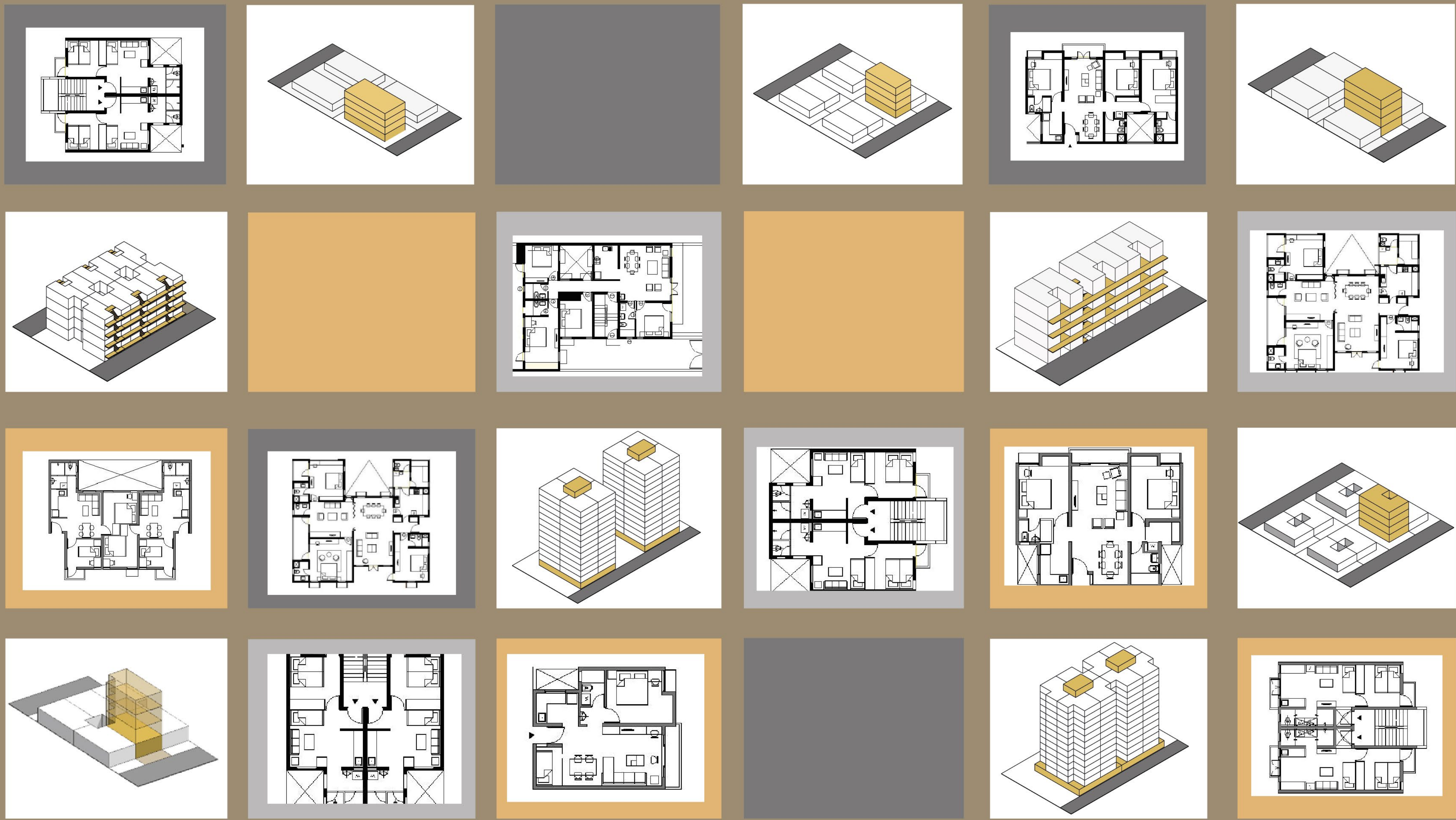
GOVERNMENT OF INDIA
MINISTRY OF POWER

HANDBOOK OF REPLICABLE DESIGNS FOR ENERGY EFFICIENT RESIDENTIAL BUILDINGS



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Disclaimer

This publication has been developed after an extensive review of all relevant data and documents and in consultation with a number of experts and stakeholders of the building energy sector. The analysis, interpretations, and recommendations expressed herein do not necessarily reflect the view of the Bureau of Energy Efficiency and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). BEE and GIZ disclaim liability for any personal injury, property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, application, or reliance on this document.

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HANDBOOK OF REPLICABLE DESIGNS FOR ENERGY EFFICIENT RESIDENTIAL BUILDINGS

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Message from BEE

To accelerate the adoption of energy efficiency in upcoming residential buildings, BEE in association with Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) India has developed replicable type designs for residential buildings. The purpose of this project is to essentially understand and prioritize appropriate technologies for India that are most feasible for residential buildings in order to increase the efficient use of energy. In this context, BEE and GIZ, with support from Ashok B Lall Architects have prepared a Handbook of Replicable Designs for Energy Efficient Residential Buildings

The development of these design templates takes into consideration different residential typologies and sizes of dwelling units across five different climatic zones of India. Recognizing the importance of thermal comfort, the designs templates would recommend improvement measures such as additional insulation, suitable ventilation systems, air-tightness of the building fabric etc. Ultimately, the complete database of design options with cost details and energy performance parameters would be made available to the user in the form of a web-based tool and a Handbook.

The Handbook illustrates type designs in a consolidated and easy to comprehend format. It discusses the step by step process for energy performance improvement across different climate zones and explains the procedure and parameters for the selection of housing typologies. Similarly, the web tool enables building design professionals and developers to access design solutions for all types and sizes of residential buildings for each of the climatic zones of India. It provides computer simulated analyses of all representative residential types and shows how design improvements lead to enhanced energy performance.

By providing access to the building simulation files, construction and cost details, the tool enables informed decision-making and encourages further exploration in design options. For policy makers, the web tool evaluates the life-cycle costs and payback periods vis-à-vis the energy efficiency measures for progressively higher performance.

SH. ABHAY BAKRE

Director General, Bureau of Energy Efficiency

Ministry of Power, Government of India

> *“By providing access to the building simulation files, construction and cost details, the tool enables informed decision-making and encourages further exploration in design options.”*

Message from GIZ

India's aim is to reduce the emissions intensity of its gross domestic product (GDP) by 33 to 35 percent by 2030 from 2005 level. Any effort to achieve this target is contingent upon the increase in efficiency of energy use across all sectors, especially in the building sector. The building sector in India consumes over 30% of the total electricity consumed in the country annually and is second only to the industrial sector. With nearly two-third of the built infrastructure yet to come up till 2050, the nation calls for advancement and innovation in the construction sector.

Out of the total electricity consumed in the building sector, about 75% is used in residential buildings. The energy demand in the domestic sector has been on the rise since the late 2000s, with increasing demand for appliance ownership, especially of fans and televisions in urban and rural areas, and an increase in refrigerators and air conditioners in urban areas. Electricity consumption increased from 146 BU in 2009-10 to 280 BU in 2018-19 with CAGR of 6.74%.

According to India Cooling Action Plan, approximately 8% of the current households have room air conditioners. This is anticipated to rise to 21% and 40% in 2027-28 and 2037-38 respectively. The demand for air-conditioning will continue its exponential growth with improvement in household incomes and will become the dominant contributor of GHG emissions nation-wide owing to increased electricity consumption.

This situation calls for an immediate energy conservation action plan. Building energy codes have been adopted as a regulatory measure for ushering energy efficiency in the building sector by many countries.

In India, Energy Conservation Act, 2001 provides the basic framework for regulating all initiatives relating to the efficient use of energy include building energy codes. The commercial sector among buildings has been addressed through Energy Conservation Building Code (ECBC) for Commercial Buildings. Given the current and anticipated rapid growth in the residential building stock across India and the consequent opportunities as well as the necessity for energy conservation in this sector, the Energy Conservation Code for residential Buildings (EcoNiwas Samhita Part I) was launched by the Ministry of Power to set minimum building envelope performance requirements to limit heat gains (for cooling dominated climates) and to limit heat loss (for heating dominated climates), as well as for ensuring adequate natural ventilation and daylighting potential.

GIZ is implementing the Indo-German Energy Programme (IGEN) on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ). The Energy Programme promotes measures to improve energy efficiency and integrate renewable energy into the grid. Under this programme, The Eco-Niwas Samhita (Part II) has been developed and is an integrated code specifying minimum energy performance requirements for building envelope as mentioned in ENS Part I, building services, electrical end-use and renewable energy system. The code also provides five appendices for annualised embodied energy, better construction practices, retrofitting of residential buildings, improved air cooling and Smart Home, which are recommendatory in nature and envisaged to be added in future revision of the code.

The purpose of EcoNiwas Samhita Part-II is to provide the minimum requirements for building envelope, building services, indoor-electrical end-use and renewable energy systems for new residential buildings. As a policy driver for guiding building construction, the EcoNiwas Samhita is a progressive and future-fit code and will push the residential building sector towards net zero energy targets. The code also supports many of the Government of India's objectives for achieving energy security, economic growth and environmental sustainability.

GIZ is proud to be associated with Bureau of Energy Efficiency and the Ministry of Power on such a progressive and innovative residential building energy code, EcoNiwas Samhita (Part II). I congratulate Bureau of Energy Efficiency and the Ministry of Power on the launch of EcoNiwas Samhita (Part II). This code can be a transformative and guidance tool for integrating energy efficiency in all new residential buildings.

Dr. WINFRIED DAMM

Cluster Coordinator,
Indo German Energy Program

> *"As a policy driver for guiding building construction, the EcoNiwas Samhita is a progressive and future-fit code and will push the residential building sector towards net zero energy targets."*

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Introduction

The overarching context of this project are the twin objectives of the Government of India – to capture the potential of energy efficiency in the buildings sector as it expands rapidly in tandem with rapid urbanisation; and, importantly, to achieve a reduction in GHG emissions intensity of GDP by 33 to 35%,from the 2005 level, by 2030

India's National Action Plan on Climate Change 2008 points to building energy efficiency measures as being essential to carbon dioxide emission reductions.

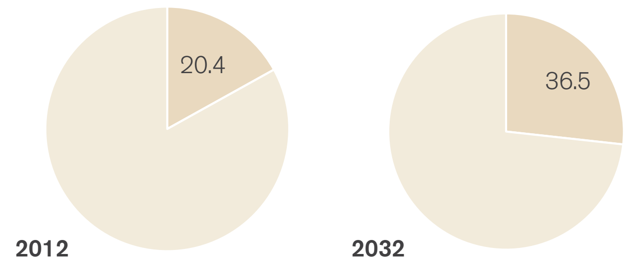


Figure 1 : Expected increase in energy consumption of residential building by 2032. [Source

Total energy consumed by residential buildings

In 2012 residential buildings accounted for 20.4% of total energy consumption in India. This is predicted to grow seven-fold by 2032 when it would account for 36.5 % of the total energy demand in India.
The rapid growth of energy consumption in residential buildings is attributable to three factors.

•The addition of new housing stock required to meet the current shortfall as well as the increase in demand for homes due to rapid urbanisation.
•The new building stock will progressively be built in the formal sector in the form of multi-storey housing, which would incur an increased energy intensity of construction on account of a greater reliance on RCC as a common method of construction.
•Rising standards of living progressively raise the demand for better indoor thermal comfort, which is being met, increasingly, by room air-conditioning. This trend constitutes the dominant cause of increase in energy consumption in the residential sector.

The requirement for residential buildings in the growing metropolitan areas will be largely met in the form of multi-storey apartments. There will continue to be some middle-income homes built on independent plots in the suburbs of small towns. And there will be very few high-income homes built on independent plots.

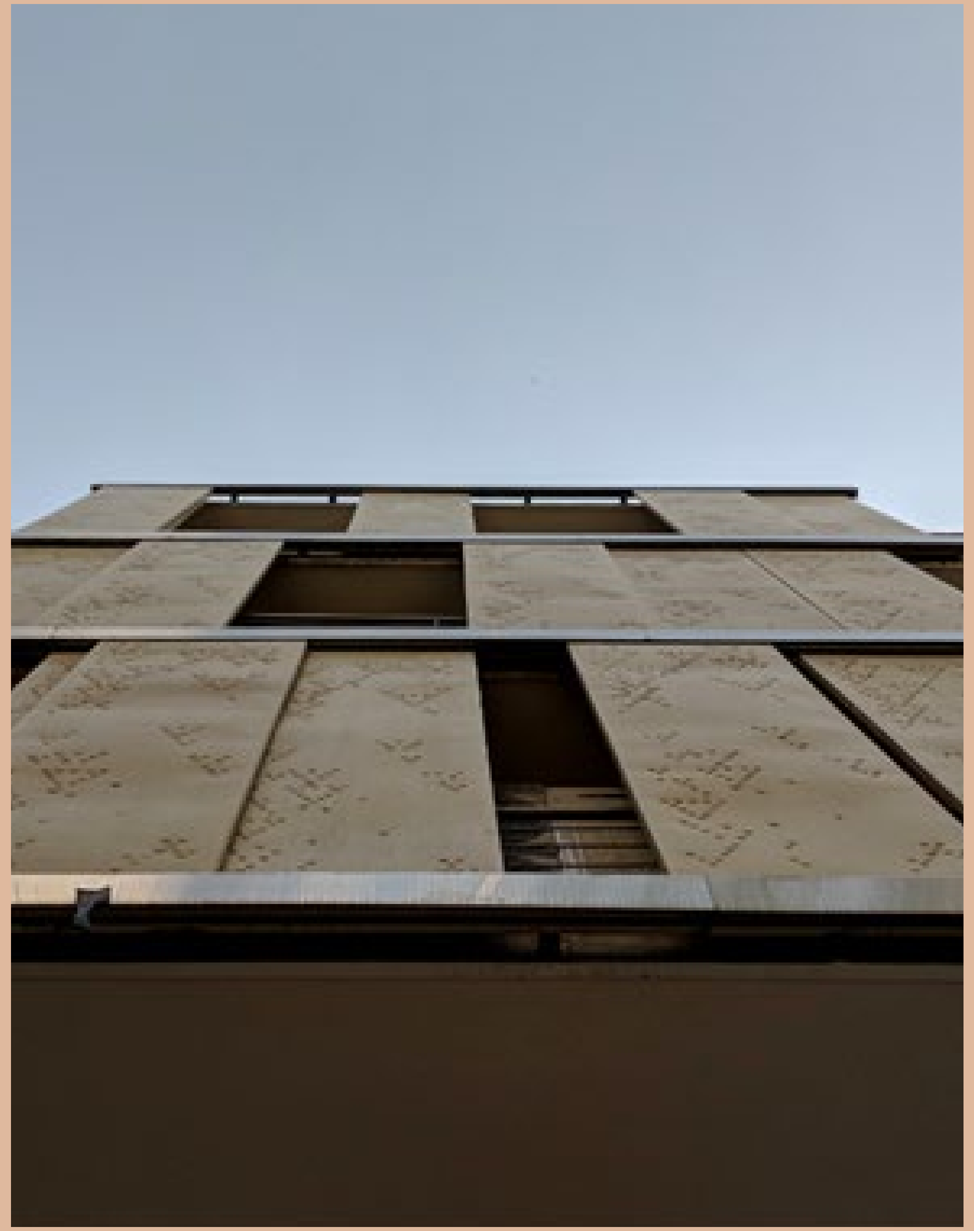
Architectural and engineering design services that will be available to and afforded by the developers and home buyers for the vast majority of the residential buildings to be built in the next decade are yet to develop the knowledge and skills for integrating energy efficiency into building design as a standard practice. On the other hand, advanced architectural and engineering services for the upper-income category of residential buildings are yet to pay systematic attention to energy efficiency.

Energy efficiency requires integrated design to minimise the demand for energy to obtain the desired environmental performance and to minimise dependence on electro-mechanical systems for illumination, ventilation or cooling/heating. This project provides integrated energy efficient designs for all types of residential buildings.

▪The type designs range from small projects on independent residential plots to multi-storey apartment buildings.
▪For dwelling unit sizes ranging from 30 sqm to 225 sqm.
▪The designs have been developed for all 5 climatic zones in India.
▪Their base level environmental performance meets the Eco Niwas Samhita (ECBC-R) and other environmental certification programmes – GRIHA, IGBC, EDGE
▪For all typical building types, design variations for higher levels of environmental and energy performance are also shown backed with simulation results.
▪Technical data is made available for ready adoption and adaptation by prospective designers and builders.

The type designs, appreciated through the technical data and the performance data that is provided alongside, enable users to learn the application of energy efficient design principles systematically. This would transform the knowledge and capability of designers and builders for energy efficient residential buildings design.

All of the above mentioned material will be on the Eco Niwas Samhita website – open source, downloadable! This book illustrates the structure and content of the website, and can be used as a technical guide for energy efficient design.



02

Scope Of Work

2.1 Replicable Designs

Generally, persons or builders who are building the smaller homes may well find it convenient to replicate the type design provided in this project. But when it comes to larger homes, for middle and high-income groups, the type designs are less likely to be replicated. Rather, they would be used as references to guide the designer toward energy efficient design and they would be adapted to suit varying needs and preferences.

2.2 Dwelling unit sizes and building typologies

Who will find these 'replicable' designs useful, and how will they be adopted?

The residential buildings that will be built will be of diverse types. The diversity of dwelling unit size depends on income and affordability – ranging from small homes of 40 sqm floor area to homes of 250 sqm. The type of residential building will also be diverse depending, largely, on the availability and cost of land – ranging from homes built on independent plots, to row-houses and walk-up apartments, to mid-rise six or seven storey tall buildings, to tall apartment buildings.

2.3 Climate zones & representative cities

The climate of India has been classified into five climatic zones. All types of buildings are likely to be built in each of the climatic zones.

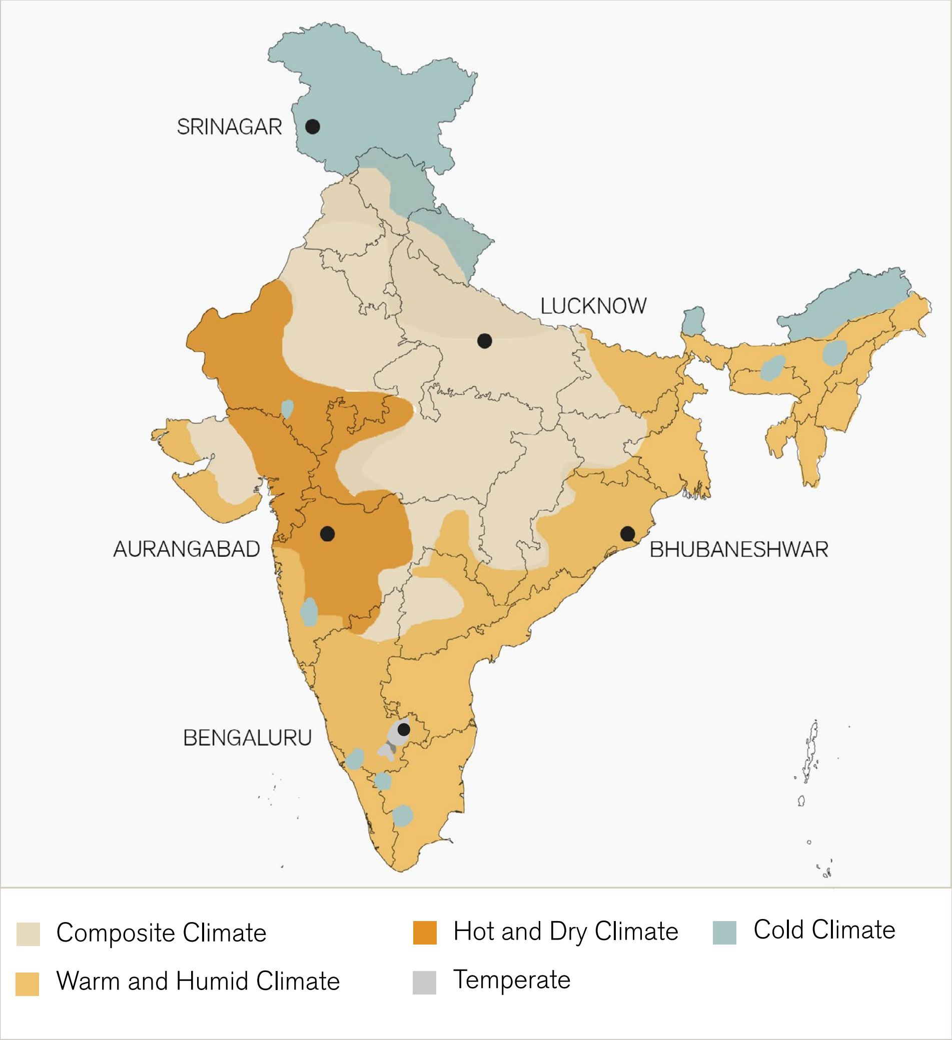


Figure 2 : Climate Zone Map Of India

For the purpose of simulating the thermal performance of the type designs and evaluating their energy efficiency, a representative city has been selected in each of the 5 climatic zones. These cities are - Srinagar, Lucknow, Bhubaneshwar, Bengaluru and Aurangabad.

The thermal performance of a building and the demand for cooling or heating to achieve comfort depends on its design and the climate where it is located. For the purpose of simulating the thermal performance of the type designs and evaluating their energy efficiency, a representative city has been selected in each climatic zone.

These 5 cities have been selected as they are a fair representation of the climate characteristics of the zone and have a high residential development potential in the coming years. The simulation results that are reported in this project are for the representative cities. This acts as a reasonable indication of the performance of the type design located in that climatic zone.
However, these are not absolute solutions for all locations falling in a particular climate zone as conditions vary geographically. The methodology and rationale of improving energy performance step by step is to be understood from this example and adapted for each specific case.

2.4 Principles of energy efficient design –

All designs developed as part of the catalogue are based on the principles discussed below:

2.4.1. Thermal Comfort:

Thermal comfort is complex and there are many influencing factors. Mainly temperature, humidity and air movement. We feel reasonably comfortable within a range of temperatures. This science is expressed as the Adaptive Thermal Comfort Model which is commonly used in India. The comfort standard varies and has an impact on the affordability of adopted measures to achieve comfort. Based on the accepted definitions of thermal comfort, this project shows designs of residential buildings in a way that minimises the need for electrical heating or cooling - the worst culprit being refrigerant based air conditioning.

Below we discuss the main Passive Design features of climate conscious design for thermal comfort.design for thermal comfort.

2.4.2. Passive Design :

The configuration of the building plan and the design of the building's external envelope – its external walls, windows, shading elements and roof - contribute to the building's environmental performance. Working out optimal designs combining the effect of each of these elements is 'Passive' design. The idea is to maximise the duration of comfort by Passive design in the living spaces so as to minimise the need for either heating or cooling by energy consuming devices. The Type Designs shown in this project are derived by optimising Passive design.

2.4.3. Compactness of building plan:

This principle requires minimising the external wall area while planning the arrangement of dwelling units -whether as a single unit on its plot of land or as a group of units. Lesser the area of exposure of the external envelope to the outside, for a given floor area, lesser will be the heat transfer into the building. Simple rectangular shapes are more efficient. Similarly, adjacent units can share walls and thereby reduce their exposure to the outside. These simple methods of achieving compactness in planning also reduce the cost of construction.

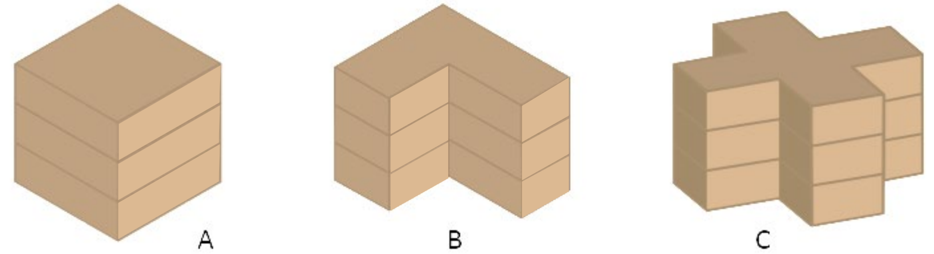


Figure 3 : Compactness of Building - Compactness depends on the geometry of the building and it varies with the building typology. In this figure the surface to volume ratio increases from A to C as the built form gets more complicated, the compactness reduces.

2.4.4. Window to wall ratio (WWR) :

The external perimeter that separates the outside from the inside, is made up as walls and windows. Opaque masonry walls will have a greater capacity to resist the flow of heat compared to windows. The larger the ratio of window are to wall area, the greater the flow of heat from outside to the inside.

2.4.5. Insulation :

Heat will flow across the building envelope - its walls, roofs and windows, whenever there is a difference in temperature between the inside and outside. In order maintain the indoor temperatures within the comfort range this flow of heat needs to be controlled. Insulating the roof is critical. Walls too need to be insulated. Windows tend to be the weakest link – the thin glass and a conductive window frame material are the culprits. PVC or timber frames with double glazing will be advantageous, especially when the room is being air-conditioned.

2.4.6. Shading :

This is the most neglected aspect of design for comfort and energy conservation in buildings being built nowadays. And it is often the chief cause of discomfort, which then pushes occupants to resort to expensive, energy guzzling, air conditioning. Direct sunshine and indirect sky radiation entering a room through a glazed window is the largest contributor to discomfort during warm and hot seasons. Direct sunshine must be blocked and diffused radiation should be filtered. Shading elements are designed according to the direction from which the unwanted sun would strike the window.
In winters and in cold climates, however, sunshine would be welcome. Glass panels can let in direct sunlight and 'trap' the heat absorbed by the room. Insulating double glazed windows will help in retaining the warmth through the night too.

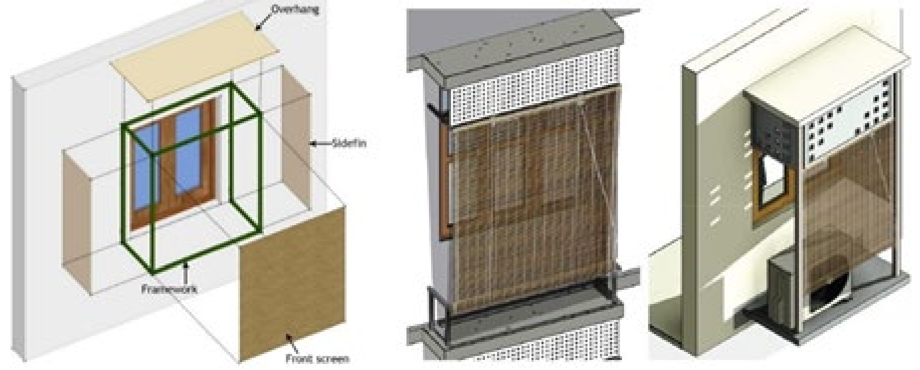


Figure 4 : Protection through shading

Effective placement and designing of shading elements can help cut down direct sun and filter diffused radiation.

2.4.7. Ventilation :

When the air outside is pleasant and cooler than the inside we open our windows to flush out the heat. How effectively and quickly this brings relief from stuffiness and makes the rooms comfortable depends on how quickly the inside air is replaced by the more pleasant air. Windows that open fully, like casement windows, will be more effective than sliding windows which can open only partially. High level ventilators and cross ventilation that allows air to flush through the room helps a great deal, but when it is too cold or too hot outside windows and doors must shut tight, leaving no cracks or gaps through which the unwanted air can infiltrate. This is most important when you are air conditioning a room. Use of mechanical ventilation with heat recovery / energy recovery becomes important in such cases.

When there is no breeze the process will be slow. At such times an exhaust fan that assists the ventilation process will help greatly. In this project we assume the occupants make good use of the provisions for ventilation in the designs of the dwelling units.

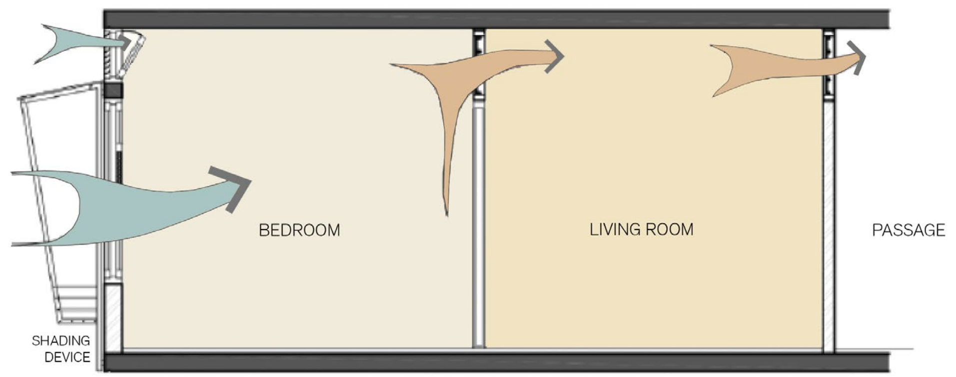


Figure 5 : Ensuring cross ventilation through living spaces
Optimize openings & windows for ventilation

2.4.8. Thermal mass :
Dense and heavy elements of the building, such as the floors and masonry walls, act as temperature stabilisers. Their temperature varies relatively little through the day and night cycle. They can 'store' heat as well as coolth. This property is referred to as thermal mass.

In warm climates the trick is to open the windows during the cool period of the evening and nights to store the coolth in the heavy inner floors and walls of the house, and to shut the windows during the hot part of the day to keep the inside of the house from getting heated up. In cold seasons, the warmth of sunlight let in through glass windows will be stored in the floors and walls. The walls must be insulated on the outer face of the thermal mass to retain the heat in the thermal mass and to retain warmth for the night.

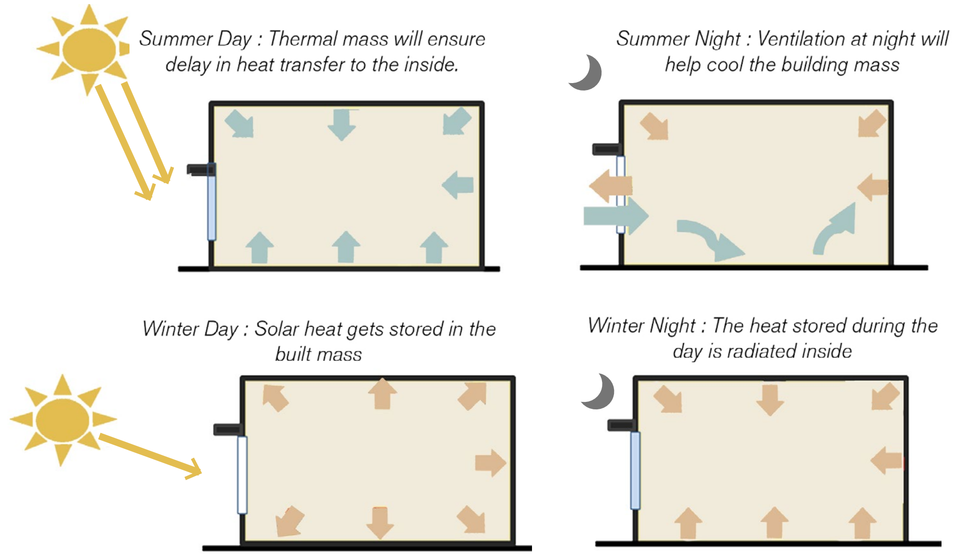


Figure 6 : Use of thermal mass and solar gains to make indoors comfortable

2.5 Catalogue of replicable house designs

There is a wide variety of building types for construction of residential buildings. This project concerns itself primarily with residential buildings being built in towns and cities. They are either built by home-owners on plots of land that they own, or they are built by developers or institutions as multi-family blocks of flats or group-housing schemes. These range from small dwelling units of 30 to 40 sqm carpet area to large dwelling units of 220sqm plus! The types of buildings for multi-family blocks can also vary.

Considering the abovementioned factors, the Catalogue in this project gives 35 type designs which represent the common and likely size and type of residential units being built in the urban areas across the country. These type designs will, therefore be useful for a wide range of home builders and residential building developers, serving a varied market and demand.

The Type Designs are represented as dwelling unit plans, building plans and site layout plans.

2.6 Step-by-step energy performance improvement and simulation of performance.

Representative samples of the Type Designs of each building type are selected for evaluating their energy efficiency and thermal performance. The type designs are first designed to meet the base requirements of Eco Niwas Samhita. The construction materials and techniques used are

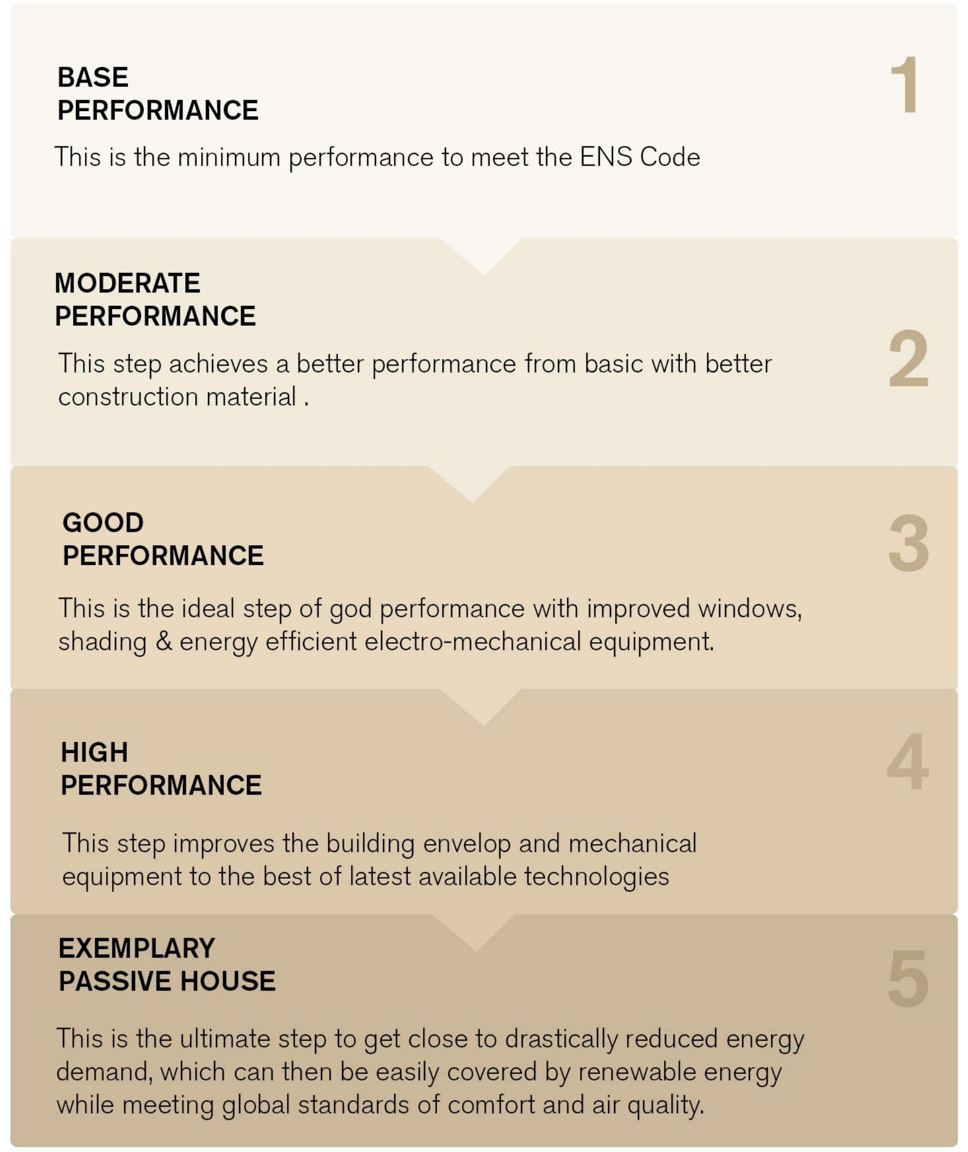


Figure 7 : The step-by-step energy performance improvement

commonly used or available in most regions of India. The materials of construction and the elements of the external envelope of the Base Design are then modified to improve the thermal performance and energy efficiency over that of the Base Design. This is done for three steps of progressive improvement.

For 5 sample designs we propose the most advanced improvements and report the high performance achieved. This is the ultimate step to get close to drastically reduced energy demand, which can then be easily covered by renewable energy while meeting global standards of comfort and air quality.

The performance is predicted by simulation software in which the building design is modelled for a range of variations.

2.6.1 Climate zone variation:
The performance of the Type Designs is then evaluated for different climatic zones. The warm climate set serves the 4 warm Climate Zones : Hot & dry, Warm & Humid, Composite and Temperate with variations in openings and materials as required for each climate. The cold climate set, where the predominant need is for heating rather than for cooling, is specially designed to suit cold climate conditions.

2.6.2 Orientation Variation:
The variation in performance when a building is turned through different orientations with respect to the sun is also reported by simulation.

Figure 8 : Dwelling Unit in different orientations

Different orientations of the same unit will result in different energy performances . These changes with change in orientation can also be recorded via simulation.

2.6.3 Dwelling unit placement:
The differences in performance due to the positioning or placement of a dwelling unit – ground floor, middle floor or top floor , middle unit, end unit etc. is also reported.

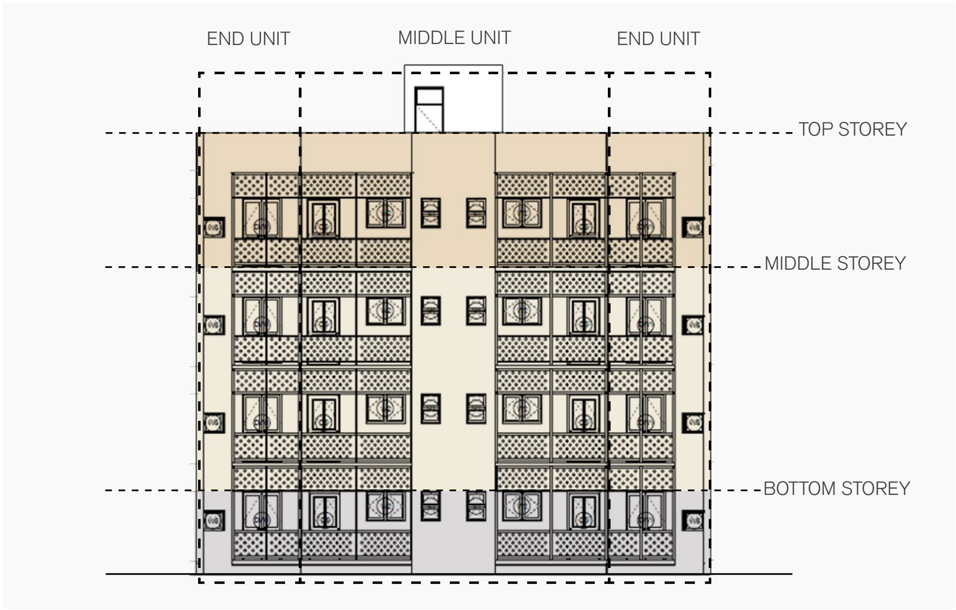


Figure 9 : Dwelling unit locations in multi-family building

The placement of a unit within the block both vertically and horizontally influences the energy performance of that unit.

2.7 Key performance parameters

For the representative Type Designs selected for simulation, the following key performance parameters are reported: Building envelope performance (RETV), Ventilation Potential, Daylight Availability, and Comfort Hours with natural Ventilation. Energy Performance Index.
In order to assess the techno-commercial feasibility of the energy efficiency measures the following information about each Type Design and its variants for improved performance levels is also provided: Payback duration, Life Cycle Cost (LCC), Energy savings etc.

03

Residential building typologies and dwelling unit sizes

3.1 Residential building configurations

A Dwelling Unit is an independent secure space for residential use. It may have several rooms, balconies and verandahs as part of this secure space. It will usually have facilities for cooking, bathing and toilet. The convention is that each dwelling unit is occupied by a household or family.

In plotted residential development, independent plots may have a single family dwelling unit. It is now common in cities for such single family dwelling units to be raised up to four stories with identical plans. The size of the dwelling unit will usually be determined by the size of the plot. The larger the plot, the larger the dwelling unit.

Multi-family residential buildings are buildings that have several dwelling units attached horizontally and/stacked vertically within the building. These buildings can be several stories tall. This type of residential building will be the dominant form of housing provision in urban areas.

