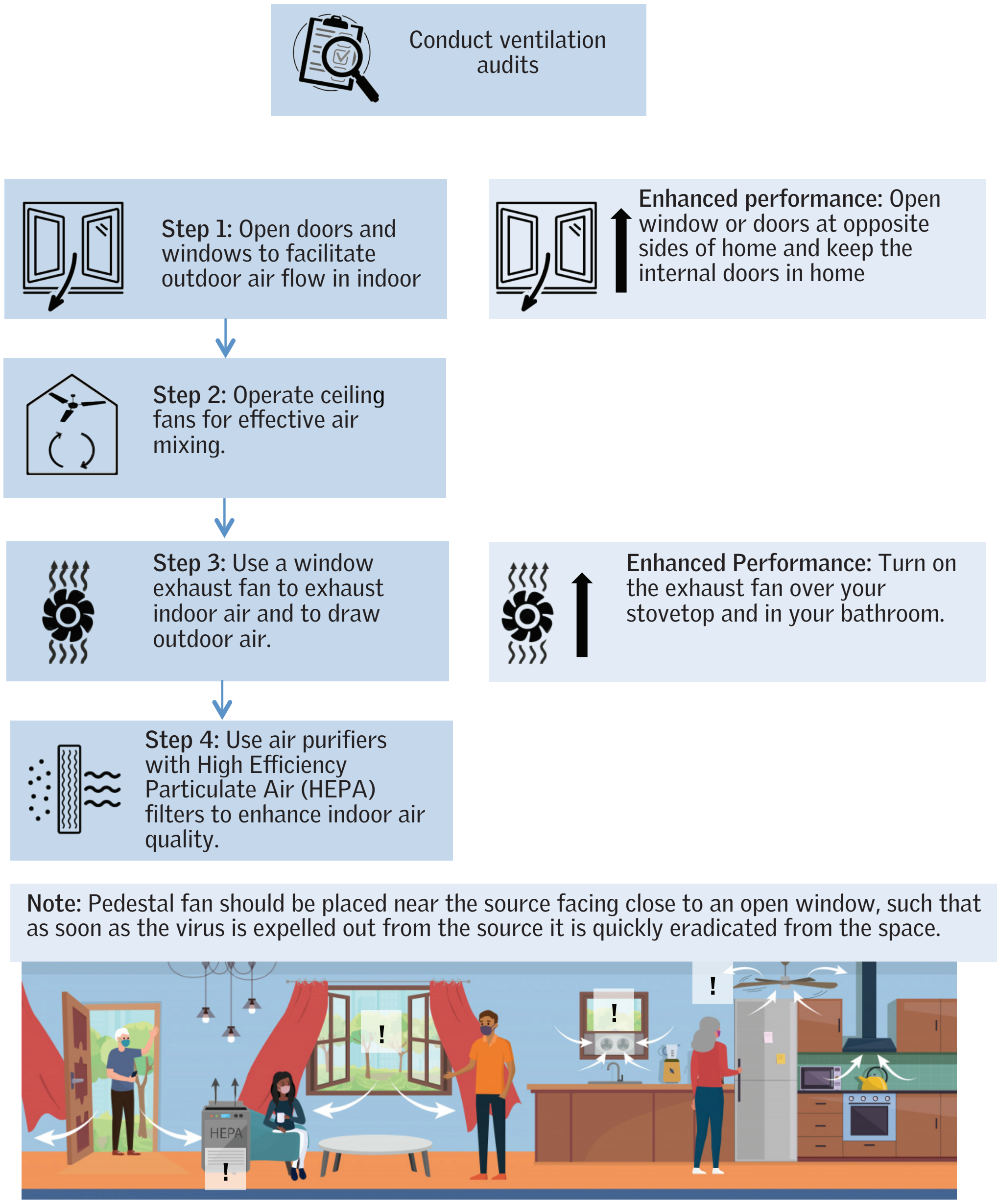
Requirement for enhanced air change rates

Ventilation Indicator	Possibility of Isolation room	Cross Ventilation	Air change rate
Openable window to Floor area ratio + Habitable rooms opening into open space + Appropriate design typology + Orientation as per wind direction + Optimized site layout to mitigate wind obstruction			

Predominant wind, building heights, site conditions, site planning and obstructions all play a part in how wind behaves on a site. Wind might speed up, slow down or change its course due to these conditions which was revealed by CFD analysis. All factors are needed to ensure desirable ventilation in buildings.

Source: CSE

Figure 22: Guidelines for improving natural ventilation in buildings



Source: Centre for Disease Control and Prevention (CDC), Jan 2021, Improving ventilation in your home

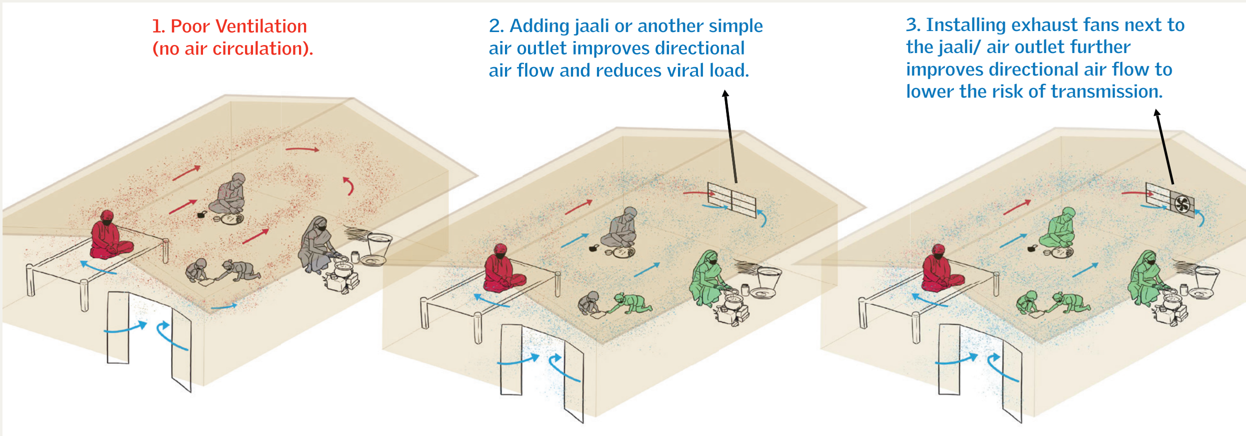
Source: CSE analysis

COMPOSITE GUIDELINES FROM SEVERAL AGENCIES

In India, several guidelines have been laid down by different agencies during the pandemic. These include CSIR's Guidelines for Ventilation of Residential and Office Buildings for SARS-CoV-2 Virus (2021), one from Principal Scientific Adviser to the Government of India in May 2021, and the PSA Advisory to Prevent Transmission of SARS-CoV-2 Virus.

