UNIVERSITY OF BATH

CREEDA

Climate Resilient Energy Efficient Design in Architecture: a design manual for India

Learning to play with tools and data
to design super-efficient buildings.

विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE AND TECHNOLOGY

With support from
PSI
PARTNERSHIPS FOR
SUSTAINABLE INDIA

Funded by
BRITISH
COUNCIL

UKRI
Engineering and
Physical Sciences
Research Council

Credits

Authored by Prof Sukumar Natarajan, Prof David Coley and Dr Francis Moran, Department of Architecture and Civil Engineering, University of Bath, UK.

ZEBRA models created by Dr Francis Moran and Prof Sukumar Natarajan.

Sketches by Prof Sukumar Natarajan.

Case Study selection and conversion to ZEBRA format, technical advice and support, courtesy Mr Gaurav Shorey (Psi Energy, Pvt. Ltd. India.) and Dr Nishesh Jain (University College London, UK; DesignBuilder Software, UK).

Funding sources

This manual has been produced through funding from two research and training projects: Zero Peak Energy Building Design for India (ZED-I, funded by UKRI, grant number EP/R008612/1) and Climate-Resilient, Energy Secure and healthy built environmenTs (CREST, funded by British Council grant number 877766384).

The underlying research was funded by UKRI via Zero Peak Energy Building Design for India (ZED-i) EP/R008612/1 from which this manual uses current and future weather data for India and Active Building Centre (ABC) EP/S016627/1 from which the ZEBRA model was developed.

Ongoing support for users of this manual is made possible through Impact Acceleration Account funding by the University of Bath.

Acknowledgments

The authors gratefully acknowledge the following practices and teams who have kindly shared drawings, data and pictures for the case studies featured in this manual:

- *SpaceMatters, C- 9, 9812, Vasant Kunj, New Delhi, Delhi 110070.*
- *Anagram Architects, K 110 Basement Hauz Khas Enclave New Delhi 110016.*
- *Visarg Design Studio, E-156, Greater Kailash Part 2, New Delhi – 110048.*
- *Muralage, A 3/269, Vibhav Khand, Gomti Nagar, Lucknow, U.P. – 226010.*
- *Solar Decathlon India, Competition Award Winning Entry, SPA - New Delhi (Team Sparikam).*
- *Design Plus Architects, C312-315A, Cosmopolitan, Sector 66, Gurugram - 122018, Haryana - India.*
- *Design and Development Atelier (DADA) - B 99, Sushant Lok 1, Gurugram, Haryana 122002, India.*

ISBN 970-0-86197-206-7

Contents

1 Preface

The goal of the CREEDA manual is to immerse you in the process of designing buildings that are resilient to a changing climate whilst also being highly energy efficient. Indeed, it is possible to design a truly zero-energy and zero-carbon building using the tools and techniques you will see here.

The approach we take in these manuals is one of "learning by doing". That is, rather than teaching you concepts or calculations, we show you how to reason out a strategy for the design of your building at a very early stage in the design process – maybe even before you have drawings. Thus, we wish you to learn how to PLAY with these types of tools through a process of self-education.

This manual contains a series of case study buildings – each based on a real building in India. We show you how to transform data for such buildings into a free-to-use tool called ZEBRA, use current *and future* weather data for any part of India at a 25 km spatial resolution and leverage existing knowledge and practices within India to achieve our goal of a truly low-energy climate resilient building.

We take each case study building through carefully selected changes to expose the ramifications of designing them differently – in effect showing you how to PLAY with your own designs.

How to play games

As with any game, you have to learn the rules before you can PLAY and some games have rules that can seem difficult to learn. As we want these manuals to be used by anyone who is computer literate, we have chosen the simplest means of embodying our design tool ZEBRA, i.e. a spreadsheet. The advantage of this is that almost anyone can open a spreadsheet without needing to pay large license fees. The downside is that if you, like many of us, are trained to play with lines and shapes, then you might initially find these new rules a little less visually appealing because they are written in the language of numbers and graphs. The fact is that if you want a truly super-performing building, there is simply no way to get around the need to understand and deal with some numbers.

In tests with users, we have found that much of what we cover in any given manual can be completed and understood in about a day. Like with any other technique, mastering these ideas and developing a deep intuition for them is completely dependent on how often you use it. Like the Sitar teacher who first checks the callouses on his pupils fingers, you'll need to build your low-energy callouses up before you will feel completely at ease with the tools described here.

Throughout, we use:

- **text in blue** to represent inputs to ZEBRA.

- **text in red** for important terms, useful contextual information and links to resources.

- **text in green** for material build-ups.

Good luck and have fun playing!

[1]CREEDA (krīḍā | क्रीडा) is the Sanskrit word for play or fun.

Part 1
ZEBRA Tutorial

If you've never used **ZEBRA** before, or want a refresher, go through this part before you attempt Part 2.

The tutorial is designed to on-board you as rapidly as possible in getting to know and use ZEBRA. The text in this section is accompanied by a series of videos which you can find by scanning the QR code on the right, where you can also download your free copy of ZEBRA.

Download **ZEBRA** – use QR code to navigate to website:

Click on the "download" tab, you will need to enter your details so the ZEBRA team can get feedback on where to tool is being used. Then you can download the tool, there is no cost.

1 What is the game?

In this part, we want to show you ZEBRA in action and the kind of results and information that can be obtained by using ZEBRA at a very early stage, and how the results might be useful in focusing the thoughts of the design team with respect to energy and/or carbon during the next iteration of the design. For example:

1. Is air conditioning really needed in the building?
2. What might happen to the energy use and carbon emissions if the occupants became more affluent and elected to use the air conditioning more frequently and with a lower setpoint?
3. What strategies might be used to offset this increase and how much impact might they have?

At such an early-stage of the design, energy and carbon modelling might best be thought of as a *scoping exercise* where we try and see if the environmental ambitions of the project are likely to be met, or if a radical rethink of the design is needed. Due to modelling teams being appointed late to a project, such decisions are normally made without numeric evidence. ZEBRA is designed to help *bring modelling to the start of the project* and before specialist engineers have been appointed. We have hence tried to make it useable by almost anyone and quick to use even on first acquaintance.

This part first lays out the design brief, then considers the information ZEBRA needs. The building is then modelled and the results presented. In the Results section you will find a large number of graphs, these are the direct outputs from ZEBRA, not graphs we have constructed for this document. One of the nice things about ZEBRA is that it presents the results in graphical form automatically, and is targeted at helping you understand the energy/carbon implications of your design and where it might be improved.

The following sections take you through to inputting an example building into ZEBRA. However, please remember that ZEBRA is under constant development, so some things might be a little different in your copy and the results shown here.

2 What is ZEBRA?

ZEBRA is a “monthly” model. That is, it uses statements about the climate in each month and the average occupancy of the building to estimate the energy use. ZEBRA also provides contextual information about many aspects of low-energy design, from glazing to the provision of hot water. This information is contained in the pink/purple boxes within the tool. To most people this will be a refresher. We hope this information will help point people in the right direction from the start.

Alongside heating and cooling energy use, ZEBRA also considers hot water, **electrical loads**, systems and their efficiencies and, to a lesser degree, **embodied carbon** and renewables. Hence in many ways it takes a whole-life, whole-building approach.