3.2 Building typologies and dwelling unit sizes

There can be innumerable designs for residential buildings. There will be differences of size, type and height. There may be differences in the detailed requirements of rooms to be provided in dwelling units and many dwelling unit plan configurations can be devised to meet these requirements.

The Type Designs recommended in this project cover all prevalent variations of size (accommodation), building type and building height. The planning of these recommended designs is derived by application of principles of climate responsive passive design. The plans for climate zones where cooling is the main concern, (Composite, Hot-dry, Temperate and Warm-humid), are designed to protect the building from external heat. Whereas, for Cold Climate zone, where the main concern is to protect from the cold while taking advantage of solar radiation, the plans are designed to receive sunshine into the habitable rooms.

In the case of individual family homes, the larger the plot of land the larger the dwelling unit size. They would range from a 1BHK at the small end to a large 4bhk at the larger end.

In the case of multi-family apartment blocks there are three sub-types – 1) row-house and walk-up apartment blocks, which will be up to four stories high; 2) linear corridors types, and 3) tower blocks around vertical lift cores. Which can be 6 to 12 stories and more in height. In buildings taller than four stories, the linear corridor types tend to have smaller dwelling units, whereas the tower block types tend to have large dwelling units.

It is also seen that smaller dwelling units (30 sqm to 80 sqm) are built in low-rise, linear row-house type of building or in buildings with a doubly-loaded corridor arrangement. Larger dwelling units are built on large single- family plots or in tall tower blocks, which share a lift core between three of four flats on each floor.

The building typology cum dwelling unit size chart in Table 02 and 03 shows that the complete range of size and type is represented in the selected series. Now, it would be possible for all users to find a type design that is close to their particular requirements.

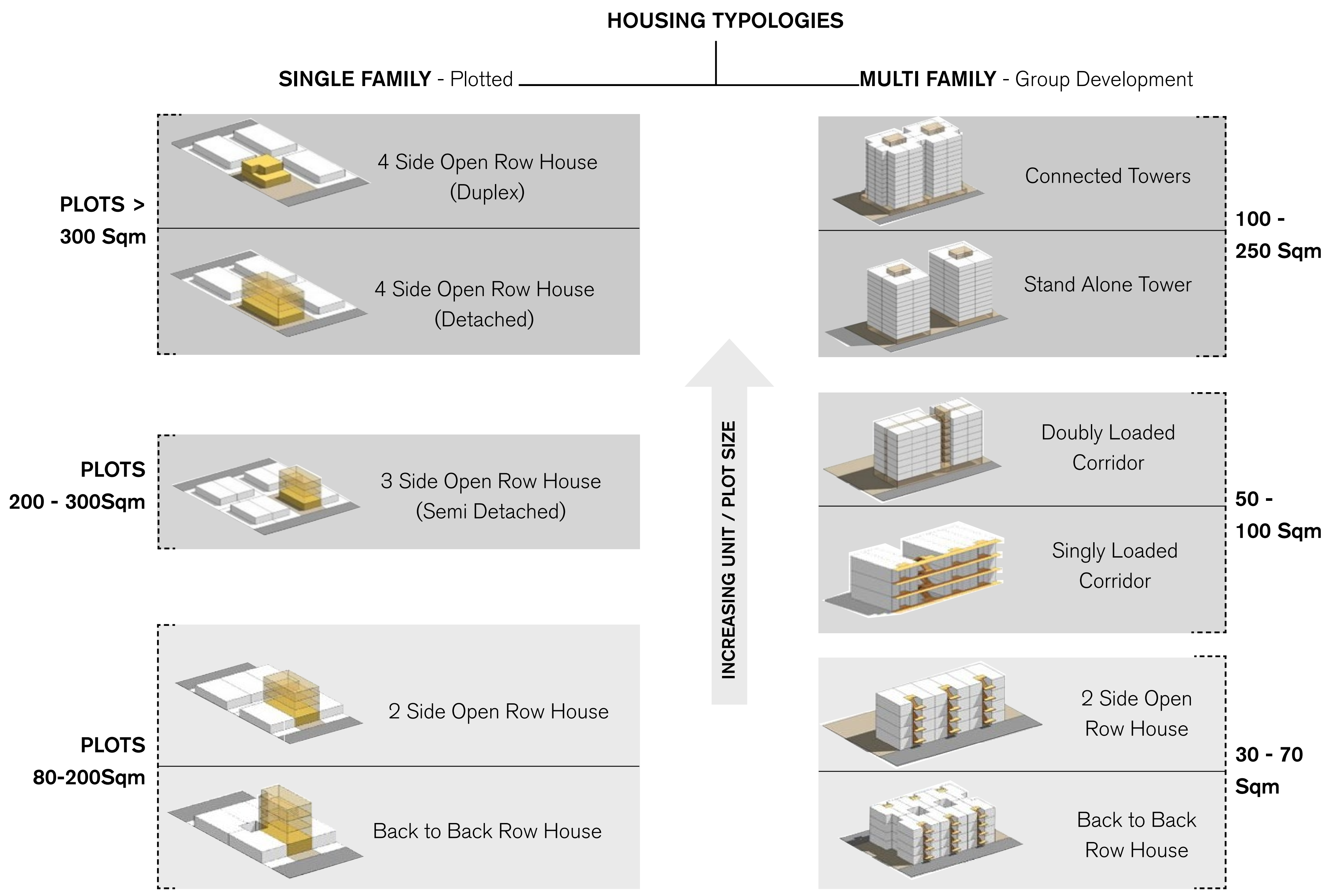


Table 01 : The Type Designs recommended in this project cover all prevalent variations of size (accommodation), building type and building height. The planning of these designs is derived by application of principles of climate responsive passive design.

Single family Building

Low Rise (Building Height <15m)				
Two side open Row House	1 BHK (80 sqm) (2.1A)	2 BHK (160 sqm) (2.2A)		
Semi- Detached	2 BHK (160 sqm) (2.2B)	3 BHK (200 sqm) (2.3A)	4 BHK (240 sqm) (2.4A)	3 BHK (300 sqm) (2.5A)
Detached	4 BHK (300 sqm) (2.5B)	3 BHK (400 sqm) (2.6A)		
Detached (Duplex)	5 BHK (400 sqm) (2.6B)			

Table 02 : For single family plotted homes the typology is defined by thenumber of open sides in the building. This is determined by the set back requirements depending on the plot sizes.

Multifamily Building

Low Rise (Building Height <15m)				
Back-to-Back Row house	1 BHK (30 sqm) (1.1A)	2 BHK (41 sqm) (1.2A)	3 BHK (55 sqm) (1.2D)	
Two side open Row House	1 BHK (32 sqm) (1.1B)	2 BHK (48 sqm) (1.2B)	3 BHK (68 sqm) (1.3A)	3 BHK (68 sqm) (1.3C)
Doubly Loaded Corridor	1 BHK (30 sqm) (1.1C)			
Mid/High Rise (Building Height >15m)				
Doubly Loaded Corridor	1 BHK (44sqm) (1.2C)	2 BHK (65 sqm) (1.3B)	3 BHK (85 sqm) (1.4A)	
Connected Towers	3 BHK (105sqm) (1.4B)	3 BHK (125 sqm) (1.5A)		
Stand-Alone Towers	3 BHK (105sqm) (1.4C)	3 BHK (125 sqm) (1.5B)	3.5 BHK (156sqm) (1.6A)	4.5 BHK (225 sqm) (1.7A)

Table 03 : There are three sub-types multi-family apartment blocks – 1) row-house and walk-up apartment blocks up to four stories high; 2) linear corridors types, and 3) tower blocks around vertical lift cores 6 to 12 stories high.

3.3 National Building Code and Building By-laws.

The Type Designs are consistent with the recommendations of the National Building Code (NBC) and the Model Building Bye-laws of the Ministry of Housing and Urban Affairs, GoI. In so far as most local building bye laws of Urban Local Bodies, Development Authorities and Municipalities are based on the NBC and the Model Building Bye-laws, the Type Design would be generally suitable for all cities. They may require some modification in case of special provisions in the local bye laws.

The NBC has included the Adaptive Comfort Model as a standard for design for Thermal comfort in India. The Code also lays down recommendations for window design from the point of view of daylighting and natural ventilation.

3.4 Eco Niwas Samhita, Part 1

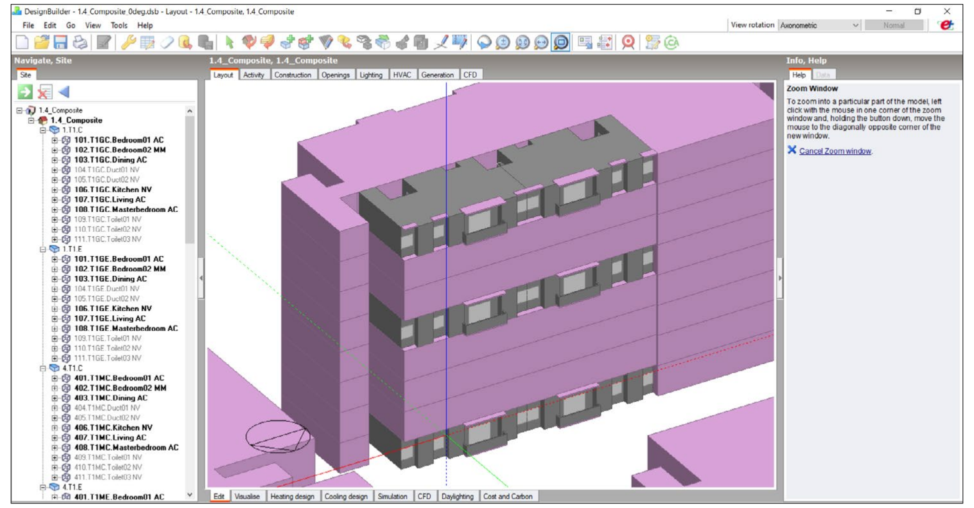
The Bureau of Energy Efficiency (BEE) has notified a code for the design of the external envelope of residential buildings from the point of view of thermal performance. This is the Eco Niwas Samhita Part 1; Building Envelope. The energy efficient Type Designs that we have developed in this project satisfy the RETV performance requirement of the building as its base case. This base case design is then improved step by step to achieve higher levels of energy efficiency.

04

Energy and Daylight Performance

4.1 Introduction to Energy and Daylight simulation

Through the process of energy simulation computer models of energy systems are built to analyse the building performance. The building designs in the catalogue – complete with architectural, mechanical and electrical systems are replicated in the energy simulation software to analyse the energy data, design effectiveness, the performance of different systems, energy demand, energy consumption etc.



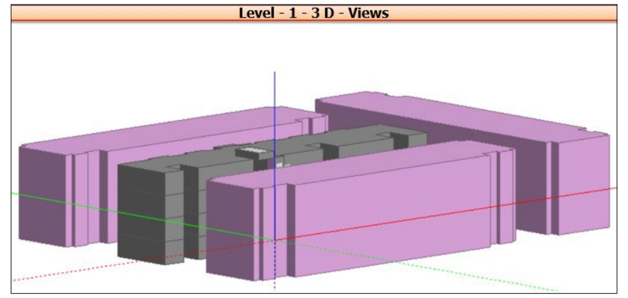


Figure 10 :
The building simulation model holds all relevant information including context in the Design builder model

Beginning this process at the initial stages of design helps make informed design decisions for the type designs in terms of material selection and opening sizes to optimise thermal comfort & energy performance.

This chapter discusses the simulation methodology followed for the Base, Moderate, Good & High levels of energy performance. For the highest level : Exemplary Passive house simulation is carried out with with the Passive House Planning Package (PHPP) using useful energy for heaitng and cooling as well as overall primary energy for the energy performance indicator. (PHI modeling is not discussed further in this chapter, please see chapter 5 for details)

Energy Plus is the energy simulation software used through the course of this project, using Energy Performance Index (EPI) to evaluate the Energy performance. This is the measure of annual energy consumption per unit built-up area (KWH/sq.m/year)

Daylight is also an important criterion of environmental comfort in residential spaces. Therefore this project also analyses the daylight performance of all living spaces within the unit. As part of daylight simulation, a software model is developed to calculate interior daylight levels in a space using real-world weather data files for a specific location. Daylight simulation is carried out on an annual basis. Design-Builder Software is used to calculate daylighting levels and Useful Daylight Illuminance (UDI) is used to measure daylight performance of each habitable space. The percentage of the area having an illuminance between 100 Lux and 3000 Lux for at least 50% of the potential day lit time is calculated.

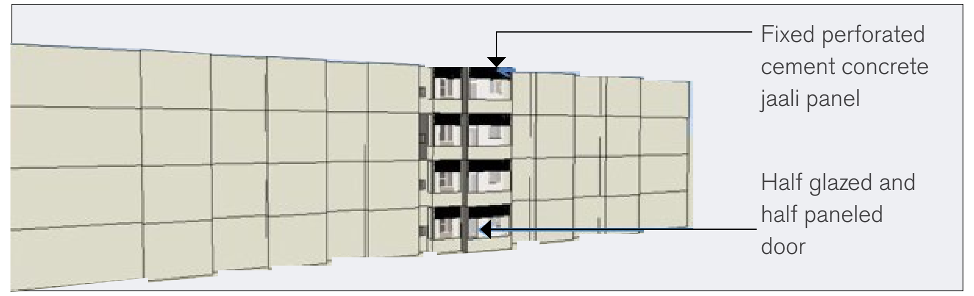


Figure 11 : Shading devices and screens are modeled as per design to get accurate daylight and EPI results

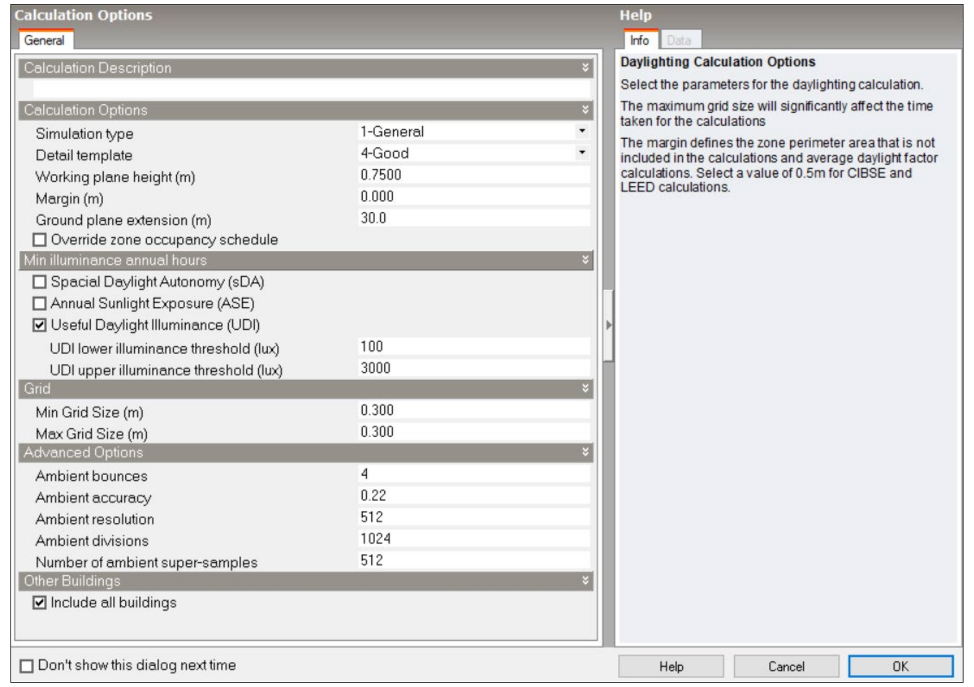


Figure 12 : Example of Daylight Simulation

4.2. Simulation Methodology

While doing energy performance analysis to predict EPI for Replicable Designs, energy consumption attributed to lighting and cooling/heating demand is calculated through simulations. The internally generated loads for equipment and occupancy are assumed, based on observed cultural trends. Annual energy simulations across different orientations are conducted.

Recognizing the fact that residential buildings that are built today would move progressively towards room air-conditioning, the project recommends additive improvement measures such as additional insulation, avoidance of thermal bridging, suitable ventilation systems, high-performance windows and air-tightness of the building fabric. This is presented as an integral part of a culture of cyclical home improvement and upgrade that occurs in the lifetime of typical buildings. Passive design plays a major role in reducing the air-conditioned hours.

4.2.1 Simulation Variants

For multi-story apartment designs simulations are carried out for typical unit layout situated in lower story, middle story and top story for both center and corner units to understand variation in thermal gains and energy performance based on the location of a unit within a multi-family building block. Each layout is assessed for 4 different orientations (0 deg, 90 deg, 180 deg and 270 deg). A base case representing the common present practice is established w.r.t Eco Niwas Samhita (ENS) Code for Residential Buildings against which the incremental cost of construction, reduction in discomfort hours and potential energy savings due to the reduction in air-conditioning demand is measured as the levels of performance keep improving.

4.2.2 Comfort Standards

The building designs ensure compliance with ENS Code requirements for a given climatic zone. The modelling methodology adopts the comfort standard used for the Residential Building Energy labelling program being developed by BEE viz. Approximately 25% of the building is considered to be air conditioned with a set point temperature of 24 deg C for cooling and 21 deg C for heating, while the remaining regularly occupied spaces work in mixed mode operation with set point temperatures based on the India Model for Adaptive Comfort (IMAC).

Mixed Mode Setpoint temperature (IMAC)

Lucknow	Cooling	Heating
January	26.8	22.04
February	27.72	22.96
March	28.97	24.21
April	30.19	25.43
May	30.22	25.46
June	29.4	24.64
July	28.48	23.72
August	28.12	23.36
September	28.19	23.43
October	28.09	23.33
November	27.66	22.9
December	26.86	22.1

For example, in the 2BHK dwelling unit, one-bedroom is considered conditioned with a set point temperature of 24 degC for cooling and 21 deg C for heating. The living room and the other bedroom is run on mixed-mode where the cooling and heating set point temperatures are derived from IMAC.

Figure 13

Sample image showing setpoint temperatures for the city of Lucknow based on the India Model for Adaptive Comfort (IMAC).

4.2.3 Input Parameters

Detailed inputs in terms of number floors, building geometry, envelope details, internal loads and active systems are provided in the simulation software. Internal loads are based on the current trends as observed, in the use of household appliances. Detailed natural ventilation modelling is carried out in Energy Plus. The schedule for window operation, based on temperature, is defined in the Energy management system for improved accuracy in modelling.

Figure 14: Input Parameters

<table>
<tr><th colspan="17">1.2B Row House (5persons)</th></tr>
<tr><th rowspan="2">Description</th><th colspan="4">Base</th><th colspan="4">Moderate</th><th colspan="4">Good</th><th colspan="4">High</th></tr>
<tr><th>0 Deg</th><th>90 Deg</th><th>180 Deg</th><th>270 Deg</th><th>0 Deg</th><th>90 Deg</th><th>180 Deg</th><th>270 Deg</th><th>0 Deg</th><th>90 Deg</th><th>180 Deg</th><th>270 Deg</th><th>0 Deg</th><th>90 Deg</th><th>180 Deg</th><th>270 Deg</th></tr>
<tr><th colspan="17">Building Envelope</th></tr>
<tr><th>Exterior Wall</th><td colspan="4">230mm thick Solid Burnt Clay Brick</td><td colspan="4">200mm thick AAC Block wall</td><td colspan="4">200mm thick AAC Block wall</td><td colspan="4">200 mm thick AAC Block wall with 50mm EPS wall insulation</td></tr>
<tr><th>Roof construction</th><td colspan="4">50mm thick EPS+Light coloured glazed tile</td><td colspan="4">50mm thick EPS+Light coloured glazed tile</td><td colspan="4">50mm thick EPS+Light coloured glazed tile</td><td colspan="4">50mm thick EPS+Light coloured glazed tile</td></tr>
<tr><th>Floor slab</th><td colspan="4">100 mm thick RCC slab</td><td colspan="4">100 mm thick RCC slab</td><td colspan="4">100 mm thick RCC slab</td><td colspan="4">100 mm thick RCC slab</td></tr>
<tr><th>Glazing (Exterior)</th><td colspan="4">50 mm Steel Frame; Single glazed Unit - U Value = 5.7 W/m2k, SHGC = 0.56, VLT=0.51</td><td colspan="4">50 mm Steel Frame; Single glazed Unit - U Value = 5.7 W/m2k, SHGC = 0.56, VLT=0.51</td><td colspan="4">50 mm UPVC Frame; Double glazed Unit - U Value = 1.64 W/m2k, SHGC = 0.36, VLT=0.52</td><td colspan="4">50 mm UPVC Frame; Double glazed Unit - U Value = 1.64 W/m2k, SHGC = 0.36, VLT=0.52</td></tr>
<tr><th>Glazing (Interior)</th><td colspan="4">50 mm Steel Frame; Single glazed Unit ST 167 - U Value = 5.6 W/m2k, SHGC = 0.67, VLT=0.67</td><td colspan="4">50 mm Steel Frame; Single glazed Unit ST 167 - U Value = 5.6 W/m2k, SHGC = 0.67, VLT=0.67</td><td colspan="4">50 mm Steel Frame; Single glazed Unit ST 167 - U Value = 5.6 W/m2k, SHGC = 0.67, VLT=0.67</td><td colspan="4">50 mm Steel Frame; Single glazed Unit ST 167 - U Value = 5.6 W/m2k, SHGC = 0.67, VLT=0.67</td></tr>
<tr><th>Door</th><td colspan="4">Timber frame and Timber Door - Conductivity = 0.144 W/m K</td><td colspan="4">Timber frame and Timber Door - Conductivity = 0.144 W/m K</td><td colspan="4">Timber frame and Timber Door - Conductivity = 0.144 W/m K</td><td colspan="4">Timber frame and Timber Door - Conductivity = 0.144 W/m K</td></tr>
<tr><th>Bamboo roll screens</th><td colspan="4">None</td><td colspan="4">Diffuse solar reflectance: 0.5 Diffuse visible reflectance: 0.20 Thermal Hemispherical emissivity Conductivity: 0.05 W/mk (Hardwood) Screen material spacing: 0.005m Screen material Diameter: 0.005m Screen to glass distance:0.9m in kitchen & Bedroom-1, 0.6m in Bedroom-2 Bottom opening multiplier:0.4 Top, left, right opening multiplier: 0</td><td colspan="4">Diffuse solar reflectance: 0.5 Diffuse visible reflectance: 0.20 Thermal Hemispherical emissivity Conductivity: 0.05 W/mk (Hardwood) Screen material spacing: 0.005m Screen material Diameter: 0.005m Screen to glass distance:0.9m in kitchen & Bedroom-1, 0.6m in Bedroom-2 Bottom opening multiplier:0.4 Top, left, right opening multiplier: 0</td><td colspan="4">Diffuse solar reflectance: 0.5 Diffuse visible reflectance: 0.20 Thermal Hemispherical emissivity Conductivity: 0.05 W/mk (Hardwood) Screen material spacing: 0.005m Screen material Diameter: 0.005m Screen to glass distance:0.9m in kitchen & Bedroom-1, 0.6m in Bedroom-2 Bottom opening multiplier:0.4 Top, left, right opening multiplier: 0</td></tr>
<tr><th>Window to wall Ratio</th><td colspan="4">22.55%</td><td colspan="4">22.55%</td><td colspan="4">22.55%</td><td colspan="4">22.55%</td></tr>
<tr><th colspan="17">Electrical loads</th></tr>
<tr><th>Interior Lighting power Density (W/m2)</th><td colspan="4">4.842</td><td colspan="4">4.842</td><td colspan="4">4.088</td><td colspan="4">4.088</td></tr>
<tr><th>Equipment loads</th><td colspan="4">3 star rated equipments</td><td colspan="4">3 star rated equipments</td><td colspan="4">4 star rated equipments</td><td colspan="4">5 star rated equipments</td></tr>
</table>

Figure 15

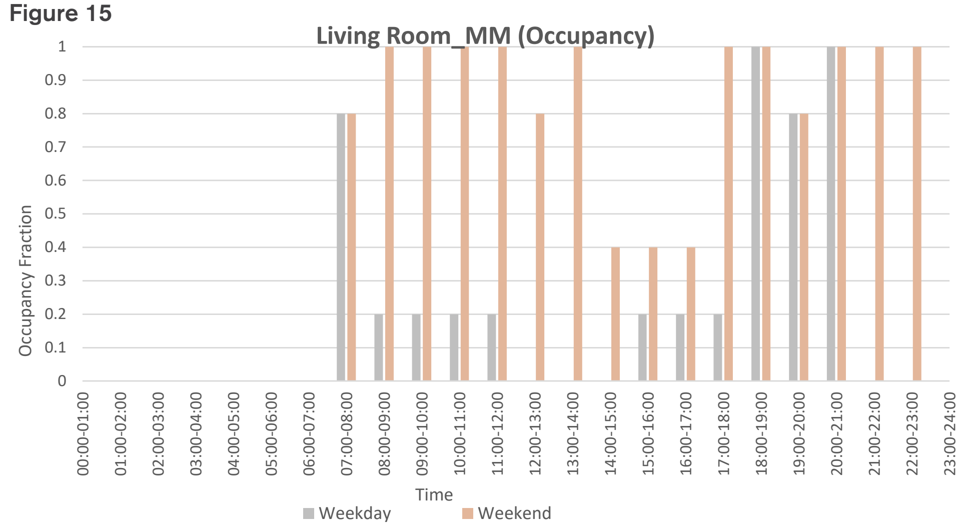


Figure 14 : Detailed parameters for all material specs, envelope, glazing, shading, electromechanical systems are fed into the simulation model . **Figure 15 :** Schedules for occupancy, lighting and equipment are established based on culturally prevalent norms

4.2.4 Minimum Compliance requirements

All designs are tested to achieve Minimum Energy compliance requirements based on existing codes and guidelines. These are discussed below:

▪**Building Envelope** requirements of the ENS Code– The building envelope requirements such as Openable Window-to-floor Area (WFR), Visible Light Transmittance (VLT) in windows, doors and ventilators, Window to Wall Ratio (WWR), Thermal transmittance of roof, Residential Envelope Transmittance Value (RETV) for the building envelope.

▪**EPI ranges** for Residential BEE Star Rating Plan – Bureau of Energy Efficiency (BEE) provides a Residential building Star Rating Plan based on the EPI values calculated for each climatic zone.

▪**Thermal comfort criteria** met as per - Indian Adaptive Thermal Comfort Model. The IMAC calculation tool is used to determine temperature set points for different climate zones and seasons

4.2.5 Key Performance Indicators

The key parameters used to measure and compare the energy efficiency and comfort of different building designs and their variations are discussed below:

1.Building Envelope Efficiency: This is measured by the RETV, which is the net heat gain rate (over the cooling period) through the building envelope, excluding the roof, per unit area of the dwelling unit. All unit designs should meet the base RETV < 15. Improved levels envelope design lead to decreasing values of RETV.

Key Performance Indicators-Envelope Performance

Residential Envelope Transmittance Value (RETV) — **Standard: ECBC – R**

Performance Indicator	RETV (Residential Envelope Transmittance Value)	Standard	Units	Simulation required
Building Envelop Efficiency	RETV - net heat gain rate (over the cooling period) through the building envelope (excluding roof) of the dwelling units divided by the area of the building envelope (excluding roof) of the dwelling units.	• All levels to meet an RETV < 15 • 4 levels of energy efficiency leading to decreasing values of RETV as the envelop performance increases	W/sq m	Calculation based on formula (wall area, window area, material properties)

Building Envelop Efficiency

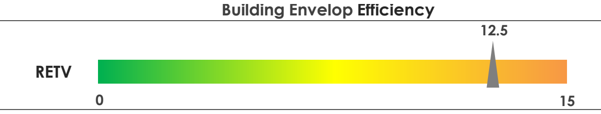


Figure 16 : **Envelope Performance indicator -** Residential Envelope Transmittance Value (RETV)

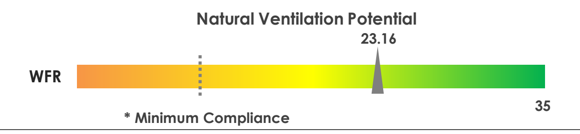
2.Natural Ventilation Potential: This is measured as Window to Floor Area Ratio (WFR). It is the ratio of the openable area of windows to the carpet area of dwelling units. All unit designs meet the minimum ECBC-R standard of ventilation.

Key Performance Indicators-Envelope Performance

Natural Ventilation Potential

Performance Indicator	WFR (Window to Floor area Ratio) Unit %	Remarks	Units	Simulation required
Natural Ventilation potential	WFR -Is the ratio of openable area to the carpet area of dwelling units.	• Meet min. standards of ventilation (WFR) as per ECBC-R requirements	%	Calculation based on formula (wall area, window area, material properties)

Natural Ventilation Potential



Climatic zone	Minimum WFR_{op} (%)
Composite	12.50
Hot-Dry	10.00
Warm-Humid	16.66
Temperate	12.50
Cold	8.33

Figure 17 : **Envelope Performance indicator -** Window to Floor Area Ratio.

3. Thermal Comfort: This is measured as % of hours in one annual cycle that are comfortable using only Natural ventilation. IMAC defines comfortable temperature range for naturally ventilated spaces for each climate zone/city. By energy simulation, the percentages are derived. As the design of energy efficient, passive measures is enhanced the percentage of hours a space is within the comfortable temperature range also increases.

Key Performance Indicators- Thermal Comfort

Percentage of hours without Air conditioning

Performance Indicator	Percentage of hours without Air conditioning	Remarks	Units	Simulation required
Thermal Comfort	IMAC refers to India model for adaptive thermal comfort tool, has defined temperature set points for naturally ventilated spaces are considered for heating and cooling for all the selected cities.	•Energy performance performed to arrive at naturally ventilated hours for each space	%	Design Builder / Energy Plus

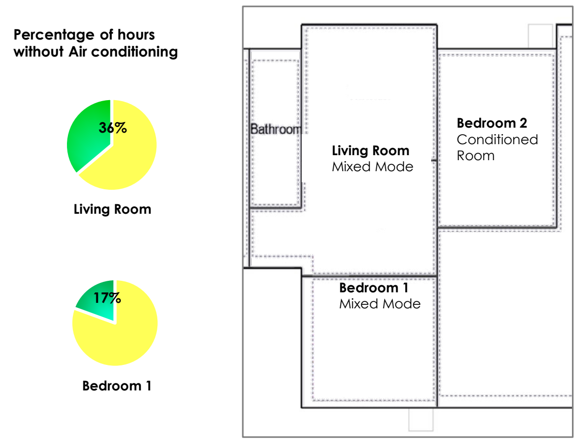


Figure 18 :
Envelope Performance indicator:
Thermal Performance indicator: Percentage of comfortable hours without air-conditioning

4. Visual comfort: This measures the access to natural daylight in the rooms of a residential unit. A standard of sufficient daylight has been assumed – that the daylight illumination in a room should lie between 100 lux and 3000 lux for at least 50% of potential daylight hours (8am to 5pm) in a year. This is represented in two ways. A graphic representation on the floor plan shows the distribution of daylight in each of the habitable spaces. Each room's Useful Daylight Index is also calculated, giving the % of daylight hours its average daylight illumination satisfies the standard. Daylight simulations have been carried out on Radiance based lighting simulation software.

Key Performance Indicators- Visual Comfort

Useful Daylight Illuminance (UDI)

Performance Indicator	Useful Daylight Illuminance (UDI)	Remarks	Units	Simulation required
Visual Comfort	Daylight simulation is performed to calculate interior daylight levels in a space for a specific location.	• Daylight performance of a typical dwelling unit is assessed by the Percentage of hours receiving UDI (between Level - 100 Lux to 3000 Lux) in a year for 50% potential daylit time (8 am – 5 pm)	%	Daylight (UDI) Software: Design Builder/Energy Plus

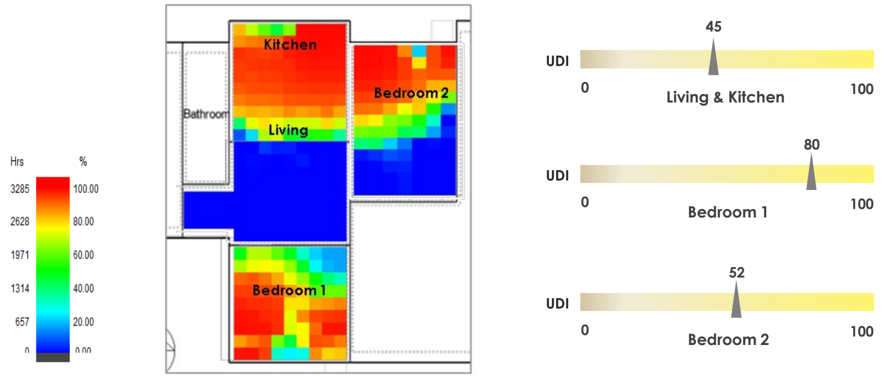


Figure 19 : **Envelope Performance indicator -** Visual Comfort Indicator - Useful Daylight Illuminance (UDI)

5.Energy performance: This is measured as Energy Performance Index (KWH/sqm/year). BEE is developing a Residential Building Star Rating Plan based on the EPI values for each climatic zone. The EPI of the unit designs in the Catalogue may be compared with the BEE's Residential Building Energy Labelling Program. As we adopt better energy conservation measures, the energy performance improves and EPI reduces.

Key Performance Indicators-Energy Efficiency

Energy Performance Index (EPI)

Performance Indicator	Energy Performance Index(EPI)	Standard	Units	Simulation required
Energy Efficiency	Bureau of Energy Efficiency (BEE) provides a Residential building Star Rating Plan based on the EPI values calculated for each climatic zone.	• EPI Calculation for Composite, Hot & Dry and Warm & Humid = EPI for air conditioned spaces (25% area) with 24 deg C as set point (E1) + EPI for other spaces (75% area) with natural ventilation (E2) set points defined by IMAC with Air conditioner switched ON* • For Temperate: 100% area operated at IMAC-NV set-point temperature • Energy saved, cost of energy saved and reduction in co2 emission	kWh/sq m /year	Energy simulation through Design Builder/ Energy Plus

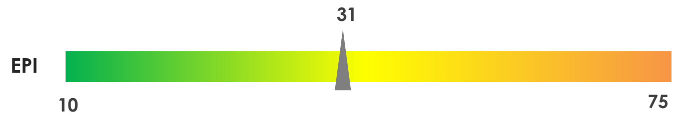


Figure 20 : **Envelope Efficiency -** Energy Performance Index (EPI)

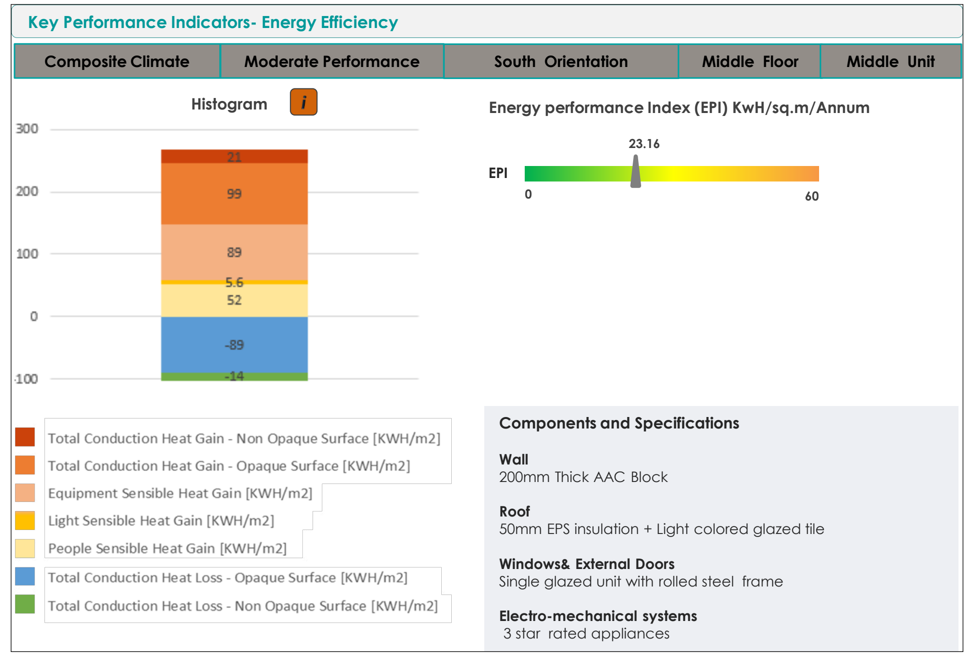


Figure 21 : **Envelope Efficiency -** Energy Performance Index (EPI)

4.2.6 Levels of Energy Efficiency

The study documents 4 levels of energy efficiency that are achieved for the same unit layout by improving its envelope design and the efficiency of the heating/cooling devices. Stepwise improvements in the building envelope design and the selection of heating/cooling devices produce the successive levels of energy efficiency. All levels comply with the basic requirements of ECBR-R and fall between 1-star to 5-star EE rating

for residential buildings of the BEE. These EE levels are derived from computer simulations. The simulations adopt comfort standards that are currently prevalent for most households in India.

For some selected designs for each of the climate zones, the energy efficiency performance approaching the possibility of Net Zero carbon emissions are reported. This requires the use of advanced construction techniques and heating/cooling devices. These are discussed in the following chapter.

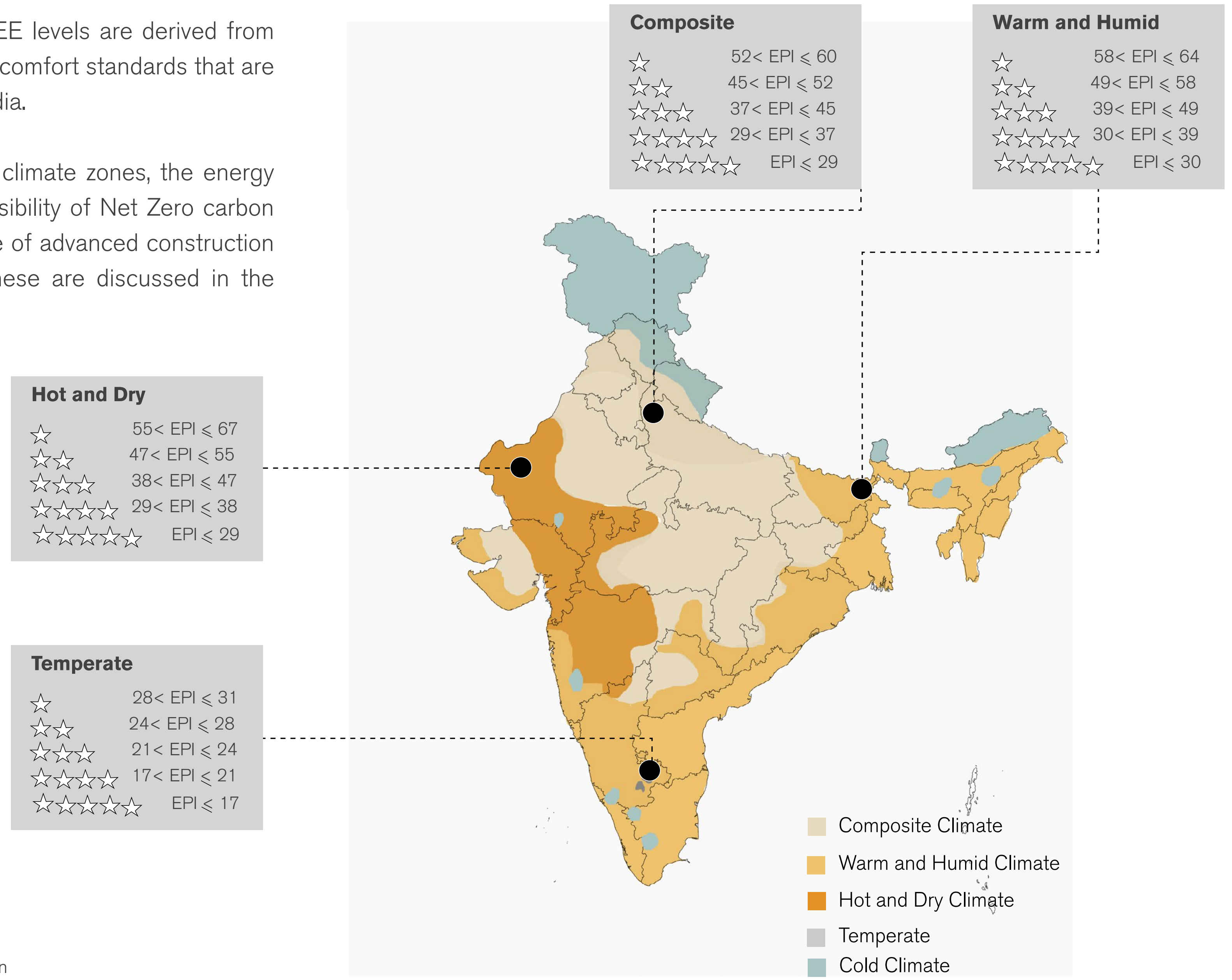


Figure 22: BEE's Residential Building Star Rating Plan

Passive House prototypes in Morelia, Mexico © Passive House Institute

05

Exemplary Passive House

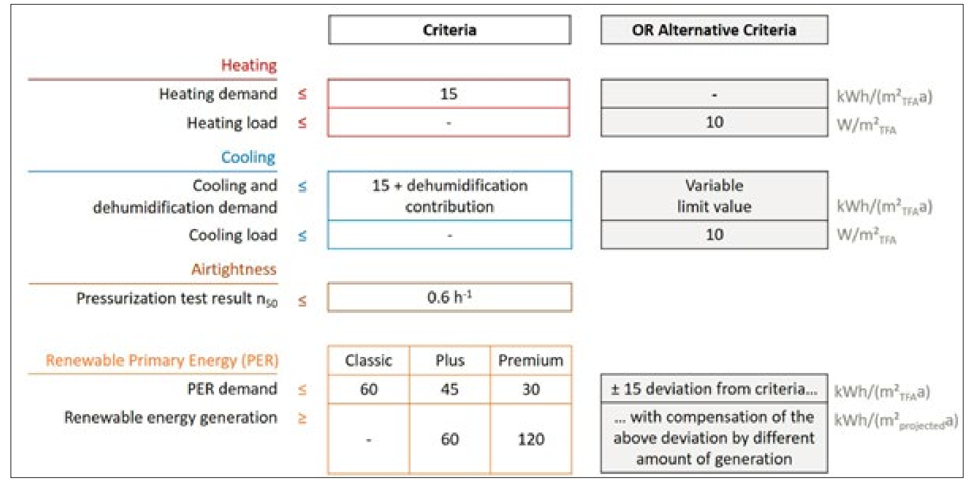
5.1. Introduction

The Passive House standard is an international standard for high performance buildings. It is mostly known for drastically reducing the energy demand: such buildings consume up to 90% less heating and up to 80% less cooling energy than existing buildings, depending on climate. At the same time, they provide better living and working conditions to their occupants (comfortable temperatures, no drafts or mould, good indoor air quality). In addition these buildings are also future-proof, because they won't need a deep retrofit already in the next decade and people will be able to afford their low operation costs. As part of this study, 5 prototypes were selected to be optimized to the Passive House standard in the selected climate regions allowing to show the technologies needed in different climatic conditions.