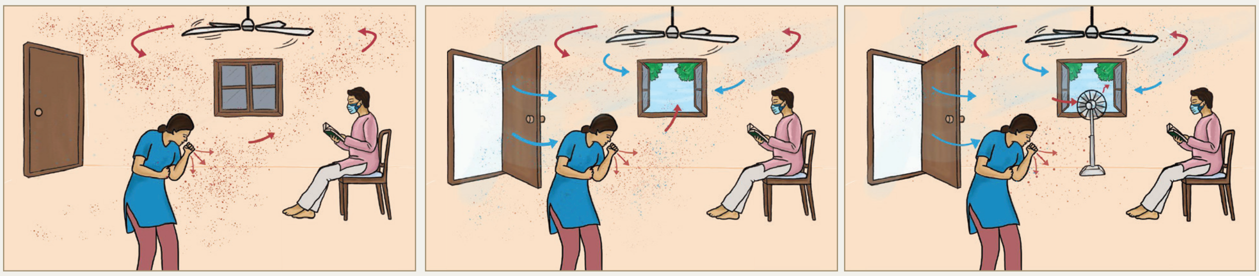
- Open doors and windows for facilitating outdoor air flow into indoor spaces. Do not open windows and doors if doing so poses health risk to occupants (e.g., risk of falling or triggering asthma symptoms).[27]
- Ventilation can be increased through cross-ventilation by opening window or doors at the opposite sides inside homes and keeping internal doors open.[28]
- Operate ceiling fans for effective air mixing and dilution of aerosols.
- Use a window exhaust fan, placed safely and securely in a window, to exhaust room air to the outdoors. This will help draw outdoor air into the room via other open windows and doors without generating strong room air currents.[29]
- Keep the exhaust fan turned on over your stove-top and in your bathroom if you have visitors in your home.[30]
- Use standalone air purifiers with HEPA filters for enhancing indoor air quality.[31]
- Avoid placing fans in a way that could potentially cause contaminated air to flow directly from one person to another.[32] Pedestal fan should be placed near the source facing close to an open window opening towards outdoor air, such that as soon as the virus is expelled out from the source it is quickly removed from the space without circulating it throughout the room.[33]

Figure 23: Increasing cross-ventilation in a room



Source: Principal Scientific Adviser to the Government of India, May 2021, PSA Advisory to Prevent Transmission of SARS-CoV-2 Virus

Figure 24: Schematic representation of poor (left), good (centre) and ideal (right) natural ventilation



Source: Principal Scientific Adviser to the Government of India, May 2021, PSA Advisory to Prevent Transmission of SARS-CoV-2 Virus

Optimization of mechanical ventilation in non-residential buildings

As non-residential typologies are dominated by mechanical ventilation, CSE has reviewed the latest guidelines on mechanical ventilation such as those by EPA, CDC, ISHRAE and Office of the Principle Scientific Advisor to the Government of India. This review has helped to draw operational nuances for these typologies, described in this section. Operational nuances in buildings, comprising of do's and don'ts, are the immediate strategies to respond to the risks from COVID-19 pandemic.

How does the latest evidence on COVID-19 transmission affect air conditioned spaces?

Recent case studies on COVID-19 outbreaks offer insights into recirculated air in confined spaces with air conditioning playing a part in the transmission of the virus.

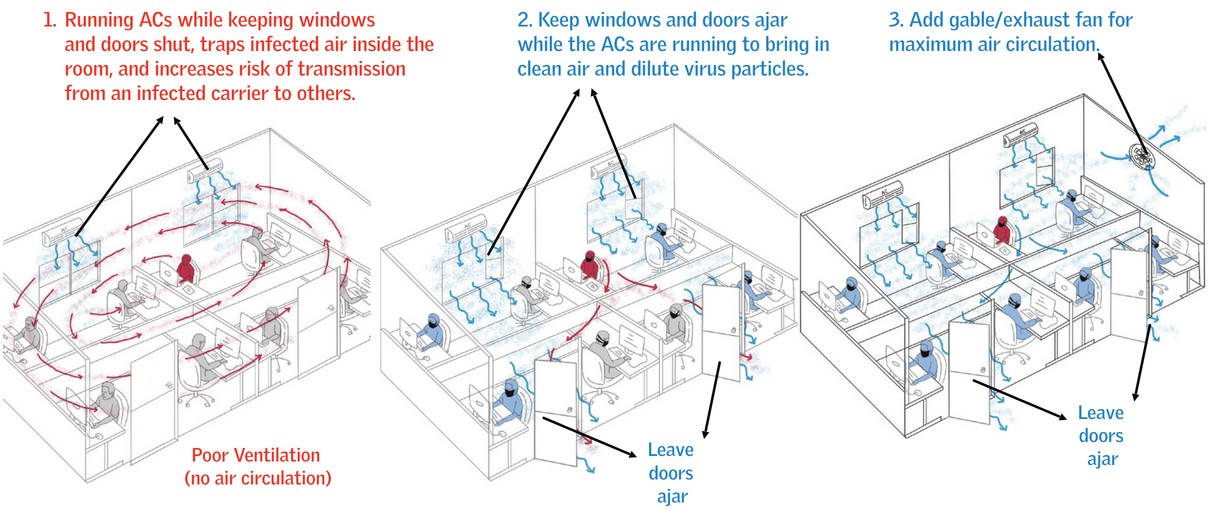
Globally, three case studies on such assessment are available from an office building in Seoul, South Korea, a restaurant in Guangzhou, China and a bus in Zhejiang, China.[34] A research paper on the case of the restaurant in Guangzhou concluded that 'droplet transmission was prompted by air conditioned ventilation'.[35] These studies make it imperative to understand air conditioning procedures in a building.

Air conditioning primarily works on recirculation of air—once the air has been cooled down, it is more efficient to recirculate the same air molecules while re-cooling them. However, as COVID-19 particles are airborne, the virus can build up in these indoor spaces. As per the guidelines issued by the Office of the Principle Scientific Advisor to the Government of India, 'Operating air conditioning systems with closed doors and windows keeps on recirculating the air without removing it from the room, this increases the risk of infection among the occupants.'[36]

There are several ways to address the issue of ventilation in air conditioned spaces but all of them come with associated problems.

- **Introducing fresh air:** As one increases the rate of inflow of fresh air into a building, air conditioning has to work more to cool the external air, this would increase the energy consumption of the system. Moreover, some HVAC systems

Figure 25: Advisory for air conditioned work spaces



Source: Principal Scientific Adviser to the Government of India, May 2021, PSA Advisory to Prevent Transmission of SARS-CoV-2 Virus

such as split units are not designed to take in fresh air. In such a scenario, the fenestrations of the building will have to be left open, increasing the leakages and making air conditioning more energy-inefficient and expensive.

- **Using high grade filters in air conditioning systems:** This option needs retrofitting of existing systems with high grade filters, which might not be possible in every system and in the systems where it is possible, the capital expenditure might be high.

There are multiple challenges associated with mechanically ventilated buildings, however, many building typologies in the country are dependent on mechanical ventilation.

Figure 26: Modes of ventilation in non-residential buildings

Building Classification	Modes of Ventilation				
Hospitality	Central air conditioning	Stand alone systems	Mixed mode	Natural ventilation	Co-exist
Healthcare	Central air conditioning	Stand alone systems		Natural ventilation	Co-exist
Educational	Central air conditioning	Stand alone systems		Natural ventilation	
Shopping Complex	Central air conditioning			Natural ventilation	Co-exist
Business	Central air conditioning	Stand alone systems		Natural ventilation	Co-exist
Assembly Building	Central air conditioning			Natural ventilation	
Mixed Use Building		Stand alone systems		Natural ventilation	