Electrical loads such as lights and plugged in appliances are tracked in two ways in ZEBRA. Firstly, they contribute to heat gains indoors, thus raising temperatures and, secondly they create an energy demand that must be met by the connection to the grid. This demand is tracked separately from other demand, such as that for space cooling.

Embodied carbon: Any activity that results in the production of a product or service will use energy, which will usually result in carbon emissions. For example, fired brick produces carbon during its manufacture. This carbon is said to be “embodied” within the brick.

3 Is ZEBRA difficult?

ZEBRA is flexible to the needs of your design and the depth of your understanding of the modelling process. It achieves this by allowing you to model at any of three *complexity levels* (there is also a fourth for programmers). The level you choose will depend on how well developed the design is, but also on how well-versed you are with its use. For example, do you know the dimensions and locations of the windows and the shading provided by surrounding buildings, or are you just working with statements like “20% of the south facade is glazed and the building is in an urban location”. It also depends on whether you wish to use defaults for things like the efficiency of PV modules, and finally, the level of detail you wish to see in the results.

Passivhaus is a composite word made from the German *passiv* which refers to a tradition of low-energy building design that does not rely on active methods (e.g. a ground-source heat pump) to be efficient, and *haus* the word for “building” (and not “house” as some might think). More information on Passivhaus can be found by scanning the QR code.

4 What does ZEBRA not do?

ZEBRA has not been designed to be a replacement for dynamic simulation and other methods used by experienced modellers once a full description of the building is to hand. Rather it is a tool targeted at those most involved in the initial stages of a project and who do not in general use dynamic simulation. We also think it makes a great teaching tool. It uses much the same calculation method used to certify **Passivhaus** buildings - the **PHPP (Passive House Planning Package)**. One implication of this is that it should only be used for reasonably well insulated relatively **airtight** buildings, or as is the case here, where the internal/external temperature difference is relatively small. As insulation and airtightness understanding and implementation in new build has advanced greatly in the last decade, this is not much of a restriction. We are, of course, conscious that airtightness is yet to make an impact in India – but we are confident this will be the direction of travel as it has been in many other countries.

PHPP, like ZEBRA, is a spreadsheet based design tool. Scan the QR Code to learn more about PHPP.

Airtightness: A major source of heat gain is the outside air, as you can imagine. What is generally less well understood is that a lot of this gain is completely uncontrolled in most buildings because it leaks in through the many gaps and cracks in construction, say between the window frame and wall. Airtightness can hence be defined as the resistance to unplanned / unintentional inward or outward air movement through leakage points or areas in the building envelope. Scan the QR code to read more on airtightness in Passivhaus.

5 The brief and initial thoughts

We have based this example on a real set of flats in Chennai, Tamil Nadu, see Figure 1. This has the advantage that we can compare our results to the actual energy use of the building. We will do this later, but for the moment we will step back in time and imagine the building only exists as a brief.

- At this stage many details remain unknown, and you are new to ZEBRA, so you decide to model mostly at **complexity level 1** (which requires the fewest inputs and least modelling knowledge).
- The brief is for an apartment block with a floor area of around **7,000 m^2** in Chennai, India.
- Initial discussions with the local planning department point to a 14-storey building as being possible.
- The client has asked for a low-carbon design. However, it is not clear whether by this the client expects the embodied carbon of the building (that arising from the materials etc. used to build the building) is to be included in the calculation and so we focus on **operational carbon**.
- The build time is expected to be short and the budget modest, so you decide to try and use a **standard construction system** rather than using natural materials – in which you have little experience.
- You have read that best practice for embodied carbon is currently considered to be **500 kgCO_{2e} per m^2** of TFA (Treated Floor Area), so plan to match this.
- Your first thoughts are to use 150 mm RC frame with no external insulation and single glazing. Whilst this is not the norm to achieve a low-energy building it is a common method of construction for buildings in this area.

6 To what standard?

You have heard of the following Passivhaus energy standards:

1) Maximum heating or cooling energy demand of **15 kWh/m^2 (TFA)** per annum. From here on, we will simply use the letter "a" to represent annum and write kWh/m^2/a.

2) Maximum **primary energy demand** standard of 120 kWh/m^2/a (TFA). This is all the energy used by the building, including plug loads, lights and hot water, and accounting for the fact that production and transmission of electricity via the grid is inefficient.

3) Airtightness requirement of 0.6 ac/h at **50 Pa**.

Unlike embodied carbon, **operational carbon** is that which arises from the energy used for space conditioning, hot water, lighting etc. in our buildings over its operational lifetime. We generally measure this on an annual basis and hence you will see much of ZEBRA uses a metric of per annum.

Energy benchmarks: As you are likely to be unfamiliar with these benchmarks, it is worth comparing them against GRIHA benchmarks for different typologies in the table in Annex 1.

TFA: The Treated Floor Area (TFA) is the conditioned (heating and/or cooling) internal floor area within the Thermal Envelope. The thermal envelope is boundary within which cooling and heating demand will occur.

The TFA requires accurate assessment as total operational energy demand is divided by the TFA to determine the energy use per m^2 per annum.

Primary energy demand is a concept similar to embodied carbon. When you consume a unit of energy from your wall socket, a significant quantity of energy has already been consumed in bringing that energy to your socket: coal was likely extracted, transported to a power station, burned to produce electricity (with a maximum efficiency of about 40%), then transmitted through the power network. Each of these processes consumes or loses energy which the primary energy metric accounts for.

Pa stands for Pascals, a unit of pressure. When we measure how airtight a building is, we pressurise and depressurise it (using a strong fan) to the same standard of 50 Pa so we can compare how well it is doing against a known standard, which is 0.6 air changer per hour in the case of Passivhaus.

You now consider how to proceed as follows:

- **Choosing an energy target:** You are worried that requiring the building to be a Certified Passivhaus might be impossible, and you do not have the skills in your company to deliver one, so decide instead to look at whether it would be possible to achieve double the energy values, i.e. **30kWh/m²/a** (heating/cooling energy), **240 kWh/m²/a** (primary energy) and ten times the airtightness, i.e. **6 ac/h** at 50Pa.
- **Fabric standard:** Initial U-values for the opaque elements of U-value of **2.46 W/m²/K** and **5 W/m²/K** for the glazing (i.e., single glazing), but plan to look at the impact of using insulation and double glazing.
- **Ventilation:** You plan to use **natural ventilation**.
- **Shading:** The design includes averagely shaded windows. So, for this scoping study, you decide to just select the one associated with average shading in the suggested values (see small red triangle), i.e. **0.23**.
- **Thermal Comfort:** You decide that the ZEBRA default cooling setpoint of 26°C is probably not appropriate in this context. This is due to two reasons. Firstly, ZEBRA assumes this temperature is constantly delivered in every room whenever the building is assumed to be occupied. This may, of course, not be true for many homes with air-conditioning only being turned on for a few hours each day. Secondly, studies have shown that people prefer a wide range of temperatures so 26 °C may overestimate cooling energy consumption. So, you momentarily drop into complexity level 3 to set the cooling set point to a more realistic value, then return to complexity level 1. This is explained further in Section 10.
- **Renewables:** You plan to cover a large percentage of the roof in Photo Voltaic **(PV)** panels to generate electricity, hopefully generating enough to match the energy use of the building - thereby achieving an operational carbon target of 0 $kgCO_{2e}/m^2$(TFA)/a, and ideally enough to offset the embodied carbon of the building too. You conclude that 60% of the roof can receive PV panels and a reasonable expected lifetime for the building is **60 years**.