5.1.1. Passive House criteria :

New buildings must meet the following performance-based targets in order to comply with the Passive House standard, with the entire dwelling unit kept at 20°C during the heating period, 25°C during the cooling period and an absolute humidity of maximum 12g/kg (60% relative humidity at 25°C). The criteria shown in Figure 23 apply for all climates worldwide.

The variable limit value for cooling and dehumidification demand is subject to climate data, necessary air change rates and internal moisture loads of the building (calculation in the PHPP). All the energy demands of the building are considered in the primary energy calculation: heating, cooling, dehumidification, DHW, lighting, auxiliary electricity as well as



		Criteria			OR Alternative Criteria	
Heating						
Heating demand	≤	15			-	$kWh/(m^2_{TFA}a)$
Heating load	≤	-			10	W/m^2_{TFA}
Cooling						
Cooling and dehumidification demand	≤	15 + dehumidification contribution			Variable limit value	$kWh/(m^2_{TFA}a)$
Cooling load	≤	-			10	W/m^2_{TFA}
Airtightness						
Pressurization test result n_{50}	≤	$0.6\ h^{-1}$				
Renewable Primary Energy (PER)		Classic	Plus	Premium		
PER demand	≤	60	45	30	± 15 deviation from criteria...	$kWh/(m^2_{TFA}a)$
Renewable energy generation	≥	-	60	120	... with compensation of the above deviation by different amount of generation	$kWh/(m^2_{projected}a)$

Figure 23 : Performance based target for Passive House standard. [Source - PHI 2016]

electrical appliances. *More details about the Passive House criteria can be found online.*

5.1.2. Comfort definition :

Thermal comfort generally depends on air temperature, radiative temperature, humidity and air velocity. The right combination of these parameters depends mainly on a subject's activity and clothing. There are currently two different approaches regarding thermal comfort: the first are the heat balance models, which basically assume that thermal comfort is achieved if the body temperature can be held in a narrow range, skin moisture is low and physiological effort of regulation is minimized ([ASHRAE 2005] and [ISO 7730]). On the other side, adaptive comfort models claim that a much broader temperature range is considered comfortable by users of free-running buildings because they can adapt to varying boundary conditions.

As soon as active cooling/ heating is available and affordable, the expectation of comfort indoors rises to fall in line with the ISO 7730 comfort standards. Moving towards highest levels of energy efficiency and achieving the goal of net-zero energy requires stricter controls of indoor environments with the higher standards of comfort.

Figure 24 : The Passive House standard uses a comfort definition according to ISO 7730 [Source ISO 7730].

For the type designs, the initial stages of improvement as modelled by LEAD follow the adaptive comfort model with affordable mixed-mode systems, whilst the high performance Exemplary Passive House level will refer to the ISO 7730 model moving towards more controlled air-conditioned space solutions wherever necessary. Please note that this means that the calculation results of energy needs are not directly comparable. If the initial stages of improvement were to be operated at the higher ISO 7730 comfort levels the cooling demand is expected to be considerably higher.

5.2 Passive house Principles

5.2.1.General strategies

The Passive House approach is a whole house approach. This means that the high energy efficiency can only be achieved through the interaction between the different energy measures: the whole is more than the sum of its parts. It is a design task to optimise the building as a whole in its orientation, layout, compactness and finally the quality of components to achieve high thermal comfort under the given local climate conditions. The general idea is to keep the heat inside in cold climates and the heat outside in warm climates, which can be achieved by applying the following principles (beside a good orientation):

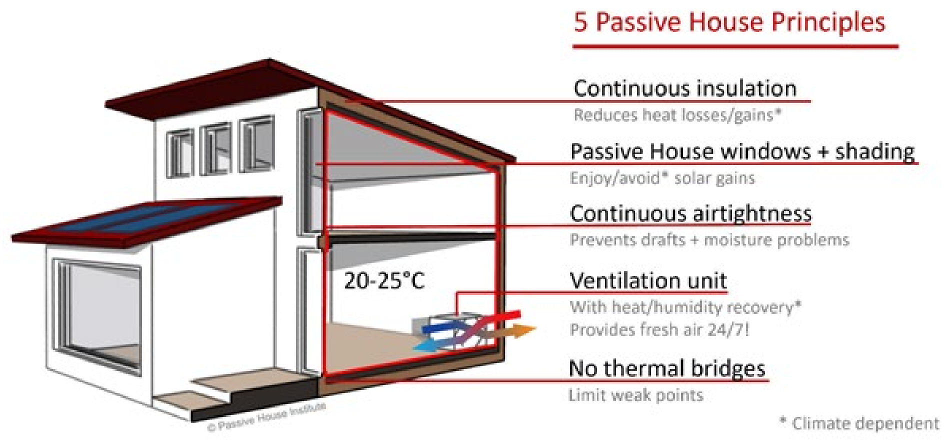


Figure 25 : The five Passive House Principles. [Source PHI]

5.2.2. Insulation

A continuous insulation layer throughout the thermal envelope, including the slab, is the starting point. Only in certain cases, an uninsulated slab may be beneficial, as the earth can then be used as a seasonal buffer. This, together with the optimal insulation thickness for the specific climatic requirements and characteristics of the project, can be defined through the energy balance calculation.

For insulation, it is also important to consider elements such as fire humidity and wind protection, and how the insulation will be fixed to the wall: low conductivity fixing (e.g. plastic fasteners like on the picture right) should be used.

Figure 26 : Plastic fasteners for insulation [Source PHI]

5.2.3. Windows/doors

Depending on the climate, single, double or triple glazing may be needed. For instance, if there is a high temperature difference between the interior of the building and the outside, glazing with a low U-value will be required, for example, triple glazing. Noble gas filling and low-emissivity coating (which suppress heat radiation to escape), can further reduce heat losses/gains.

Another important characteristic value of the glazing is the g-value, also called total solar energy transmission. It defines how much energy is transmitted from direct solar radiation and from secondary heat emission from the outside towards the inside. In heating-dominated climates, the g-value should be between 50 and 60%, to let in enough solar energy in the winter. However, in hot climates where solar gains are unwanted, the g-value should be significantly lower, around 30% and windows should be shaded with moveable or fixed shading devices, preferably on the outside.

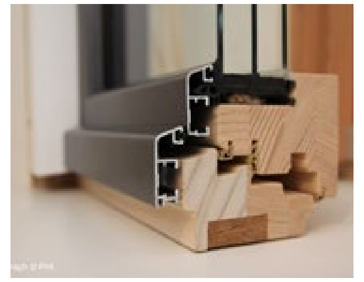


Figure 27 : Triple Glazed Windows [Source PHI]

The different glass panes should be separated using low conductivity spacers (e.g. plastic spacers) and the frames should have at least 2 airtight seals. Furthermore, it is best if the insulated frame is slim, to allow for more daylight (and solar gains in heating climates).
By installing windows and doors aligned to the insulation layer of the wall system, the installation thermal bridges can be reduced. In hot climates, this should be evaluated against locating the windows aligned to the interior of the wall to increase shading – the most beneficial in terms of the energy balance should be used.

5.2.4. Airtightness

One single continuous airtight layer on the thermal envelope is needed to improve living comfort. This prevents undesired infiltration of outside air and humidity, drafts, entry of pollutants into the room, and making controlled ventilation possible as well as enhances noise protection. This layer would be usually on the interior surface in heating dominated climates, while in hot and humid climates it may be more beneficial to have it on the exterior.

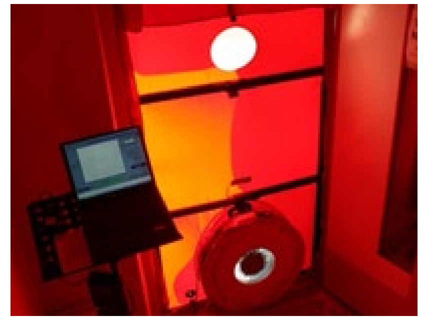


Figure 28 : Airtightness test [Source PHI]

In solid construction, concrete surfaces can be considered airtight, but masonry is not airtight by itself. In this case, applying a sufficiently thick plaster layer will be needed. It is important to apply it also in hidden spaces (e.g.: behind WC and equipment) and to make sure any perforations are sealed (e.g.: sockets). Connections between different airtight surfaces or at the edge of components penetrating the envelope like ducts and pipes should be made airtight by using tapes and other products designed for this purpose. In all cases, manufacturer instructions must be followed to guarantee the correct installation of the airtightness products.
Passive House airtightness levels can reliably be achieved once designers have gained some experience. To verify the airtightness level achieved in practice, a test must be carried out. It is recommended that the airtight layer is still accessible to allow for improvements during the test.

5.2.5. Ventilation

To ensure occupants receive enough fresh air, a good ventilation strategy is needed. Instead of relying only on natural ventilation through windows and possible openings in the façade, the Passive House concept includes mechanical ventilation with controlled air flow rated to ensure a fresh and filtered air supply at all times. Depending on climate, the ventilation system may be only for extract air or a combination of supply and extract with heat recovery or heat and humidity recovery. In milder climates, using a ventilation system without heat or energy recovery may be sufficient, since the temperature difference between the inside and the outside may not be enough to justify the additional investment cost required for such a unit. In hot climates or cold climates, a ventilation unit with heat/humidity recovery will reduce the heating and cooling demand while keeping a high indoor air quality.

Figure 29 : Ventilation Units [Source PHI]

Each unit should have efficient fans (electric power < 0.45 Wh/m^3), suitable air filters (F7 / G4), and a heat recovery rate higher than 75%, where applicable. The system should be designed to prevent any noise transmission between the different rooms and the ventilation unit itself should also produce limited noise.

5.2.6. Thermal bridges

A thermal bridge is an interruption of the thermal insulation layer - a localised area of the building envelope where the heat flow is different (usually higher) in comparison with adjacent areas. These "weak" points should be avoided because they increase the energy demand, especially in climates where the difference between the indoor and outdoor temperatures is high.

Sino-German Eco Park | ID4674

Figure 30 : Limited number of punctual thermal bridges [Source PHI]

Thermal bridges can be minimized following these rules:

•**Connection Rule:** the insulation layers from different building components merge into each other without interruption when these components connect with each other.

•**Avoidance Rule:** prevent any interruption of the insulating envelope where possible (e.g. use a balcony with a separate structure or limit the number of corridors)

•**Penetration Rule:** If penetration is unavoidable, the thermal conductivity of the penetrating material should be as low as possible and the cross section as small as possible (e.g. plastic or stainless steel brackets)

While the concept is the same, the strategies must be adapted according to the different climate conditions. The strategies recommended in heating and cooling dominated climates as well as in temperate climates are described below.

5.3 Strategies for exemplary passive house energy performance

5.3.1. Strategies in heating-dominated climates

In heating-dominated climates like Srinagar, the main objectives are to keep the heat inside the building and to take advantage of solar and internal heat gains.

Figure 31 : Photo of Bahnstadt Heidelberg | ID 3879 [Source PHI]

A compact building design proves to be a very significant factor in terms of a building's energy performance and should be optimised first before applying energy-efficiency measures such as insulation. If a small Area /Volume ratio is combined with an optimised orientation and window size, financial and energy benefits can be achieved more easily. In addition, less insulation also means energy savings in terms of the production of the materials and their installation. Besides adequate insulation levels and the avoidance of thermal bridges, double to triple glazing with high solar transmission is recommended in most cases. Most windows should be on the South façade. Furthermore, a good airtightness and heat recovery ventilation will help to limit heat losses through the air flow.

5.3.2. Strategies in cooling-dominated climates

Three of the five climate zones in India can be considered as cooling-dominated. The warm and humid climate zone features high humidity levels and thus requires a focus on reducing the energy need for dehumidification. In the hot and dry climate zone the main design task is less on dehumidification but more on protecting from the high outdoor temperatures. The composite climate zone also has some cooler winter months and calls for balanced design choices that provide comfort during both the cold and the warm seasons.

Most importantly, heat loads should be limited, as the need for cooling is related to unwanted heat in the building. Both internal and external heat and humidity loads affect the need for cooling and dehumidification. Internal heat gains can be limited by choosing energy efficient appliances and electronic devices, and paying attention to the electrical efficiency of the fans. In addition, warm water pipes and tanks should be insulated to avoid unwanted heat in the rooms – in hot climates it might be best to install the hot water tank outside the building envelope.

To limit external heat gains, sufficient insulation levels in the thermal envelope are needed. Using light colours or even reflective coatings or "cool colours" (absorptivity lower than 0.2) for the roof is recommended. Airtightness is also important to limit unwanted heat and humidity gains through leaks. Installing fixed or movable shading is an essential factor in limiting limiting solar heat gains. In general, large windows to the east or west should be avoided.

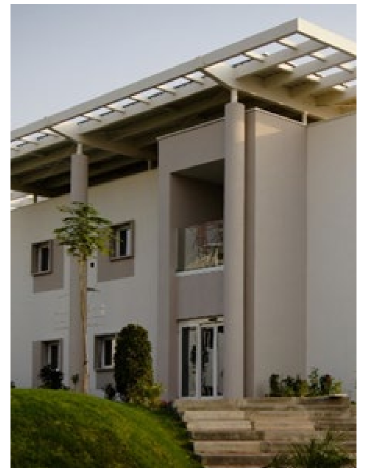


Figure 32 : First Passive House building in Dubai | ID 5065 © MBRSC/Dubai

Depending on the climate, double or triple glazing may be needed, coatings for solar control to achieve a low g-value are recommended. Finally, an efficient ventilation system with heat and/or humidity recovery will also be helpful. In the climates of Lucknow, Aurangabad and Bhubaneswar it will prevent air at high temperature and high humidity from entering the building through the fresh air flow. For similar reasons it is also recommended to use a recirculation instead of extract hoods in the kitchen.
Window ventilation is an important passive cooling measure but only when outdoor conditions are similar to or cooler than the indoor climate (especially night flushing). Open windows during hot and humid periods is counterproductive as it will lead to an increase in temperature and humidity levels.
If all these passive strategies are not enough to limit the overheating frequency to 10% of the year or less, then active cooling is needed. But the remaining cooling demand and cooling load will be much smaller than in conventional buildings once the strategies described above are implemented – thus allowing for smaller and alternative active cooling systems.

In most cases the fresh air provided through the ventilation system may be enough to supply the cooling load without the need for recirculation. There are different possibilities for active cooling systems, the most common being split-units. In any case it is important to ensure a high overall system performance. If split units are being used they should have a high COP, variable air volume, noise protection and a standby power consumption below 1 W. In efficient buildings with lower cooling loads, cooling systems can operate at lower air speeds and supply air at higher temperatures, thus ensuring more comfort at lower operational costs.

It is of critical importance to understand the dehumidification need of a building and the sensible heat ratio (i.e. the fraction of sensible and latent cooling needs). The lower the sensible cooling need in an highly energy efficient buildings, such as Passive Houses, the higher the relative fraction of dehumidification. Additional dehumidification may be required, especially during monsoon seasons. For most efficient solutions it is recommended to use an active cooling system that allows independent control of sensible cooling and dehumidification.

5.3.3. Strategies in temperate climates

In temperate climates like Bengaluru, the requirements are usually lower: A few centimetres of insulation and single to double glazing with solar protection may suffice.

Figure 33 : Passive House in Mexico City | ID 2959 © Moritz

Thermal bridges should always be avoided, but would have less of an impact than in more extreme climates. Reflective coatings are recommended for the roof. With the appropriate passive design strategies, very little active cooling will be required in such climates to keep temperatures between 20 and 25°C. As mentioned previously, using a ventilation system without heat or energy recovery may be sufficient in such climates e.g. a simple extract ventilation approach.

06

Introduction to Web Portal

The web-based platform is a learning tool that helps designers, builders and promoters of residential buildings to understand the ways of designing energy efficient residential buildings.

The tool covers various aspects of energy efficient design for residential buildings bringing to the user sample designs with detailed simulations and identified criteria for measuring the performance of the building. The platform provides type designs and the energy efficiency performance for a wide range of residential building types and sizes of residential units in different climatic regions.

With the help of this tool a user can select the most suitable Energy Efficiency Measures (EEMs) applicable to their building to reach a desired performance bench mark. Further, the Web Portal provides access to technical data for representative type designs. This comprises of architectural and MEP drawings, Bills of Quantity with cost estimates and the simulation data files for thermal and daylight performance. The parametric assumptions for the simulations and the simulation methodology is also explained. This enables the technically proficient users to customise the type designs and to try variations for optimal performance and cost-benefit.

6.1. Web tool

The web-tool is interactive as well as informative. It gives background information and theoretical explanation at each step in order to serve as a learning tool. It takes the user through design options for each climate and size of dwelling unit. It brings to the user detailed information on the simulation results in the form of selected key indicators. In the end it gives the users access to all working models for BIM and simulations in order to customise the design and work on it further.

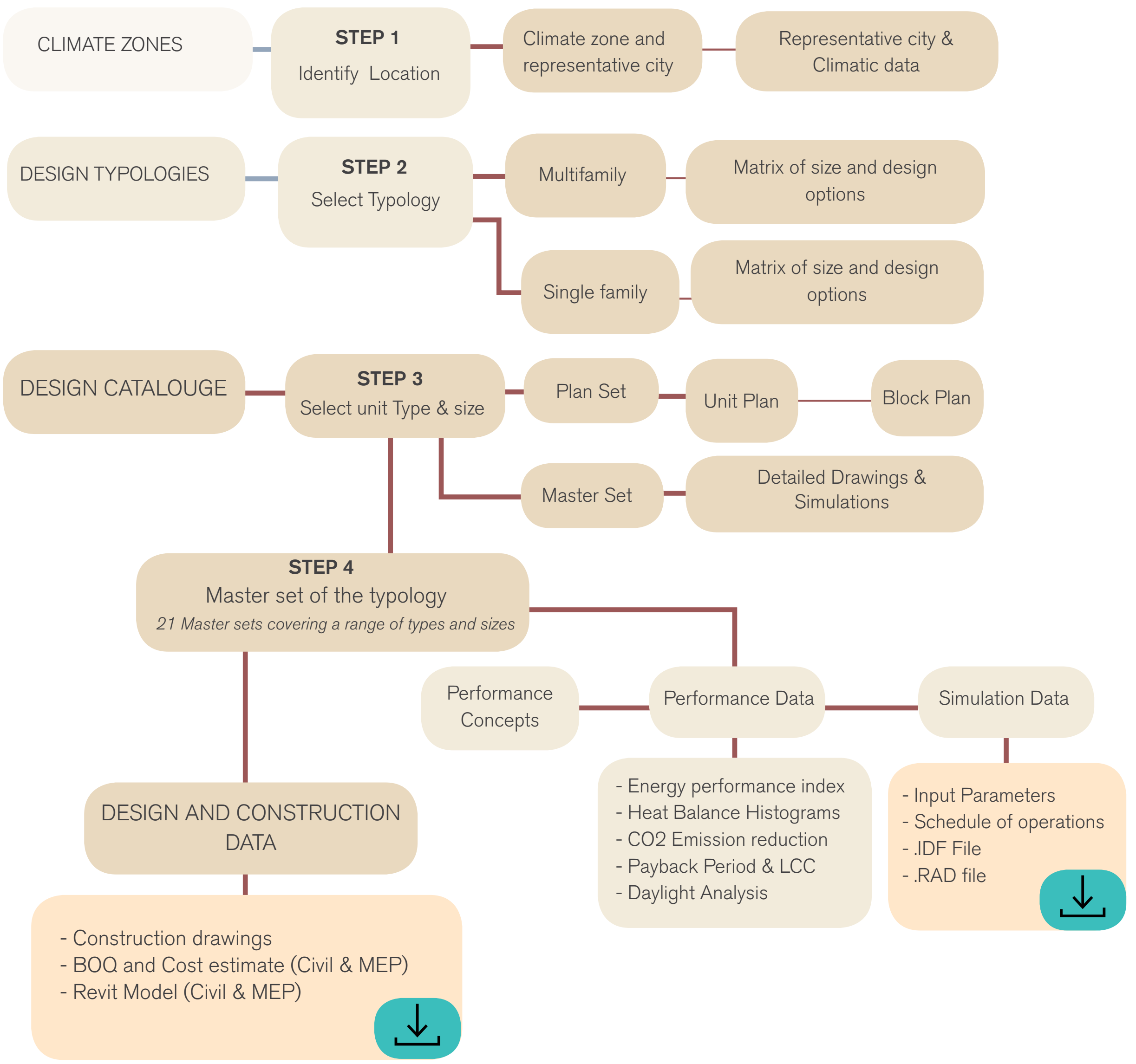


Figure 30 : Website map with the levels of information that the user can access

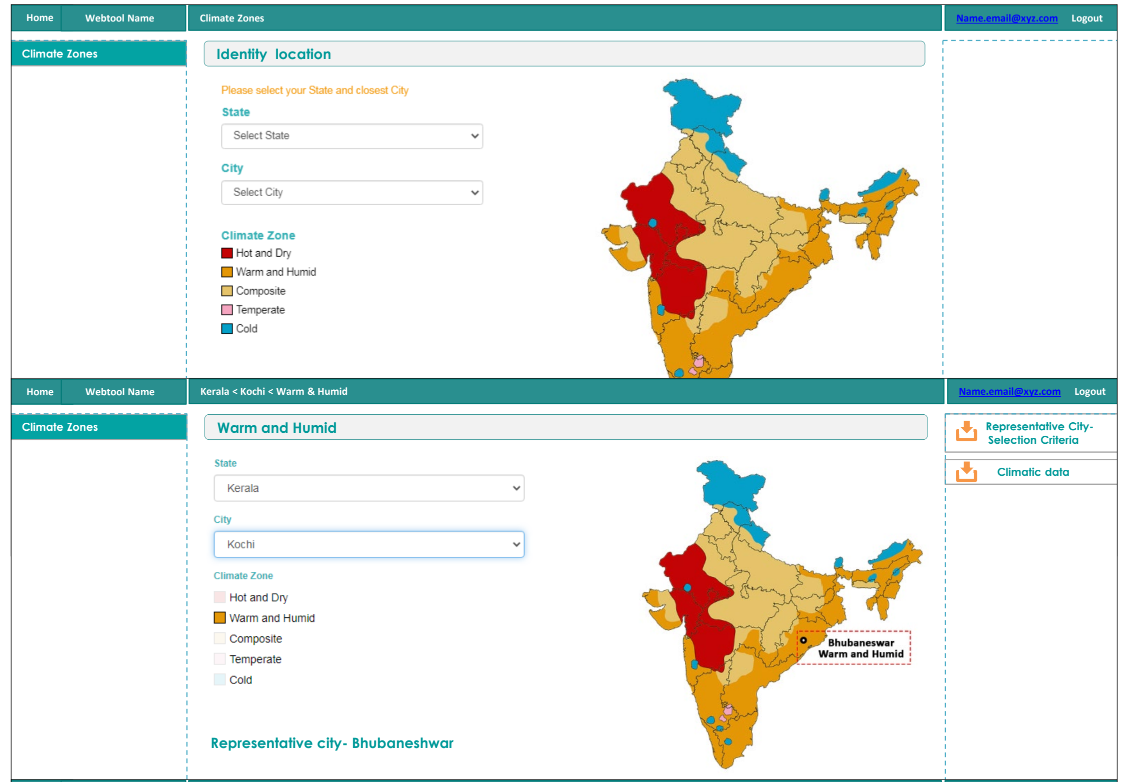
6.2. Illustration of website navigation

The following pages illustrate how users might navigate the website. The predominant use of the website would be by designers, developers and home builders to search the Type Designs most suitable for their project. They can review the key performance parameters of the selected type designs, for their climate zone. They can see design improvements to enhance the energy efficiency step by step and see their financial implications. They can download the technical drawings, BOQ to facilitate construction. Further, if they wish to refine or adapt the design, they can download the simulation software files of the Type Design.

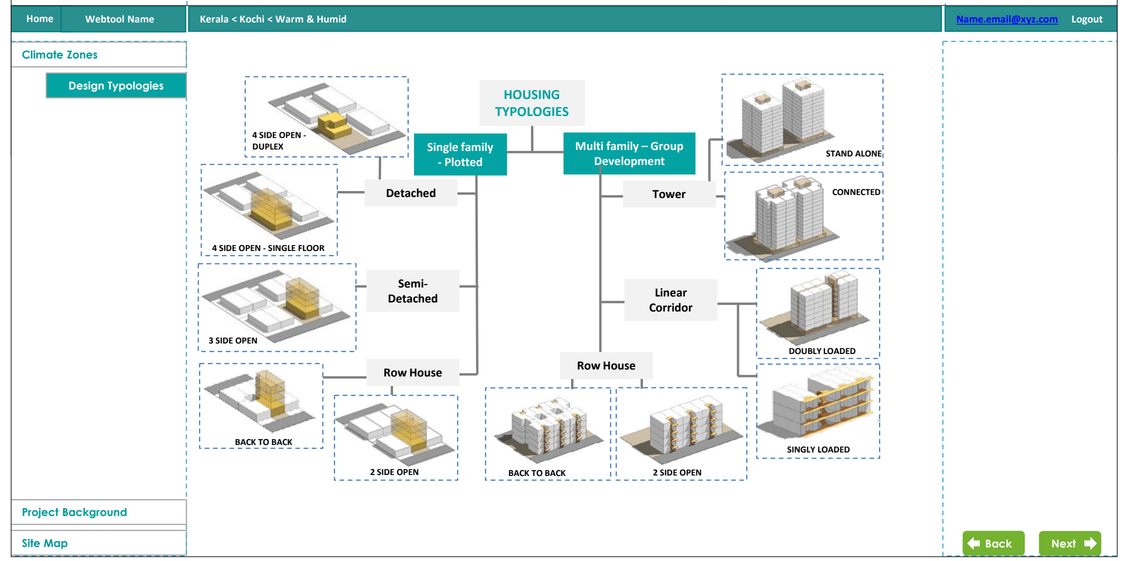
The tool is interactive and based on user inputs through a series of simple steps:

Figure 31:

A).Identifying the climate zone and representative city as per user's Location:



B) Then the user is prompted to select a type of residential building:



This section of the tool introduces the user to the range of residential typologies that have been included in the Catalogue to represent the current trends in single family- plotted homes as well as multi-family – group developments. The web tool offers detailed information and description for each typology for the users to make informed choices on the type of building they want to build.

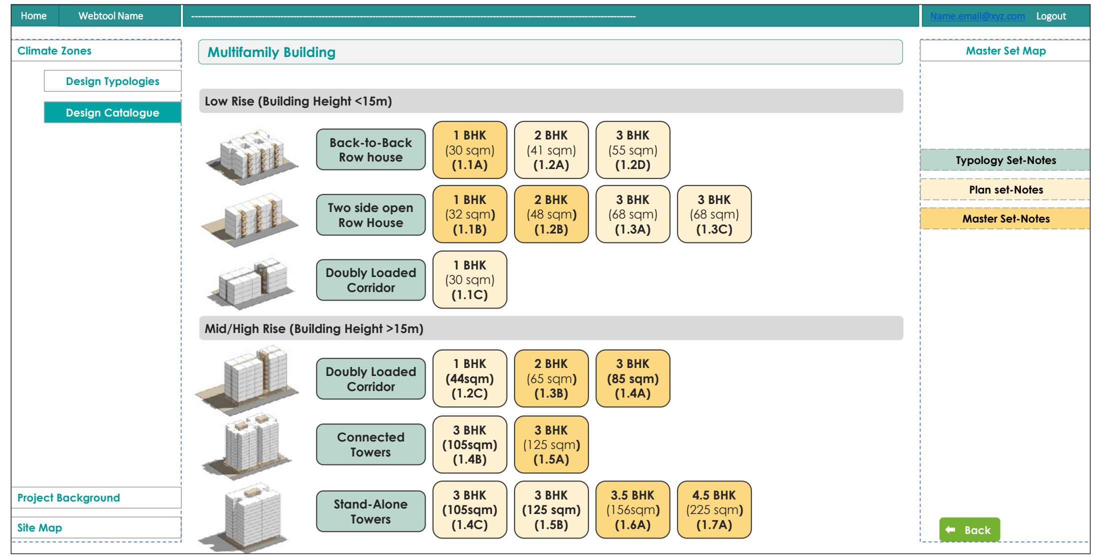


Figure 32 :

C) From the range of different sizes and plan configurations in each typology, the user can select a Master Set which is the representative unit for obtaining all detailed technical information for that typology.

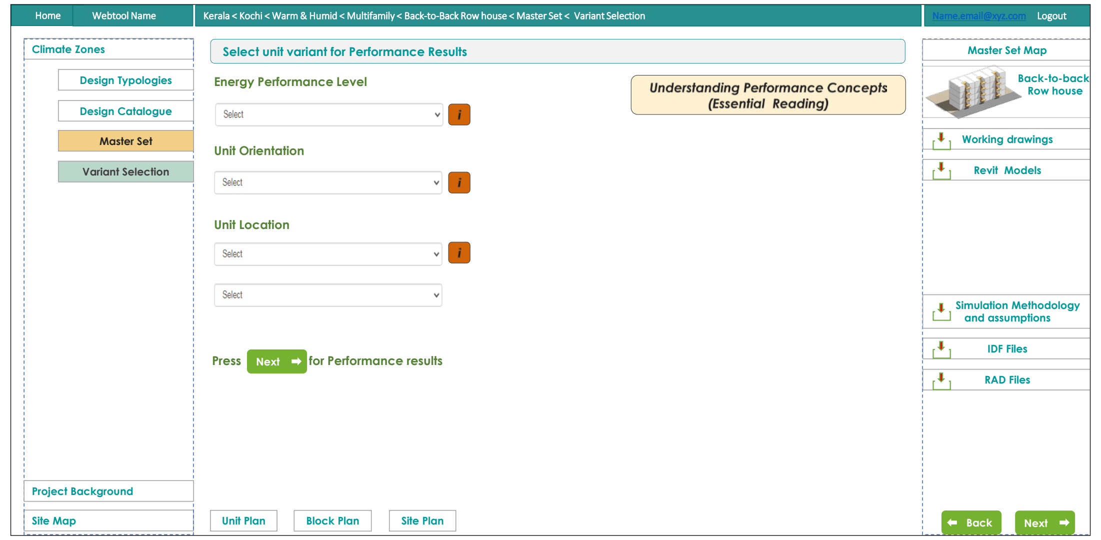


Figure 33 :

D). To access the simulation results for the selected master set, the user is prompted to identify the specific variant by three inputs :

1). The Energy Performance level they are interested in

2). The orientation of the building as per site conditions

3). The location of the unit in the building, i.e. the floor the unit is situated on and whether it is in the centre or the edge of the building

Unique results are displayed based on the inputs provided by the user

6.3. Master set

The Master Set is a representative unit of a typology which has technical information made available to the user of Type Designs so that they can be readily adopted or adapted for implementation in residential projects. Following detailed information is available for the user for each Master Set:

Since the principle of building design and construction is consistent across all sizes/ configurations in a given typology, e.g. a multiple of standard bays in row houses or different sizes of dwelling units in doubly-loaded corridor arrangement, the performance trends and construction details, as given for the Master Set, hold good for all dwelling units of that typology. Thus the Master Set gives guidance to the user to understand and apply the energy conservation measures to the similar units of that typology.

1. Design and Construction data

1.1 Revit Model

1.2 Construction drawings
- 1.2.1 Marking Plan
- 1.2.2 Block Layout
- 1.2.3 Site Layout
- 1.2.4 Elevations
- 1.2.4 Sections
- 1.2.5 Design variants detail
- 1.2.6 Detail Drawings

1.3 Bill of quantities and Estimate
1.3.1 Civil
1.3.2 MEP

2. Simulation and Performance data

2.1 IDF File
2.2 RAD File

2.3 Master sheet
- 2.3.1 Climate analysis
- 2.3.2 Schedule of operation
  - 2.3.2.1 Occupancy
  - 2.3.2.2 Lighting
  - 2.3.2.3 Equipment
  - 2.3.2.4 HVAC
- 2.3.3 Input Parameter sheet
  - 2.3.3.1 Building Envelope
  - 2.3.3.2 Electrical Loads
  - 2.3.3.3 HVAC system
  - 2.3.3 4Ventilation

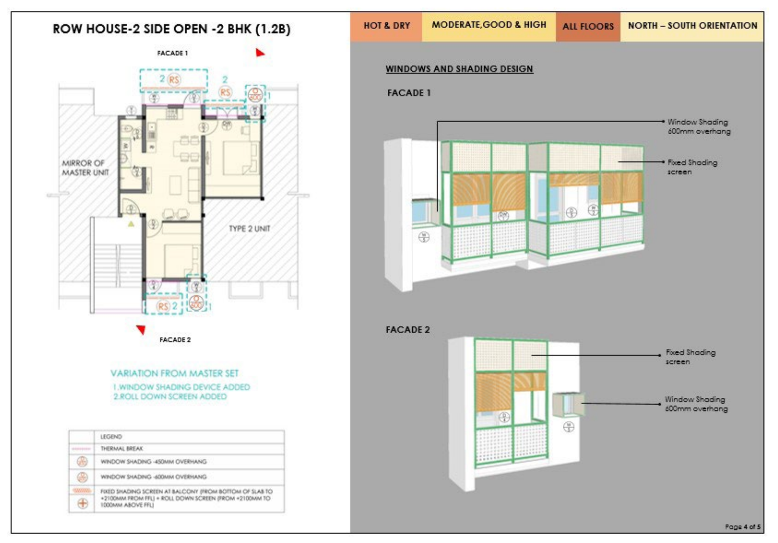
2.3.4 ENS Code compliance
- 2.3.4.1 WFR, WWR, VLT, URoof & RETV

2.3.5 Performance Indicators
- 2.3.5.1 Energy performance index
- 2.3.5.2 Heat Balance Histograms
- 2.3.5.3 CO2 Emission reduction
- 2.3.5.4 Payback Period & LCC
- 2.3.5.5 Daylight Analysis & False UDI renders
- 2.3.5.6 % of comfortable hours without AC

Additional information provided for PH cases
- .ppp file for PHPP energy modelling
- Examples for typical Passive House details
- Qualitative ventilation recommendations

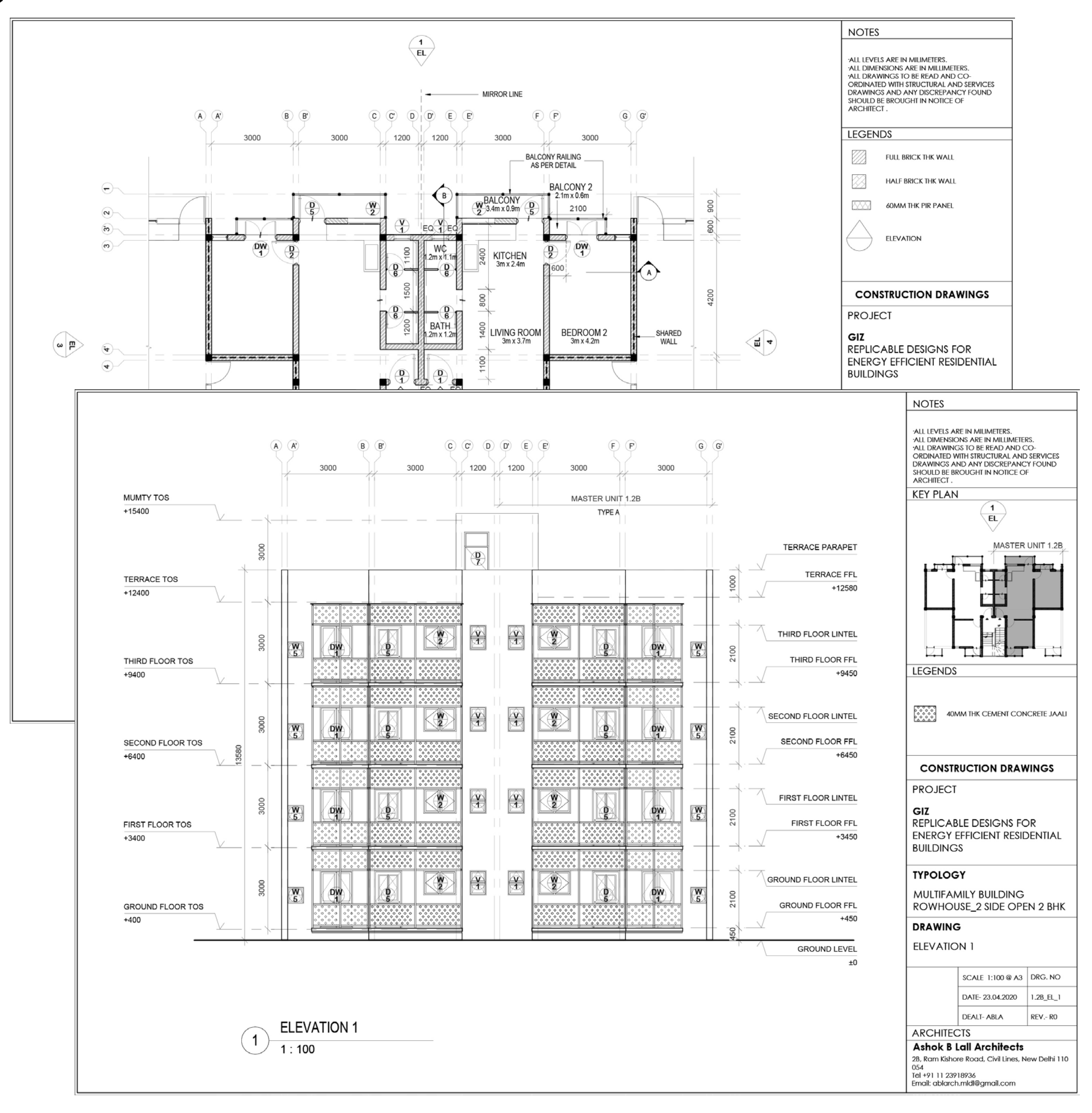

Revit Model

Shading Device variations



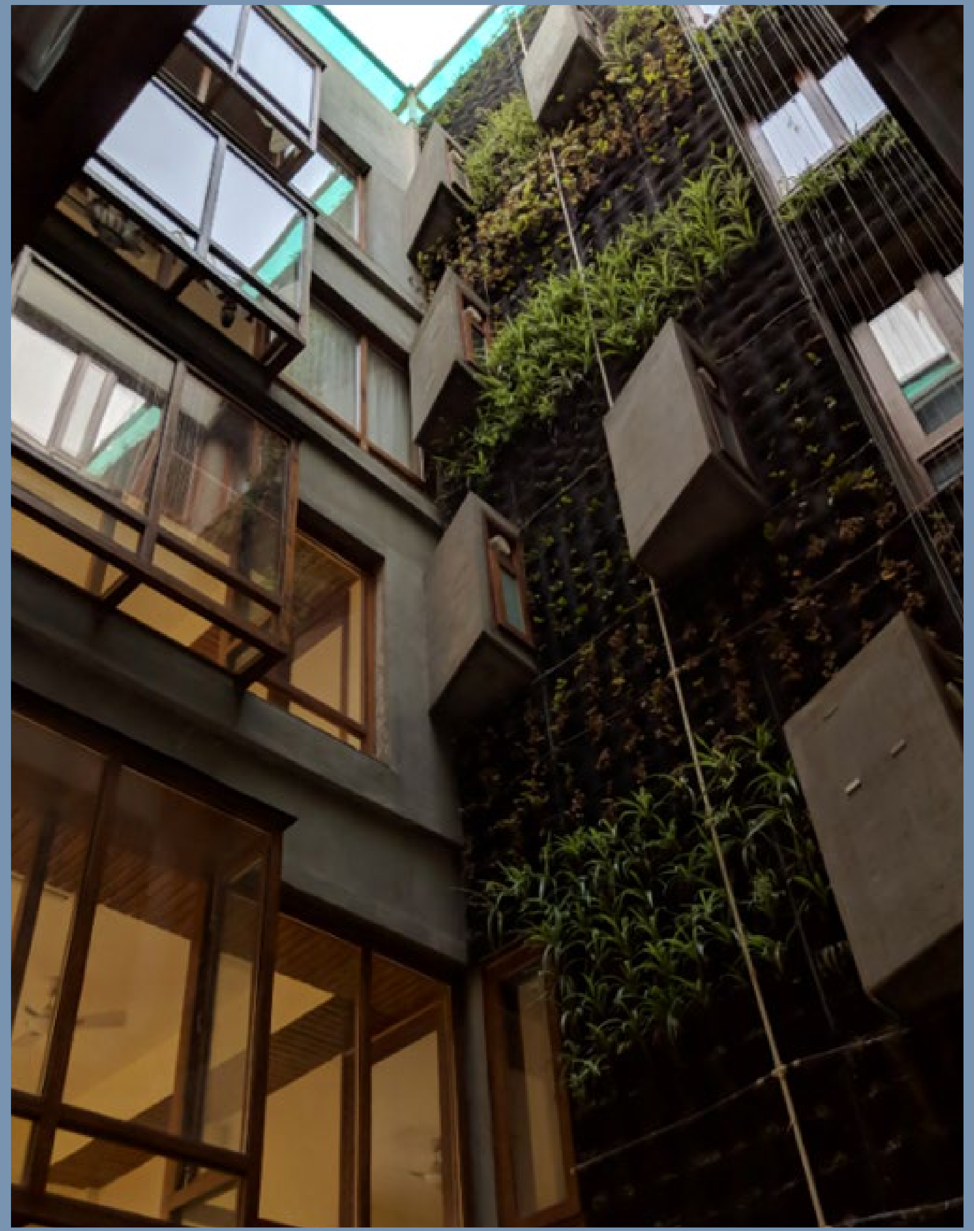
BUILDING TYPE 1.2B		COMPOSITE & HOT DRY							
		BASE		MODERATE		GOOD		HIGH	
		N & S	E & W	N & S	E & W	N & S	E & W	N & S	E & W
		Contribution of cost	Contribution of cost	Contribution of cost	Contribution of cost	Contribution of cost	Contribution of cost	Contribution of cost	Contribution of cost
Item of Work		Amount	Amount	Amount	Amount	Amount	Amount	Amount	Amount
CIVIL WORK (Building Envelop)		74.3%		72.3%		62.7%		56.1%	
TOTAL		275259		262874		262874		262874	
DOOR, WINDOW & BALCONY		16.1%	17.4%	18.0%	18.9%	29.0%	29.7%	25.9%	26.6%
TOTAL (Composite & Hot dry)		59779	65415	65453	69664	121499	125711	121499	125711
FINISHING (External Walls & Terracing)		8.3%		8.5%		7.3%		7.2%	
TOTAL		30750		30750		30750		33577	
INSULATION		1.2%		1.2%		1.1%		10.9%	
TOTAL		4463		4463		4463		50909	
TOTAL COST OF CONSTRUCTION (INR)		370250	375887	363540	367751	419586	423798	468859	473071
Unit Carpet Area (sqft)	518								
Cost/ sqft carpet area		714	725	701	709	809	817	904	913
Percentage increase over Base				-1.8%	-2.2%	13.3%	12.7%	26.6%	25.9%
Cost Increase over Base (INR)				-6710	-8136	49336	47911	98609	97184

Bill Of Quantities



Construction Drawing set

Figure 34 : Various downloadable outputs of the master set made available to the user on the website.