Source: CSE compilation

PENETRATION OF MECHANICAL VENTILATION IN EDUCATIONAL CAMPUSES

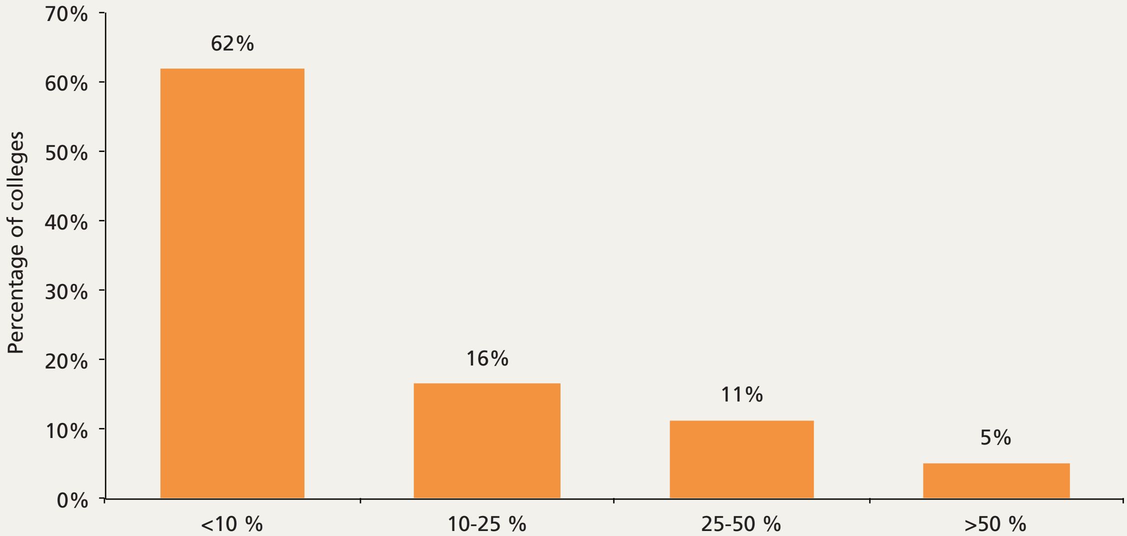
During the pandemic, educational institutions have emerged as one of the most vulnerable building typology. CSE has assessed data from around 100 colleges in the country that indicate that penetration of air conditioning is substantial.

There is a clear trend in favour of usage of mechanical ventilation in educational buildings. Among the campuses under review, about 62 per cent have air conditioning in less than 10 per cent of their building space; 16 per cent have air conditioning in 10–25 per cent of their building space; 11 per cent have air conditioning in 25 per cent of their building space; and only 5 per cent have air conditioning in more than 50 per cent of their building space (see Graph 1: *Percentage of air conditioned building spaces on campus*).[37]

More data is required to ascertain the composition and installed capacities of mechanical ventilation systems being used in all typologies of buildings as well.

However, this points to the fact that all educational buildings will have to pay attention to ventilation strategies and retrofit for operations when they reopen during the pandemic.

Graph 1: Percentage of air conditioned building spaces on campus



Source: CSE analysis

Guidelines for operation of centralized and standalone air conditioning systems

This assessment has underscored the need for ventilation audits in non-residential buildings considering the diversity of typologies. Such audits are the first step in guiding appropriate ventilation in different building typologies (see *Figure 27:*

Guidelines for operation of centralized air conditioning and *Figure 28: Guidelines for operation of standalone air conditioning system*). This section covers guidelines for centralized and standalone air conditioning systems.

Figure 27: Guidelines for operation of centralized air conditioning

Conduct ventilation audits.

Step 1: Start the system 2 hours prior to occupancy period on Economizer

Step 2: Disable demand control ventilation

Step 3: Open outdoor air dampers to reduce air re-circulation.

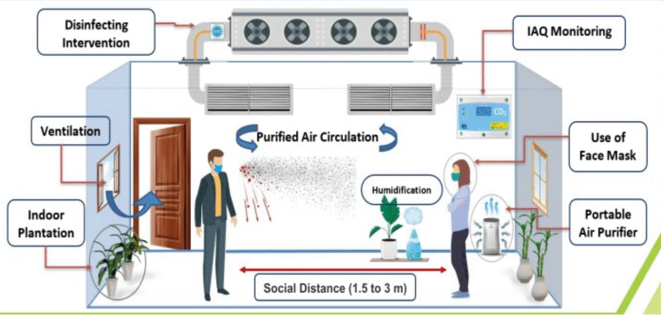
Enhanced Performance: Keep doors and windows ajar while operating the system

Step 4: Use high quality filters such as Minimum Efficiency Reporting Value

Enhanced Performance: Use Ultraviolet Germicidal Irradiation (UVGI).

Step 5: Turn off the system 2 hours after the occupancy period is over.

Note: Inspect and maintain the system by consulting HVAC Professionals.



Source: Council of Scientific and Industrial Research (CSIR), 2021, CSIR Guidelines for ventilation of Residential and Office Buildings for SARS-CoV-2 Virus

Figure 28: Guidelines for operation of standalone air conditioning system

Conduct ventilation audits.

Step 1: Run window AC with outdoor intake air vent open.

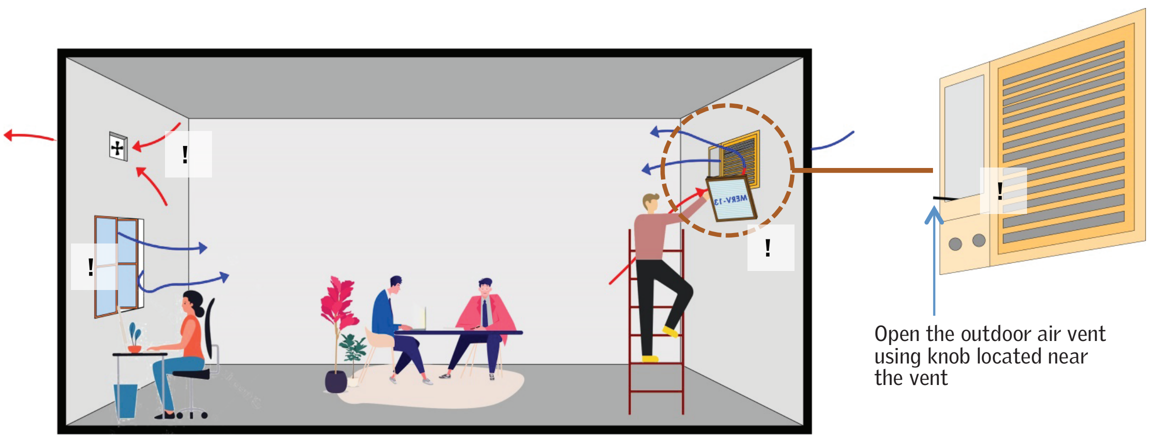
Step 2: Keep doors and windows ajar while operating the system

Step 3: Turn on Exhaust fan to promote air circulation

Step 4: Clean the air filters regularly.

Enhanced Performance: Use high quality filters such as Minimum Efficiency Reporting Value 13 (MERV-13).

Note: Regularly clean and maintain the system.