The **U-value** is the thermal transmittance of a building element (wall, window, roof, floor etc) is the rate at which heat is lost or gained through it. It is best thought of as the opposite of resistance to heat flow. Learn more about it by scanning the QR Code.

Natural ventilation: That is, relying purely on natural air-movement through your building and no air-conditioning. There is a whole science to this and you can learn a little more by scanning the QR code.

7 The initial design

The plan below represents your first thoughts. This is in part based on your preference for buildings that look similar on all sides.

a) The actual building

b) Early-stage sketch plan.

Figure 1: (a). The actual building and (b) an early stage sketch plan.

8 ZEBRA inputs

Tutorials:
There are tutorial videos explaining each of ZEBRA's worksheets on the website.

You first download a fresh blank copy of ZEBRA from the website to ensure there is no data remaining from a previous project. This is critical because the tool is being continually updated and improved. Additionally, it is always best to start with a new copy for each project to avoid inputs (and perhaps mistakes!) from previous projects being carried forward into this new project.

The complexity level default setting is '1' (see **Instructions** sheet **F-16**) and requires the list of defined values shown in Table 1 (column 4). First determine those labelled 'u' (i.e. user defined). Once this is done you now start to enter this information into the correct sheets – whilst reading all the information in the light purple areas of each sheet so you get a better understanding of low energy/carbon design and so you understand the precise definitions of the inputs.

Having the data shown in Table 1 to hand is the key to modelling efficiently with ZEBRA. Once you have this data the model should take no longer than an hour to create in ZEBRA, and half this time for experienced users. Hence it might be worth creating a similar table for any new project.

8.1 Major inputs

You decide to use the default values for many optional inputs. Most of the inputs are already known from the brief or your initial thoughts, or can be found from manufacturers' data sheets or easily calculated, for example, areas. For this building and for complexity level 1, this implies 26 user inputs, the remainder being default settings.

We decide to model the whole apartment block as a single entity, rather than just a single apartment, although ZEBRA can do either. We decide this because we are interested in the average energy demand of the apartments, not trying to draw out differences between those facing in different directions or on different floors.

Table 1. Essential inputs required by ZEBRA mostly at complexity level 1.
Cells with a darker background are explained in greater detail in the text that follows this table.

Sheet	Input	Value	Default (d) or user (u) defined value	Unit
Requirements	**Space heating demand standard**	0	u	kWh/m²(TFA)/a
Requirements	**Space cooling demand standard**	30	u	kWh/m²(TFA)/a
Requirements	**Primary energy standard**	240	u	kWh/m²(TFA)/a
Requirements	**Assumed lifetime of the building**	60	u	A
Requirements	**Embodied carbon limit**	500	d	$kgCO_2e/m^2(TFA)$
Requirements	**Operational carbon limit**	0	u	$kgCO_2e/m^2(TFA)/a$
Requirements	**Treated floor area (TFA).**	6,669 without the central lobbies.	u	m²
Requirements	**Cooling setpoint**	30. Requires momentarily dropping into complexity level 3 to set this.	u	°C
Weather	**Approximate location of the building**	Chennai, 13.1°N 80.3°E	u	<from list>
Walls+doors	External **Wall area** (after subtraction of window and door areas)	3,905 (hand calculation)	u	m²

Sheet	Input	Value	Default (d) or user (u) defined value	Unit
Walls+doors	**Wall area** of walls adjacent to lobby	1,674 (hand calculation)	u	m^2
Walls+doors	External **Wall U-value**	2.46	u	$W/m^2/K$
Walls+doors	**Door area** (doors to lobbies)	105.8	u	m^2
Walls+doors	**Door U-value**	0 initially then 2.46 as part of parametric modelling	u	$W/m^2/K$
Walls+doors	**Lobby wall U-value**	0 initially then 2.46 as part of parametric modelling	u	$W/m^2/K$
Calculators	**Ground floor type**	Slab on ground	d	
Ground floor and Calculators	**Ground floor area**	529 this does not include the lobby area	u	m^2
Calculators	**Ground floor perimeter**	184	u	M
Calculators	Unadjusted **Ground floor U-value**	1.03	u	$W/m^2/K$
Calculators	**Ground conductivity**	2.0	d	
Calculators	**Wall thickness**	0.15 (initial estimate)	u	M
Roof	**Roof U-value**	4.20	u	$W/m^2/K$
Roof	**Roof heat-loss area.** For a flat roof this normally includes the wall thickness.	529 this does not include the lobby area	u	m^2
Thermal bridges	**Psi value and length of any thermal bridge or area.**	As the design is not well developed you decide to use the Thermal Bridge Calculator. This gives a Point thermal Bridge Coefficient of 992.6 W/K	u	-
Glazing	**Mid-pane U-value**	5.0 (i.e. single glazing)	d	$W/m^2/K$
Glazing	**Glazing g-value**	0.85	d	-
Glazing and calculators	**Area of windows**	176 m^2 per elevation. This is the area of the holes in which the widows fit, not the glass	u	m^2
Glazing	**Shading** (given in terms of what fraction of the sky is obstructed)	0.23-average shading (ZEBRA default =0-no shading)	u	-
Glazing	**Temporary shading**	Default =0 i.e. assume blinds etc. not regularly used	d	
Calculators	**Format of windows**	Type "h" in the photos in the calculators sheet	d	
Glazing	**Orientation of windows (relative to north)**	0/90/180/270 degrees	u	°
Air	**Assumed infiltration rate**	6	u	ach@50Pa
Air	**Internal volume of building**	17,774 (quick hand calculation after subtracting floors and very approx. volume of internal walls and the lobbies)	u	m^3
Air	**Average number of occupants** (this is averaged over the hours in a year)	ZEBRA dwelling suggestion (0.014 x TFA). However, a better approach would be based on the expected number of occupants and the hours the building will be in use.	u	P
Incidental gains	**Electrical gains** (e.g. lighting, computers etc.)	1.1 (ZEBRA suggestion for residential)	u	W/m^2(TFA)
Space conditioning	**Heat Recovery (HR). Efficiency of MVHR unit (if fitted)**	Blank as not fitted	d	-

Sheet	Input	Value	Default (d) or user (u) defined value	Unit
Systems	**Form of DHW system**	We select "on the spot with storage" as that is a common solution	u	<varies>
Systems	**Total daily hot water requirement of building**	For now we have used the UK residential default 25 litres/person/day. You have the option if you think hot water use is lower in this part of the world due to the high external temperature, so you could assume half this. (25/2) x 168 occupants = 2,100 litres. The 168 occupants estimated from an occupancy of 3 people per apartment	u	<varies>
Systems	**Roof area** (flat roof, so the same as roof heat-loss area). This is the area over which PV might be fitted	529	u	m^2
Systems	**Fraction of roof area suitable for PV**	0.6 The is just a guess at this point, but seems reasonable when you look at systems on other flat roofs.	u	-
Systems	**Efficiency of the heating system**	2.0 assumed value for the CoP of an air conditioning unit	u	-
Systems	**Fuel type used by heating**	Electricity	u	<choose from list>
Systems	**Fuel type used for DWH**	Electricity	u	<choose from list>
Systems	**Efficiency of DWH heating**	1.0 as direct electrical heating	u	-
Systems	**Efficiency of the cooling system**	2.0 assumed value for the CoP of an air conditioning unit	u	-
Systems	**Fuel type used by Space cooling**	Electricity	u	<choose from list>
Embodied Carbon	**Building Type** (school, office…)	Apartment – residential	u	<choose from list>
Embodied Carbon	**Construction Type** (standard, proven low carbon….)	Standard (w.r.t carbon)	u	<choose from list>
Embodied Carbon	**Questions about the materials and design**	Left as n/a, as yet to decide on the construction	d	

In the following subsections we look at some of the inputs in the more detail, but you will need to enter all the inputs in Table 1 into the tool.