07

Replicable Design Catalogue

The Design Catalogue has 2 sets of dwelling unit plans:

•Set1: This set of plans is designed for predominantly hot climate zones : s Hot-dry, Warm-humid, Composite and Temperate. The primary design strategy is to reduce solar heat gain and heat gain from ambient air and to optimise ventilation to remove internal heat.

•Set2: This set of plans is designed for the Cold Climate. Here the strategy focuses on capturing solar heat gains and restricting heat loss.
In both sets there are variable or adjustable devices for shading and operable windows. These variable devices enable the dwelling unit to adapt to the changing seasons and the swing in outdoor conditions from during the day and night.

7.1 Catalogue of all floor plans and site plans

The Catalogue of floor plans has type designs ranging from small one-bedroom dwelling units to large four-bedroom dwelling units. The designs are derived by adhering to the following principles:

a) The provision of accommodation and facilities planned in the homes, in terms of the division between living and dining spaces, bedrooms kitchens and toilets, follows the general trends that are prevalent in India. The designs also adhere to the standards prescribed in National Building Code (NBC).

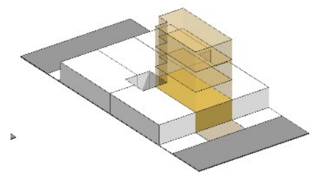
b) Efficiency in the utilisation of construction resource is another guiding principle in the design of the floor plans. The internal layouts of dwelling units and layouts for the shared areas of stairs and access lobbies utilise built space efficiently. The geometry of the buildings is rectilinear and the spans of the structural bays are kept as short as possible. The structural grids are aligned for simplicity and clarity.

c) Compactness in the planning, which maximises shared walls between adjacent dwelling units and reduces the perimeter length of the building in relation to the enclosed floor area is the most important principle for building resource conservation as well as energy efficiency of the building. All layout plans have sought to optimise these measures in their planning.

7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

MULTI - FAMILY UNITS

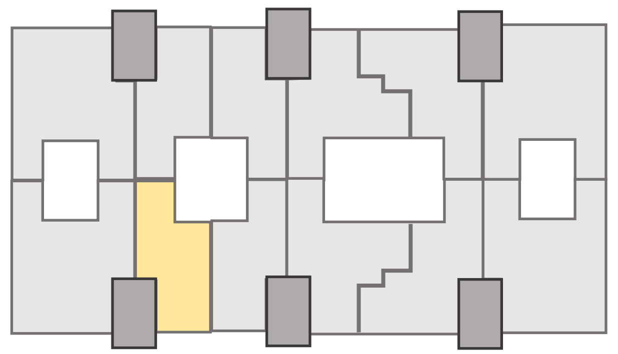
Multi-Family home comprise of a large block/ building housing many units together. These share a common circulation space and resources. The units are of a similar typology and many range from low rise, mid rise to high rise.

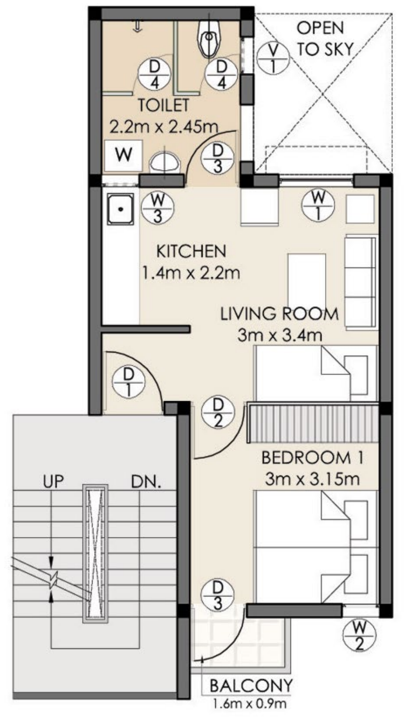


ROW HOUSE BACK TO BACK

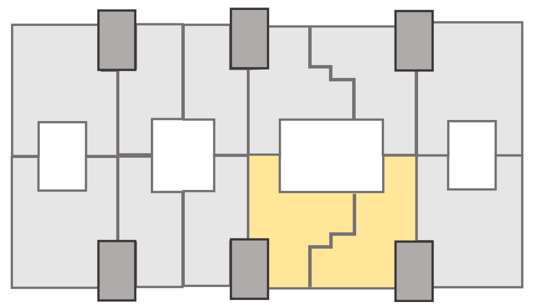
For the smallest of plots maximum ground coverage is permissible and the building is built up to the edges on all 3 sides. There is a requirement for a set back on the front. This leads to a house with shared walls with the neighbours on 3 sides with a court in the middle for light & ventilation. This row house typology with shared wall on 3 sides is most energy efficient as it has the least envelop exposure to solar radiation.

1.1A		
	HEIGHT	Ground+ 3 Floors
	CONFIGURATION	1 BHK
	CARPET AREA	30Sqm

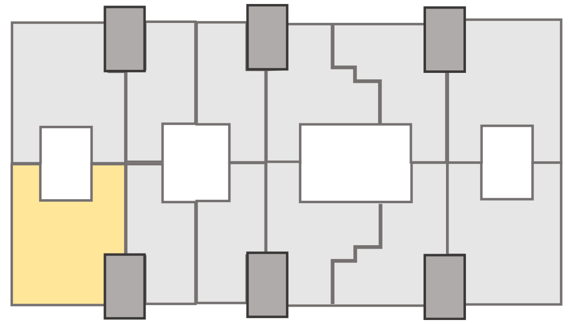


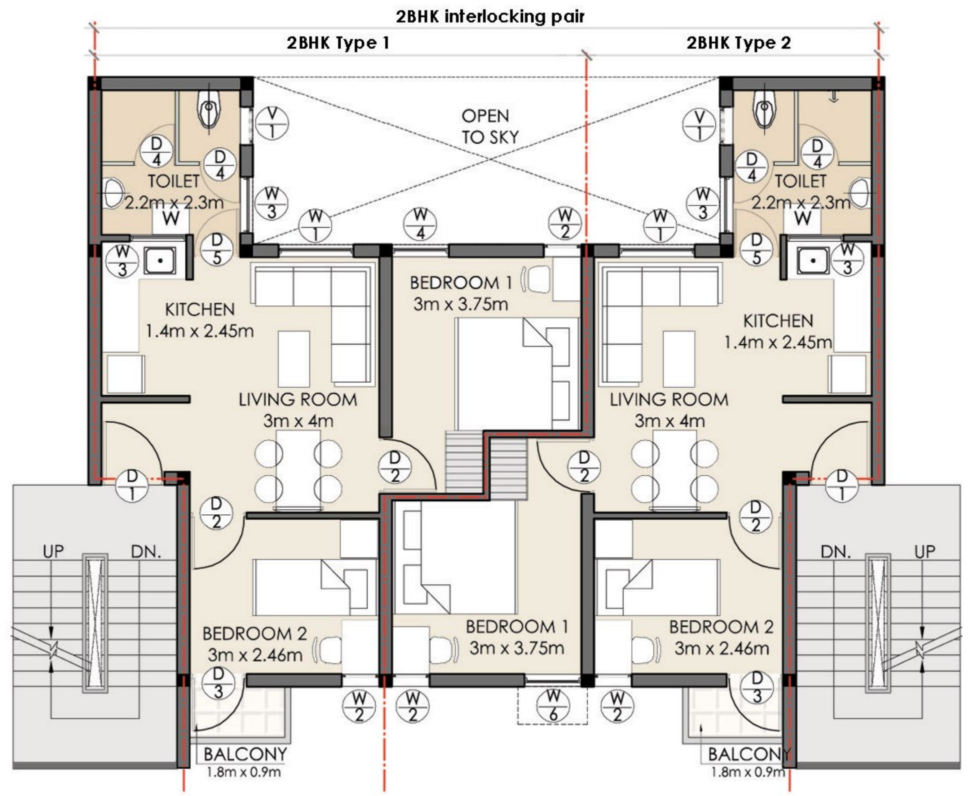


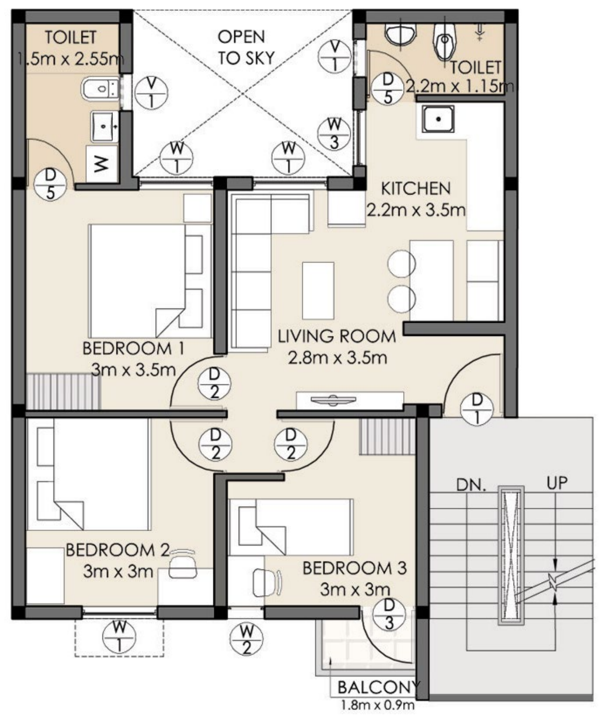
1.2 A		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	2 BHK
	CARPET AREA	41Sqm



1.2 D		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	55Sqm



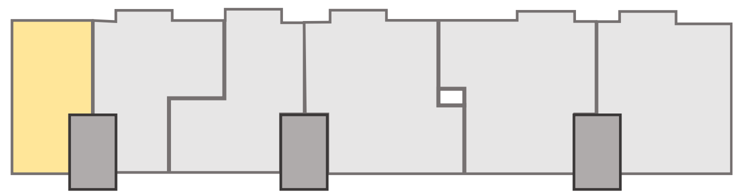


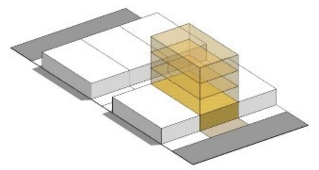


7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

MULTI - FAMILY UNITS

1.1B		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	1 BHK
	CARPET AREA	32Sqm



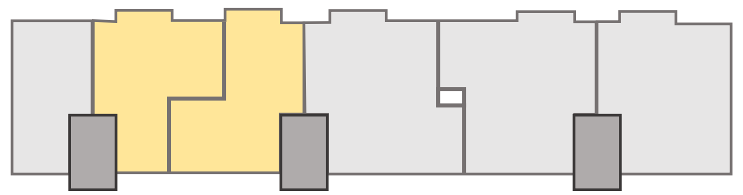


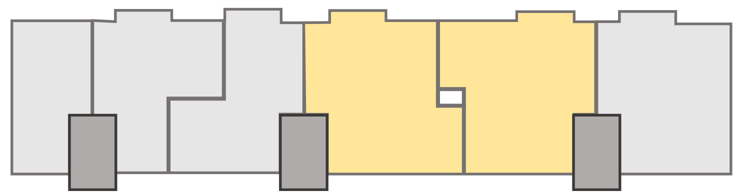
ROW HOUSE 2 SIDE OPEN

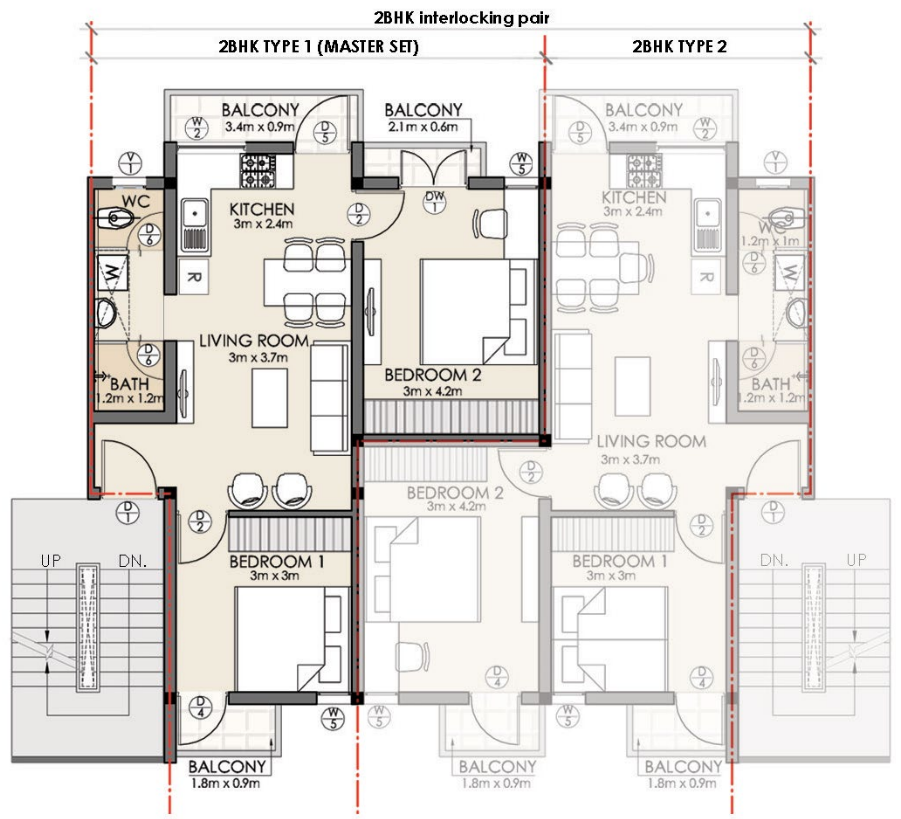
To achieve greater economy, the frequency of the staircase is reduced. Each staircase can now serve multiple homes at every floor connected through a common passage. A significant advantage of this arrangement is that it enables a lift to be installed, the cost of the lift being shared by a large number of homes . For accommodating a large number of units in a compact built form, continuous linear blocks can be developed connected through corridors. This is ideal for low rise structures (Ground+3/ stilt+4) high density development.

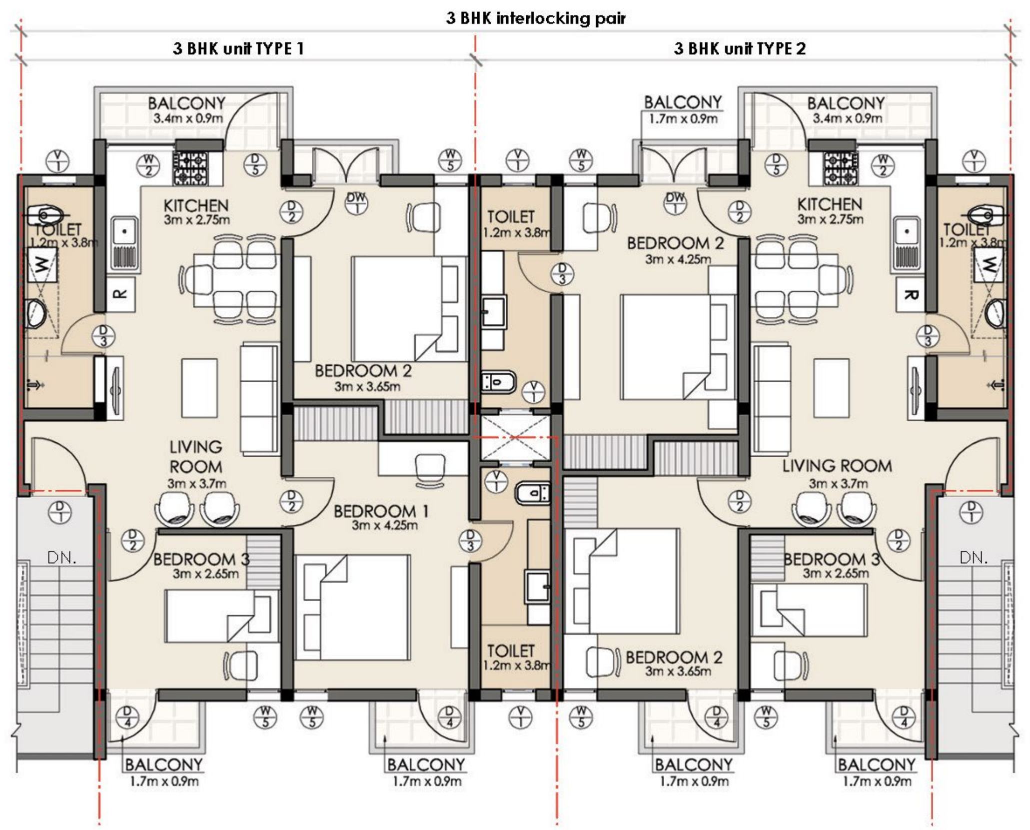
1.2B		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	2 BHK
	CARPET AREA	48sqm

1.3 A		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	68Sqm





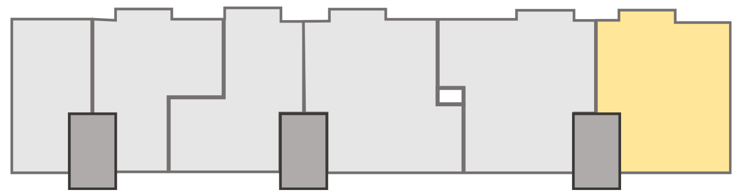


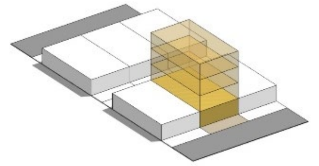


7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

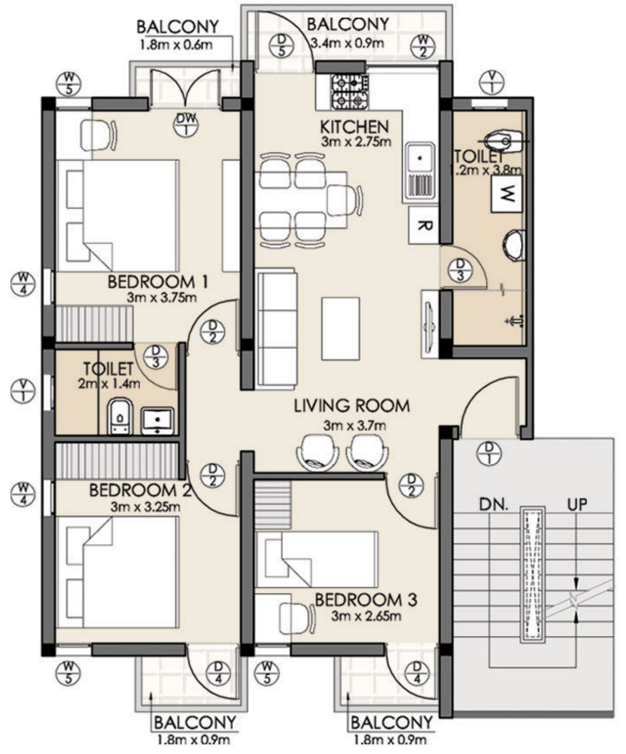
MULTI - FAMILY UNITS

1.3 C		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	68Sqm

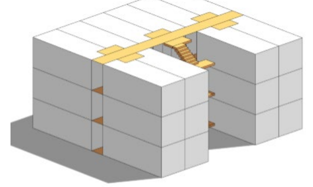




ROW HOUSE 2 SIDE OPEN



MULTI - FAMILY UNITS

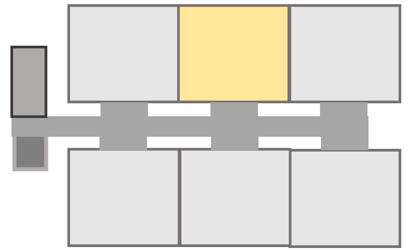


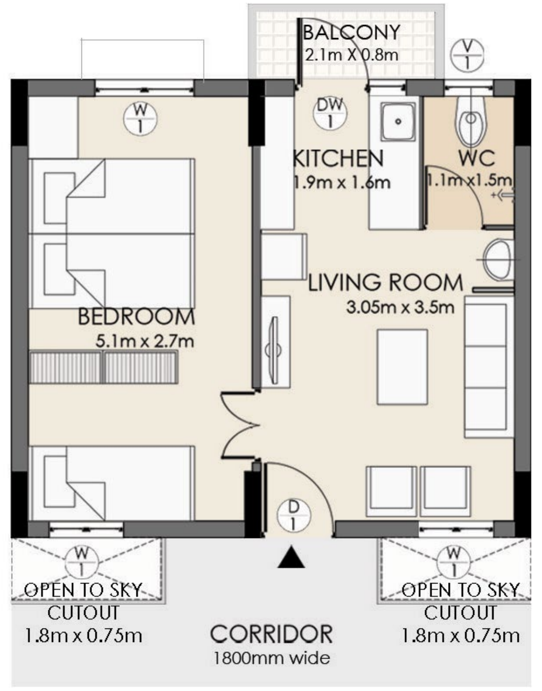
DOUBLY LOADED CORRIDOR

LOW-RISE

To achieve greater economy, the frequency of the staircase is reduced. Each staircase can now serve multiple homes at every floor connected through a common passage. A significant advantage of this arrangement is that it enables a lift to be installed, the cost of the lift being shared by a large number of homes . For accommodating a large number of units in a compact built form, continuous linear blocks can be developed connected through corridors. This is ideal for low rise structures (Ground+3/ stilt+4) high density development

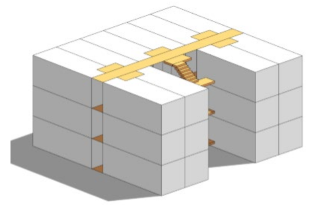
1.1 C		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	1 BHK
	CARPET AREA	30Sqm





7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

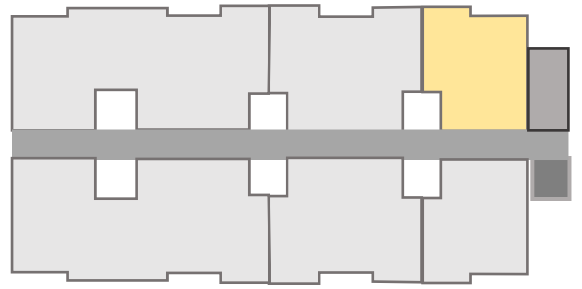
MULTI - FAMILY UNITS

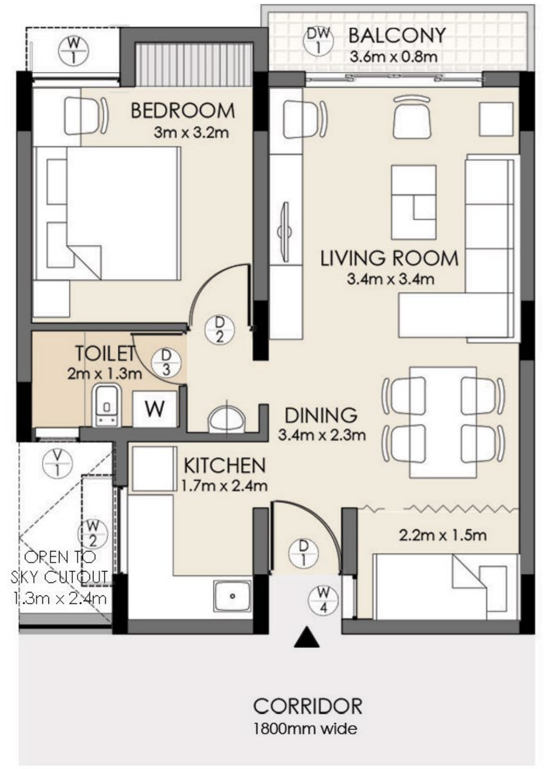


DOUBLY LOADED CORRIDOR

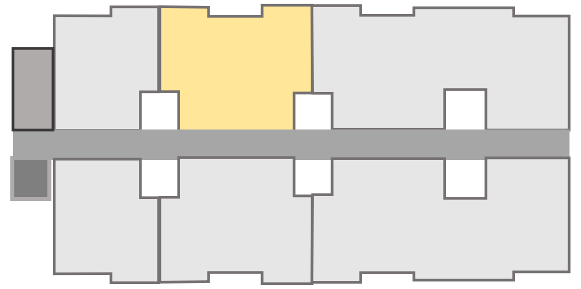
MID-RISE

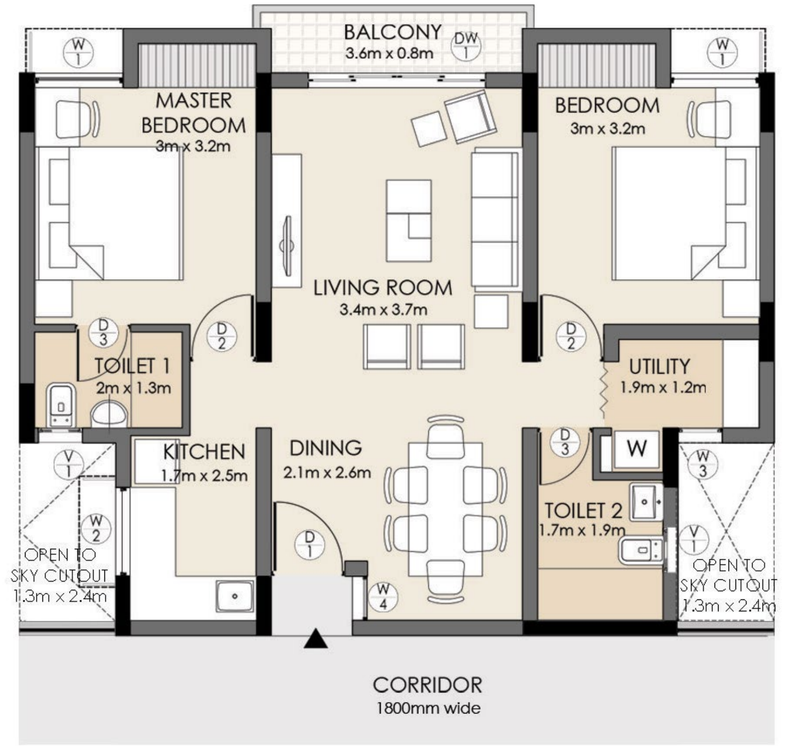
1.2 C		
	HEIGHT	Ground + 7 Floors
	CONFIGURATION	1 BHK
	CARPET AREA	44Sqm



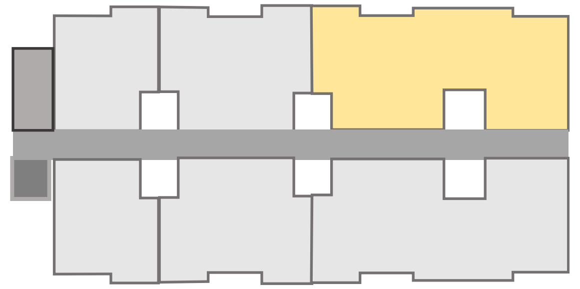


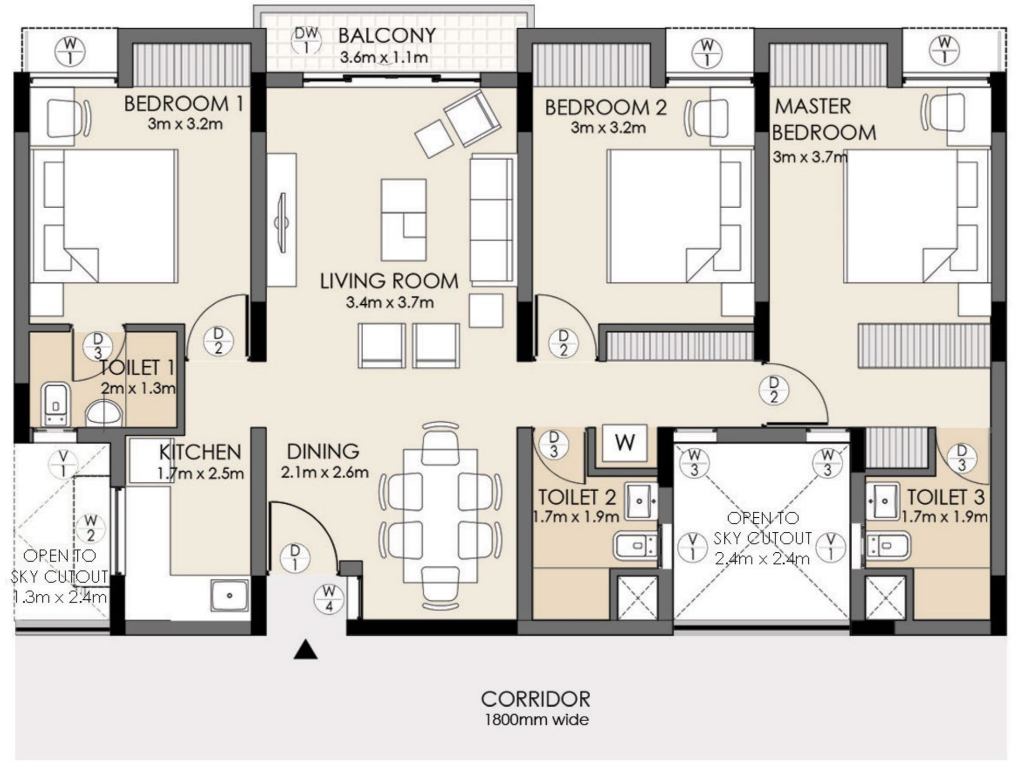
1.3 B		
	HEIGHT	Ground + 7 floors
	CONFIGURATION	2 BHK
	CARPET AREA	65Sqm





1.4 A		
	HEIGHT	Ground + 7 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	85Sqm

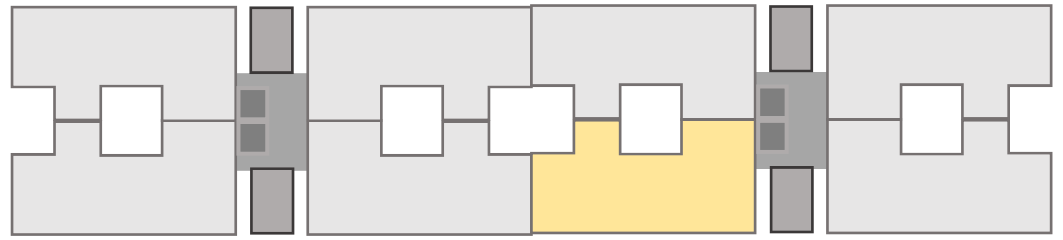


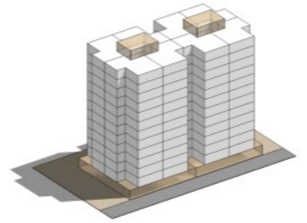


7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

MULTI - FAMILY UNITS

1.4B		
	HEIGHT	Stilt + 12 Floors
	CONFIGURATION	3 bhk
	CARPET AREA	105Sqm

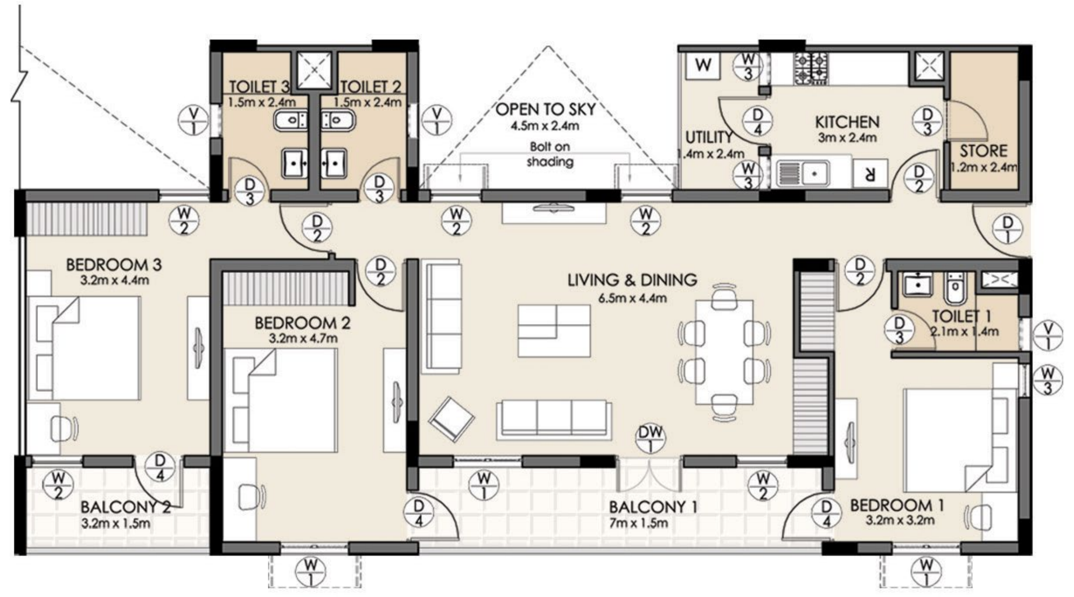




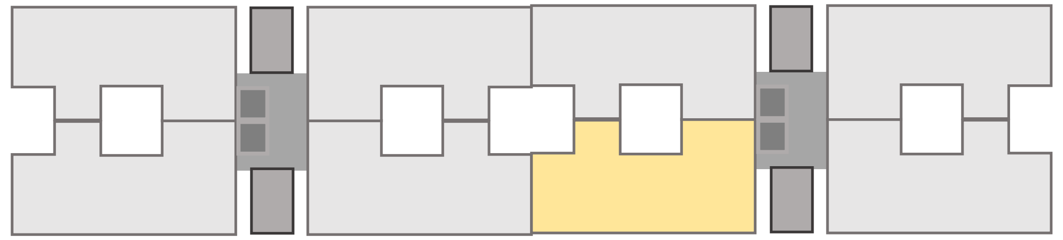
TOWER CONNECTED

MID-RISE

The tower typology has a central core for vertical circulation around which units are arranged. Many variations are also possible in the tower typology. The towers can be split into 2 broad design typologies: the ones that are designed as independent stand-alone towers and the ones that are designed as connected towers which can add up to a linear form.