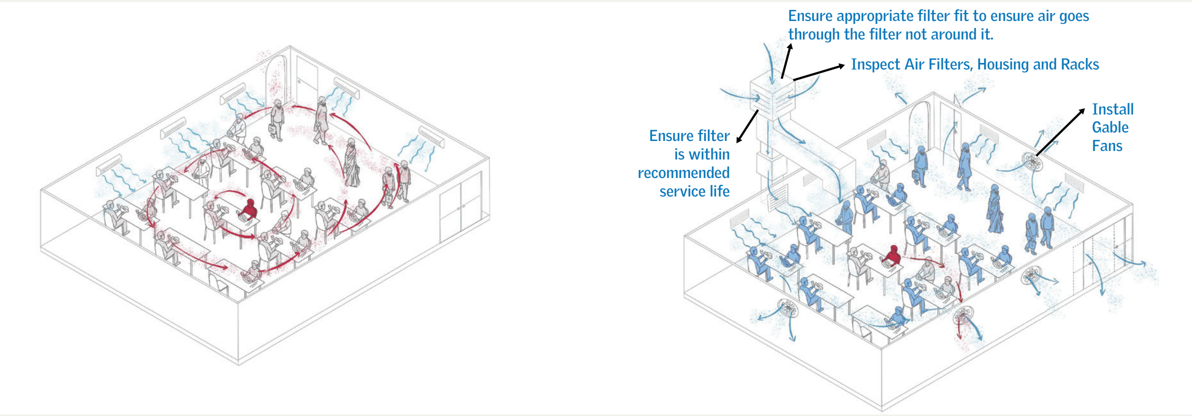


Source: CSE compilation

HIGHLIGHTS OF SOME GUIDELINES ON VENTILATION IN AIR CONDITIONED BUILDINGS SET AT SEVERAL AGENCIES

- Ventilate indoor environments with outdoor air as much as possible. This can be done effectively by mechanical ventilation and air conditioning systems that allow improvement in the quality of air with outdoor air filtration.[38] This can be done by operating the economizer mode of HVAC system at 100 per cent capacity.[39]
- Allowing outdoor fresh air in the room by keeping doors and windows slightly open while operating air conditioning systems to reduce the risk of transmission of virus, this can be reduced further by installing a gable exhaust fan that creates a directional air flow. Higher directional airflow removes contaminates away from people, curtailing the transmission of the virus.[40]
- Any operating Heating Ventilation and Air Conditioning (HVAC) system should be kept on for two hours before and after the occupancy period.[41]
- Disable the "auto" mode of Demand Control Ventilation (DCV) that works automatically, adjusting as per the occupancy percentage, instead it is recommended that air conditioning be kept "on" throughout the occupancy time while operating on its ultimate capacity to increase the air flow rate irrespective of the occupancy number.[42]
- Generate clean-to-less-clean air movement by evaluating and repositioning system parts like exhaust air grills, dampers and supply louvers.[43]
- Open outdoor air dampers beyond minimum settings to reduce or eliminate HVAC air recirculation.[44] If the system does not have provision for fresh air, it is advisable to introduce a fresh air duct attached to the central inline fan filter unit and distribute fresh air by grill.[45]
- Install High-efficiency Particulate Air (HEPA) filters on air return duct in consultation with HVAC professional as per system capacity to enhance air cleaning,[46] especially in areas that are at high risk.
- When directional flow of air through the air conditioning system is required, it should have high quality filters such as MERV14 / ISO ePM1 70–80 per cent or the best the system can accommodate.[47]
- Using Ultraviolet Germicidal Irradiation (UVGI) is an additional measure to disable SARS-CoV-2, when the options for increasing filtration and ventilation rate are limited.[48]
- Indoor air should be filtered before discharging it into the outdoor environment and at least 4m of fencing around the outdoor air exhaust should be provided with prohibition on human or animal activities.[49]
- A well-maintained and operated system can reduce the spread of COVID-19 in indoor spaces by increasing the rate of air change, reducing air recirculation and increasing the amount of outdoor air coming in.[50]

Figure 29: Ventilation; centralized air management system, installing filters and exhaust fans



Source: Principal Scientific Adviser to the Government of India, May 2021, PSA Advisory to Prevent Transmission of SARS-CoV-2 Virus

HIGHLIGHTS OF GUIDELINES BY OTHER AGENCIES

Operating air conditioning systems with closed doors and windows keep recirculating air without removing it from the room, thus increasing the risk of infection among the occupants. Allowing outdoor fresh air into the room by keeping the doors and windows slightly open while operating air conditioning devices reduces the risk of transmission of virus.[51]

- Operate a window air conditioner that has an outdoor air intake or vent, with the vent open.[52]
- The use of split system units for cooling and heating increases the air mixing within the room or space. Air mixing should be done keeping in consideration the isolation room and rest of the house separately.
- Create negative pressure relative to the corridor (outside the room) by increasing general or toilet exhaust airflow.[53] Install gable fans that create a directional air flow, higher directional airflow removes contaminates away from people curtailing the transmission of the virus.[54]
- In collaboration with a HVAC professional, if the device is equipped with filters, consider replacing existing air filters with MERV 14 / ISO ePM1 70-80 per cent (grades of filter) filter or the highest compatible with the filter rack.
- Air conditioning split systems should be periodically cleaned and maintained. Filters should also be regularly cleaned or changed.
- Try to ensure that non-ducted recirculating units do not replace ventilation under any circumstances.[55]

The way forward

The COVID-19 pandemic has finally forced policy and public attention on the primacy of ventilation strategies in buildings to reduce health risks. The same requirements that were earlier included in building guidelines and standards for improving overall thermal comfort are not adequate and have often been neglected in building design and operations, especially in mechanically cooled buildings and affordable housing.

Yet, the emerging science on SARS-CoV-2 behaviour, especially its ability to stay airborne for considerable lengths of time indoor and within the breathable area, has made both health and regulatory agencies redefine the guidelines on ventilation and air change in built spaces to reduce the risk from viral load inside buildings.

As this review shows, global bodies and Indian regulatory agencies have issued modified guidelines for addressing operations of buildings for proper ventilation. Strong public understanding of the strategies to change current practices is needed. These have largely focussed on improving internal ventilation, adequate air flow towards the opening, cross-ventilation, and ensuring opening the windows while using air conditioning. This may cause an energy penalty. But this also underscores the importance of improving thermal comfort inside buildings to reduce air conditioned hours.

CSE's assessment has simulated existing building designs to apply some of the key criteria related to ventilation in existing regulations and standards to them, while considering the requirements that are relevant from the perspective of reducing risk from COVID-19. The criteria have been applied to the current building stock in residential and non-residential sectors, including affordable housing under PMAY. Various parameters were considered under the assessment—openable window-to-floor area ratio,placement of windows, orientation in response to wind direction, avoiding obstruction by other elements, habitable rooms opening to open spaces, and air exchange rates in rooms. These parameters have been particularly assessed from the perspective of spaces to be used for isolation and quarantine. The assessment has borne out the inadequacy of the ventilation strategy.

Thus, addressing the risk due to indoor build-up of the virus load requires strong guidance, public advisories and mandatory building audits to ensure that buildings are being modified and retrofitted to improve ventilation during operation. All commercial and office buildings need to adopt the requisite protocol for building operations for naturally ventilated areas as well as air conditioned areas to enforce implementation. They also need to retrofit poorly ventilated spaces based on building audits.

For new building stock, especially in the affordable housing sector, and keeping in view that India is yet to develop the majority of its building infrastructure to meet the needs of its population by 2030, there is a great opportunity for disease-proofing upcoming building stock. WHO guidelines for healthy housing recommend about 129 sqft per capita of habitable space. This requirement easily gets pushed up a notch now as the need for home quarantining and isolation amidst the COVID-19 circumstances is going to increase.

Current affordable housing schemes provide around 80 sq ft of habitable space per capita. To enable healthy habitable spaces and indoor environment for all in the wake of the ongoing COVID-19 pandemic, it is crucial to leapfrog to design strategies that incorporate ventilation mechanisms. Since our cities are already facing a space crunch, decongesting or planning new building stock by providing additional space may be hugely constrained. Manoeuvring of built space through effective operations and playing with design strategically to disease-proof buildings are measures that need to be adopted on a priority basis.