8.2 Requirements

Entering the information from Table 1, our complete **Requirements** sheet looks like:

Requirements		
Energy and carbon philosophy	**Value**	**Unit**
Space heating demand standard	0	kWh/m²(TFA)/a
Space cooling demand standard	30	kWh/m²(TFA)/a
Primary energy standard	240	kWh/m²(TFA)/a
Assumed lifetime of the building	60	a
Embodied carbon [A1-A5]	500	$kgCO_2e$/m²(TFA)
Operational carbon	0	$kgCO_2e$/m²(TFA)/a
Key characteristics	**Value**	**Unit**
Treated floor area (TFA)	6,669.00	m²

8.3 Weather

ZEBRA comes bundled with weather data for 3,000 worldwide locations. We begin by trying to use this built-in weather data for our model by entering the latitude and longitude into the left side of the table. This throws up some suggested locations on the right side. Cuddalore is the closest, despite being about 170 km away from our site in Chennai. For now, we select Cuddalore from the drop down menu in cell F6 (you can also copy and paste, but it should be pasted as a value). In Part 2, you will see how new weather data from the **ZED-i project** now allows us to select highly-localised weather for almost any part of India.

To obtain weather files for the proposed location navigate to the **ZED-i** webpage:

Weather						
				Units	-	km
Location	**Value**	**Unit**	**Comment**	**Suggestion**	**Name**	**Distance to location**
Latitude	13.10	°	Convention: North > 0°.	1	Cuddalore	159
Longitude	80.30	°	Convention: East > 0°.	2	Tiruchirappalli Intl AP	312
Selection	Cuddalore	-	Weather data selected.	3	Anantapur	332
				4	Gannavaram Vijayawada AP	385
Site height	8.00	m	Defaults to that of the weather data.			
Temperature correction	0.00	°C	Due to site-weather elevation difference.			

Cuddalore is North of the equator, but below the Tropic of Cancer. Looking at the **solar irradiation** plot ZEBRA generates (Figure 2), we see that in this part of the world during the summer months the irradiation on the east and west facades is close to twice that of the south façade. However, in winter, when **solar gains** might be useful, the south has greater irradiation than the east or west. It is worth noting that this plot is based on the raw weather data and does not account for any shading by hills and adjacent buildings.

Solar Irradiation is the energy from the sun arriving at the building, usually over a period of time. In ZEBRA we are working on a monthly basis so our data are expressed in kWh/ m^2/month. It is important to not confuse this terms with solar irradiance which is measured in W/m^2 and is hence power, not energy. Please scan the QR code to learn more about irradiance.

Solar gain is the energy gained by the building due to exposure to solar irradiation. This gain will usually result in an increase in temperature inside the building and is something to be avoided for many months in several parts of India.

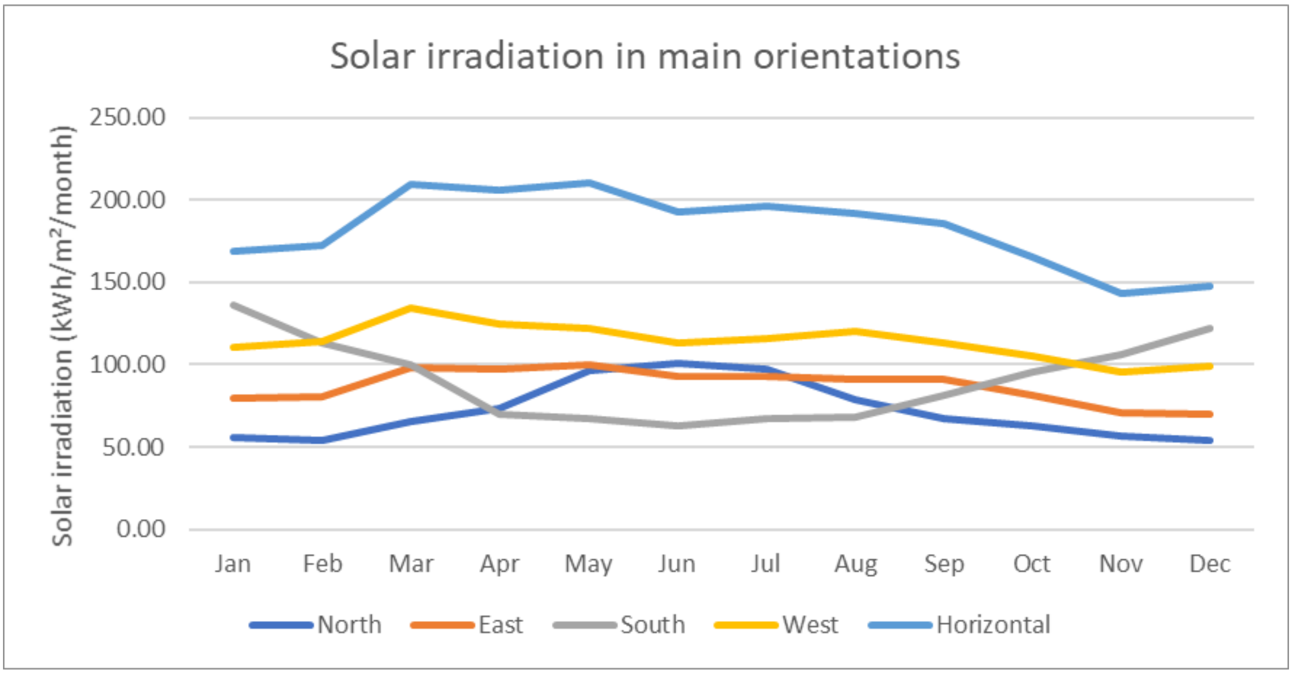


Figure 2: Solar irradiation received at Cuddalore, Tamil Nadu, by different surfaces in each month as shown in ZEBRA.

The plot of external temperature in Figure 3 also shows the set points (see next subsection) which suggests many hours of high temperatures. While the temperatures may not look high to you, it is worth noting that the plot shows the *monthly mean* temperature and so represents times of higher and lower temperatures than the ones you see.