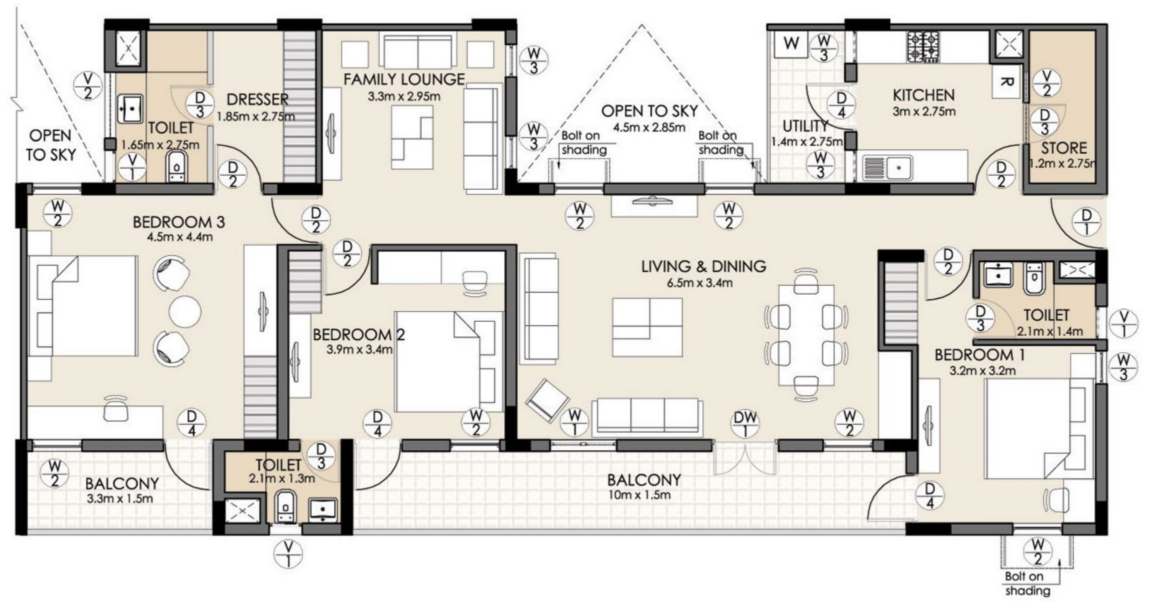


1.5A		
	HEIGHT	Stilt + 12 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	125Sqm



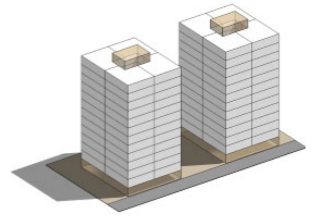
TOWER CONNECTED

HIGH-RISE



7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

MULTI - FAMILY UNITS

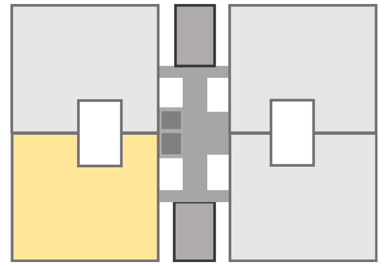


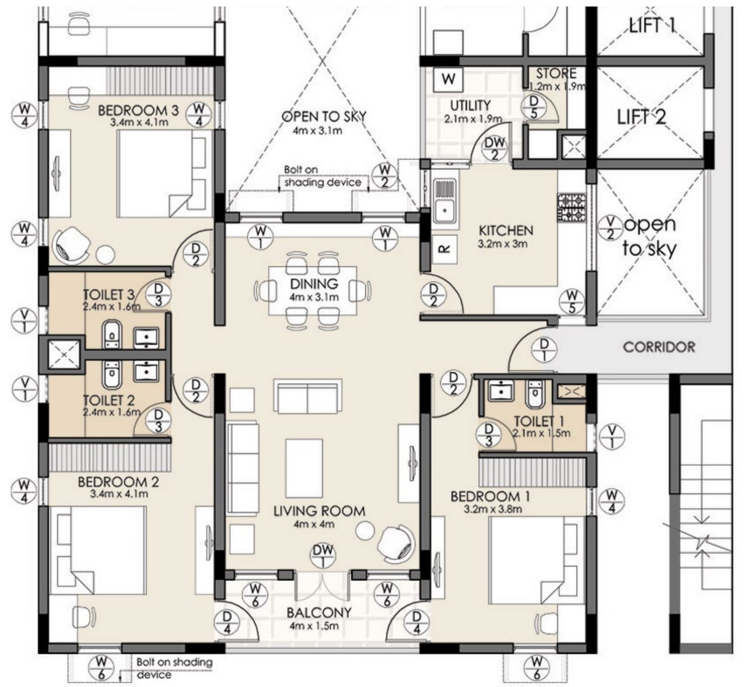
TOWER STAND ALONE

HIGH-RISE

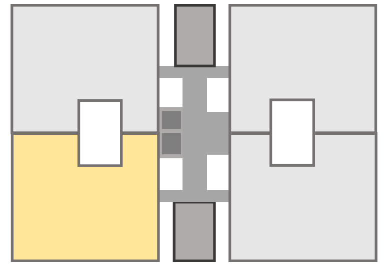
The tower typology has a central core for vertical circulation around which units are arranged. Many variations are also possible in the tower typology. The towers can be split into 2 broad design typologies: the ones that are designed as independent stand-alone towers and the ones that are designed as connected towers which can add up to a linear form.

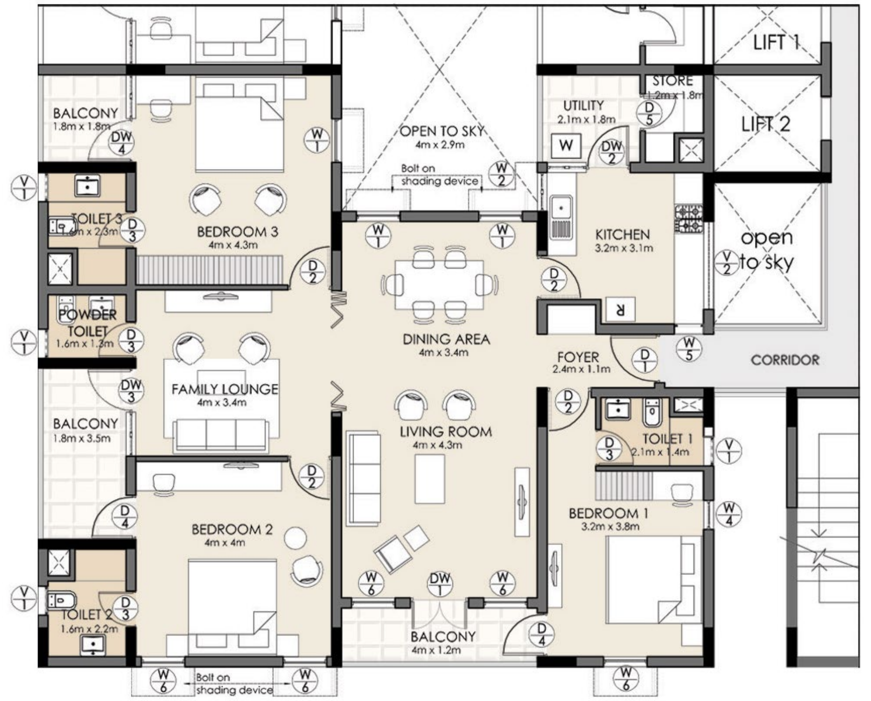
1.4C		
	HEIGHT	Ground + 12 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	105Sqm





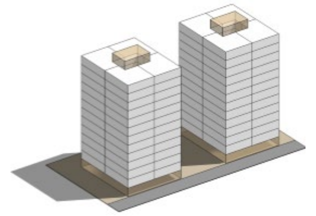
1.5B		
	HEIGHT	Ground + 12 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	125Sqm





7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

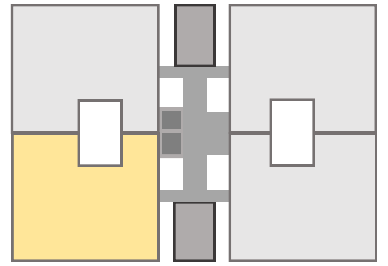
MULTI - FAMILY UNITS

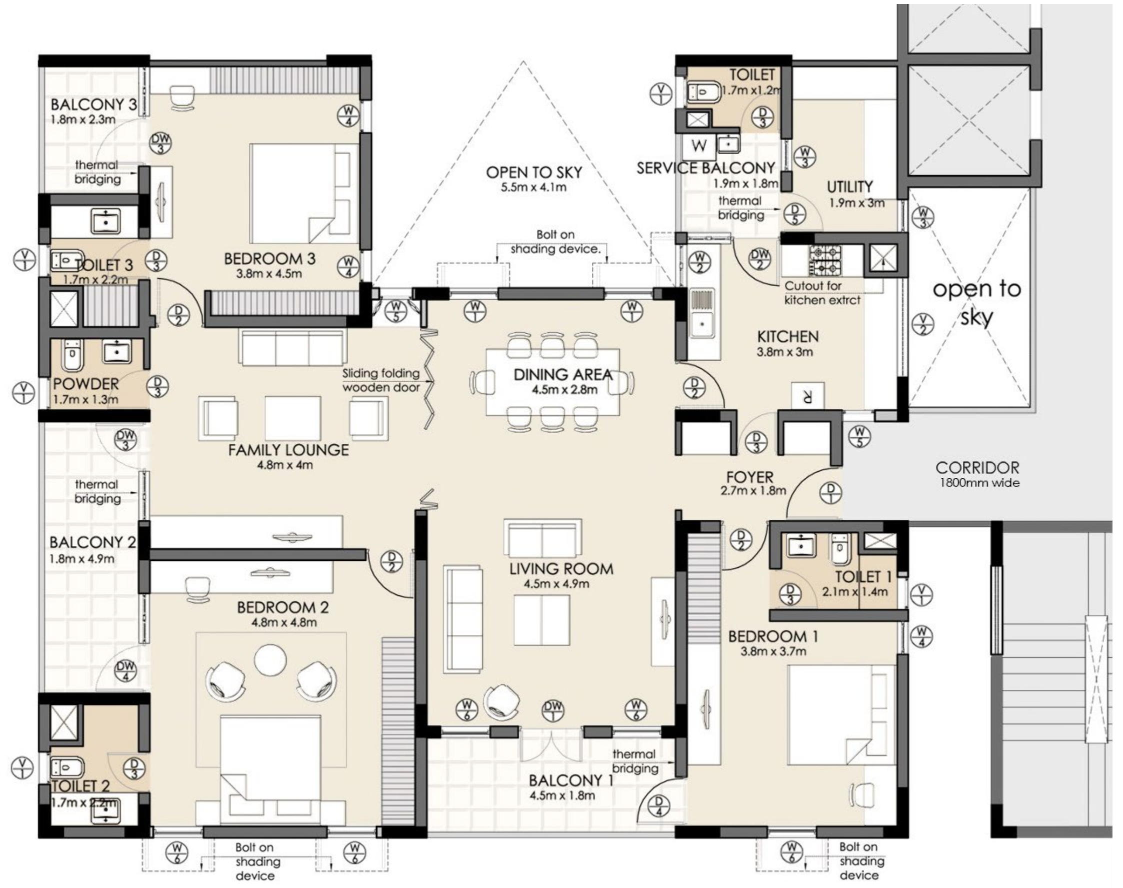


TOWER STAND ALONE

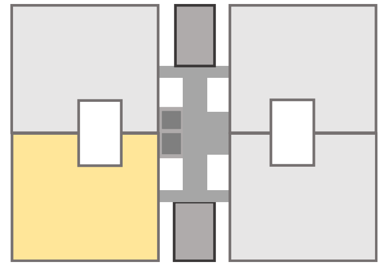
HIGH-RISE

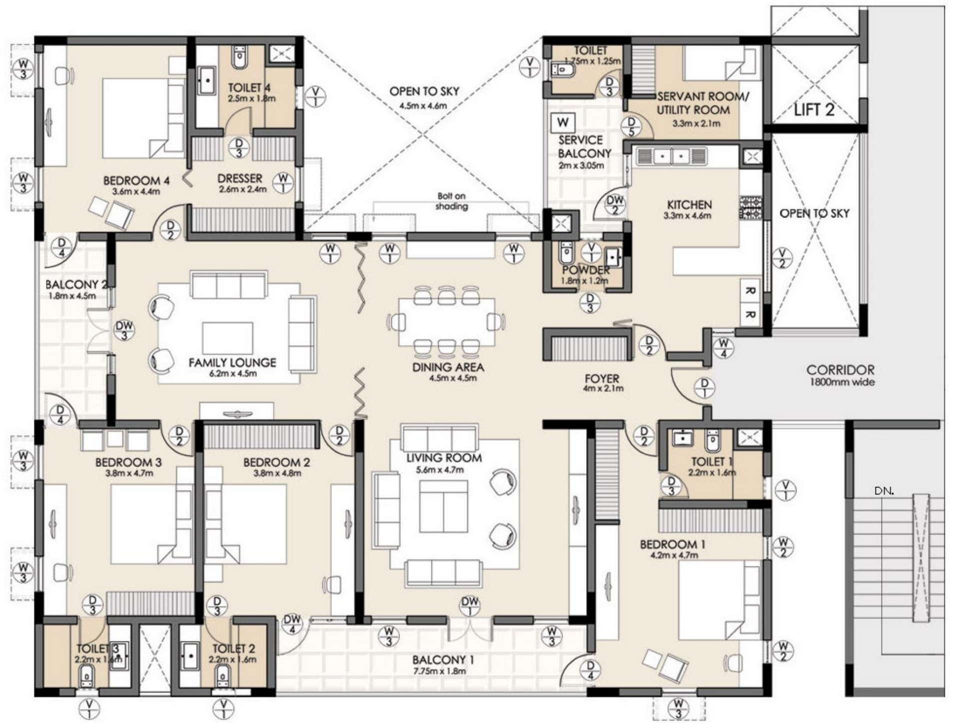
1.6A		
	HEIGHT	Ground + 12 Floors
	CONFIGURATION	3 BHK + Servant room
	CARPET AREA	156Sqm





1.7A		
	HEIGHT	Ground + 12 Floors
	CONFIGURATION	3 BHK + Servant room
	CARPET AREA	225Sqm



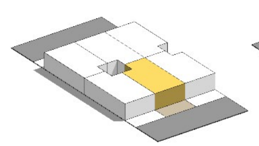


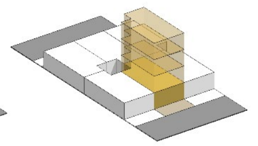
7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

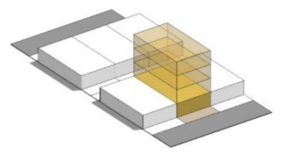
SINGLE - FAMILY UNITS

PLOTTED HOUSING

the typology is defined by the size of the plot and the number of sides the building is open to the outside. In dense urban conditions many of the single owner plots are now converting to low rise typology with each family occupying a floor. While designing for single family homes this provision for future expansion needs to be accommodated.



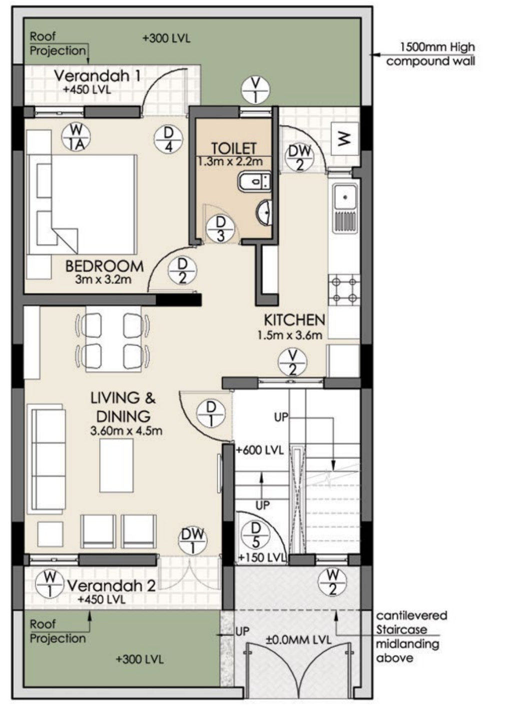




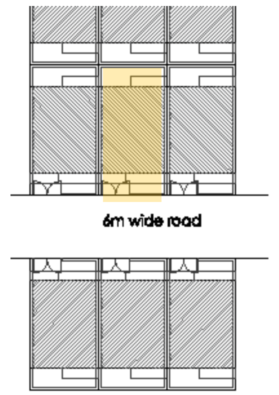
ROW HOUSE 2 SIDE OPEN

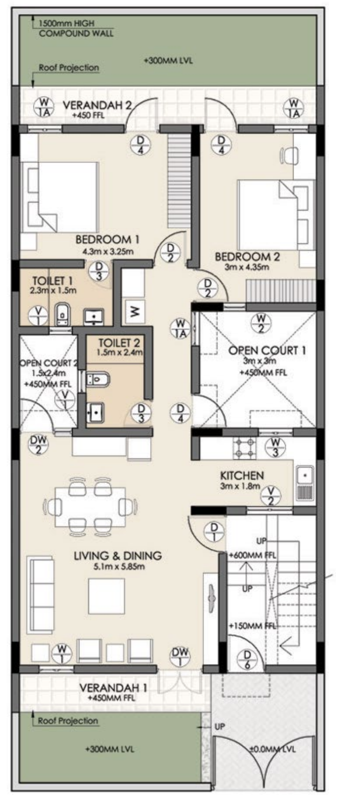
For larger plots or plots in situated in warm & humid or temperate climate zones the ventilation requirements may not be met by a single side open plot. Therefore, the two side open row house typology is adopted in such cases. This opens to the front street as well as a back street or a back set-back while the side walls remain shared with the neighbours.

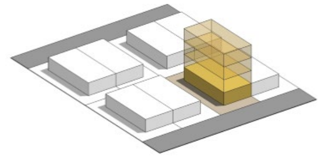
2.1A		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	1 BHK
	PLOT SIZE	80Sqm
	PLOT DIMENSIONS	6.5m x 12.5m
	CARPET AREA	38Sqm



2.2A		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	2 BHK
	PLOT SIZE	160Sqm
	PLOT DIMENSIONS	8m X 20m
	CARPET AREA	77Sqm



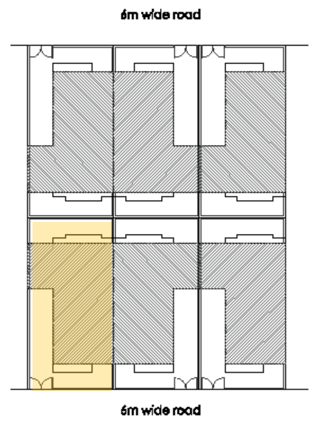


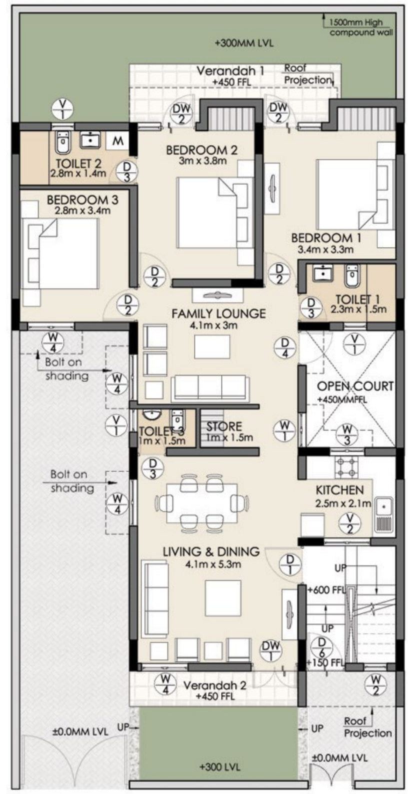


SEMI - DETACHED

The set-back guidelines as defined in NBC suggest that for larger plot sizes set-backs are required on 3 sides. This leads to the semi-detached typology which has one shared wall and is open on three sides. When dealing with larger plots internal courtyards or shafts can be introduced to meet the light & ventilation needs.

2.3A		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	3 BHK
	PLOT SIZE	200Sqm
	PLOT DIMENSIONS	10m X 20m
	CARPET AREA	90Sqm

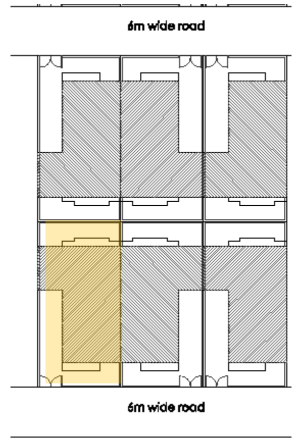


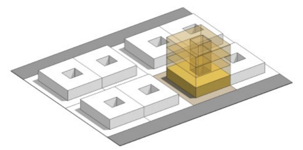


7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

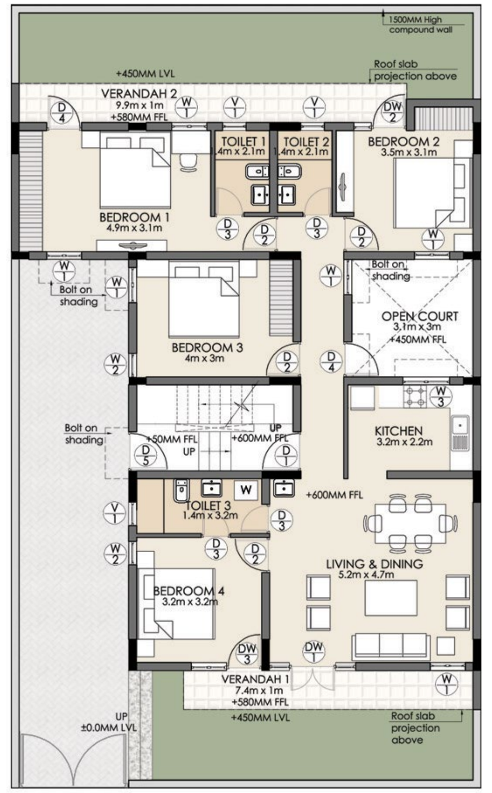
SINGLE - FAMILY UNITS

2.4A		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	4 BHK
	PLOT SIZE	240Sqm
	PLOT DIMENSIONS	12m X 20m
	CARPET AREA	107Sqm

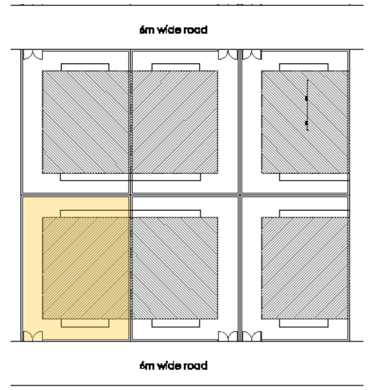


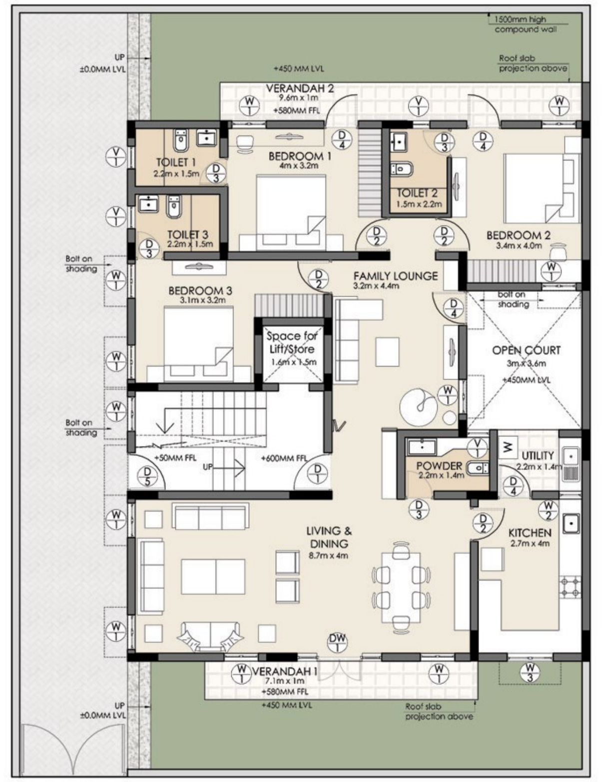


SEMI - DETACHED



2.5A		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	3 BHK
	PLOT SIZE	300Sqm
	PLOT DIMENSIONS	15m X 20m
	CARPET AREA	128.8 Sqm

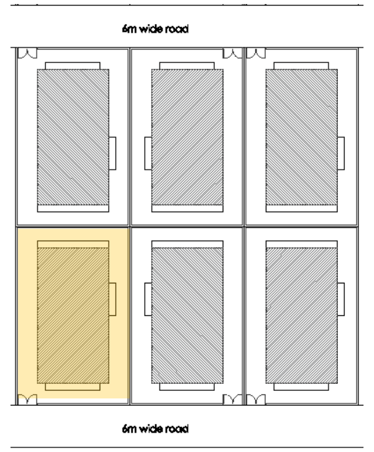


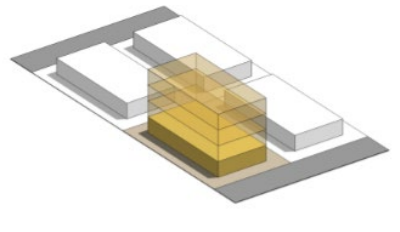


7.1.1. Design Set 1 - Hot-dry, Warm-humid, Composite, Temperate Climates

SINGLE - FAMILY UNITS

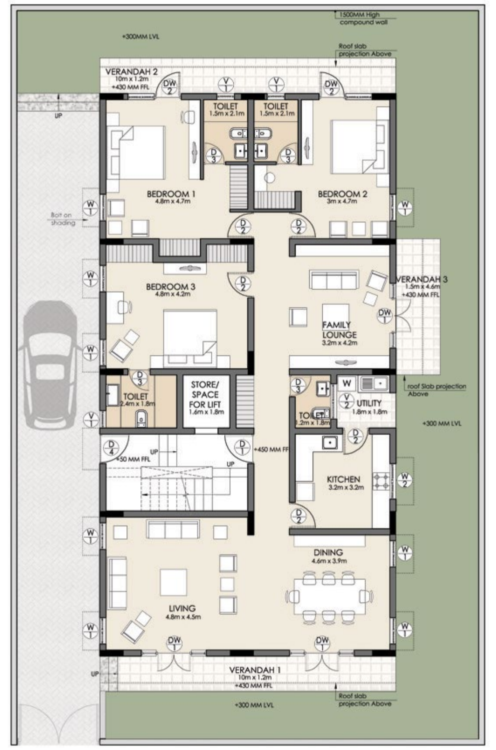
2.6A		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	3 BHK
	PLOT SIZE	400Sqm
	PLOT DIMENSIONS	16m X 25m
	CARPET AREA	163.5 Sqm



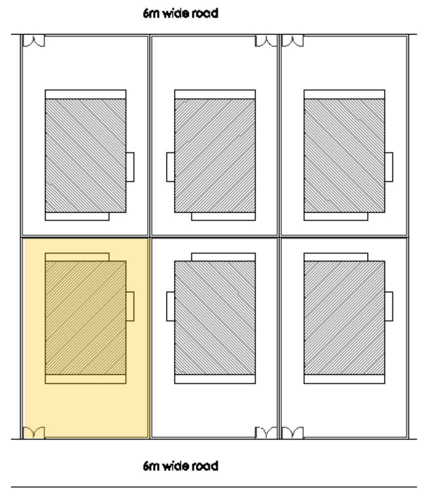


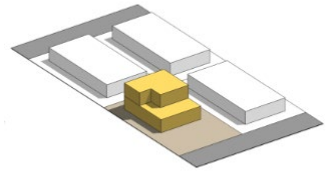
DETACHED

For the largest of plot sizes detaching buildings work better. These can be independent home on a single storey, open on all four sides or it can also be a single family duplex unit with a larger open area devoted to green, parking etc.

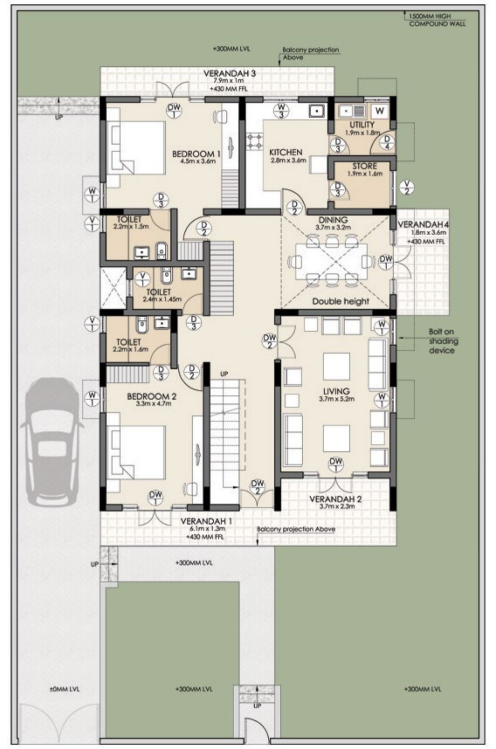


2.6B		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	5 BHK
	PLOT SIZE	400 Sqm
	PLOT DIMENSIONS	16m X 25m
	CARPET AREA	202 Sqm

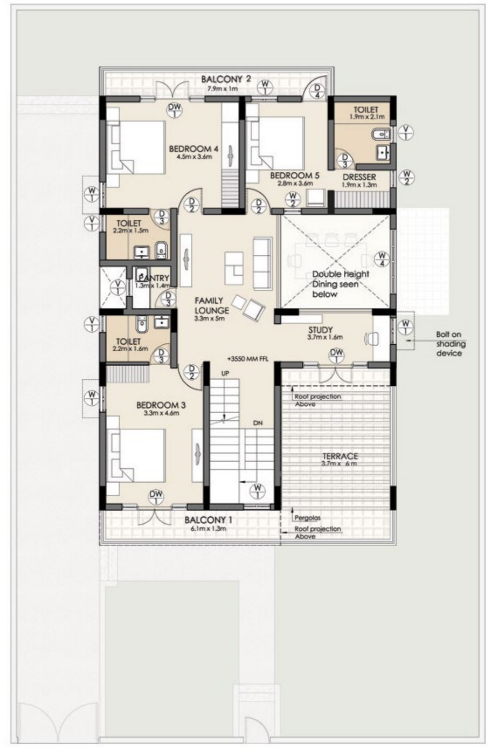




DETACHED DUPLEX



Ground Floor

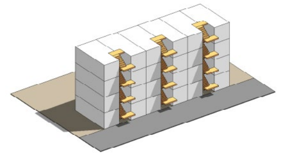


First Floor

7.1.2. Design Set 2 - Cold Climates

MULTI - FAMILY UNITS

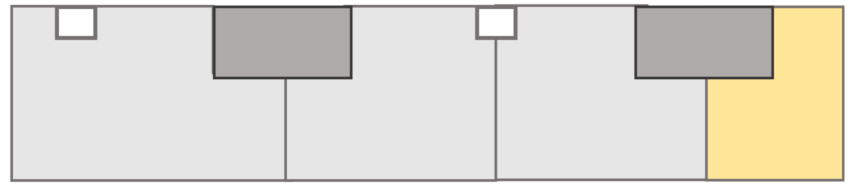
Multi-Family home comprise of a large block/ building housing many units together. These share a common circulation space and resources. The units are of a similar typology and many range from low rise, mid rise to high rise.

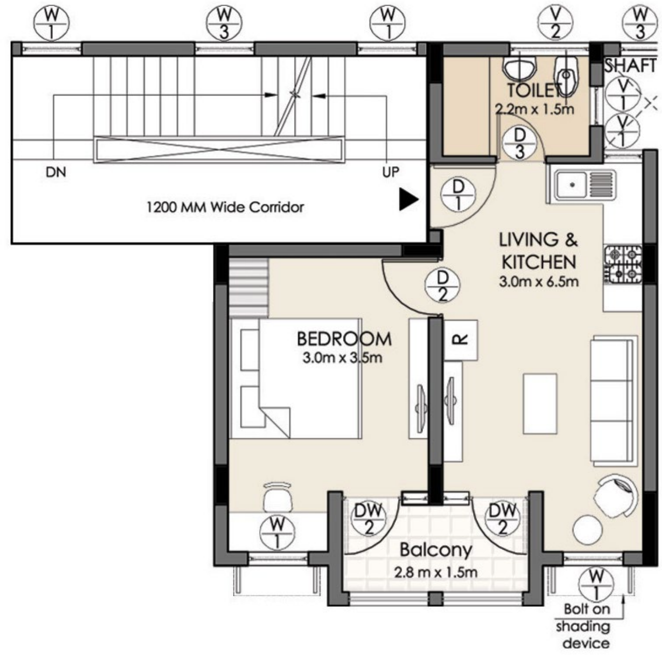


ROW HOUSE 2 SIDE OPEN

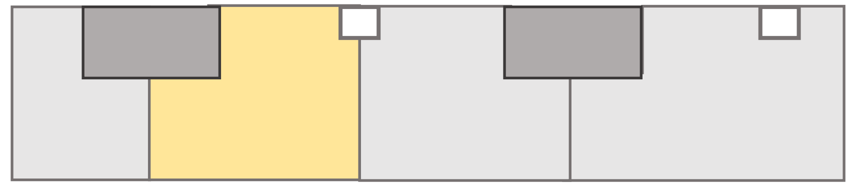
To achieve greater economy, the frequency of the staircase is reduced. Each staircase can now serve multiple homes at every floor connected through a common passage. A significant advantage of this arrangement is that it enables a lift to be installed, the cost of the lift being shared by a large number of homes . For accommodating a large number of units in a compact built form, continuous linear blocks can be developed connected through corridors. This is ideal for low rise structures (Ground+3/ stilt+4) high density development

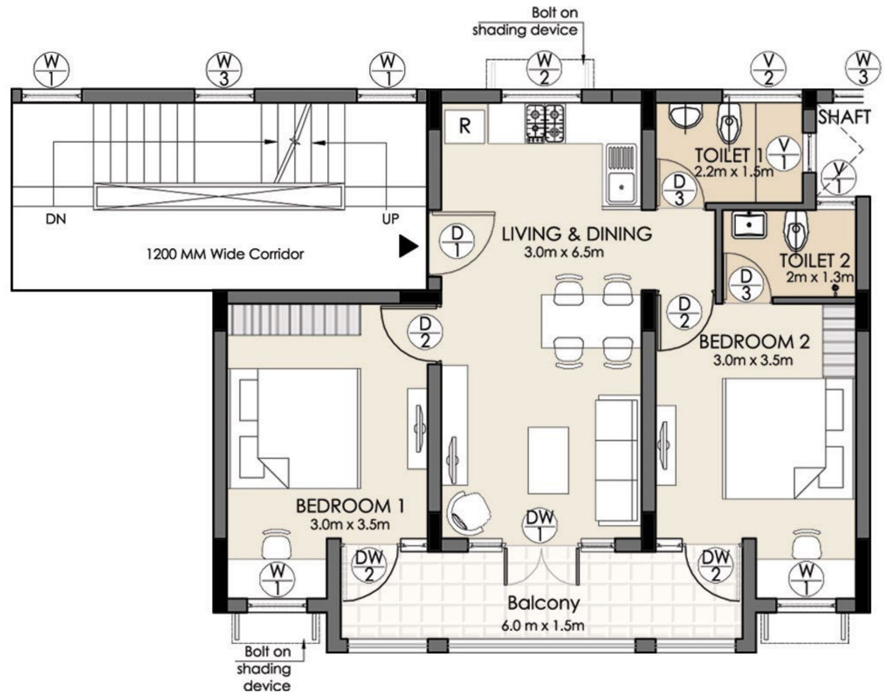
1.1CL1		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	1 BHK
	CARPET AREA	32 Sqm



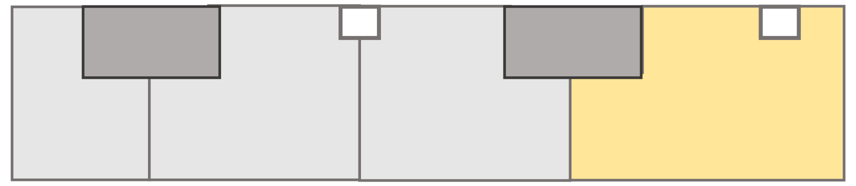


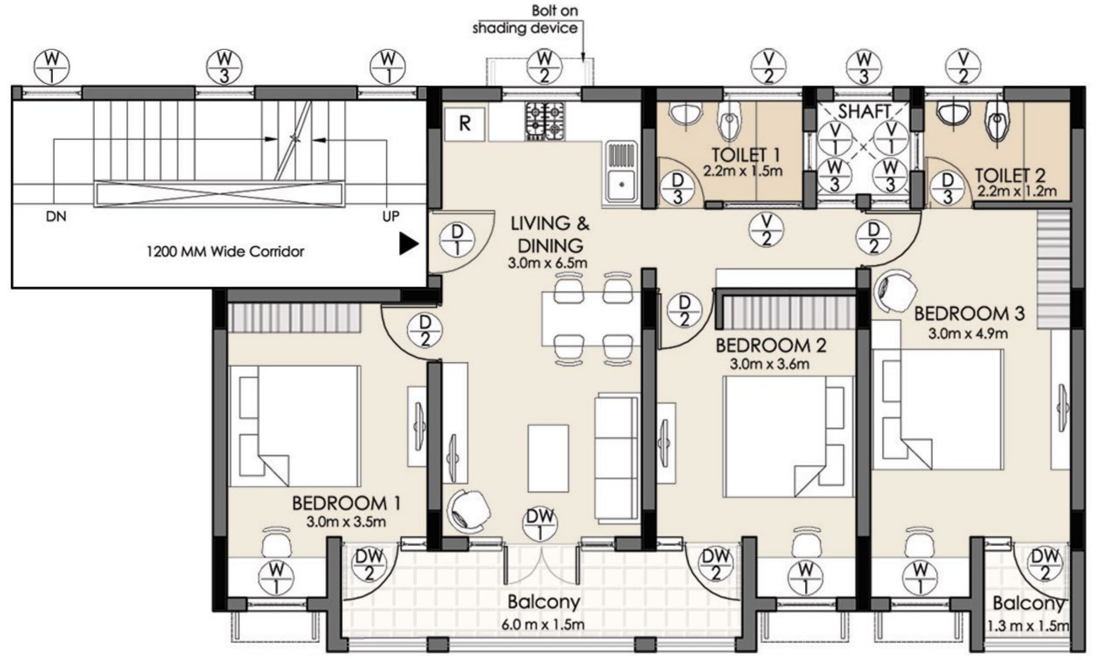
1.2 CL1		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	2 BHK
	CARPET AREA	51 Sqm





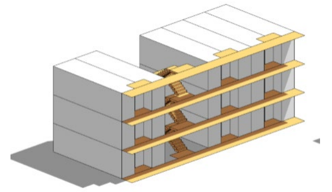
1.3 CL1		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	70 Sqm





7.1.2. Design Set 2 - Cold Climates

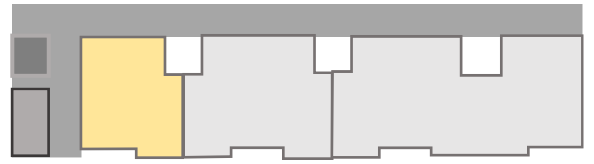
MULTI - FAMILY UNITS

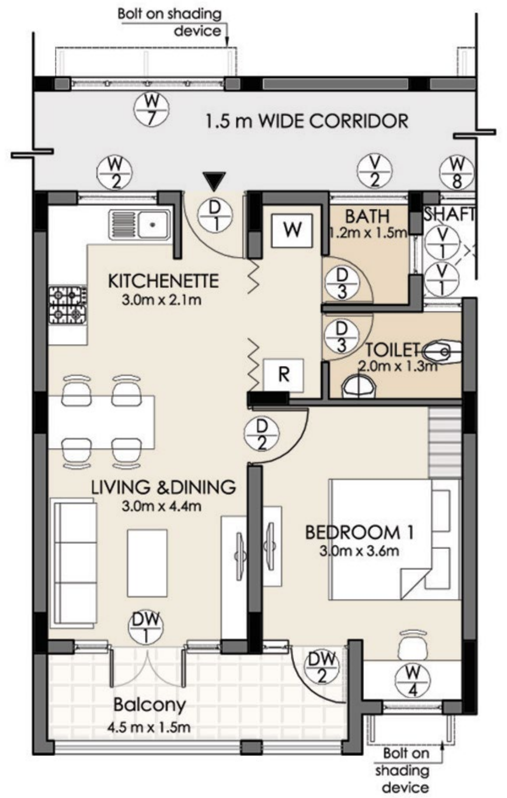


SINGLY LOADED CORRIDOR

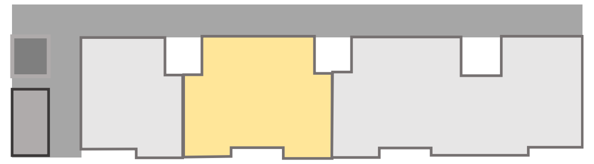
The homes are laid adjacent to each other with shared side walls along a corridor for circulation. These share a common staircase and lift core. These homes get the advantage of access to sunlight and ventilation from the corridor side as well as the open side at the other end.