This assessment has revealed that COVID-19 response in buildings needs to have clearer focus in the following respects:

Evaluate housing templates and adopt operational do's and don'ts in the existing housing stock: The current guidelines and their applications are inadequate to address ventilation requirements to reduce infection risk. This assessment has provided evidence on the kind of rooms that can be used for isolation for home quarantining. Such rooms need windows opening onto external open spaces; rooms with windows or doors opening to exchange spaces such as corridors are not suitable for quarantining. Some of the existing typologies do not qualify. Similar assessments of state housing templates can bear out specific guidelines focusing on operational do's and don'ts in residential buildings based on what can be done immediately in the houses to contain the spread of SARS-CoV-2. To enable this, more and more housing typologies need to be studied for their effects on health. State governments have always worked with fixed templates for affordable housing. These templates need to be assessed and compared with the latest COVID-19-related guidelines—both national and international—to draw on how these templates perform on the spread of infection risk.

Mainstream design strategies for natural ventilation in future building stock and improve thermal comfort for healthy living while reducing air conditioned hours: Ventilation strategies need to improve not only to reduce infection risk but also to improve thermal comfort in buildings. This assessment has gathered evidence through simulations of existing building design and building form, clustering, height of the buildings and overall layout that either enable or constrict ventilation in buildings. Future housing designs should maximize access to open spaces through positioning, size and openability of windows. Similarly, more assessments are needed to build a knowledge bank consisting of different typologies of buildings and how they behave in certain climatic conditions and identify remedies to regulate the flow of air inside and around the buildings. This is needed for disease-proofing the future building stock. Nearly 80 per cent of the buildings in India are naturally ventilated or mixed-mode. This scenario is unlikely to change substantially in the near future. Thus, there is a strong case for the government to promote mixed-mode buildings with more naturally ventilated spaces, especially in affordable housing, while also setting codes to incorporate ventilation strategies in new constructions and retrofits.

Rooms with windows opening onto external open spaces are crucial for isolation rooms and quarantine areas: The assessment has revealed that a COVID-19 patient must not be isolated or quarantined in rooms with windows not opening onto external open spaces as well as rooms with windows or doors opening onto poorly ventilated common spaces. For instance, assessment of some housing typologies with living rooms opening into doubly loaded corridors that are often misunderstood as open space results in spread of the air-borne diseases as such corridors are in fact common spaces that often have limited ventilation. Isolation or quarantining in a room with windows opening to such corridors will risk the spread of infection to people using the corridor as well as those living in other dwelling units accessed by that corridor as contaminated air will keep on exchanging.

Maximize access to open spaces to enable cross-ventilation: Simulation analyses on different housing typologies have provided evidence of the fact that a habitable room opening to external open spaces perform better in terms of cross-ventilation than rooms with windows opening to common spaces such as closed corridors. Keeping in mind the isolation and ventilation requirements, future housing designs should go for building typologies that maximize access to open spaces through positioning, size and openability of windows. CSIR–CBRI has come up with a tool that can calculate the window opening size based on the size of the room for the desired air change rates. The tool takes into account the average wind speed in the city, wind direction (coefficient value changes if wind hits the window perpendicularly or obliquely) and the placement and number of windows (coefficient value changes if there is a single window in the room). The tool can also be used to determine the preferred direction and size of windows to achieve thermal comfort for occupants. This can be a useful instrument for building designers to get a rough idea of the sizes of windows required while designing.

Wind hydraulics need to be studied and integrated with site planning to enhance air change rates inside buildings: A regression analysis has revealed a positive co-relation between outdoor wind speed and indoor air changes per hour. When placed in the predominant wind directions, dwelling units showed an R^2 value above 0.83, representing a strong correlation between indoor ventilation (air changes per hour) and outdoor wind speed. Moreover, factors such as building form, clustering, positioning of blocks, height of the buildings and overall layout are shown to play a vital role in enabling or constricting ventilation in buildings. Therefore, wind hydraulics need to be studied well and integrated with site planning to ensure desirable air change rates in buildings.

Reform building design and operation codes: Building codes like the Eco Niwas Samhita target energy conservation while the National Building Code guides thermal comfort and health through appropriate design. The pandemic has shown that these codes need to converge to comprehensively addresses adaptive thermal comfort, energy penalty and disease-proofing. There is a need for detailed merged design codes ensuring the combination of appropriate building typology with existing guidelines on provision of cross-ventilation, mid-rise height of buildings, adequate spaces between blocks, staggered arrangement, windows opening on to open spaces, etc. This will enable code-vetted practices in the long term. The enhanced codes need better health performance as well as an energy penalty. A ventilation audit has to ensure ventilation effectiveness. This will require use of strategies like fans, etc. to dilute the air and expel air effectively and prevent contamination of air ducts of mechanically cooled buildings.

Need ventilation audits and operation protocols for different building typologies: There is an immense need to develop and disseminate immediate plans for existing buildings to contain the spread of SARS-CoV-2. However, there is a dearth of studies and data on ventilation performance in different building typologies that range from partially mechanically ventilated, fully mechanically ventilated, equipped with centralized air conditioning or standalone air conditioning among others. In order to optimize ventilation in these buildings, it is crucial to get audits performed by HVAC experts. Based on these audits, operational guidelines will be needed to enhance air changes and prevent the spread of the COVID-19 infection.

COVID-19-related operational guidelines for mechanically ventilated spaces must address the associated energy penalty: In a COVID-19 scenario, a number of guidelines for mechanically ventilated spaces stress on introducing more fresh air by keeping the windows open even when the ventilation is running. Keeping windows open in centrally air conditioned buildings as well as houses amidst the emerging COVID-19 requirement is going to have a tremendous impact on energy consumption. While it is too early to estimate energy consumption based on this new requirement, it is certain that air conditioners will not work on part load with their compressors continuously active in open windows. In this unavoidable scenario, considering the health emergency, set-point temperature can be an effective tool. Setting air conditioning temperature close to the outside ambient temperature can help mitigate some of the energy spike caused by this new requirement.

Further, according to ISHRAE, instead of increasing fresh air intake into a mechanically conditioned space to achieve the desired air change rates, equivalent air changes per hour must be focused upon. ISHRAE is proposing a combination of fresh air intake and a right form of filtration system for effective infection control. This is expected to save energy by decreasing the need to bring outside air and condition it. Several institutional and educational buildings have started to adopt this strategy. These strategies need to be assessed from the perspective of disease control. Architects point out that there is a need to pre-cool air and prevent cross contamination of indoor and outdoor air. Overall, heat ingress must be reduced.

Mandatory protocols in leased commercial spaces: Leased commercial spaces have limited control and less possibility of re-capitalization for infrastructure retrofits. With these limitations, the building users might not be able to operate the building in response to the updated health requirements, hence these spaces need to be brought under mandatory operation protocols.