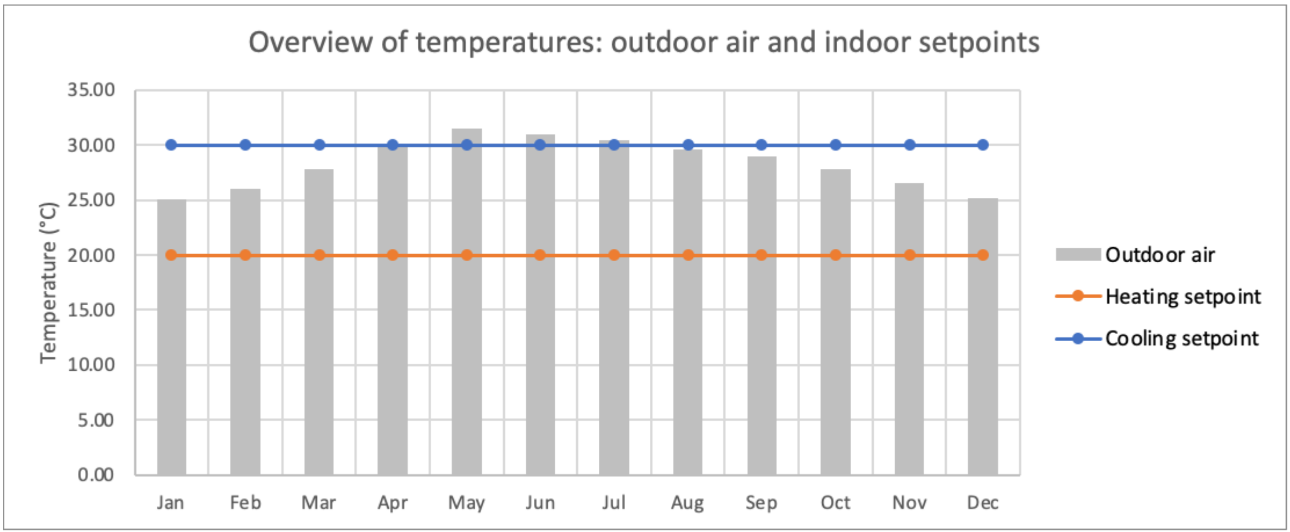


Figure 3 Monthly mean temperatures (grey) and heating and cooling set-points for Cuddalore as shown as shown in ZEBRA.

8.4 Cooling setpoint

The term setpoint is used to indicate the temperature cooling or heating systems are trying to bring the building to. At complexity level 1 and 2 these are defined for you as 20°C for heating and 26°C for cooling.

Zebra uses the setpoints to calculate the theoretical heating and cooling energy demand. This doesn't mean your building will use heating or cooling. This requires a heating and cooling system and fuel type to be defined in the **Systems** sheet. The default is gas heating and no cooling (which is common in the UK, where Zebra was developed). So if you want a cooling system, remember to define it in the Systems sheet. This will then give you the heating and cooling consumption.

To choose suitable setpoints you can: (i) use your personal experience but reflecting the location and culture of where the building is located, or (ii) look for a relevant standard, again for the location in question, or (iii) look for some research or contact a facilities manager, or (iv) use Adaptive Comfort Theory **(ACT)**. In India, your best bet is the recently developed IMAC standard, has a version each for residential and non-residential conditions.

ACT is an attempt to account for the role external temperature plays in defining the internal temperature we are comfortable with – check the ZEBRA website for a more comprehensive explanation.

To enter a non-default setpoint, we briefly drop into **complexity level 3** (**Instructions** sheet) and change the setpoint in the **Requirements** sheet then reset the complexity level back to 1 so we are not distracted by the many adjustable parameters ZEBRA has, which are of no interest at this stage of the design process.

This illustrates that in ZEBRA you don't need to fix a particular complexity level for a model. You can dip in and out of the various complexity levels. This is because ZEBRA never ignores parameters at lower complexity levels. It always uses all parameters, but at lower complexity levels the hidden parameters are set to default values.

8.5 Walls and doors

ZEBRA uses the same convention used by PHPP, whereby areas of wall, ground floor and roof are the external dimensions. As all the walls have the same construction, only one wall needs to be defined in ZEBRA. As we haven't decided on the wall construction, we just select "other – wall" as the construction and type in the wall U-value (**2.46** W/m²/K).

Looking at the plan of the building (Figure 1) we see there is a central un-conditioned lobby on each floor. As these are un-conditioned (i.e. no heating or cooling) we do not wish to include them in our estimate of energy use and have not included them in our estimate of TFA. As the lobbies are somewhat sheltered from the external conditions, the heat exchange through the lobby walls (per m² of wall) will be less than through the external walls. This is similar to the case of modelling a "middle" house in a row of houses each of which shares at least one wall with a neighbour, or a single apartment, in which case we just assume the adjoining house/apartment is at the same temperature as our house/apartment and there is no heat exchange through the walls, and set the U-value of such walls to zero. However, as we can't guarantee the lobbies are at a similar temperature to the apartments it would be sensible to run ZEBRA a second time with the lobby wall U-value set to the same value as the external walls, just in case it makes a significant difference to the energy use. This use of more than one value for a parameter in a model is called **parametric modelling** and is a great way to add confidence to your modelling. In our case, the truth lies somewhere between our two assumptions for the heat transfer through the lobby walls.

For more information on **parametric modelling** see:

To represent these lobby walls we declare a second wall type and initially set the U-value to **0** W/m²/K.

Simple parametric modelling with a single or a few parameters is very easy in ZEBRA and is one of the reasons we wrote the tool: you just enter a different value for a parameter and the energy/carbon predictions are updated immediately. This makes ZEBRA ideal for playing with possibilities or dealing with unknowns.

The real building includes 56 opaque doors between the apartments and lobbies of 2.1 m × 0.9 m, i.e., a total of 105.84 m². So, we declare one door type with this area. And our wall and door sheet looks like this:

	E	F	G	H	I	J	K
4	External wall+door	Construction	Insulation thickness	U-value	U-value	U-value	Area
5	name (optional)			from construction	from other	final	
6	a	Other - Wall			2.46	2.46	3,905.00
7	b Lobby Doors				0.00		1,055.80
8	c Lobby Walls				0.00		1,674.00
9	d						
10	e						
11	f						

8.6 Ground floor and roof

The **Ground floor** sheet requires the input of the area of the floor and the U-value. Although we can just enter the raw U-value (1.03 W/m^2/K) into the sheet, this will overestimate the heat losses through the floor. This is because the floor is not in contact with the outside air, but rather the ground. This ground, particularly under the middle of the floor of a large building is sheltered from the outside world. So, to get a better estimate, ZEBRA can adjust the U-value of the floor to more accurately account for this by applying **ISO 13370:2017**. For a building with a long narrow footprint the heat loss from the slab will be higher than for a square building, as more of the floor is in closer proximity to the perimeter where the heat loss is higher.

ISO 13370: This assesses the thermal performance of buildings through calculating heat transfer via the ground. The calculation takes into account the perimeter of the building. For more information on ISO 13370 use QR Code:

To do the calculation we navigate to the **Calculators** sheet and enter the information required (floor area, building perimeter, wall thickness). Note, ZEBRA can do a similar calculation for suspended ventilated ground floors. Once we have the adjusted U-value, we transfer that by hand to the **Ground floor** sheet.

The completed table in the Ground Floor **Calculators** sheet is:

	S	T	U	V	W
3					
4		**Ground floor: static U-values (ISO 13370:2017)**			
5					
6		**Case: slab on ground**			
7		**Parameter**	**Value**	**Units**	**Comment**
8		U-value (unadjusted)	1.03	W/m²/K	U-value as per construction detail and surface resistance.
9		Floor area	529.	m²	This refers to the overall area, including the thickness of perimetral walls.
10		Perimeter	184.	m	Exposed perimeter of the floor, including the thickness of perimetral walls.
11		Wall thickness	0.15	m	
12		Conductivity ground	2.	W/m/K	If unknown, the ISO norm recommends to use a default of 2.
13		b	5.75		Interim calculation, please ignore.
14		d	2.09		Interim calculation, please ignore.
15		**U-value adjusted**	**0.4496**	**W/m²/K**	**This is the value you should be using in ZEBRA's Ground floor sheet.**
16					

It should now be clear that accounting for the ground being in contact with the floor halves the effective U-value. If this wasn't accounted for in a model the heat loss through the ground floor would be overestimated.