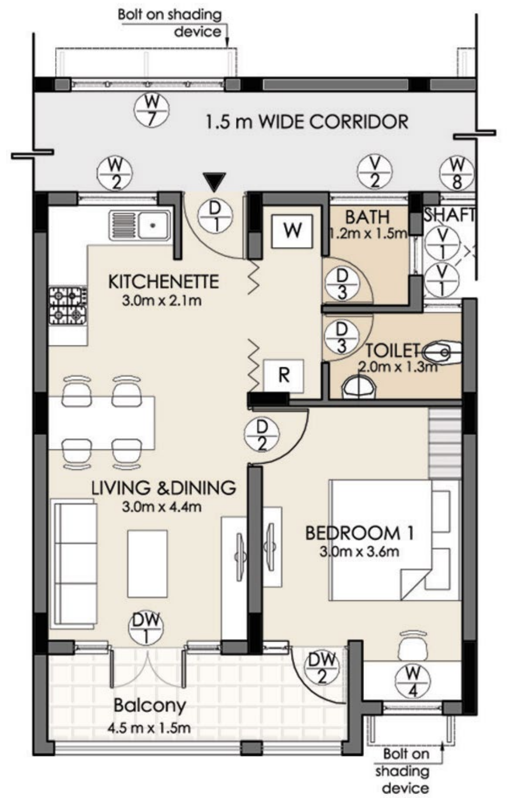
1.1 CL2		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	1 BHK
	CARPET AREA	39 Sqm





1.2 CL2		
	HEIGHT	Ground + 3 Floors
	CONFIGURATION	2 BHK
	CARPET AREA	58.2 Sqm

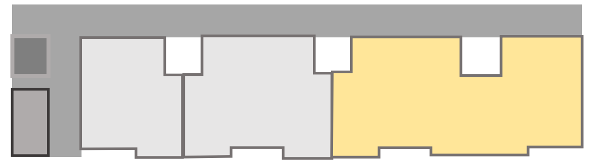


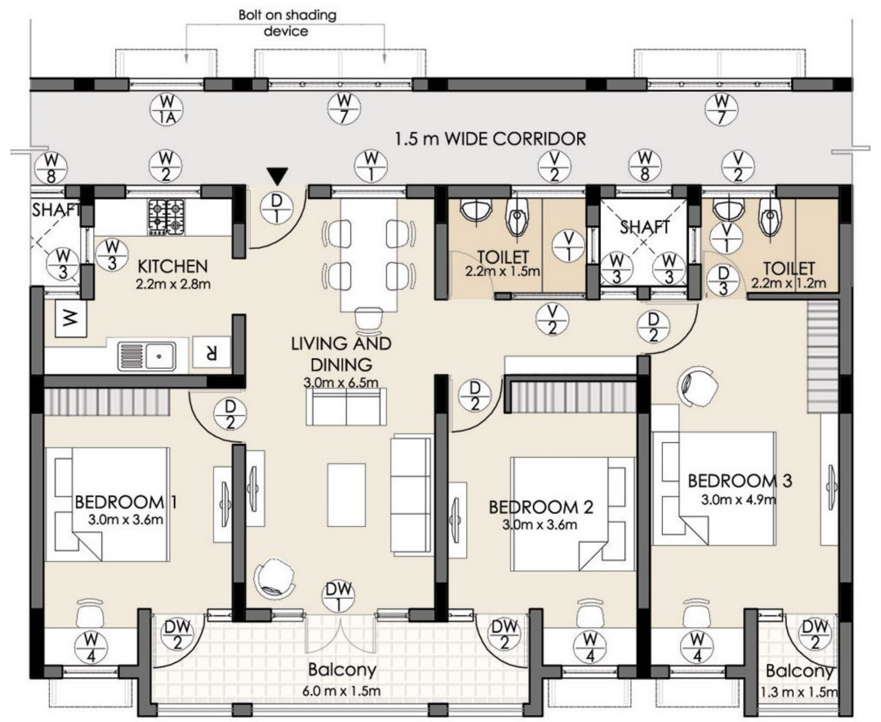


SINGLY LOADED CORRIDOR

MID-RISE

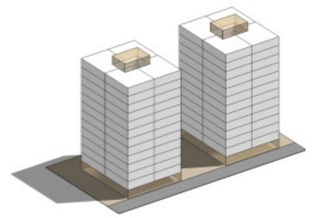
1.3 CL2		
	HEIGHT	Ground + 7 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	78 Sqm





7.1.2. Design Set 2 - Cold Climates

MULTI - FAMILY UNITS

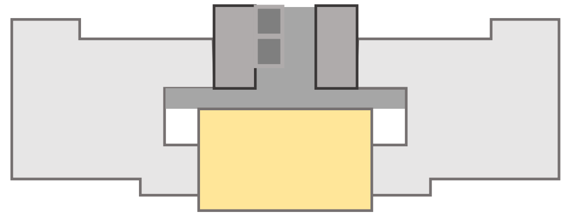


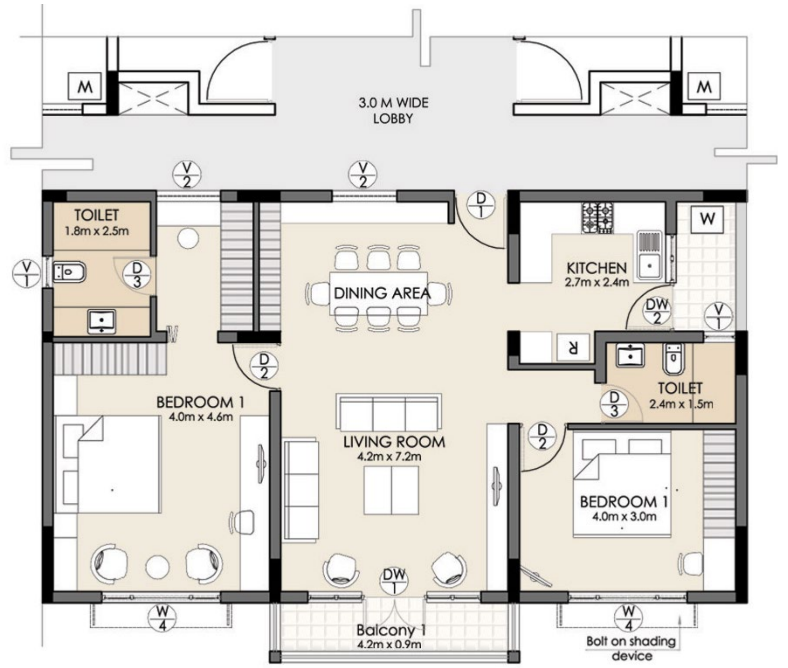
TOWER STAND ALONE

MID-RISE

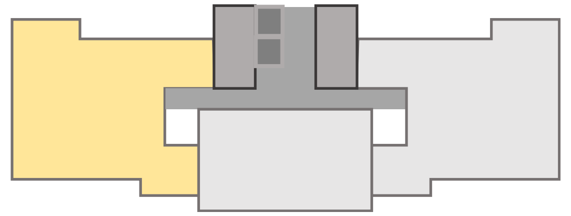
The tower typology has a central core for vertical circulation around which units are arranged. Many variations are also possible in the tower typology. The towers can be split into 2 broad design typologies: the ones that are designed as independent stand-alone towers and the ones that are designed as connected towers which can add up to a linear form.

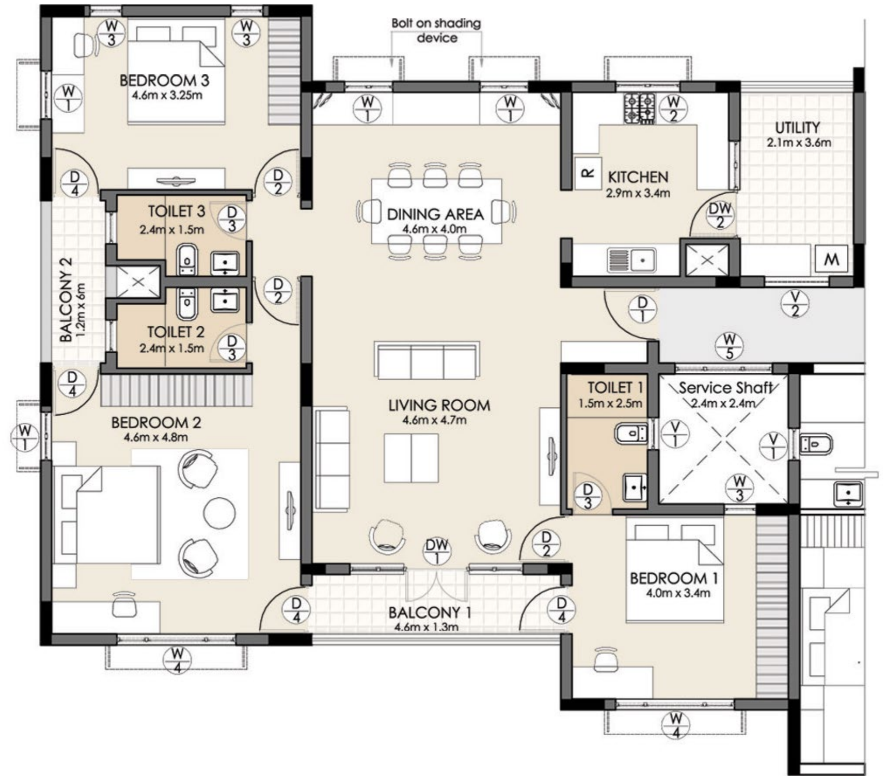
1.4CL		
	HEIGHT	Ground + 7 Floors
	CONFIGURATION	2 BHK
	CARPET AREA	84 Sqm





1.5 CL		
	HEIGHT	Ground + 7 Floors
	CONFIGURATION	3 BHK
	CARPET AREA	116.5 Sqm

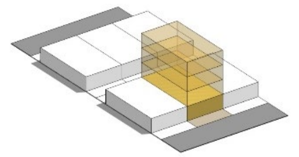




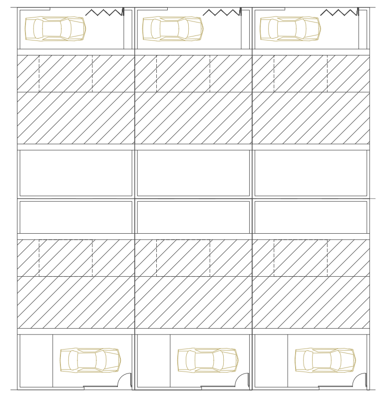
7.1.2. Design Set 2 - Cold Climates

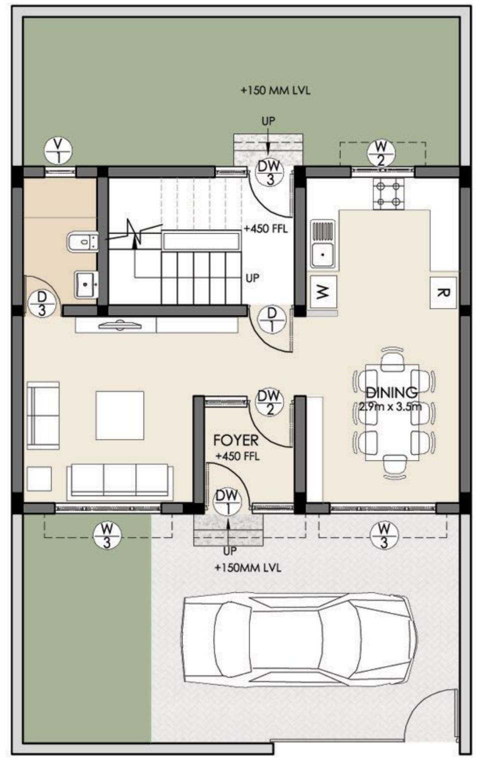
SINGLE - FAMILY UNITS

2.1CL	HEIGHT	Duplex
	CONFIGURATION	3 BHK
	CARPET AREA	79 Sqm

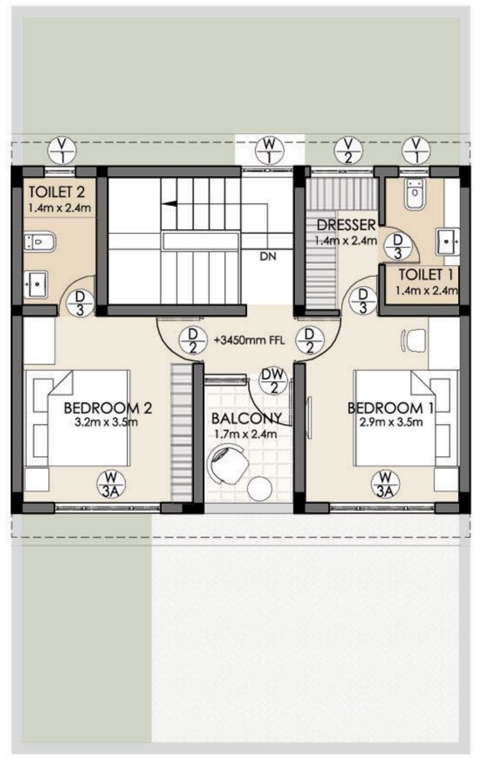


ROW HOUSE 2 SIDE OPEN





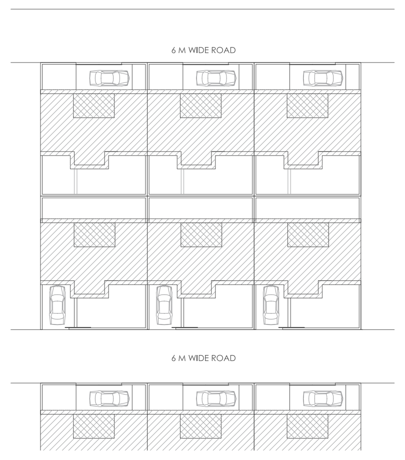
Ground Floor Plan

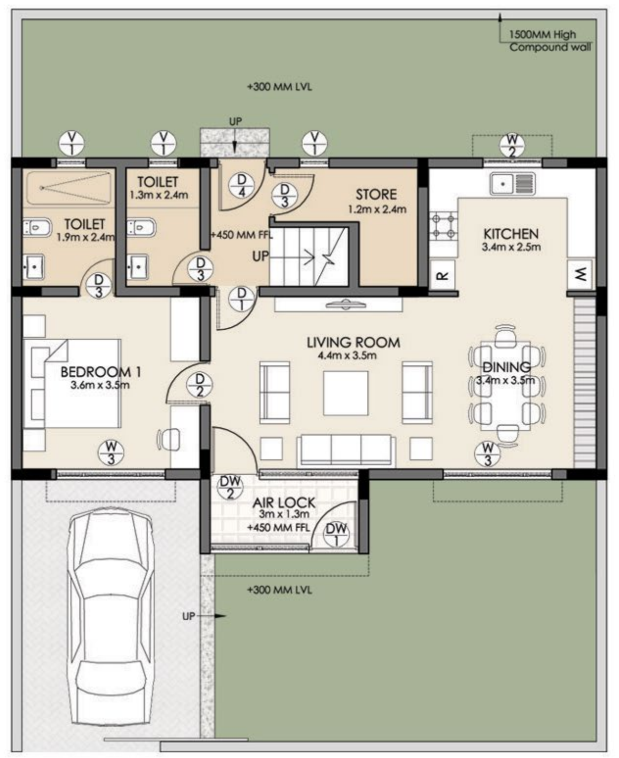


First Floor Plan

SINGLE - FAMILY UNITS

2.2CL	HEIGHT	Duplex
	CONFIGURATION	3 BHK
	CARPET AREA	143 Sqm





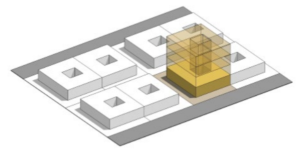
Ground Floor Plan

First Floor Plan

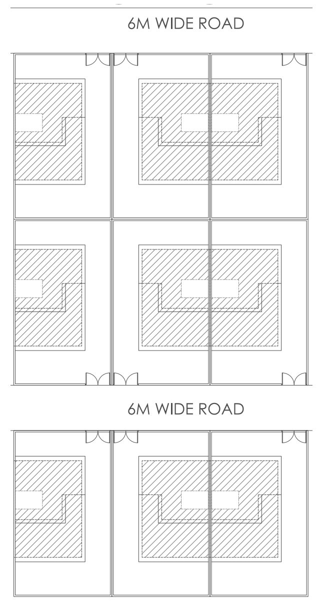
7.1.2. Design Set 2 - Cold Climates

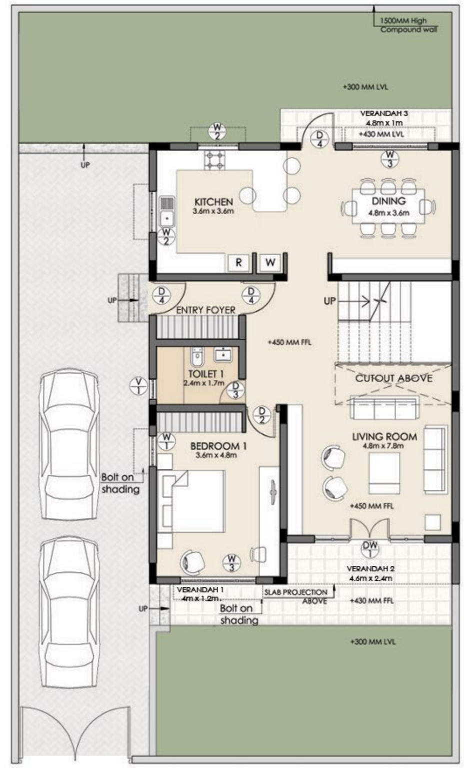
SINGLE - FAMILY UNITS

2.3CL		
	HEIGHT	Duplex
	CONFIGURATION	3 BHK
	CARPET AREA	181 Sqm

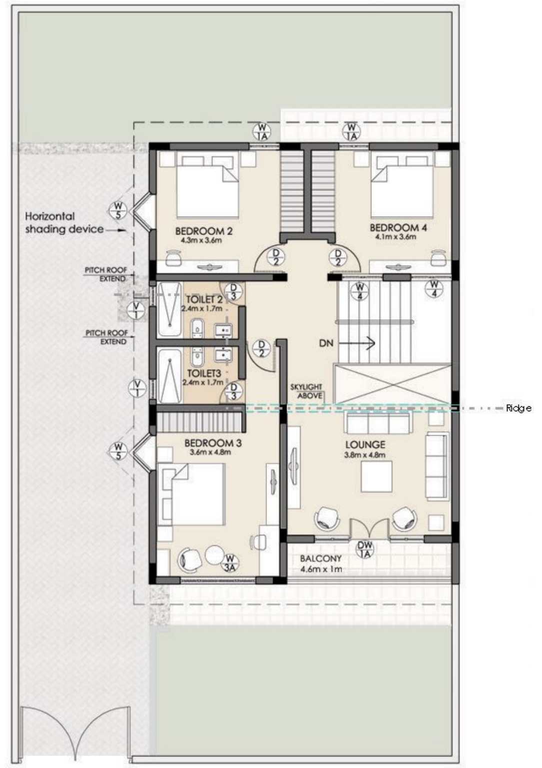


SEMI - DETACHED





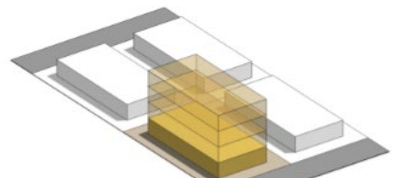
Ground Floor Plan



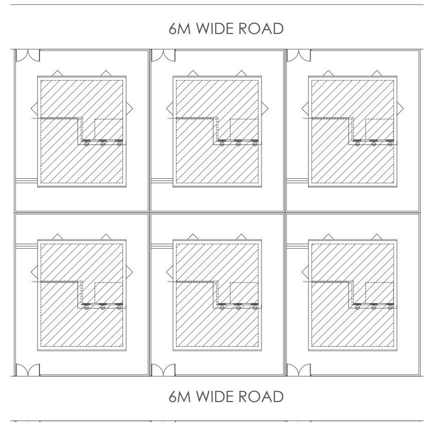
First Floor Plan

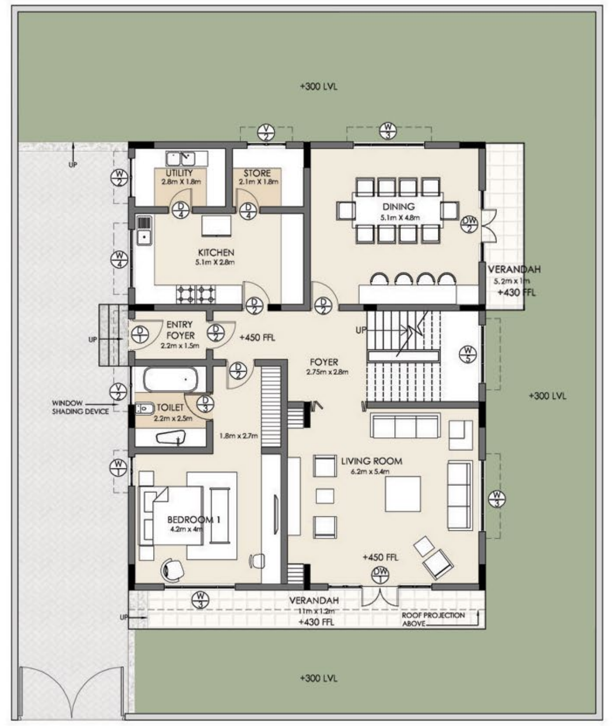
SINGLE - FAMILY UNITS

2.4 CL		
	HEIGHT	Duplex
	CONFIGURATION	4 BHK
	CARPET AREA	243 Sqm

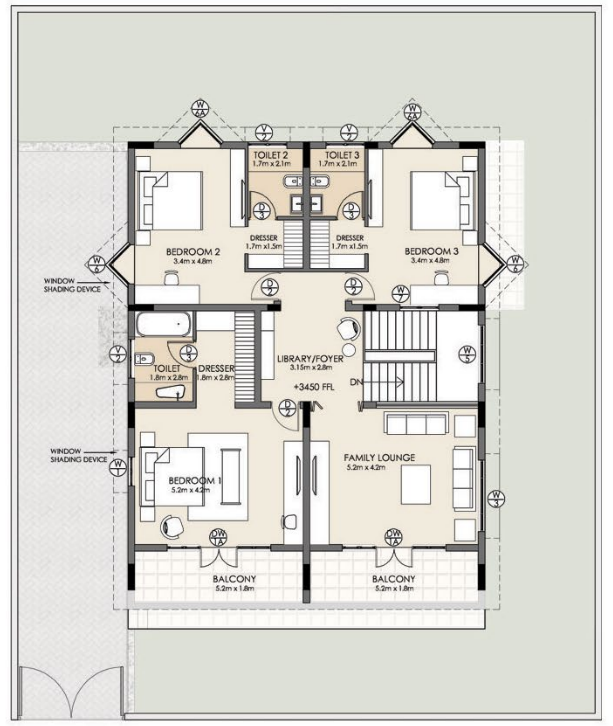


DETACHED





Ground Floor Plan



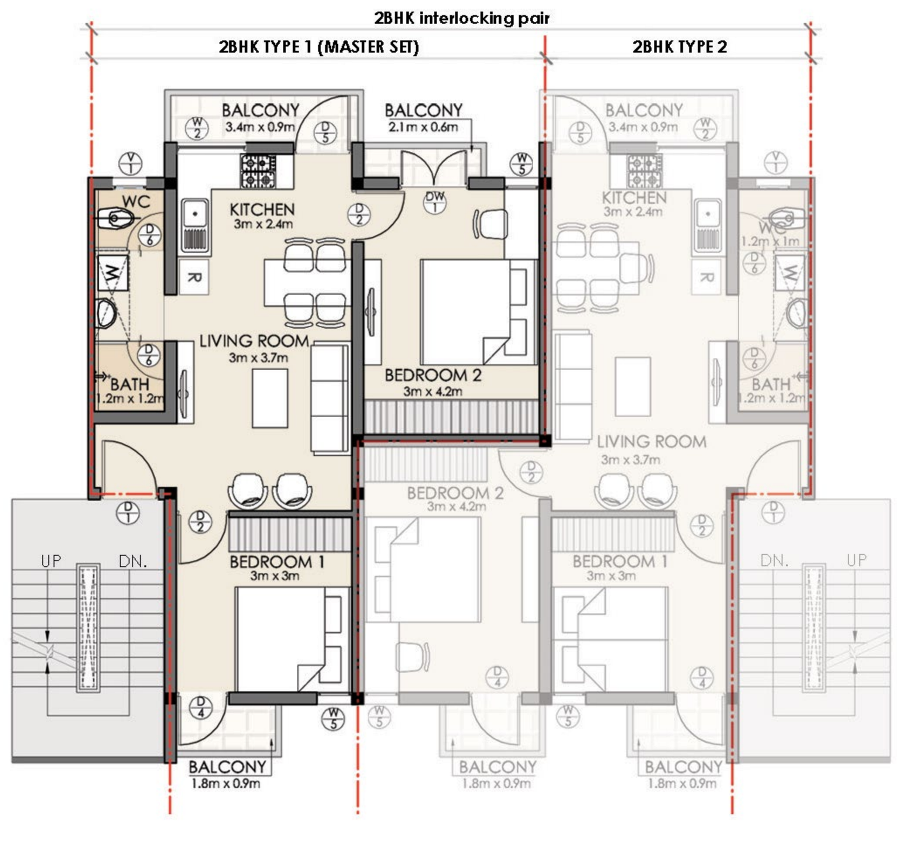
First Floor Plan

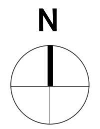
7.2. Master Sets with performance results

Following pages illustrate drawings & simulation result outputs for four different sample building types.

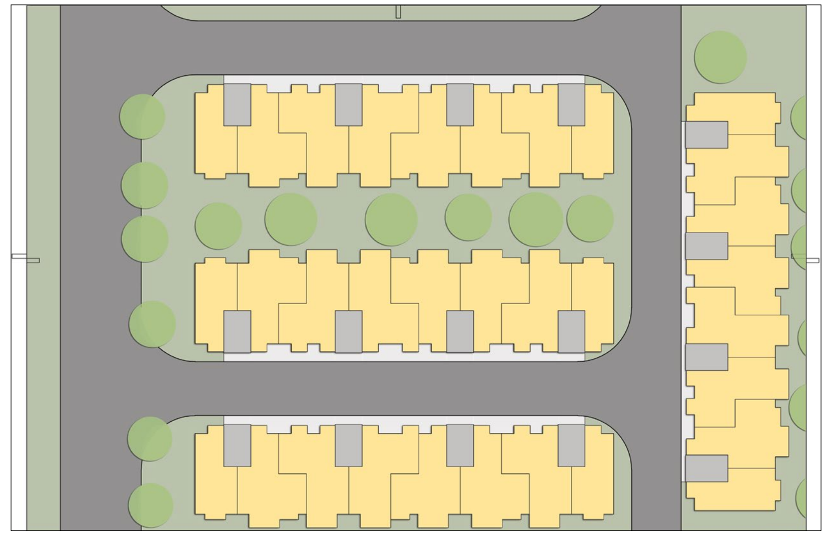
7.2.1. Low Rise – row house, 2 side open: 2BHK

1.2B

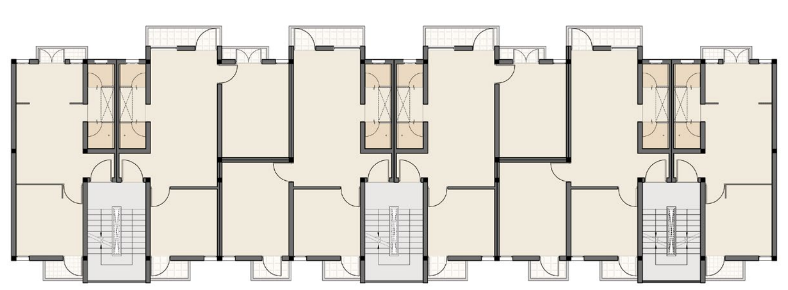




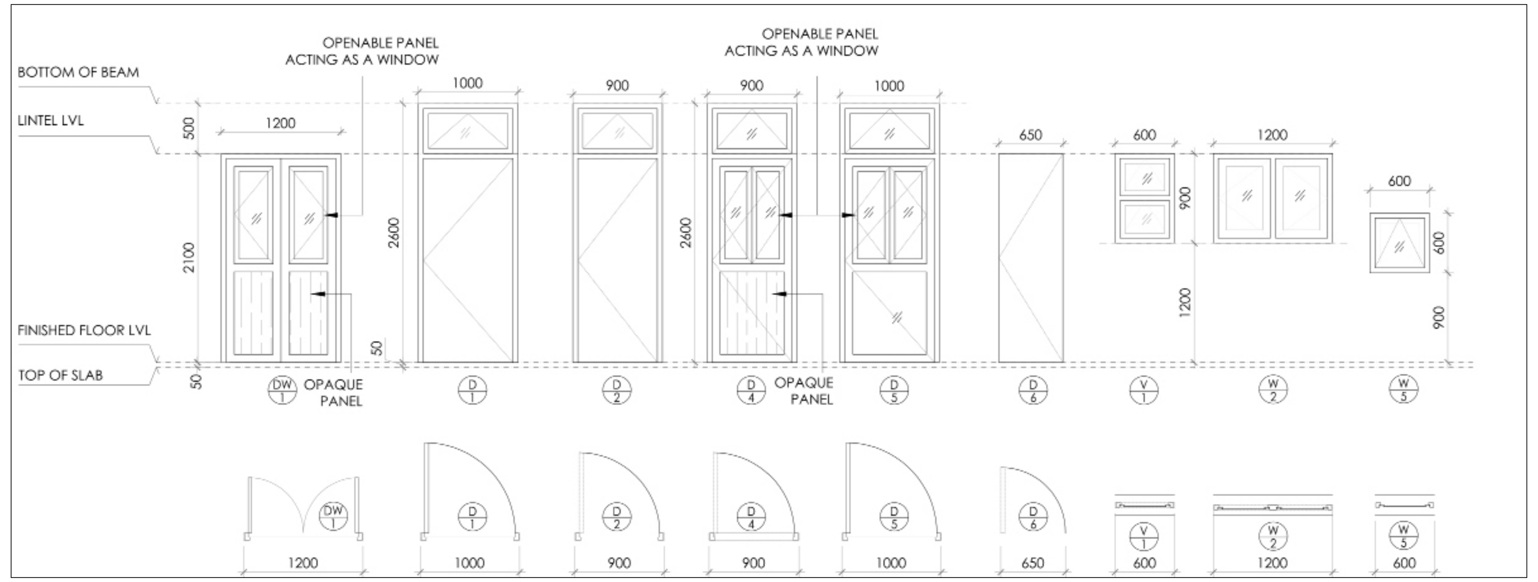
SITE PLAN



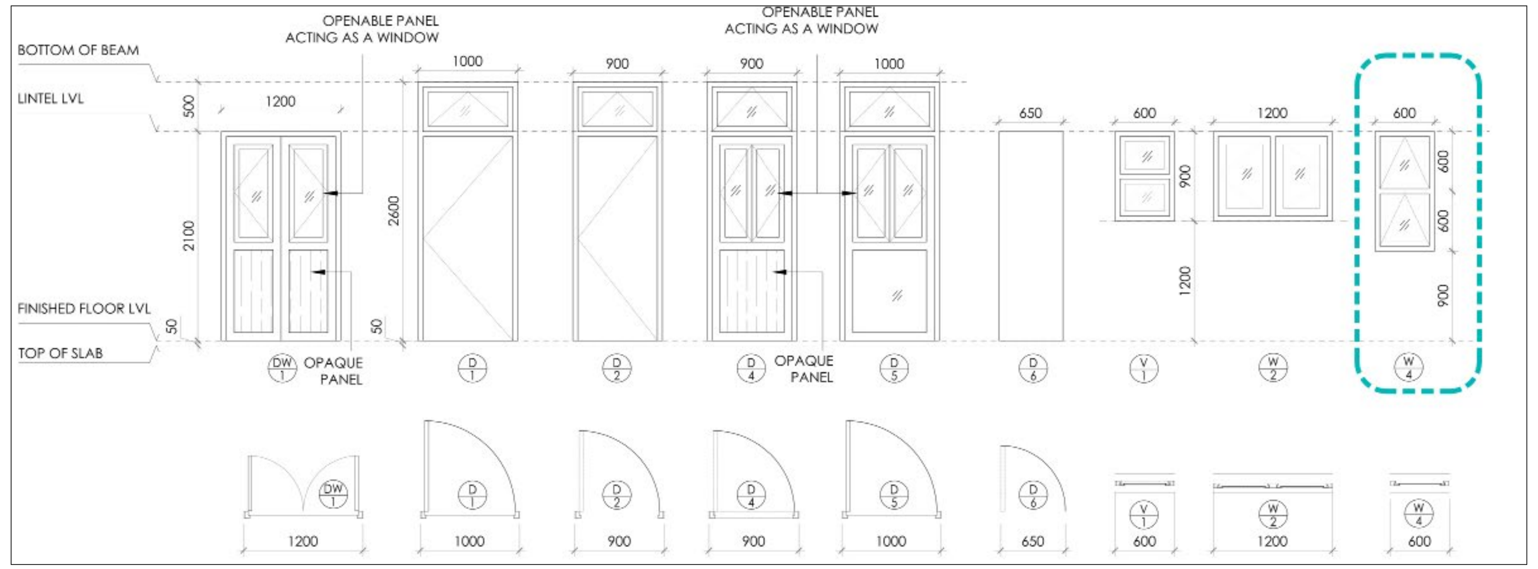
BLOCK PLAN



DOOR WINDOW SCHEDULE - Hot, Dry and Composite climates



DOOR WINDOW SCHEDULE - Warm & Humid and Temperate climates



ENERGY PERFORMANCE RESULTS FOR BASE PERFORMANCE LEVEL

COMPOSITE CLIMATE				
	NORTH	EAST	SOUTH	WEST
TOP FLOOR	57.58	58.85	60.85	61.55
MIDDLE FLOOR	54.36	52.81	56.03	54.77
BOTTOM FLOOR	50.66	49.17	51.20	50.79

HOT AND DRY CLIMATE				
	NORTH	EAST	SOUTH	WEST
TOP FLOOR	50.49	51.02	53.56	54.36
MIDDLE FLOOR	47.16	45.18	49.77	47.31
BOTTOM FLOOR	43.66	41.95	44.34	42.69

TEMPERATE CLIMATE				
	NORTH	EAST	SOUTH	WEST
TOP FLOOR	35.08	36.61	35.94	38.15
MIDDLE FLOOR	31.21	29.15	32.12	29.97
BOTTOM FLOOR	27.29	25.50	27.73	26.08

WARM AND HUMID CLIMATE				
	NORTH	EAST	SOUTH	WEST
TOP FLOOR	59.77	60.04	62.22	62.57
MIDDLE FLOOR	55.48	53.98	57.59	55.53
BOTTOM FLOOR	51.68	50.24	52.18	51.44

7.2.1. Low Rise – row house, 2 side open: 2BHK

EPI AND COST EFFICIENCY FOR EACH PERFORMANCE STATUS

1.2B

Composite Climate | Middle Floor | North Orientation

EPI (Excluding equipment)			
BASE	**MODERATE**	**GOOD**	**HIGH**
54.36	50.36	43.06	35.04
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	4	11.3	19.32
Annual CO2 emission reduction over base case (t CO2)			
-	0.16	0.59	1.12
Cost of Construction (INR)			
5,33,095	5,26,385	5,90,991	6,46,264
Construction Cost Increase over base case (INR)			
-	-6,710	57,896	1,13,169
Pay back period (years)			
-	immediately	13.3	13.87
Life Cycle Cost (INR) (Over 40 years)			
25,61,508	24,79,848	23,40,883	21,77,017

Hot and Dry Climate | Middle Floor | North Orientation

HOT AND DRY CLIMATE		**MIDDLE FLOOR**	**NORTH ORIENTATION**
EPI (Excluding equipment)			
BASE	**MODERATE**	**GOOD**	**HIGH**
54.36	50.36	43.06	35.04
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	3.72	8.82	14.73
Annual CO2 emission reduction over base case (t CO2)			
-	0.15	0.50	0.93
Cost of Construction (INR)			
5,29,595	5,22,885	5,84,991	6,38,764
Construction Cost Increase over base case (INR)			
-	-6,710	55,396	1,09,169
Pay back period (years)			
-	Immediately	15.23	15.98
Life Cycle Cost (INR) (Over 40 years)			
24,05,143	23,28,851	22,19,307	20,87,000

Temperate Climate | Middle Floor | North Orientation

EPI (Excluding equipment)			
BASE	**MODERATE**	**GOOD**	**HIGH**
31.21	27.91	25.02	21.02
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	3.31	6.19	10.19
Annual CO2 emission reduction over base case (t CO2)			
-	0.13	0.39	0.75
Cost of Construction (INR)			
4,67,680	4,61,919	5,21,447	5,70,720
Construction Cost Increase over base case (INR)			
-	-5,760	53,767	1,03,040
Pay back period (years)			
-	immediately	18.67	18.66
Life Cycle Cost (INR) (Over 40 years)			
17,69,603	17,01,912	16,35,987	15,14,773

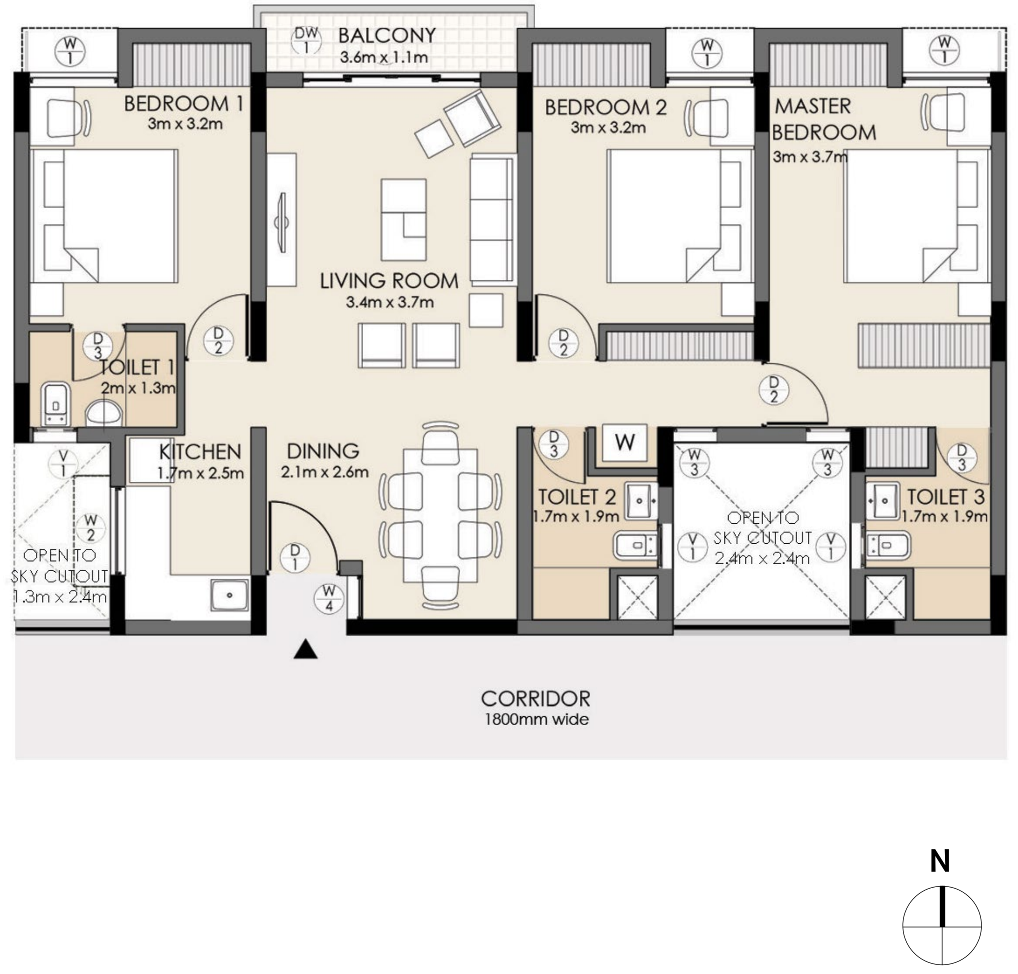
Warm and Humid Climate | Middle Floor | North Orientation