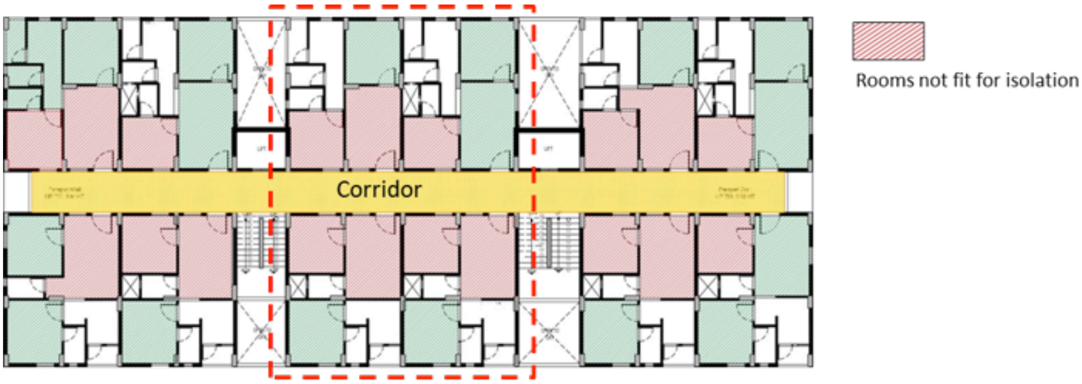
While a summary of this emerging trend is presented for public information and awareness, it has also highlighted the status of overall regulatory approach to integrating ventilation requirements in the design and layout of buildings. This builds the case for stronger action.

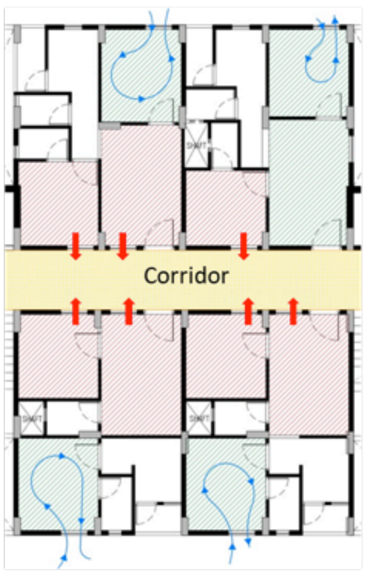
Review regulations and guidelines on ventilation to improve ventilation effectiveness: Consultations on this matter carried out as part of this study has brought out the need for further reforms to improve ventilation requirements in our existing regulations. The CSIR-CBRI guidelines, which are also a part of the framing of the new COVID-19 guidelines by the office of the Principle Scientific Advisor, said at a CSE webinar held on 20 July 2021 that WHO and EN-16798 have recommended a ventilation rate of 10 litre per second per person (which is 36 m^3 per hour per person) for the COVID-19 situation. In fact, the air change per hour requirement—in terms of the ratio of the volume of outside air allowed into a room in one hour to the volume of the room—of the National Building Code (NBC) are not sufficient to achieve these ventilation rates in different settings. In most buildings, the acceptable level of air change per hour and indoor air quality are determined by coupling the provisions of ISHRAE or NBC, 2016. Now, CSIR-CBRI guidelines are available on ventilation for residential and office buildings version that recommend increased requirements for air change per hour. For instance, if under NBC 2016, a living room and a bedroom require air change per hour of three–six and two–four respectively, the new recommendations have increased the corresponding requirements to four–seven and three–five respectively.

Annexure

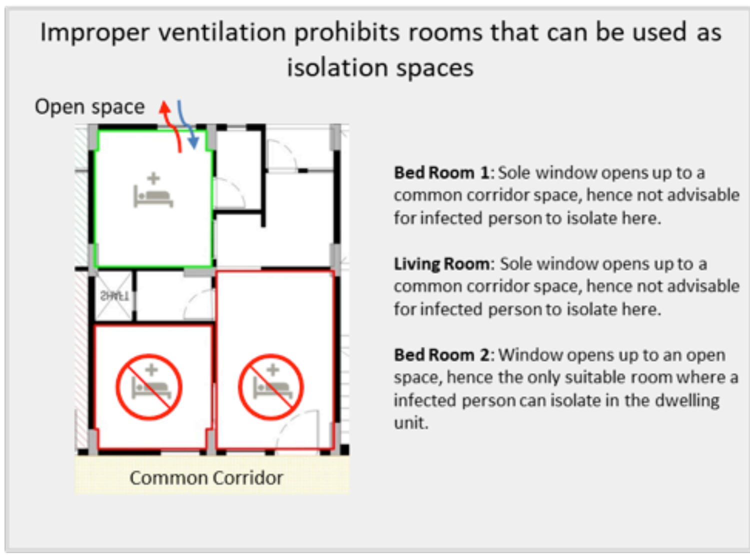
Assessment of possibility of isolation room in different housing projects

Case 1

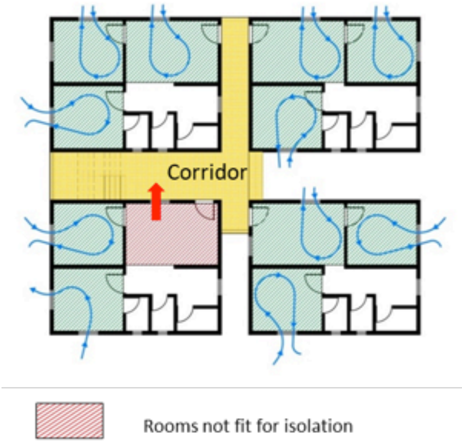


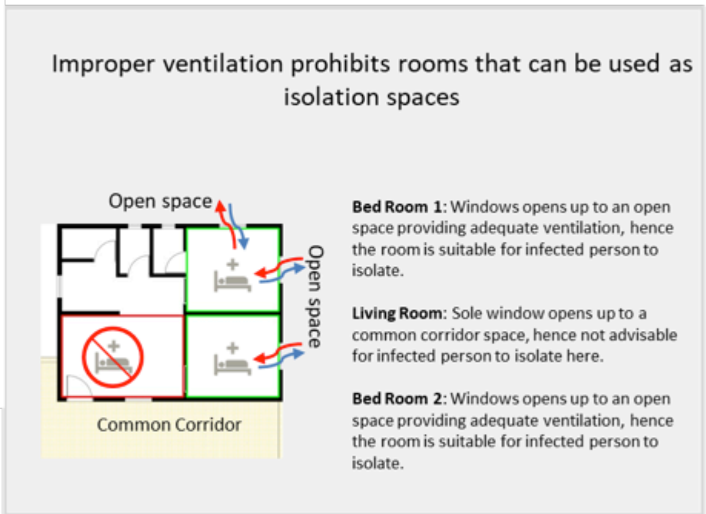


Windows of the living room and 1 bedroom open to poorly ventilated common space, decreasing the ventilation and daylighting potential of space .



Case 2





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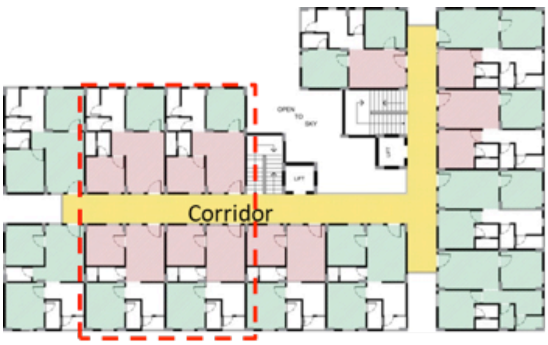
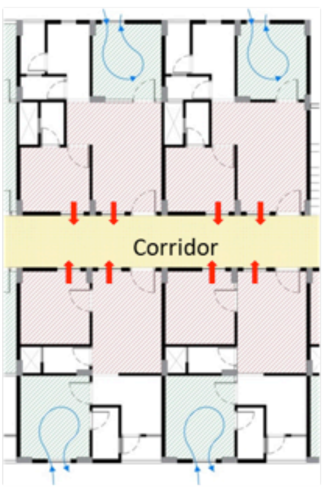
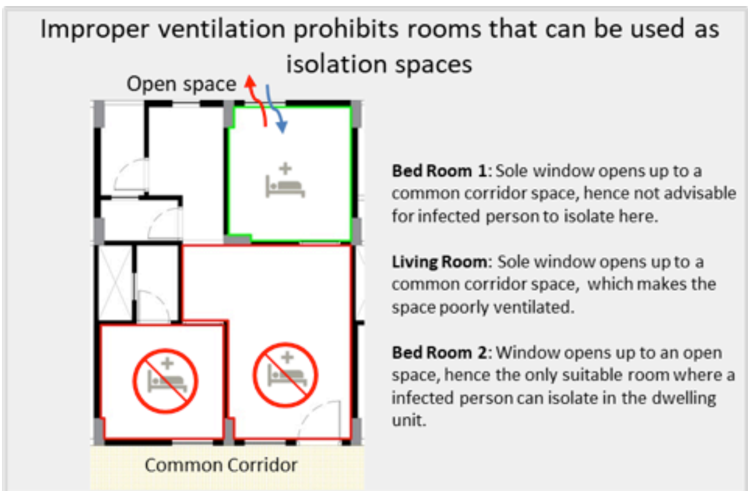