The completed **Ground floors** sheet after the adjusted U-value has been copied over looks like:

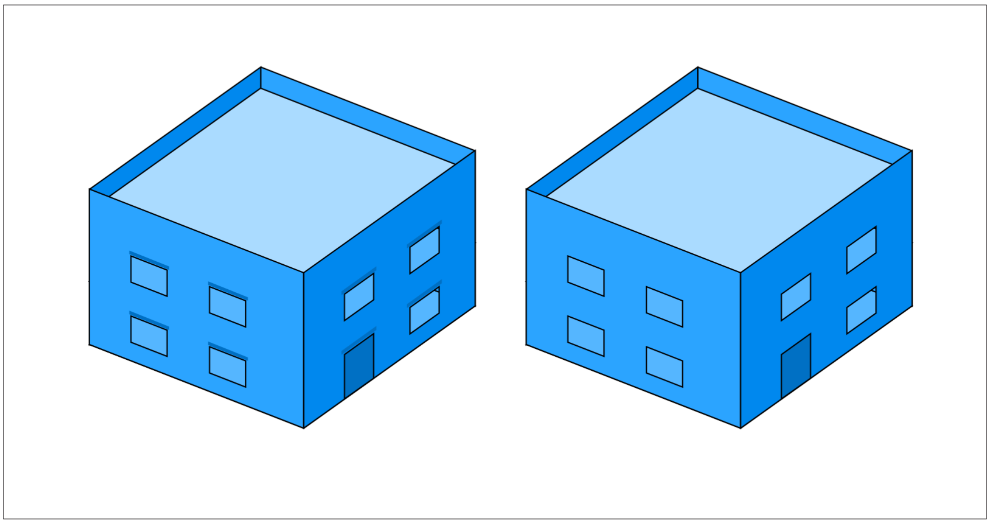
Units:	m²	W/m²/K
Ground Floor	**Area**	**U-value**
	529.00	0.45
Summary	529.00	0.45

and the completed **Roof** sheet:

Roof name (optional)	**Area**	**U-value**
a Flat Roof	529.00	4.20
b		
c		
Summary	529.00	4.20

8.7 Thermal bridges

Thermal bridges are highly-conducting elements of the building, for example concrete lintels, wall ties, balcony supports etc. Within ZEBRA you can define a length of linear thermal bridge and a linear thermal bridge coefficient, together with a number of point thermal bridges and a point thermal bridge coefficient. We don't yet have enough information about the design to provide these numbers, so you instead decide to consider using the default. In truth, the initial design of this building has such high U-values that thermal bridges are of little relevance, but they will be discussed later, and we also we wanted to take you through this sheet in the demonstration.



Spot the difference! A simple detached house in New Delhi with a Treated Floor Area (TFA) of 450 m^2, 15 x 15 x 6 m, all walls 15% glazed, triple-glazing, no frames, average shading, 3 occupants, a low wall U-value of 0.15 W/m^{2}K and a cooling setpoint of 21 °C. The left-hand side image is one with a lot of thermal bridging (illustrated through concrete lintels that cut across the envelope) and the right-hand side image is a thermal-bridge free construction. ZEBRA suggests that the right-hand side building has 15% less cooling energy demand than the left-hand building. These are significant margins when the goal is to get to net-zero energy or carbon. This shows that unaddressed thermal bridges can be a significant source of heat gain or loss, even in a well-insulated building.

Early in the design cycle you are unlikely to know much about the true values of the thermal bridge coefficients or the number of thermal bridges, so we have included a way of roughly estimating their possible impact. The Standard Assessment Procedure **(SAP)** provides a rule of thumb to estimate the effect of all thermal bridges in W/K; simply multiply the total area of all external opaque surfaces (including ground floors) by 0.2W/m^2/K. Note this surface area calculation ignores the glazed area, as the thermal bridges from glazed elements are handled separately on the **Glazing** sheet.

For example, if your building has a total opaque surface area (walls plus roof plus ground floor, but minus glazed areas) of 1000m^2, then 1000 x 0.2 = 200W/K, so enter 200 as the *point thermal bridge coefficient* and declare a single **point thermal bridge**, leaving the linear thermal bridge coefficient cell empty. In essence we have summed up all the linear and point thermal bridges into one big point thermal bridge.

SAP is the methodology used by the UK building regulations to assess and compare the energy and environmental performance of dwellings. Its purpose is to provide accurate and reliable assessments of dwellings that are needed to underpin energy and environmental policy initiatives.

For this building analysis we have simply used the Thermal Bridge Calculator (click on cell I8 on the "thermal bridges" tab). There is also the option to employ modern constructions and plan to take advice on reducing thermal bridging, in this instance you could make the logical decision to assume to do better than the default value so halve it, to give 450W/K per m^2 of fabric. As discussed above we think the lobby walls will have little heat transfer, so ignore these. This gives an opaque surface area (external walls + roof + ground floor) of 3905 + 529 + 529 = 4963 m^2. Multiplying this by 0.1W/K per m^2 of fabric we have **496.3 W/K**.

For this analysis we enter **992.6** W/K into the **Thermal bridges** sheet under **Point thermal bridge coefficient** and declare **1 point thermal bridge**:

	D	E	F	G	H
1		**Thermal bridges**			
2					
3		**Thermal bridges**	**Value**	**Unit**	**Comment**
4		Is the design free of linear thermal bridges?	no	-	Depends on detailing.
5		Linear thermal bridge coefficient		W/m/K	Ignored if thermal bridge free.
6		Total length of thermal bridge		m	Ignored if thermal bridge free.
7		Is the design free of point thermal bridges?	no	-	Depends on detailing.
8		Point thermal bridge coefficient	992.60	W/K	Ignored if thermal bridge free. ★ See calculator for basic estimate.
9		Number of point thermal bridges	1.00		Ignored if thermal bridge free. If using the calculator, use 1 point thermal bridge.
10					

Geometric thermal bridges (ones that arise from the heat exchange through the shape of corners etc.) are ignored in ZEBRA. This is because we are following the method used in PHPP of using the external dimensions of the building. Thereby automatically including the extra heat loss from corners etc.

8.8 Windows and glazed doors

Glazing can have a U-value 10 times that of opaque elements. It can also be a source of heat via the sun (solar gain) and a source of overheating. This means even when scoping the energy and carbon credentials of a design one needs to be reasonably accurate with the glazing. This can be difficult as you might not have finalised your thoughts, but there isn't a way around it. The calculations simply will not be accurate unless the glazing is reasonably accurately specified such that what is modelled is what is built. The good news is that it is easy to change your mind later and re-model, so you are not really fixing this element of the design, but rather being forced to think clearly about it. Two common mistakes in modelling windows are: not accounting for enough of the window not being glass, but frame or glazing bar; and not accounting for the shading provided by nearby buildings etc. ZEBRA helps you avoid both these errors.

The **g-value** is a measure of how much solar energy is allowed through a window. A low g-value indicates that a window lets through a low percentage of the solar heat.