EPI (Excluding equipment)			
BASE	**MODERATE**	**GOOD**	**HIGH**
55.48	51.29	45.28	38.51
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	4.2	10.21	16.98
Annual CO2 emission reduction over base case (t CO2)			
-	0.16	0.55	1.02
Cost of Construction (INR)			
5,31,470	5,25,710	5,91,737	6,45,510
Construction Cost Increase over base case (INR)			
-	-5,760	60,267	1,14,040
Pay back period (years)			
-	Immediately	14.92	15.24
Life Cycle Cost (INR) (Over 40 years)			
25,63,078	24,78,705	23,56,022	22,07,553

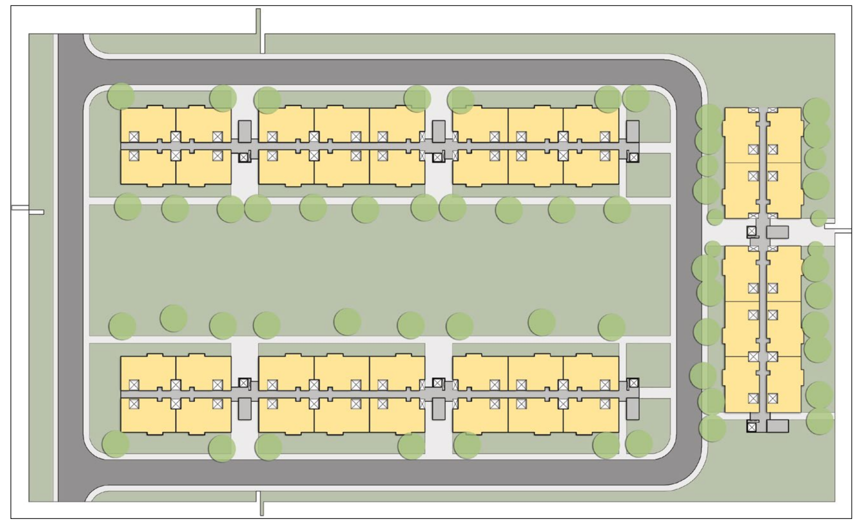
7.2. Master Sets with performance results

7.2.2 Mid rise Multi-family – Doubly Loaded Corridor

1.4A

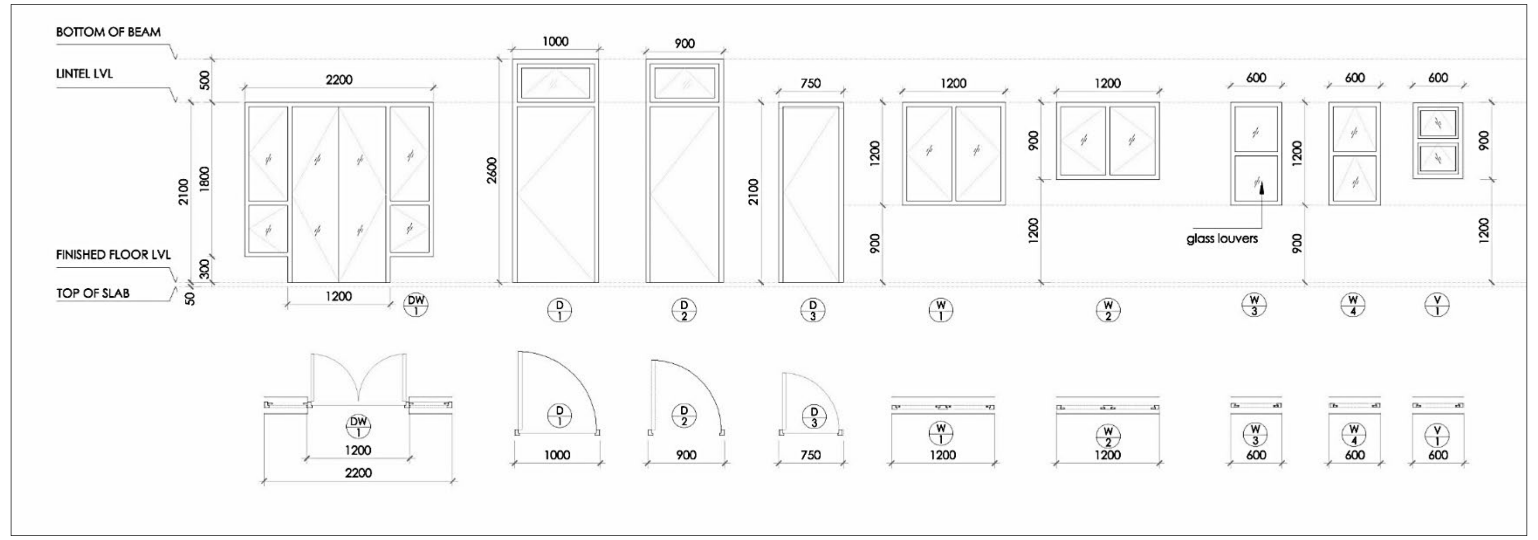


SITE PLAN

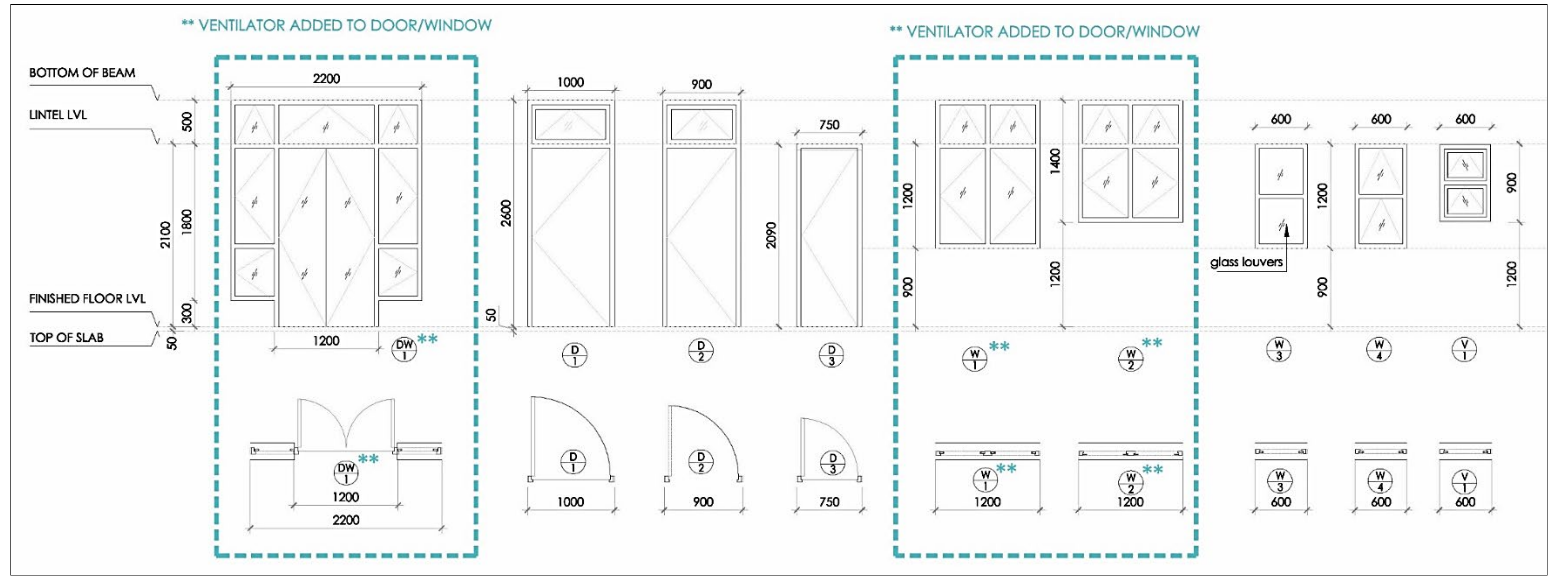


BLOCK PLAN

DOOR WINDOW SCHEDULE - Hot, Dry and Composite climates



DOOR WINDOW SCHEDULE - Warm & Humid and Temperate climates



ENERGY PERFORMANCE RESULTS FOR BASE PERFORMANCE LEVEL

COMPOSITE CLIMATE				
	NORTH	EAST	SOUTH	WEST
TOP FLOOR	44.80	47.92	46.54	47.27
MIDDLE FLOOR	44.30	47.67	46.34	46.36
BOTTOM FLOOR	40.16	42.22	41.68	41.20

HOT AND DRY CLIMATE				
	NORTH	EAST	SOUTH	WEST
TOP FLOOR	43.51	47.68	45.57	46.82
MIDDLE FLOOR	43.24	47.27	45.20	45.89
BOTTOM FLOOR	39.81	42.47	41.16	41.07

TEMPERATE CLIMATE				
	NORTH	EAST	SOUTH	WEST
TOP FLOOR	32.05	34.47	31.05	33.59
MIDDLE FLOOR	31.59	34.09	30.02	32.76
BOTTOM FLOOR	22.29	23.66	21.73	22.66

WARM AND HUMID CLIMATE				
	NORTH	EAST	SOUTH	WEST
TOP FLOOR	48.20	51.81	50.16	51.20
MIDDLE FLOOR	47.92	51.63	50.12	50.43
BOTTOM FLOOR	43.65	45.85	45.17	44.69

7.2.2 Mid rise Multi-family – Doubly Loaded Corridor

EPI AND COST EFFICIENCY FOR EACH PERFORMANCE STATUS

1.4A

Composite Climate | Middle Floor | North Orientation | Center unit

EPI (Excluding equipment)			
BASE	MODERATE	GOOD	HIGH
44.30	41.90	35.63	28.21
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	2.39	8.67	16.09
Annual CO2 emission reduction over base case (t CO2)			
-	0.17	0.82	1.94
Cost of Construction (INR)			
11,53,860	11,52,210	12,49,178	13,73,310
Construction Cost Increase over base case (INR)			
-	-1,650	95,319	2,19,450
Pay back period (years)			
-	Immediately	13.67	13.27
Life Cycle Cost (INR) (Over 40 years)			
42,56,085	41,61,738	39,69,195	36,20,987

Hot and Dry Climate | Middle Floor | North Orientation | Center unit

EPI (Excluding equipment)			
BASE	MODERATE	GOOD	HIGH
43.24	39.98	35.13	28.73
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	3.27	8.12	14.51
Annual CO2 emission reduction over base case (t CO2)			
-	0.23	0.78	1.75
Cost of Construction (INR)			
11,46,860	11,50,739	12,42,708	13,63,839
Construction Cost Increase over base case (INR)			
-	3,880	95,848	2,16,979
Pay back period (years)			
-	2.00	14.42	14.49
Life Cycle Cost (INR) (Over 40 years)			
40,37,651	39,19,884	37,51,207	34,55,701

Temperate Climate | Middle Floor | North Orientation | Center unit

EPI (Excluding equipment)			
BASE	MODERATE	GOOD	HIGH
31.59	27.13	24.48	20.65
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** –200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	4.46	7.11	10.94
Annual CO2 emission reduction over base case (t CO2)			
-	0.31	0.71	1.50
Cost of Construction (INR)			
10,43,636	10,47,515	11,75,630	12,87,761
Construction Cost Increase over base case (INR)			
-	3,880	1,31,995	2,44,126
Pay back period (years)			
-	1.46	21.84	19.01
Life Cycle Cost (INR) (Over 40 years)			
30,34,205	28,77,103	28,21,167	25,61,198

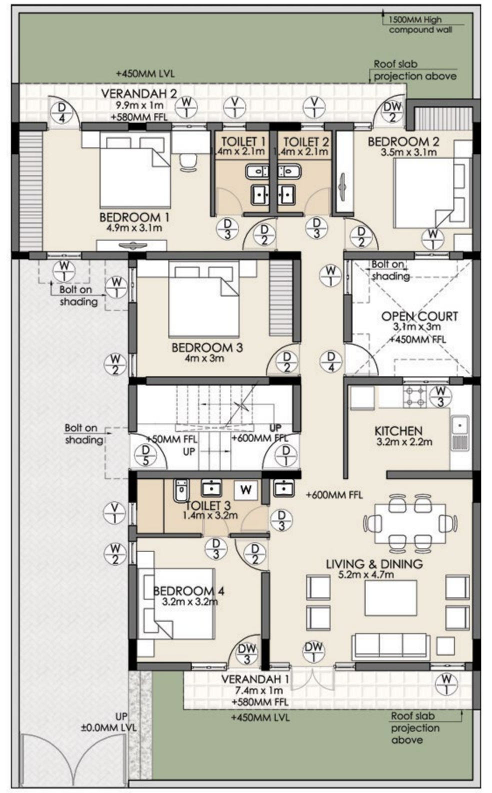
Warm and Humid Climate | Middle Floor | North Orientation | Center unit

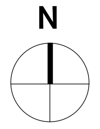
EPI (Excluding equipment)			
BASE	MODERATE	GOOD	HIGH
47.92	44.08	38.50	31.61
COMPONENTS AND SPECIFICATIONS			
• Wall – 200mm AAC Block • Roof – 50mm EPS insulation + Light colored glazed tile • Window – Single glazed unit with rolled steel frame • Shading – No shading • Electro-mechanical systems – 3 star rated appliances	• Wall –200mm AAC Block • Roof – 50mm EPS insulation + Light colored glazed tile • Window – Single glazed unit with rolled steel frame • Shading – Additional top and side shading fins & roll down bamboo screens for balcony • Electro-mechanical systems – 3 star rated appliances	• Wall – 200mm AAC Block • Roof – 50mm EPS insulation + Light colored glazed tile • Window – Double glazed unit with UPVC frame • Shading - Additional top and side shading fins & roll down bamboo screens for balcony • Electro-mechanical systems – 4 star rated appliances	• Wall – 200mm AAC Block with 50mm thick EPS insulation • Roof – 50mm EPS insulation + Light colored glazed tile • Window – Double glazed unit with UPVC frame • Shading - Additional top and side shading fins & roll down bamboo screens for balcony • Electro-mechanical systems – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	3.84	9.43	16.31
Annual CO2 emission reduction over base case (t CO2)			
-	0.27	0.87	1.88
Cost of Construction (INR)			
11,55,396	11,59,275	13,00,390	14,21,521
Construction Cost Increase over base case (INR)			
-	3,880	1,44,995	2,66,126
Pay back period (years)			
-	1.70	19.53	16.59
Life Cycle Cost (INR) (Over 40 years)			
42,00,859	40,64,215	39,19,802	36,08,225

7.2. Master Sets with performance results

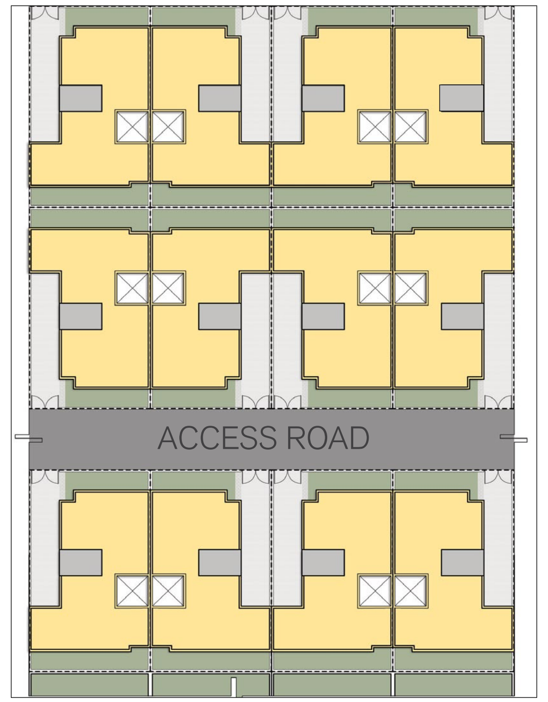
7.2.3 Plotted homes: 250 sqm plot

2.4A

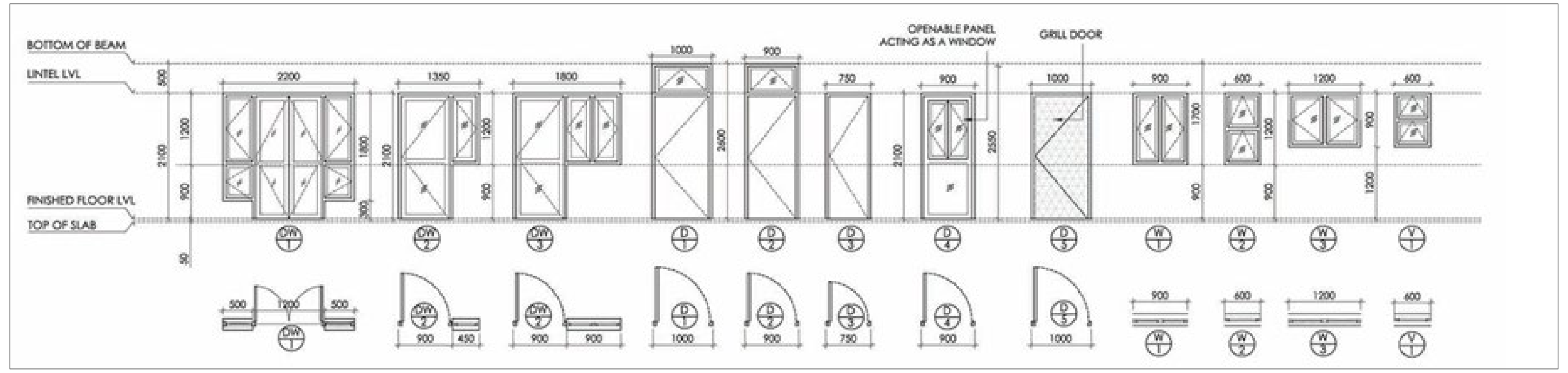




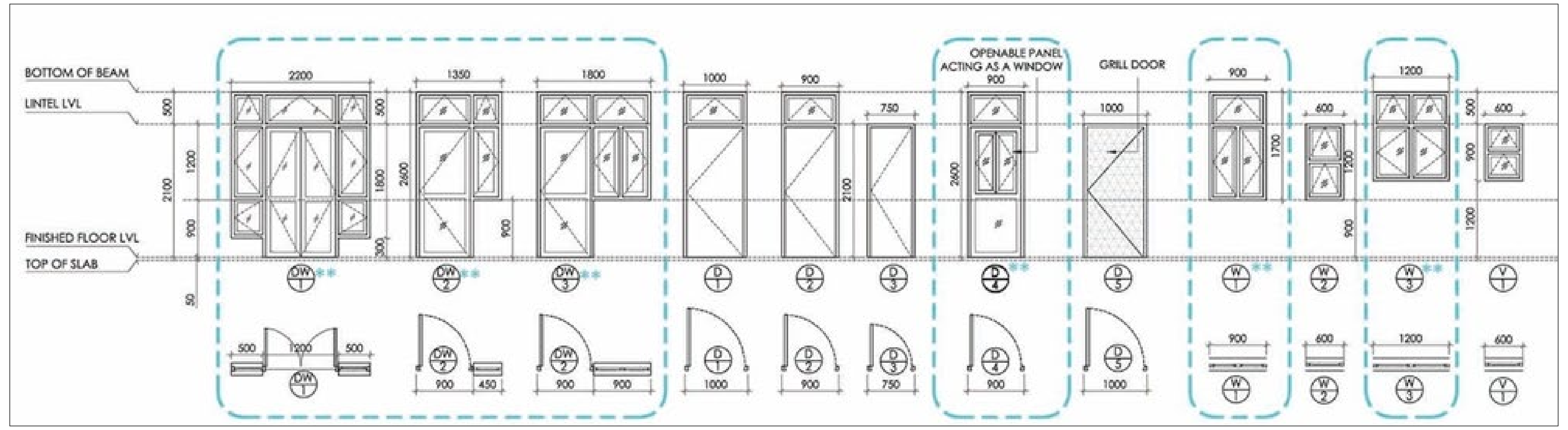
SITE PLAN



DOOR WINDOW SCHEDULE - Hot, Dry and Composite climates



DOOR WINDOW SCHEDULE - Warm & Humid and Temperate climates



ENERGY PERFORMANCE RESULTS FOR BASE PERFORMANCE LEVEL

COMPOSITE CLIMATE				
	NORTH	EAST	SOUTH	WEST
EPI	36.6	37.85	36.59	38.34

HOT AND DRY CLIMATE				
	NORTH	EAST	SOUTH	WEST
EPI	34.56	35.01	34.13	35.80

TEMPERATE CLIMATE				
	NORTH	EAST	SOUTH	WEST
EPI	18.37	19.46	17.94	19.9

WARM AND HUMID CLIMATE				
	NORTH	EAST	SOUTH	WEST
EPI	36.22	36.88	35.82	37.65

7.2.3 Plotted homes: 250 sqm plot

EPI AND COST EFFICIENCY FOR EACH PERFORMANCE STATUS

2.4A

Composite Climate | North Orientation

EPI (Excluding equipment)			
BASE	**MODERATE**	**GOOD**	**HIGH**
36.6	33.54	27.15	22.37
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	3.06	9.46	14.23
Annual CO2 emission reduction over base case (t CO2)			
-	0.26	1.03	2.05
Cost of Construction (INR)			
19,60,172	19,33,553	21,10,679	22,22,094
Construction Cost Increase over base case (INR)			
-	-26,619	1,50,507	2,61,922
Pay back period (years)			
-	Immediately	20.04	17.5
Life Cycle Cost (INR) (Over 40 years)			
50,19,616	48,79,029	46,95,224	43,93,130

Hot and Dry Climate | North Orientation

EPI (Excluding equipment)			
BASE	**MODERATE**	**GOOD**	**HIGH**
34.56	31.07	26.02	22.63
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	3.49	8.54	11.93
Annual CO2 emission reduction over base case (t CO2)			
-	0.3	0.95	1.78
Cost of Construction (INR)			
19,53,172	19,37,659	20,99,834	22,18,910
Construction Cost Increase over base case (INR)			
-	-15,513	1,46,662	2,65,738
Pay back period (years)			
-	-7.06	21.16	20.46
Life Cycle Cost (INR) (Over 40 years)			
47,52,413	45,94,483	44,42,358	42,14,804

Temperate Climate | North Orientation

EPI (Excluding equipment)			
BASE	**MODERATE**	**GOOD**	**HIGH**
18.37	16.20	13.37	11.30
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	2.16	5.0	7.07
Annual CO2 emission reduction over base case (t CO2)			
-	0.21	0.69	1.42
Cost of Construction (INR)			
18,67,958	18,52,788	20,44,693	21,54,769
Construction Cost Increase over base case (INR)			
-	-15,169	1,76,735	2,86,811
Pay back period (years)			
-	immediately	35.13	27.59
Life Cycle Cost (INR) (Over 40 years)			
35,62,663	34,50,038	34,11,352	31,79,418

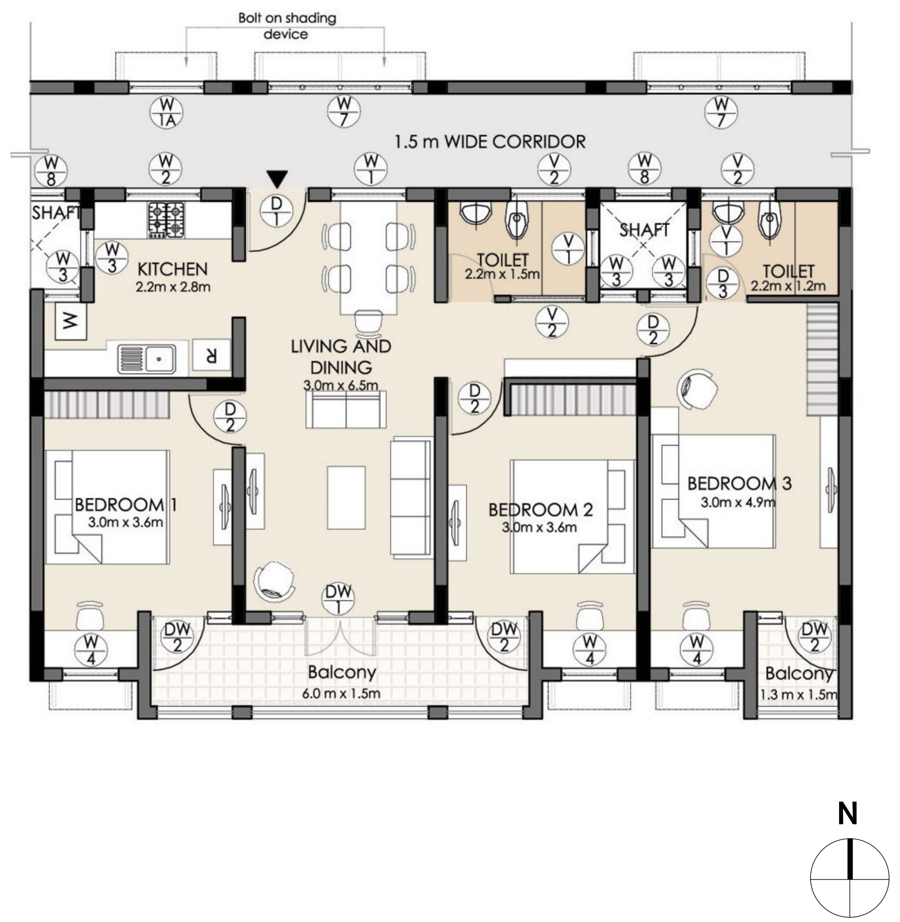
Warm and Humid Climate | North Orientation

EPI (Excluding equipment)			
BASE	**MODERATE**	**GOOD**	**HIGH**
36.22	32.95	27.61	24.14
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 230mm Brick • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame • **Shading** – No shading • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Single glazed unit with rolled steel frame **Shading** – Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200mm AAC Block with 50mm thick EPS insulation • **Roof** – 50mm EPS insulation + Light colored glazed tile • **Window** – Double glazed unit with UPVC frame • **Shading** - Additional top and side shading fins & roll down bamboo screens for balcony • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	3.28	8.61	12.09
Annual CO2 emission reduction over base case (t CO2)			
-	0.28	0.95	1.79
Cost of Construction (INR)			
19,80,958	19,65,789	21,71,403	22,90,479
Construction Cost Increase over base case (INR)			
-	-15,169	1,90,445	3,09,522
Pay back period (years)			
-	-7.34	27.29	23.64
Life Cycle Cost (INR) (Over 40 years)			
48,48,102	46,99,073	45,78,373	43,47,241

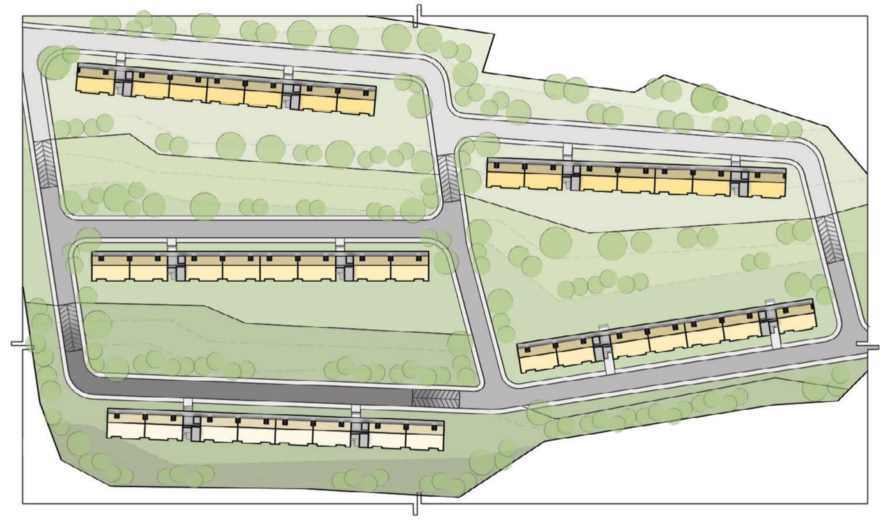
7.2. Master Sets with performance results

7.2.4. Singly loaded corridor

1.3CL

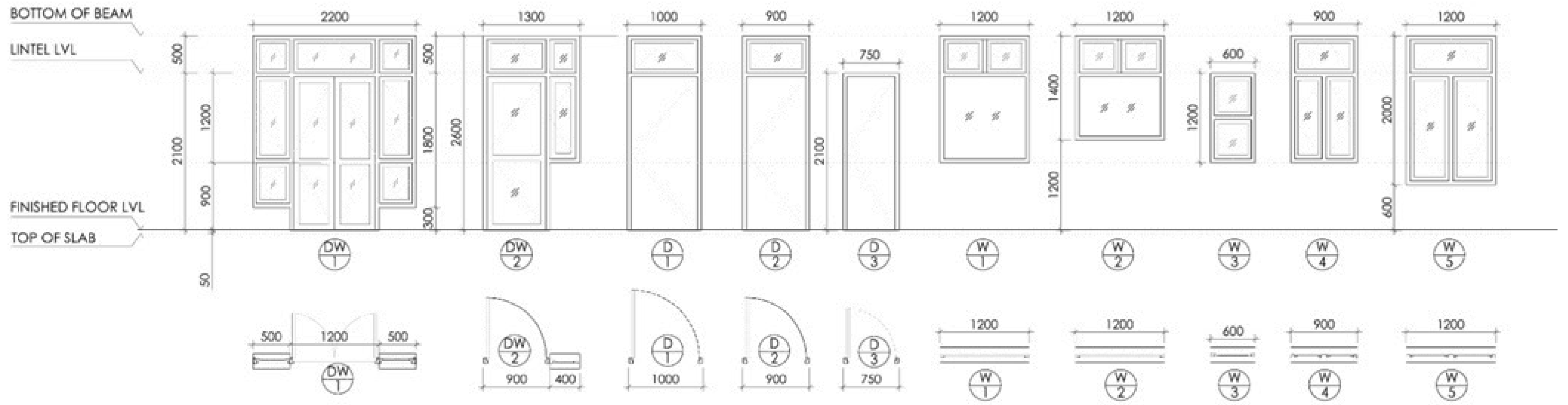


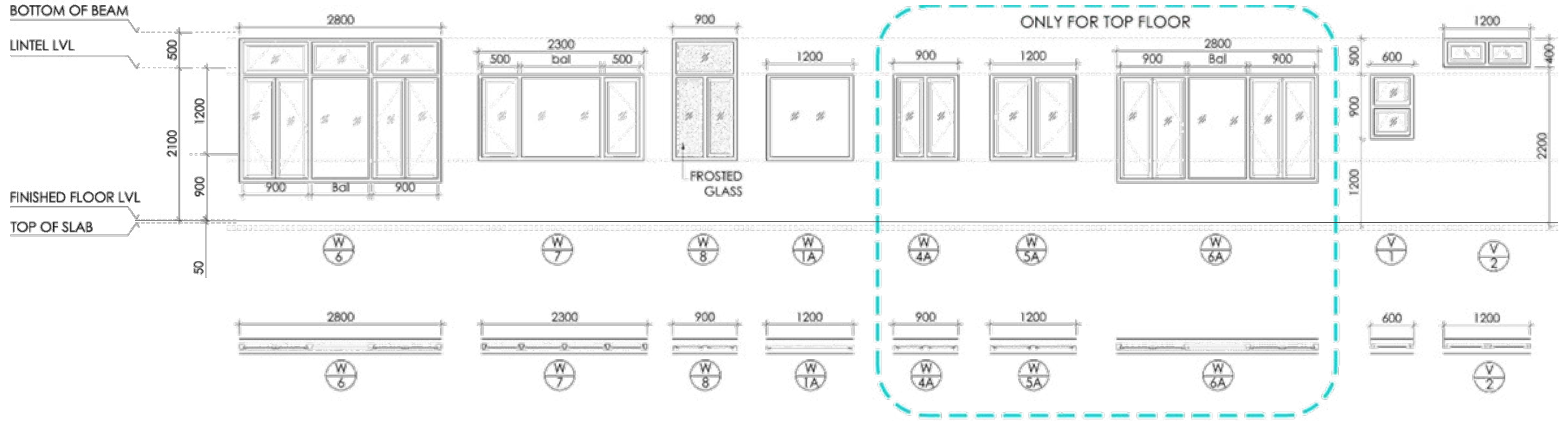
SITE PLAN



BLOCK PLAN

DOOR WINDOW SCHEDULE -





ENERGY PERFORMANCE RESULTS FOR
BASE PERFORMANCE LEVEL

MIDDLE UNIT				
	NORTH	NORTH EAST	EAST	WEST
TOP FLOOR	15.05	16.23	17.44	17.06
MIDDLE FLOOR	11.33	13.75	14.74	14.43
BOTTOM FLOOR	11.52	13.39	13.88	13.74

Cold Climate | North Orientation | Middle Floor | Center Unit

1.3CL

BASE	MODERATE	GOOD	HIGH
11.33	10.17	7.85	6.76
COMPONENTS AND SPECIFICATIONS			
• **Wall** – 200mm AAC Block • **Roof** – 6mm thick Galvalume Roofing Sheet +50mm thick wooden battens +75mm thick Insulation+ 125mm thick RCC slab • **Window** – Single glazed unit with rolled steel frame • **Sun balcony**- Open balcony with Railing. • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 6mm thick Galvalume Roofing Sheet +50mm thick wooden battens +75mm thick Insulation+ 125mm thick RCC slab. • **Window** – Single glazed unit with rolled steel frame • **Sun balcony**- Enclosed with windows • **Electro-mechanical systems** – 3 star rated appliances	• **Wall** – 200mm AAC Block • **Roof** – 6mm thick Galvalume Roofing Sheet +50mm thick wooden battens +75mm thick Insulation+ 125mm thick RCC slab. • **Window** – Double glazed unit with UPVC frame • **Sun balcony**- Enclosed with windows • **Electro-mechanical systems** – 4 star rated appliances	• **Wall** – 200 mm thick Thermo insulated concrete block • **Roof** – 6mm thick Galvalume Roofing Sheet +50mm thick wooden battens +75mm thick Insulation+ 125mm thick RCC slab. • **Window** – Double glazed unit with UPVC frame • **Sun balcony**- Enclosed with windows • **Electro-mechanical systems** – 5 star rated appliances
Annual Electricity savings over base case (KWH/sqm)			
-	1.16	3.49	4.57
Annual CO2 emission reduction over base case (t CO2)			
-	0.08	0.45	0.90
Cost of Construction (INR)			
1129725	11,51,877	14,36,065	14,92,240
Construction Cost Increase over base case (INR)			
-	22,151	3,06,340	3,62,515
Pay back period (years)			
-	33	80	47
Life Cycle Cost (INR) (Over 40 years)			
28,01,219	27,86,167	28,82,559	27,28,773

7.3. Exemplary Passive House (PH) level

7.3.1. Methodology for the Exemplary Passive House (PH) level

First of all, the geometry and the characteristics of each component of the building are entered in the Passive House Planning Package (PHPP), which is an energy balancing tool. Based on this information, the PHPP calculates a monthly heating and cooling demand for the entered building, its yearly primary energy demand including all energy uses in the building, the related CO2 emissions, as well as its cost-effectiveness. While the design used for the intermediate steps is preserved, the individual components are then evaluated and adjusted in the PHPP until the Passive House criteria are met (see chapter 5.1.1).

The standard values for occupancy density, domestic hot water demand, use of household appliances and internal heat gains typically used to model Passive House buildings are different to those set in this project to represent typical conditions in India. So the buildings were then modelled a second time to verify their performance under both scenarios.

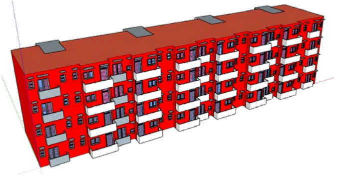
The recommended energy-efficiency measures were then reviewed in terms of their cost-benefit, using as basis the methodology from EN 15459 -1: 2017 for Life Cycle Costing. Through this analysis, the base case and the exemplary Passive House are compared in terms of not only their energy needs but also in terms of initial investment, operation and replacement costs, and residual value; assuming a lifespan of 40 years for the building.

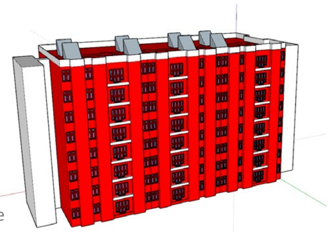
7.3.2. Result tables

The following tables include the components required to reach the PH efficiency levels for two of the prototypes analyzed: 1.2B and 1.4A. Component requirements vary by climate zone, as well as by building type. The requirements for 1.2B and 1.4A are quite similar in Lucknow (Composite climate), Aurangabad (Hot & Dry climate) and Bubhaneswar (Warm & Humid climate) with slight variations in the insulation thickness, and with double/triple glazing with solar control and a ventilation unit with heat and humidity recovery (ERV) in all cases.

Bengaluru (Temperate climate) features a much milder climate, which means that less effort is needed to ensure high energy efficiency. In this case the results of the analysis indicate single glazing with solar control and an extract air system. In all cases cool colours on the roof and good overall shading are fundamental passive cooling measures, as well as good airtightness of the building envelope, energy efficient appliances and avoiding thermal bridges. As can be seen in the result tables, high energy savings can be achieved while at the same time ensuring high comfort levels and good indoor air quality in all climates. Due to the high performance components comfortable temperatures above 20°C will be reached during the cold season in Lucknow without the need for heating.

Please note that the results calculated for the exemplary Passive House prototypes reflect the total primary energy need and equivalent CO2 emissions when heating/cooling the entire building to ISO 7730 comfort levels 20-25°C and maximum 60% relative humidity. These results cannot be directly compared to the EPI according to ECBC 2017, which is based on a different comfort level and does not cover the same energy uses in the building.