Rooms not fit for isolation

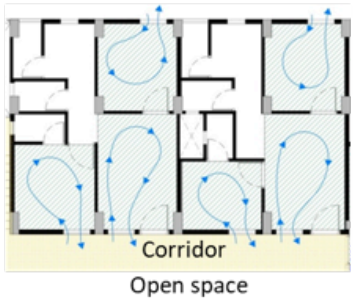
Windows of the living room and 1 bedroom open to poorly ventilated common space, decreasing the ventilation and daylighting potential of space .





Case 4

Rooms fit for isolation



Windows of all the habitable rooms open either to an open space or to a one-side open corridor, increasing the ventilation and daylighting potential of space .

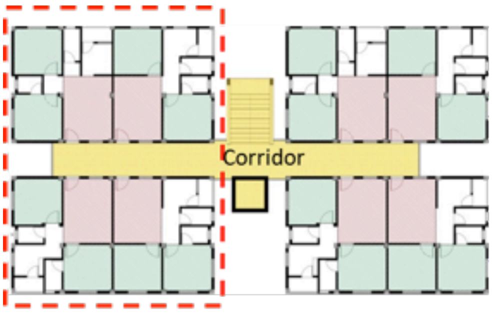
Good ventilation allows rooms to be used as isolation spaces

Bed Room 1: Windows opens up to common corridor which abuts an open space providing adequate ventilation, hence the room is suitable for infected person to isolate.

Living Room: Window of the living room opens up to common corridor which abuts an exterior open space which provides adequate ventilation.

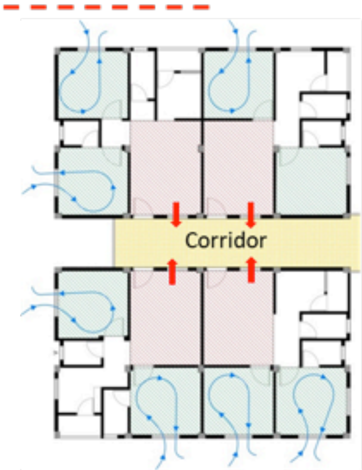
Bed Room 2: Windows opens up to an open space providing adequate ventilation, hence the room is suitable for infected person to isolate.

Case 5

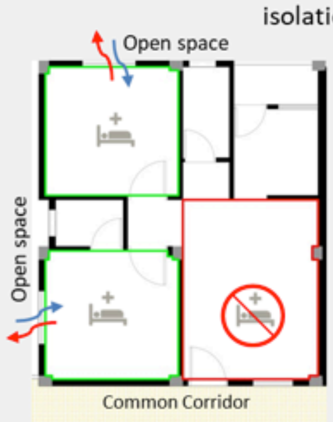


Rooms not fit for isolation

Windows of the living room and 1 bedroom open to poorly ventilated common space, decreasing the ventilation and daylighting potential of space .



Improper ventilation prohibits rooms that can be used as isolation spaces

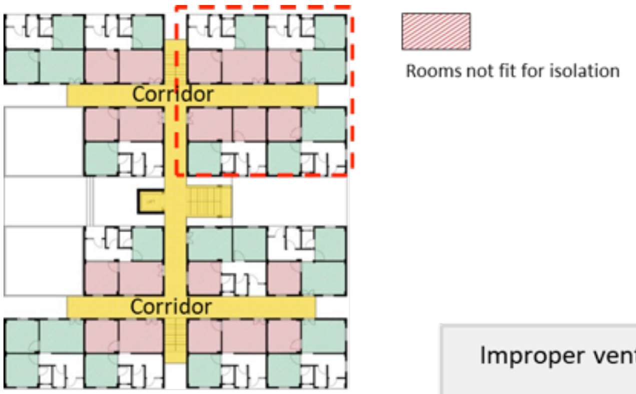


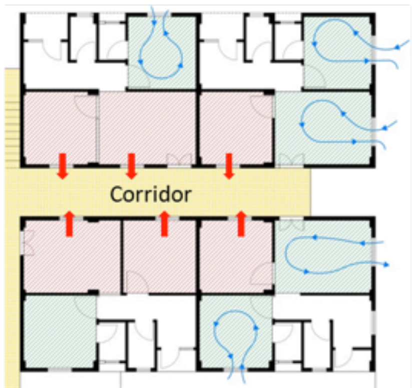
Bed Room 1: Windows opens up to an open space providing adequate ventilation, hence the room is suitable for infected person to isolate.

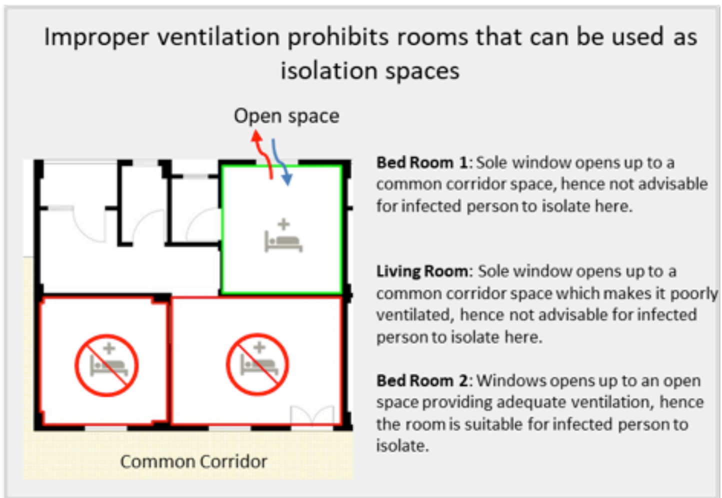
Living Room: Sole window opens up to a common corridor space which makes it poorly ventilated, hence not advisable for infected person to isolate here.

Bed Room 2: Windows opens up to an open space providing adequate ventilation, hence the room is suitable for infected person to isolate.