Once you opening the **Glazing** sheet begin by entering the U-value and **g-values** of the glazing at the top of the sheet:

	D	E	F	G	H
1		**Glazing**			
2					
3		**Parameter**	**Value**	**Unit**	**Comment**
4		Mid pane U-value	5.000	W/m²/K	Reasonable defaults are: 0.85 (triple glazing); 2 (double glazing); 5 (single glazing).
5					
6					
7					
8		Glazing g-value	0.850	-	0-1. Reasonable defaults are: 0.45 (triple glazing); 0.60 (double glazing); 0.85 (single glazing).
9					
10					
11					

ZEBRA provides various ways to enter the glazing details and which way you choose will depend on how advanced the design is. For example, have you chosen a window from a manufacturer, so know the width of the frames etc? Or are you just working with generic windows and a statement like "20% of the east façade will be glazed"? It will also depend on how detailed a description of the surroundings you have, for example, just a typical urban landscape, or the heights of the buildings opposite. We have written a document called "**Defining windows in ZEBRA**" to take you through the options - click on I8 on the "Glazing" tab to take you to the glazing calculator:

Defining Windows in ZEBRA: You can find this document on the ZEBRA Documentation page by scanning the QR code.

	D	E	F	G	H	I	J	K	
73									
74		1	2	3	4	5	6	7	
75									
76									
77									
78		**Window set 1 - Window breakdown**		See calculator for properties ★ General		★ Simpler version		★ See shading calculator	
79		Window set name (optional)	North						
80		Orientation	0.00 °						
81		Units:	m²	m²	m²	m	m	-	
82		**Window name (optional)**	**Hole area**	**Glazing area**	**Frame area**	**Perimeter**	**Length glass-(frame/divider)**	**Permanent shading**	**Temp**
83		North	176.75	132.50	44.25	708.00	885.00	0.23	
84			0.00						
85			0.00						
86			0.00						
87			0.00						
88			0.00						
89			0.00						
90			0.00						
91			0.00						
92			0.00						
93		**Equivalent window set (aggregated):**	**176.75**	**132.50**	**44.25**	**708.00**	**885.00**	**0.23**	
94									

In this example we shall imagine the windows have yet to be precisely specified – we just know the U and g-values and that they possibly look like **type h** from the photos in ZEBRA (in the **Calculators** sheet).

You don't have to enter the dimension of each window separately, which would be a long process for a large building. Instead, ZEBRA allows you to combine windows into *window sets*. The energy balance (monthly losses minus gains) of each *window set* is computed and reported separately, thus you should combine windows into sets for which you wish to know the energy balance. Note that all the windows in a window set must face the same direction.

In this case we decide to report the energy balance on each façade separately as this seems natural, and hence we have four *window sets*. The area of window on each façade is **176.75 m²**. If we thought the shading from surrounding buildings, trees or hills might make a great deal of difference to the solar gains on different levels, we might choose to split the facades into lower, middle and upper, giving 4 x 3 = 12 window sets. ZEBRA allows you define up to 15 window sets.

These window areas are the areas of the hole in which the window sits (or the sum of such holes), but the calculation of gains and losses needs to know the area of glass, so we need to subtract the area of frame and glazing bars or mullions, if present. ZEBRA also needs the area of these to allow for the thermal bridges they cause. The area of these non-glazed elements depends on the format of the windows you have in mind, from wide uPVC to minimalist aluminium frames. As the exact windows are unknown in this example we simply inserted 4 windows sets (North, East, South and West).

The **permanent shading** is a statement of how surrounded the glazing is by objects (hills, trees, other buildings, overhangs, recesses) that might obstruct light. If you have the details of the surrounding buildings, you can work this out using much the same principles as used in a **daylight factor (DF)** is the ratio of the light level inside a structure to the light level outside the structure). Typically, at an early design stage we might just choose a default value (ZEBRA offers several). Looking at Figure 1 we see many of the windows are recessed, and although the building is not heavily shaded by other buildings, those recesses on the major windows shade the glazing. So we pick the default "average = 0.23")

The **Daylight Factor** is the ratio of internal illuminance (in lux) to the external horizontal illuminance and gives a simple estimate of how daylit a space might appear. It is related purely to the geometry of a room and is therefore rather beautiful but limited in scope. Scan the QR code to learn more.

This is how it appears in the "Glazing" tab for each of the window sets:

Window set 1 - Window breakdown			See calculator for properties ★ General	★ Simpler version		★ See shading calculator
Window set name (optional)	North	-				
Orientation	0.00 °					
Units:	m²	m²	m²	m	m	-
Window name (optional)	**Hole area**	**Glazing area**	**Frame area**	**Perimeter**	**Length glass-{frame/divider}**	**Permanent shading**
North	176.75	132.50	44.25	708.00	885.00	0.23
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
Equivalent window set (aggregated):	**176.75**	**132.50**	**44.25**	**708.00**	**885.00**	**0.23**

Window set 2 - Window breakdown		★ See calculator for properties		★ See simpler calculator		★ See shading calculator
Window set name (optional)	East	-				
Orientation	90.00 °					
Units:	m²	m²	m²	m	m	-
Window name (optional)	**Hole area**	**Glazing area**	**Frame area**	**Perimeter**	**Length glass-{frame/divider}**	**Permanent shading**
East	176.75	132.50	44.25	708.00	885.00	0.23
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
Equivalent window set (aggregated):	**176.75**	**132.50**	**44.25**	**708.00**	**885.00**	**0.23**

Window set 3 - Window breakdown		★ See calculator for properties		★ See simpler calculator		★ See shading calculator
Window set name (optional)	South	-				
Orientation	180.00 °					
Units:	m²	m²	m²	m	m	-
Window name (optional)	**Hole area**	**Glazing area**	**Frame area**	**Perimeter**	**Length glass-{frame/divider}**	**Permanent shading**
South	176.75	132.50	44.25	708.00	885.00	0.23
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
Equivalent window set (aggregated):	**176.75**	**132.50**	**44.25**	**708.00**	**885.00**	**0.23**

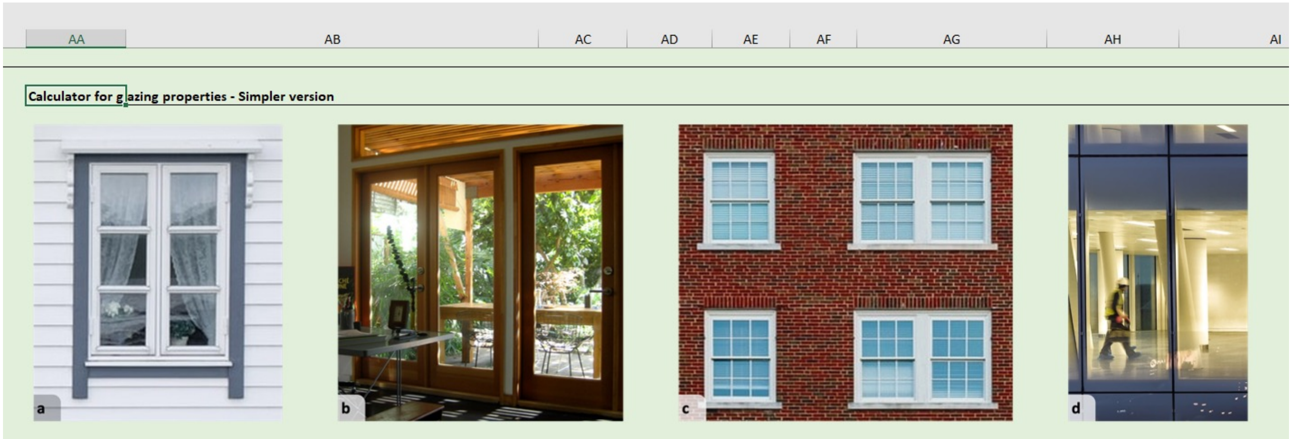
Window set 4 - Window breakdown		★ See calculator for properties			★ See simpler calculator	★ See shading calculator
Window set name (optional)	West	-				
Orientation	270.00	°				
Units:	m²	m²	m²	m	m	-
Window name (optional)	**Hole area**	**Glazing area**	**Frame area**	**Perimeter**	**Length glass-{frame/divider}**	**Permanent shading**
West	176.75	132.50	44.25	708.00	885.00	0.23
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
	0.00					
Equivalent window set (aggregated):	**176.75**	**132.50**	**44.25**	**708.00**	**885.00**	**0.23**