Row house 1.2B
© Passive House Institute


Row house 1.4A
© Passive House Institute

Climate	Composite (Lucknow)		Hot & dry (Aurangabad)		Warm & humid (Bhubaneswar)		Temperate (Bengaluru)	
	Base case	Passive House	Base case	Passive House	Base case	Passive House	Base case	Passive House
Wall / Roof / Slab insulation (mm)	0 / 50 / 0	250 / 225 / 150	0 / 50 / 0	125 / 150 / 100	0 / 50 / 0	200 / 200 / 100	0 / 50 / 0	100 / 50 / 0
Windows	Single glazing w. solar control + steel frame	Triple low e glazing w. solar control + uPVC frame	Single glazing w. solar control + steel frame	Triple low e glazing w. solar control + uPVC frame	Single glazing w. solar control + steel frame	Triple low e glazing w. solar control + uPVC frame	Single glazing w. solar control + steel frame	Single glazing w. solar control + uPVC frame
Ventilation	Windows + extract fans	ERV* + recirculation hood	Windows + extract fans	ERV* + recirculation hood	Windows + extract fans	ERV* + recirculation hood	Windows + extract fans	Extract fans
Airtightness n_{50}	$5h^{-1}$	$0.6h^{-1}$	$5h^{-1}$	$0.6h^{-1}$	$5h^{-1}$	$0.6h^{-1}$	$5h^{-1}$	$0.6h^{-1}$
Thermal bridges	The base cases have no thermal breaks, while the Exemplary Passive House cases avoid thermal bridges (through separate balconies, stairs etc)							
Elec. appliances	3 stars	5 stars	3 stars	5 stars	3 stars	5 stars	3 stars	5 stars
Heating demand (kWh/(m²a))	60	0 (-100%)	-	-	-	-	-	-
Cooling demand (kWh/(m²a)) [sensible / latent ratio]	447	142 (-68%) [84 / 58]	315	139 (-56%) [93 / 46]	629	196 (-69%) [105 / 91]	182	134(-26%) [68 / 66]
Final energy lighting + HVAC (kWh/(m²a))	314	53 (-83%)	172	56 (-67%)	361	66 (-82%)	112	63 (-44%)
Primary energy demand (kWh/(m²a))	1024	345 (-66%)	652	351 (-46%)	1140	374 (-67%)	502	374 (-26%)
CO_2-eq emissions (kg/(m²a))	211	72 (-66%)	135	73 (-46%)	235	78 (-67%)	104	78 (-25%)
Additional initial investment - NPV(₹/m²)	-	14,042	-	12,843	-	14,253	-	3,764
Operation costs–NPV (₹/m²)	2,91,157	1,09,927	1,89,658	1,11,700	3,22,877	1,17,857	1,48,930	1,13,778
Savings throughout the life cycle (₹/m²)	-	1,53,211 (53%)	-	51,052 (27%)	-	1,75,463 (54%)	-	25,771 (17%)

Table 08 : Exemplary Passive House 1.2B (North Orientation)

Climate	Composite (Lucknow)		Hot & dry (Aurangabad)		Warm & humid (Bhubaneswar)		Temperate (Bengaluru)	
	Base case	Passive House	Base case	Passive House	Base case	Passive House	Base case	Passive House
Wall / Roof / Slab insulation (mm)	0 / 50 / 0	125 / 100 / 25	0 / 50 / 0	100 / 75 / 25	0 / 50 / 0	100 / 100 / 25	0 / 50 / 0	50 / 25 / 0
Windows	Single glazing w. solar control + steel frame	Double low e glazing w. solar control + uPVC frame	Single glazing w. solar control + steel frame	Double low e glazing w. solar control + uPVC frame	Single glazing w. solar control + steel frame	Double low e glazing w. solar control + uPVC frame	Single glazing w. solar control + steel frame	Single glazing w. solar control + uPVC frame
Ventilation	Windows + extract fans	ERV* + recirculation hood	Windows + extract fans	ERV* + recirculation hood	Windows + extract fans	ERV* + recirculation hood	Windows + extract fans	Extract fans
Airtightness n_{50}	$5h^{-1}$	$0.6h^{-1}$	$5h^{-1}$	$0.6h^{-1}$	$5h^{-1}$	$0.6h^{-1}$	$5h^{-1}$	$0.6h^{-1}$
Thermal bridges	The base cases have no thermal breaks, while the Exemplary Passive House cases avoid thermal bridges (through separate balconies, stairs etc)							
Elec. appliances	3 stars	5 stars	3 stars	5 stars	3 stars	5 stars	3 stars	5 stars
Heating demand (kWh/(m²a))	13	0 (-100%)	-	-	-	-	-	-
Cooling demand (kWh/(m²a)) [sensible / latent ratio]	329	102 (-69%) [64 / 39]	238	100 (-58%) [68 / 32]	454	140 (-69%) [78 / 62]	139	94 (-33%) [52 / 42]
Final energy lighting + HVAC (kWh/(m²a))	179	38 (-78%)	121	40 (-67%)	221	47 (-79%)	79	42 (-47%)
Primary energy demand (kWh/(m²a))	657	246 (-62%)	506	250 (-51%)	764	265 (-65%)	401	262 (-35%)
CO_2-eq emissions (kg/(m²a))	135	51 (-62%)	104	52 (-50%)	157	55 (-65%)	83	54 (-34%)
Additional initial investment - NPV(₹/m²)	-	7,271	-	7,121	-	7,152	-	1,347
Operation costs–NPV (₹/m²)	1,02,030	42,098	79,579	42,676	1,18,028	44,879	63,977	42,956
Savings throughout the life cycle (₹/m²)	-	49,710 (49%)	-	26,803 (34%)	-	63,024 (53%)	-	18,904 (30%)

Table 09 : Exemplary Passive House 1.4A (North Orientation)

7.3.3. Other orientations

All prototypes were rotated to verify their performance with a different orientation. The tables on the right include a summary of the impact on main component requirements of the building.

The main impact of the change in orientation is the solar load. Buildings orientations with large window openings towards East and/or West are disadvantageous and call for additional shading measures to achieve the same high performance targets with low cooling needs. All other components (insulation, household appliances, HVAC equipment, etc.) remain the same.

The results indicate that buildings in the climate of Bengaluru are especially sensitive to the orientation. Prototype 1.2B will thus require double glazing and reduced window area if the facades with the majority of windows were facing East or West.

Orientation	North	East	South	West
Ext. walls	230mm AAC block + 250mm insulation			
Roof	225mm insulation + cool colors			
Floor	150mm insulation			
Windows	Triple glazing with solar protection + uPVC frame			
Shading	Overhangs + fins	Overhangs + additional fins for window D4, DW1,D5,W2	Overhangs + fins	Overhangs + additional fins for window D4, DW1,D5,W2

Table 10 : Components required for Row house (1.2B) in Lucknow

Orientation	North	East	South	West
Ext. walls	230mm AAC block + 250mm insulation			
Roof	225mm insulation + cool colors			
Floor	150mm insulation			
Windows	Triple glazing with solar protection + uPVC frame			
Shading	Overhangs + fins	Overhangs + additional fins for window D4, DW1,D5,W2	Overhangs + fins	Overhangs + additional fins for window D4, DW1,D5,W2

Table 11 : Components required for row house (1.2B) in Bengaluru (Temperate climate) for different orientations

7.3.4. Reducing the sensible cooling demand

The graph on the right shows the energy balance of the base case and the exemplary Passive House levels in the climate of Bhubaneswar.

The sensible cooling demand (in dark blue) can be decreased to a great extent by reducing heat gains through the building envelope and windows, by reducing the solar loads thanks to exterior shading devices and glazing with solar control, as well as by using a ventilation unit with heat recovery to reduce the heat loads coming with the fresh air flow. It can hardly be further reduced due to high internal heat loads (in orange). Once the electrical equipment has been improved, these are mainly caused by the high occupant density.

7.3.5. Reducing the latent cooling (dehumidification) demand

It is important to keep humidity within a building under a certain level for comfort and health reasons, but also to protect the building envelope. Humidity loads can be reduced mainly by preventing any excess of outdoor, humid air from entering the building. This can be done through better airtightness, using a ventilation unit with humidity recovery and recirculation hoods for cooking.

In high performance buildings, the energy efficiency measures usually lead to a shift in the sensible heat ratio i.e. the ratio between sensible and latent cooling (dehumidification) needs. As the need for sensible cooling decreases, the air conditioning systems will run at lower power and provide less incidental dehumidification. That is why in very humid climates, an additional dehumidifier may be needed for the most humid months. Under such conditions, cooling systems with separate cooling and dehumidification are generally recommended.

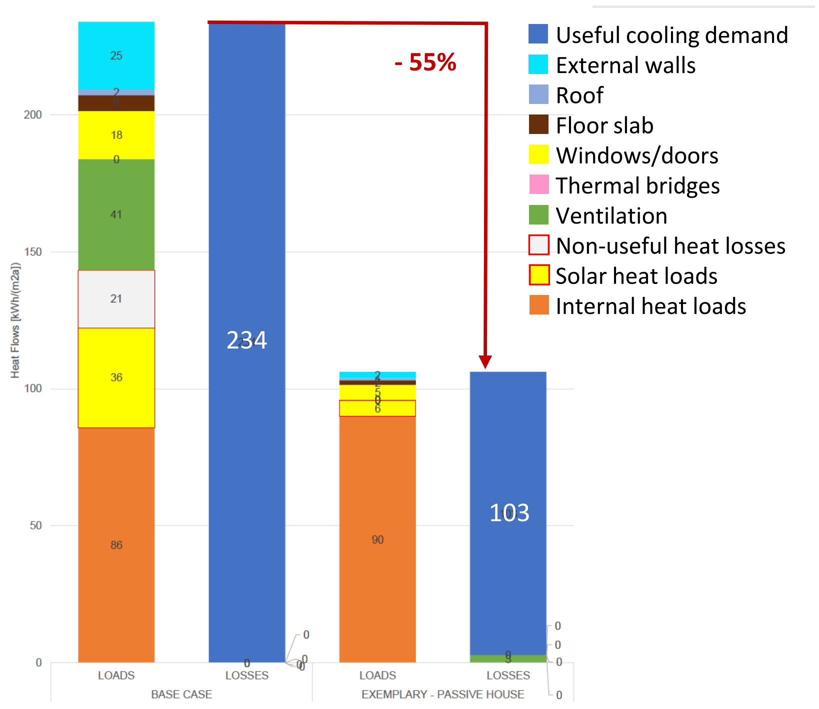


Figure 35 : Sensible cooling demand reduction for row house (1.2B) in Bhubaneswar (Warm & Humid Climate)

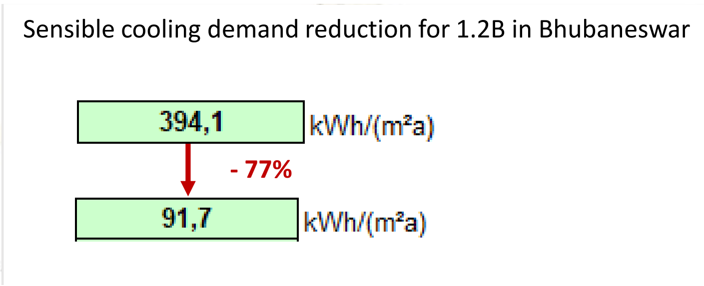


Figure 36 : Latent cooling demand reduction for row house (1.2B) in Bhubaneswar (Warm & Humid Climate)

7.3.6. Influencing factors

As mentioned in chapter 5.3, the required components depend on climate and building typology. In the case of a less compact building envelope, like for prototype 1.2B, more insulation will be needed to reach the Passive House standard than in the case of prototype 1.4A, where the compactness is much better due to the enclosed corridor and the technical patios with clerestory windows in the Passive House cases.

The floor plan also has an influence on the energy efficiency. By grouping and stacking rooms of similar uses the length and complexity of pipes and ventilation ductwork can be simplified. In addition, in cooling-dominated climates, instant geysers would be more beneficial than storage geysers, which generate heat losses to keep the water warm and thus increase the internal heat gains and the cooling demand. Alternatively, the DHW storage could be installed outside.

7.3.7. Cost effectiveness

The graph on the right shows that the higher initial investment costs for the Exemplary Passive House level can be covered by the savings in operational energy over the life cycle of the building. These annual savings are especially high in the climates of Lucknow and Bhubaneswar. In the mild climate of Bengaluru, the energy and financial savings are lower, but the additional investment to achieve the Passive House criteria is also smaller and occupants will benefit from higher comfort levels and better indoor air quality.

Having the required high performance products manufactured in India will help to reduce the additional investment cost in the future and improve the post sales services. That being said, this cost analysis is based on current costs and all Passive House variants studied so far are already cost-effective over their life cycle.

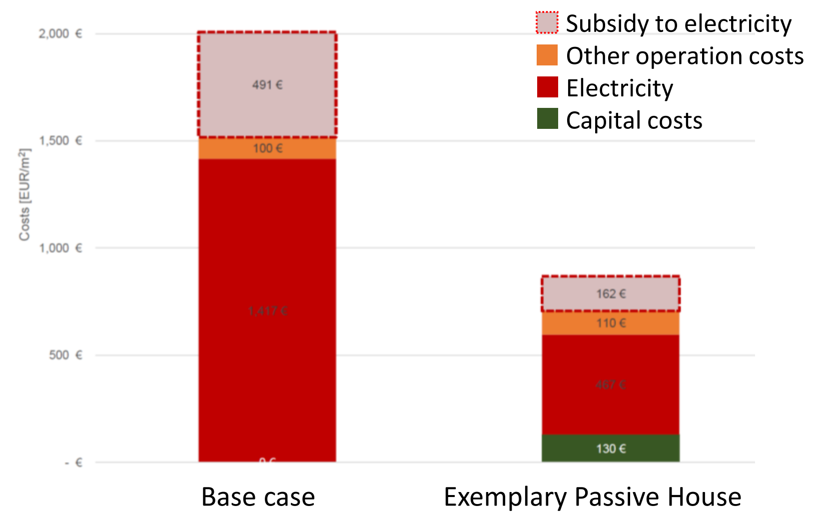


Figure 37 : Life cycle costs for Doubly loaded corridor (1.4A) in Bhubaneswar (Warm & Humid Climate)

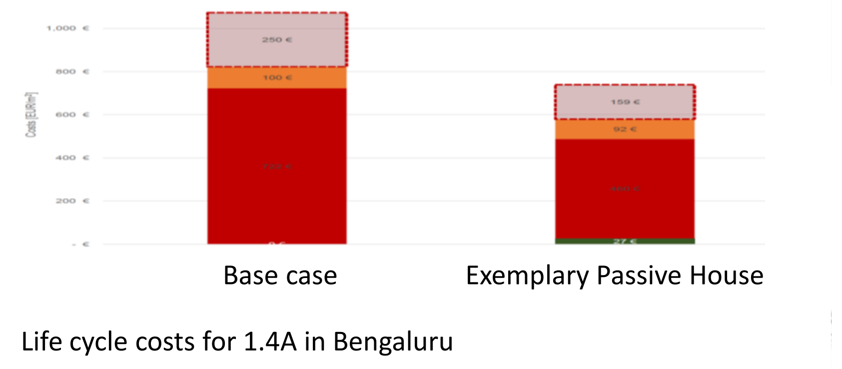


Figure 38 : Life cycle costs for Doubly loaded corridor (1.4A) in Bengaluru (Temperate Climate)

08

Observations and Conclusions

This section gives **brief notes on the salient aspects of the learnings from the project**. In these notes we summarise the principles of climate responsive and energy efficient design and construction.

•A defining feature of these dwelling unit designs is that it is in the planning and configuration of the building that the greatest energy efficiency gains are affected.
•This basic gain is then extended by the design of the external envelope – its walls, windows, insulation and external shading of windows. These are passive design strategies. The type designs are devised to maximise the duration of comfort hours.
•For those durations when passive strategies do not suffice, we resort to electro-mechanical devices for heating or cooling – the ceiling fan, the electric heater or air conditioner. The efficiency of the electromechanical systems, or their coefficient of performance (COP) matters. The better the COP the more energy efficient the device.
It is the combination of the above mentioned three steps in design that leads to energy efficiency in maintaining comfort indoors. These are termed as Energy Efficiency Measures (EEM)

An important finding of the project has been that the thermal behaviour of a particular dwelling unit, and consequently its energy performance, is affected by the location of the dwelling unit in the building as well as its orientation with respect to the sun. Shading from the sun and insulation of the external envelope can be adjusted accordingly.
The same dwelling unit type may be suitable for all the four climates in Set 1 (Hot-dry, Warm humid, Composite, Temperate) but it will have different performance according to each climatic condition. The more extreme the climate, whether on the hot and humid side or on the cold side, the greater the energy required to remain comfortable. The thermal performance of each dwelling unit is important as each home deserves to be comfortable. Design needs to be adjusted to the local conditions. Some dwellings are more at risk than others (e.g. in hot climates the top floor) which should be taken into account with envelope shape, glazing ratio, shading. So, there is a case for adjusting the design of the external envelope according to the location of the dwelling unit within the building and its orientation, for example units that are on the top floor or at the ends of the building have much more exposed wall area than middle units, therefore it becomes essential to plan for roof insulation and wall insulation to get the desired thermal comfort within these units. Similarly, there is also a case for modifications in the external envelope design according to climatic condition.

8.1. Warm Climate

8.1.1. Benefits of compact planning The analysis of the simulated efficiency performance of the type designs has shown that the most productive strategy for energy efficient design is that the building and dwelling unit layout should be compact. The more compact a design is the less exposure it has to the external environment per unit floor area. Compactness of the design automatically limits the exchange of heat across the building envelope..
Compactness has two characteristics:
a) External wall area to floor area ratio – The ratio of external wall area

to the floor area of the dwelling unit is sought to be minimised, thus minimising the exposure of the dwelling unit to the external environment. Simple rectangular plans without indentations will be more compact as compared to plans that have many indentations.

b) Attaching dwelling units horizontally and vertically - When dwelling units are attached side-by-side their exposure to the external environment reduces in comparison to stand alone homes. They also become more economical to construct because they share their 'party' walls. The same benefit is enjoyed in multi-storey flats as compared with single storey dwelling units.

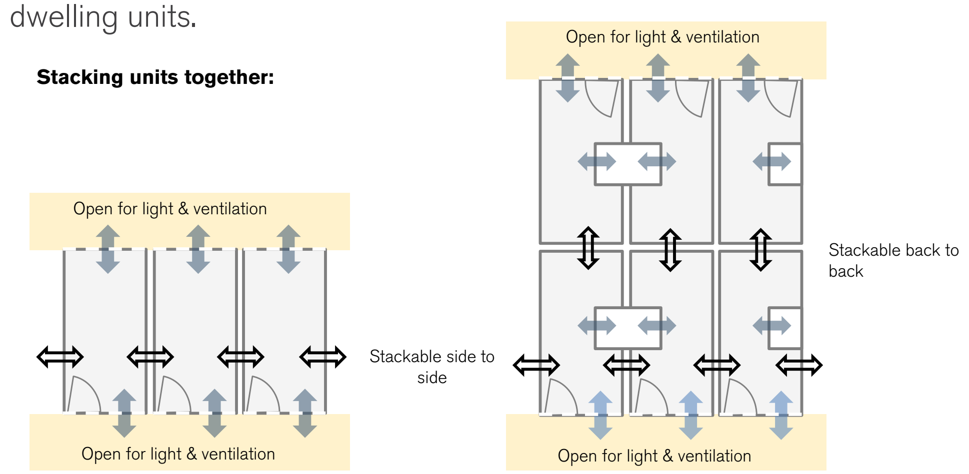


Figure 39 : Introducing courts for internal ventilation allows stacking units back to back. This gives **greater economy** of construction as **shared walls increase** and **street frequency decreases.**

From an energy conservation point of view, row housing is more efficient than stand-alone homes. Similarly, multi-storey flats will be more efficient than single or double storey houses.

8.1.2. External Envelope and building mass

▪After compactness of plan, it is the design of the external envelope that counts most. The rate of heat transmission through the external envelope is the combined effect of walls and their insulation value, windows and external shading. This is termed as the RETV. The Eco Niwas Samhita provides the method for calculating the RETV. A combination of sufficiently sized windows for day light and ventilation, which are externally shaded windows and moderate insulation of the walls achieves the prescribed RETV standard. The RETV can be further reduced by adding more insulation to the walls, better (adjustable) shading over windows and double glazing for the window glasses.

▪While the RETV is concerned with curtailing the heat transmission through the external envelope during the times when the outside temperatures are uncomfortably hot or cold, for those times when the outside temperature is pleasant and comfortable, we need to provide ventilation through openable windows. It is to be noted that for effective ventilation a casement window with a pair of openable shutters (90% opening) is preferred to windows with a pair of sliding shutters (50% opening).

▪The role played by the mass of the building is often forgotten. Heavy buildings built with RCC roofs and floors and solid masonry have high thermal mass. The fabric of heavy buildings acts like a thermal flywheel. They are slow to heat up and cool down. Light buildings are quick to heat up and cool down. A heavy building can store a lot of heat or cool.

A light building does not store much heat or cool. In warm climates when days are hot but nights are cool we can ventilate at night to flush out the heat and store the night's cool. During the day we close up to keep the heat of the day out and keep the cool in. To accelerate the cooling at night assisted mechanical ventilation by means of an exhaust fan proves to be beneficial. This is the principle of ventilation in warm climates. In cold climates the internal mass of the building can store the heat gained during the day by capturing the sun. An insulated exterior keeps the heat in.

8.1.3. Impact of orientation

Walls and windows that face in the easterly and westerly directions will receive the force of the rising and setting sun. Homes that have their major window openings and longer walls with these orientations will tend to get heated up and will therefore be less energy efficient. However, an effective antidote is good insulation of walls and adjustable shading screens to protect the windows form direct and indirect solar radiation. Southwards or Northwards facing walls and windows will receive comparatively less solar radiation and will therefore be more energy efficient.

While planning site layouts buildings can be placed to shade each other from the rising and setting sun. This can be an effective strategy for buildings that have to face in easterly and westerly directions.

In cold climates windows need to face southwards as much as possible so as to catch the low winter sun. While planning site layouts the placement of buildings in relation to one another need to be distanced and oriented such that each building gets winter sun access.

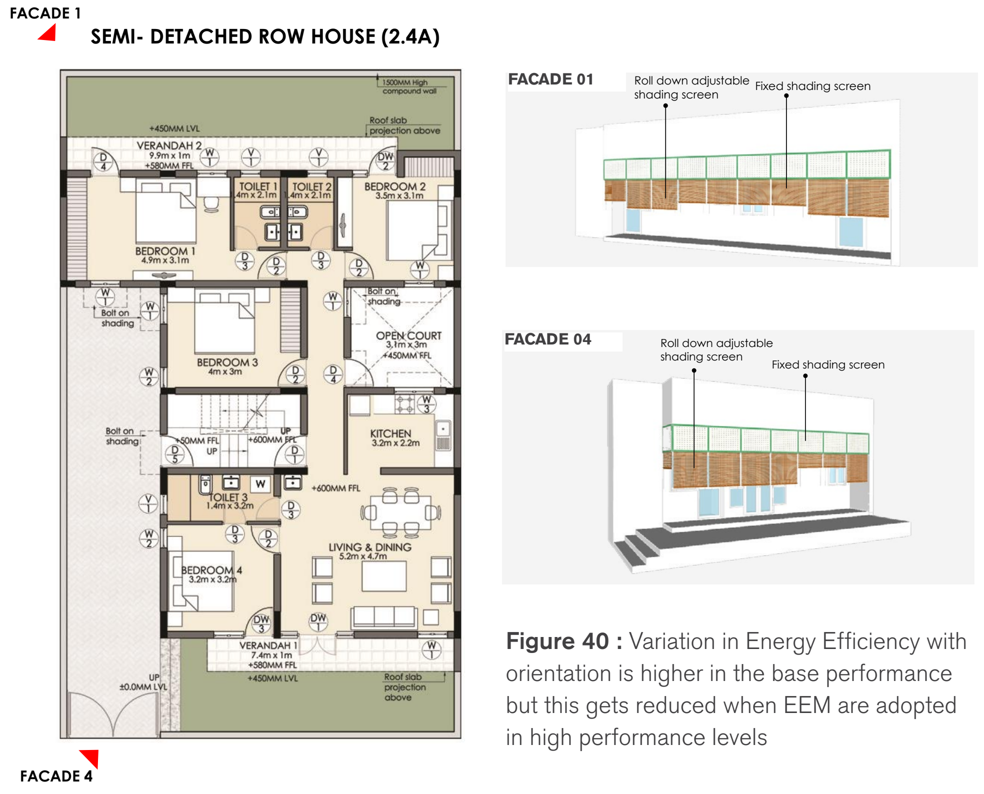


Figure 40 : Variation in Energy Efficiency with orientation is higher in the base performance but this gets reduced when EEM are adopted in high performance levels

Composite Climate				
	N	E	S	W
BASE	36.6	37.85	36.59	38.34
MODERATE	33.54	32.88	33.66	32.98

In Base case the North and South orientation perform better and result in lesser EPI as compared to East & West Orientations.This effect based on orientation is negated when orientation appropriate shading is added to achieve higher levels of performance.

Catching the sun or shading from it largely depends on the geographical location (which dictates climate, latitude, orientation) and elements surrounding the building in its own unique context. Designers must study the sun path for their site to understand and implement these strategies effectively to their own projects.

8.1.4. Impact of climate zone

When the same type design is tested for different climatic zones its performance varies. Passive EEMs by themselves can achieve comfort within a moderate range of conditions, to cope with extremes one will have to resort to active cooling or heating The more extreme the weather – on the hot side, the cold side, or the hot-humid side – the greater the requirement of energy for cooling and heating devices to keep the indoors within the comfort range. The impact of extremes on energy consumption can be reduced by additional insulation and higher performance glazing.

NORTH ORIENTATION				
	COMPOSITE	HOT- DRY	WARM- HUMID	TEMPERATE
BASE	36.6	34.56	36.22	18.37
MODERATE	33.54	31.07	32.95	16.2
GOOD	27.15	26.02	27.61	13.37
HIGH	22.37	22.63	24.14	11.3

Figure 36 : The EPI for a particular layout plan varies for different climate zones. This variation reduces as the EEMs are adopted and higher levels of Energy Efficiency are achieved.

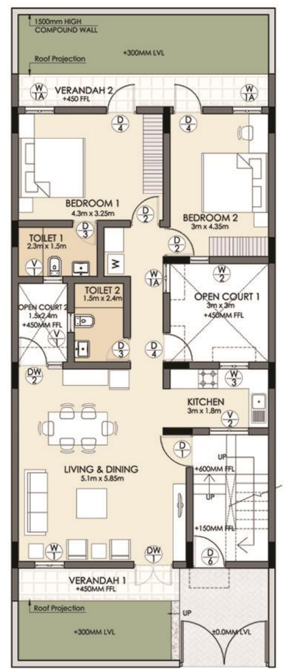
This requires a higher initial investment, but usually pays off over the life of the building, as seen for the Exemplary Passive House variants, Within the affordable range of deploying all the passive EEMs, including insulation, it is seen that the energy efficiency drops as the climate becomes more extreme.

8.1.5. Impact of occupancy

The Energy Performance Index (EPI) measures the consumption of energy per Sqm. of the carpet area of a dwelling unit or of a building as a whole. Now, the internally generated heat in a dwelling unit is dependent on the number of residents and all the heat emitting equipment that the household uses. In warm climates this heat tends to cause greater discomfort unless it is removed either by ventilation with cooler air or by an air conditioner. When homes are small, say, 30 to 50 Sqm (for LIG or EWS) they may have the same number of occupants as larger homes - say 100 to 150 Sqm (for MIG). Also, both kinds of household would have similar sets of electrical and cooking appliances in their homes.

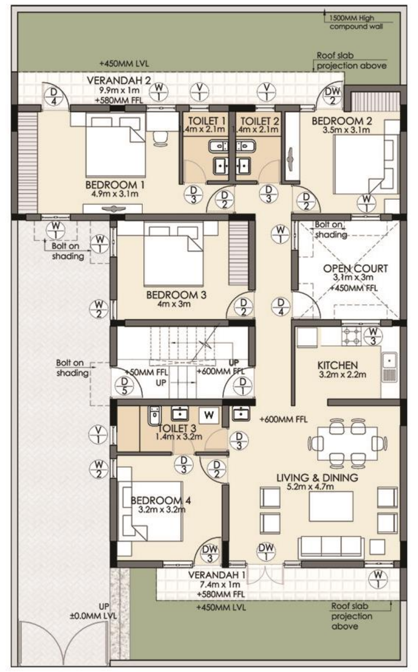
The intensity of internally generated heat loads in the smaller dwelling units is, therefore, found to be higher than that for large dwelling units. Ironically, as a consequence, the EPI of smaller homes for the less wealthy households tends to be greater than the EPI for the larger, wealthier homes.
This suggests that it might be more correct to have indicators of occupancy along with area while measuring the energy performance.

2 SIDE OPEN ROW HOUSE - 2.2A
Carpet area - 77Sqm



COMPOSITE CLIMATE
Base Case , North Orientation
EPI 44.48

SEMI DETACHED ROW HOUSE - 2.4A
Carpet area - 107Sqm



COMPOSITE CLIMATE
Base Case , North Orientation
EPI 36.6

Figure 37 : The smaller row house with shared walls on both sides is more compact in design but the high internal loads lead to higher EPI when the occupancy for both homes is similar.

8.1.6. Cost-benefit of EEM

As we should expect the law of diminishing returns applies when we look at the cost-benefit of EEM. This cost-benefit is evaluated by looking at how long it takes to pay for the additional costs of EEM by the savings in electricity consumption – the payback duration and the overall life cycle cost of the building.

▪Planning for compactness is the most beneficial EEM. Compactness reduces costs while achieving higher energy efficiency.

▪Similarly, keeping window sizes to the optimum requirement for sufficient daylight and ventilation, as against proving excessively large glazed panels, improves energy efficiency and keeps costs in check.

▪Simulation analysis shows that unshaded windows exposed to direct and diffuse solar radiation let in the most heat from vertical surfaces of the building envelope. External shading of windows is very cost-effective.

▪The roof, being exposed to the hottest sun during the day, has the greatest impact on the floor below the roof. Insulating the roof and finishing its surface with a reflective material becomes essential. Without this EEM the floor below will suffer and will not be energy efficient.

▪Further improvements in energy efficiency are effected by better insulation of walls and windows and by installing more efficient heating or cooling devices and ventilation units with heat/humidity recovery, depending on the climate.

▪Cold climate – For cold climates the situation is different. Windows need to be designed to capture the warmth of direct solar radiation during the daytime and retain the warmth indoors during the night. External walls with reasonable insulation, insulated roofs and double glazed windows become cost effective.

•As a general trend it is observed that the first four EEM listed above are more cost-effective when we are trying to achieve the basic standards of comfort. If one is satisfied with moderate level of comfort our study indicates that there is no need for complex construction.

•The last set of EEM that needs more insulation, higher performance windows and more efficient heating/cooling devices tend to be less cost-effective. As we progress and develop, expectation of better comfort standards will rise and with higher levels of income people will be able to afford more sophisticated materials and technologies. These will become more prevalent as prices come down with increasing demands in the future. The exploration of the Exemplary Passive House Performance is a pointer towards future possibilities. It prevents lock-in and provides resilience in light of warming climate, growing population and urbanisation.

•Exemplary Passive House – For some representative type plans the possibility of achieving exemplary energy efficiency has been studied by applying the Passive House Standard. In this standard, a continuous insulation layer, solar protective glazing with suitable shading devices, airtight and thermal bridge free construction as well as a ventilation unit (with heat/humidity recovery, depending on climate) drastically reduce the heating and cooling demand, while providing high levels of comfort and indoor air quality. Only a small air-conditioning unit will be needed to keep temperatures between 20 and 25C. This level requires a higher investment but simulation analysis shows that the prototypes are cost-effective over their life cycle. In addition, high performance components will become cheaper as market towards energy efficiency develops further.

8.1.7. Construction systems and building materials

The objective of the type designs is to enable the designers and builders of housing to adopt the design solutions readily. Therefore, the building materials and techniques of construction proposed in the designs are those that are now available and in practice in all regions of the country. The designs do not call for the use of new innovative technologies which are still in their infancy in India. But the existing construction practices are improved in the assembly details, especially where special care needs to be taken in placing insulation materials and to reduce thermal bridging and infiltration to achieve higher energy efficient performance.

8.1.8. Note on standardisation

Keeping in mind the objective of designers and builders readily adopting the type designs, the type designs acknowledge the need for standardisation. The design strategy is to design a type whose basic configuration and planning is inherently efficient so that the design can be used in various climates, orientations and locations of the dwelling unit within a building. The secondary components of the basic design – the windows, shading systems and additional insulation – can be varied according to the specific context. This principle is followed for each of the sets of type designs - the warm and hot climates set as well as the cold climate set. It is seen that the same efficiency of performance is not achieved in all cases, but this variation in the efficiency of performance is maintained within an acceptable range where the least efficient case meets the ECBC Star Label norm.

The principles of energy efficient design for residential buildings in cold climates differ from those for warm or hot climate in two significant ways. First, since the cold season is long and the warmer summer season is fairly comfortable. This means that it will be advantageous to let the sun shine into the rooms all through the cold season. The heat that enters through the windows needs to be stored and retained through the cold nights. During the pleasant or warm season, the sun must be kept out by shading so that the rooms do not get overheated. When the weather is pleasant it advantageous to ventilate freely. Welcoming the sun during cold season and trapping the warmth in the home is the key. Conversely, facing windows toward North or the cols sky instead of facing the sun would require a lot of artificial heating to stay comfortable indoors.

For optimising the potential of solar gains during the cold season the orientation of buildings becomes critical. Ideally, they would have windows toward the midday winter Sun. Next, facing toward the morning and evening Sun would also be beneficial. In summers overheating has to be avoided by external shading.

Buildings too need to be placed at sufficient distances between them to allow their neighbours to receive inter sunshine. Site planning.

An important overall finding is that the EPI for comfortable energy efficient residences in cold climates is much lower than in the warm and hot climates. It is seen that an average EPI of 10 to 12 Kwh/Sqm/annum is commonly achievable. With additional measures of glazed sun balcony and improved wall insulation an EPI of 6 to 8 Kwh/Sqm/annum is achievable.

8.2. Cold Climate

8.2.1. Compact Planning : Compact planning means keeping the exposed external wall surfaces to a minimum. This reduces the heat losses from the building. We find that row houses that share their part walls are more energy efficient than semi-detached or stand-alone houses. Similarly, multi storey buildings are more energy efficient than two storey buildings, principally due to the difference in exposure through the roof.

Figure 38 : Compact planning keeps exposed wall surfaces to a minimumand reduces heat loss from the building.

on the top floor are found to be relatively less energy efficient than DUs in the middle of the block. The compensation for this shortfall would be to improve the insulation on the roof and in the end walls.

8.2.2. Impact of building envelope and building mass : A heavy building mass protected by insulation on the outside works well. The warmth gathered during the day is retained in the building mass and released slowly through the night. As we change from clay bricks to AAC blocks and then to insulation sandwiched concrete block for external walls, we find an improvement of about 2 Kwh/Sqm/annum improvement with each successive step.

But the best results are obtained by making a glass enclosed balcony which catches the winter sun. This arrangement has the dual benefit of warming the external walls between the balcony and its adjacent rooms, and of keeping them well insulated for the night. During pleasant weather and summer they glazing is opened up for good ventilation.

Figure 39 : A south facing glass enclosed balcony in cold climates can catch the winter sun and help warm the external walls and insulate them for the night.

Roof insulation above an RCC (heavy mass) roof slab is a must.

8.2.3. Orientation: In the northern latitudes the best orientation is toward South as this gives the longest duration for receiving sunshine through the windows during the cold season. It is seen that as one turns eastwards or westwards the EPI increases. Facing West is a little better than facing East. When facing eastwards or westwards movable external shading is required. These shades need to cut the low sun toward the East and the West during summers to prevent overheating.

The North face being the 'cold' face, since it is exposed to the cold sky and does not receive any sunshine needs to be well insulated. Enclosed access corridors to toilets and service areas on the North face prove to be good strategies. Priority is given to the habitable rooms to face South, East or West.

In double storey DUs roof-lights are placed to bring the sun to rooms on the first floor that may be on the northern side of the house.

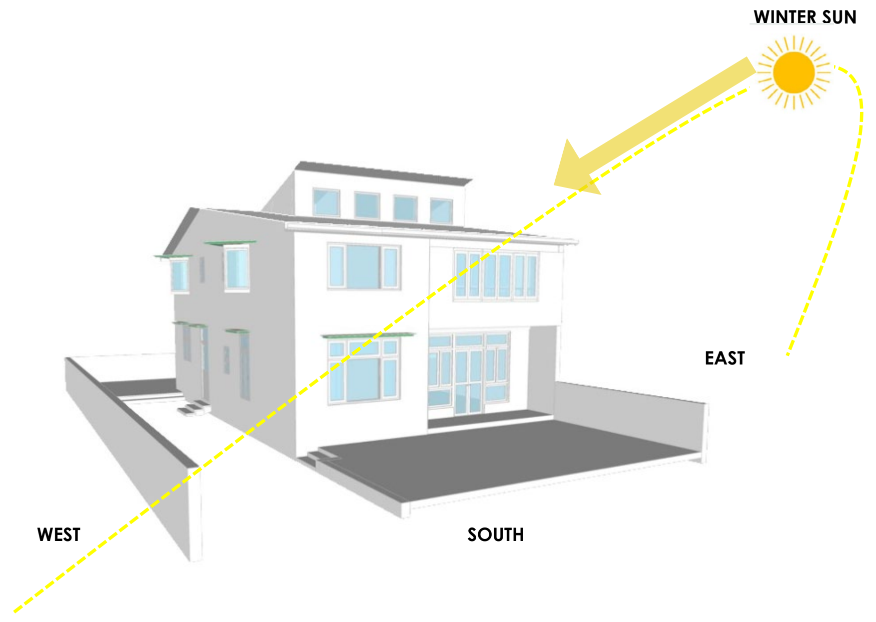


Figure 40 : In double storey DUs roof-lights are placed to bring the sun to rooms on the first floor that may be on the northern side of the house.

8.2.4. Site Planning : It should be noted that the layout of buildings and streets responds primarily to the need of favourable orientation to receive the winter sun. The house plan is arranged to have an open space toward the South. This is even when the entrance from the road may be on the North.

Distance between buildings is a critical consideration. Access to winter Sun for at least four hours during the day needs to be ensured even for the ground floor DUs. Overshadowing needs to be avoided. The same principle applies to planting of trees near buildings. Deciduous trees that shed their leaves in winter and allow sunshine through and shade against

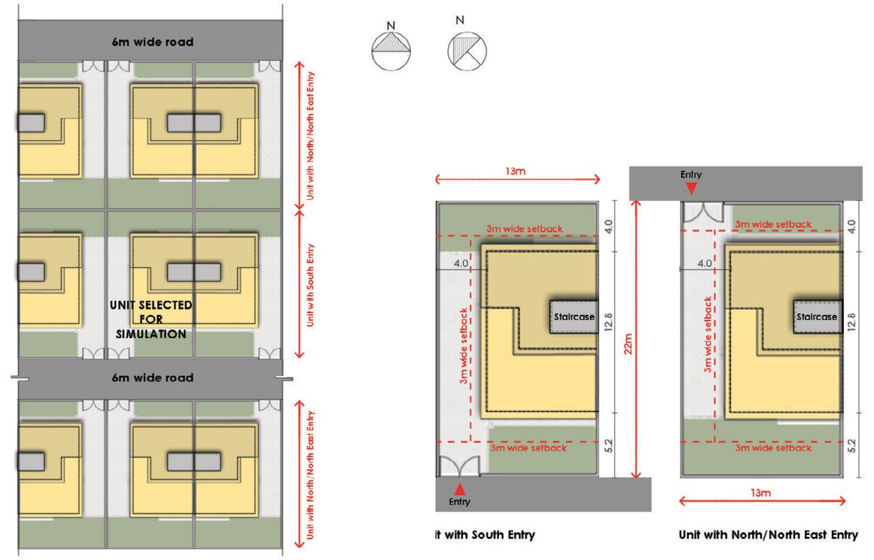


Figure 41 : The layout of buildings and streets responds primarily to favourable orientationto recieve maximum winter sun.

LIST OF ABBREVIATIONS

GHG – Green House Gases
GDP – Gross Domestic Product
GoI – Government of India
NDC – Nationally Determined Contribution
RCC – Reinforced Cement Concrete
ENS – Eco Niwas Samhita
ECBC-R – Energy Conservation Building Code for Residential Sector
GRIHA – Green Rating for Integrated Habitat Assessment
I**GBC** – Indian Green Building Council
EDGE – Excellence in Design for Greater Efficiencies
EPI – Energy Performance Index
UDI – Useful Daylight Illuminance
IMAC – India Model for Adaptive Comfort
WFR – Window to-floor Area
VLT – Visible Light Transmittance
WWR – Window to Wall Ratio
PVC – Polyvinyl Chloride
RETV – Residential Envelope Transmittance Value
LCC – Life cycle cost
BEE – Bureau of Energy Efficiency
EE – Energy Efficiency
NBC – National Building Code
EEM – Energy Efficiency Measure
PHPP – Passive House Planning Package
PHI – Passive House Institute
DHW – Domestic Hot Water
MEP- Mechanical Electrical Plumbing
COP – Coefficient of Performance
BOQ – Bill of Quantities
LIG – Low Income Group
MIG – Middle Income Group
EWS – Economically Weaker Section

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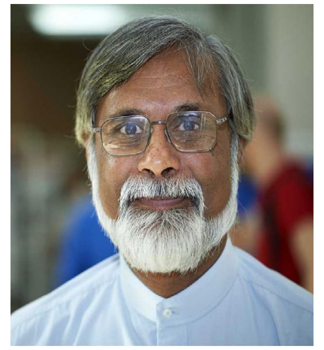

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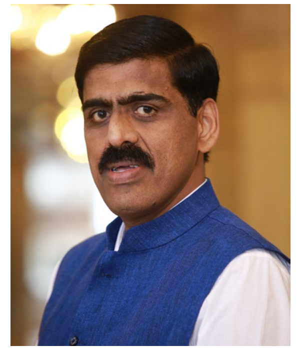

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