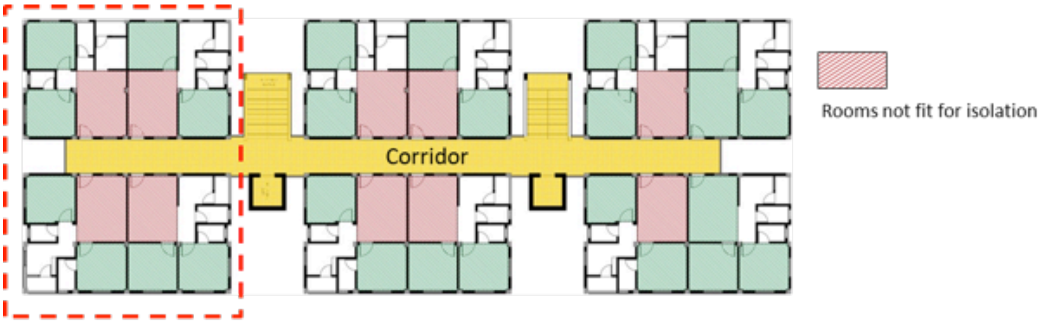
Case 6

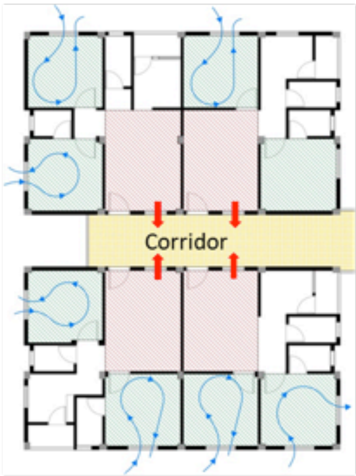

Corridor
Corridor
Rooms not fit for isolation


Corridor


Improper ventilation prohibits rooms that can be used as isolation spaces
Open space
Common Corridor
Bed Room 1: Sole window opens up to a common corridor space, hence not advisable for infected person to isolate here.
Living Room: Sole window opens up to a common corridor space which makes it poorly ventilated, hence not advisable for infected person to isolate here.
Bed Room 2: Windows opens up to an open space providing adequate ventilation, hence the room is suitable for infected person to isolate.

Case 7





Windows of the living room and 1 bedroom open to poorly ventilated common space, decreasing the ventilation and daylighting potential of space .

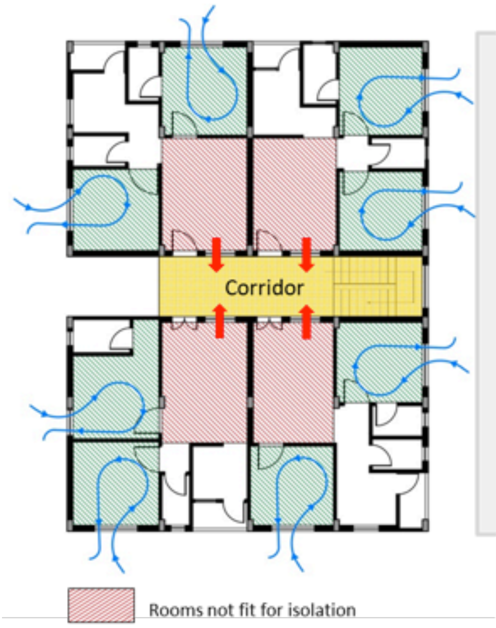
Improper ventilation prohibits rooms that can be used as isolation spaces

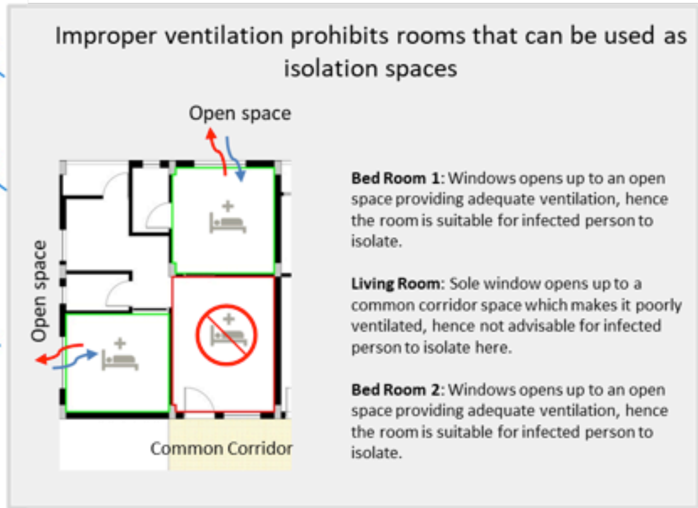
Bed Room 1: Windows opens up to an open space providing adequate ventilation, hence the room is suitable for infected person to isolate.

Living Room: Sole window opens up to a common corridor space which makes it poorly ventilated, hence not advisable for infected person to isolate here.

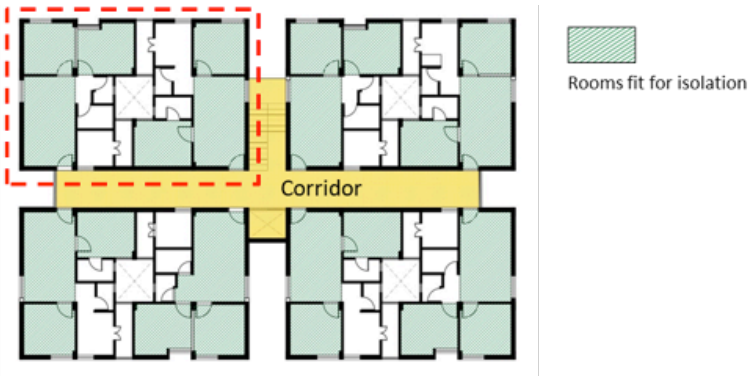
Bed Room 2: Windows opens up to an open space providing adequate ventilation, hence the room is suitable for infected person to isolate.

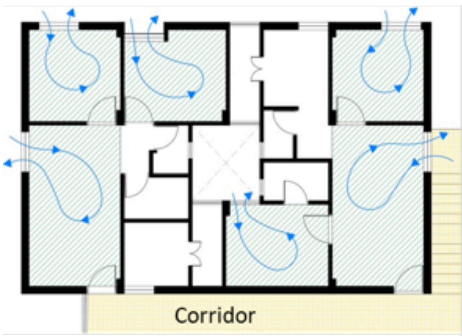
Case 8



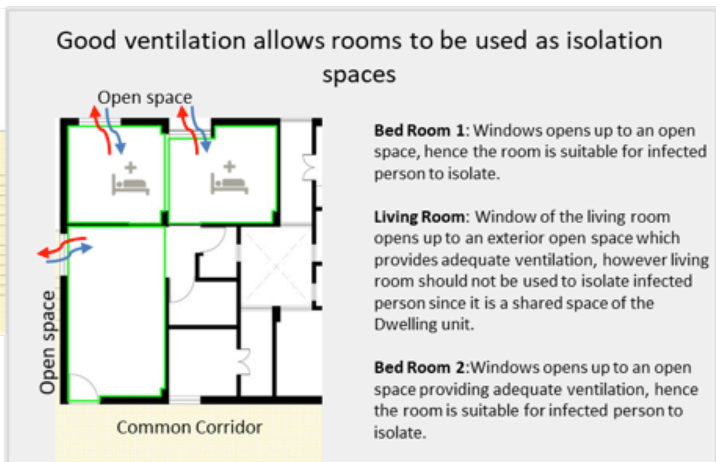


Case 9





Windows of all the habitable rooms open either into an exterior open space or interior open space which provides adequate ventilation.



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That buildings should be well-ventilated is no rocket science. However, the current pandemic and revelation that SARS-CoV-2 can remain airborne for a considerable length of time has given this ancient awareness an urgent appeal.

Keeping in view the preventive measures in national and international codes and guidelines (like Eco Samhita and the National Building Code), Centre for Science and Environment has evaluated the design and layout of various building typologies on ventilation in a COVID-19 scenario. This assessment will be an invaluable guide for disease-proofing future building stock.

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