Another option would be to estimate the likely area of frame etc. and to simply pick from the catalogue of typical window formats shown in ZEBRA (see the **Calculators** sheet). In this case we pick case **h**.

From the calculator, you can see that Glazing area (the area of glass) is quite a bit less than the area of the hole. The Perimeter is the length of frame, and the complex sounding Length glass-{frame/divider}, represents the total length of thermal bridge from the frame and glazing bars etc. The two temporary shading columns are used if we believe the occupants will use blinds or external shutters; N repeat is discussed in the "Defining windows in ZEBRA" document.

Once the above is complete you will now need to transfer the numbers from the calculator to the **Glazing** sheet. To do this we copy and paste just Glazing area, frame area, perimeter, length glass-{frame/divider}, temporary shading(heating), Temporary shading (cooling), N Repeat. We paste one row into each window set (you need to use edit / paste special / values when pasting as we only want the numbers transferred, not the equations used to generate them).

This is how it would appear in the calculator section:



Glazing format	Glazing format name	Hole area	Glazing area	Frame area	Perimeter	Length glass-{frame/divider}	Permanent shading
h	Domestic or commercial - Simple with modest frame width	176.75	132.56	44.19	707.00	883.75	0.23
							0.00
							0.00
							0.00
							0.00
							0.00
							0.00
							0.00
							0.00
							0.00

Regardless of the method chosen to enter the glazing details the window are collated into a main table that ZEBRA uses in its calculations (we have split the table in two to fit on this page):

Window set	Hole area	Glazing area	Frame area	Perimeter	Length glass-{frame/divider}	% area that is glass	Installed U-value
Units:	m²	m²	m²	m	m	%	W/m²/K
1 - North	176.75	132.50	44.25	708.00	885.00	75.0	4.57
2 - East	176.75	132.50	44.25	708.00	885.00	75.0	4.57
3 - South	176.75	132.50	44.25	708.00	885.00	75.0	4.57
4 - West	176.75	132.50	44.25	708.00	885.00	75.0	4.57
5	0.00	0.00	0.00	0.00	0.00	0.0	0.00
6	0.00	0.00	0.00	0.00	0.00	0.0	0.00
7	0.00	0.00	0.00	0.00	0.00	0.0	0.00
8	0.00	0.00	0.00	0.00	0.00	0.0	0.00
9	0.00	0.00	0.00	0.00	0.00	0.0	0.00
10	0.00	0.00	0.00	0.00	0.00	0.0	0.00
11	0.00	0.00	0.00	0.00	0.00	0.0	0.00
12	0.00	0.00	0.00	0.00	0.00	0.0	0.00
13	0.00	0.00	0.00	0.00	0.00	0.0	0.00
14	0.00	0.00	0.00	0.00	0.00	0.0	0.00
15	0.00	0.00	0.00	0.00	0.00	0.0	0.00
Summary	707.00	530.00	177.00	2,832.00	3,540.00		4.57

Orientation	Orientation	Permanent shading	Visible sky	Temporary shading (heating)	Temporary shading (cooling)	Equivalent hole (heating)	Equivalent hole (cooling)
°	-	-	-	-	-	%	%
0	vertical	0.23	0.77	0.00	0.00	33.4	33.4
90	vertical	0.23	0.77	0.00	0.00	33.4	33.4
180	vertical	0.23	0.77	0.00	0.00	33.4	33.4
270	vertical	0.23	0.77	0.00	0.00	33.4	33.4
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0
	vertical	0.00		0.00	0.00	0.0	0.0

This table shows us some possibly surprising things. (i) Summing the *Length glass-{..}* on the four sides of the building, the answer is almost 3km. This is a lot of thermal bridging to ignore if this was not included in the calculation. (ii) The **installed U-value** is 4.57 W/m^{2}K, so somewhat less than the **mid pane value** of 5. (iii) Taking into account the shading of the windows the frames and the g-value (and some more technical aspects hidden at the current complexity level) we see that only 33.4% of the solar gain that would strike an unshaded hole in the side of the building would make it through the shading and glass. This again emphasises why the windows and shading have to be accurately entered into a thermal model if the results are to be sensible, and indicates that the building is not likely to have a major issue with solar gain.

Note: The reason there is a separate heating and cooling equivalent hole (columns S and T) in the wide table on page 23 is because the temporary shading (blinds etc.) might be deployed differently in summer and winter.

The **installed U-value** includes the effect of frame and site workmanship and will hence be *higher* than the **mid-pane** value. This is important as a poor installation in a building designed to be efficient can increase heat gain and reduce efficiency.

8.9 Incidental gains

Here we just use the default value for homes:

Parameter	Value	Unit	Comment
Electrical gains (e.g. lighting, computers etc.)	1.10	W/m²(TFA)	We suggest 1.1 W/m² for homes; 1.4 for offices and 0.71 for schools.

Hidden at this complexity level (1) are the **metabolic gains** , but these have been included by ZEBRA.

Metabolic gains: Every occupant of a building is releasing heat at the rate of about 80 - 100 W. This heat increases indoor temperatures and is termed the metabolic heat gain. For more information on metabolic gains navigate to:

8.10 Air

As this is a naturally ventilated design, we just need to input the expected **infiltration rate** expressed as air changes per hour - heating and cooling systems in buildings are sized to cater for the loads imposed by air infiltration under design external and internal conditions.

In this example we insert **6.0 ach @ 50Pa**, see Table 1) in the **Air** sheet together with the average number of occupants and the internal volume of the building. We base the average number of occupants on the suggested value for homes of 0.014/occupants per m^2 of TFA and 0.014 x 6669m^2 = **93.4 people**. Note, this is the average over all the hours in the year, so is much lower than the value during occupied hours. At complexity level 1 the ventilation rate is automatically calculated for you based on providing good air quality.

Infiltration is the uncontrolled exchange of air between inside a building and outside through cracks, porosity and other unintentional openings in a building, caused by pressure difference effects of the wind and/or stack effect.

As stated in Table 1, we estimate the internal volume of the building (ignoring the lobbies) to be **17,774m^3**, and the **Air** sheet looks like:

Assumed infiltration rate	6.00	ach@50Pa	0.6 or better to be a Passivhaus, the average value in the UK is probably 6 for a small building.
Justification for the chosen infiltration rate	Architect-10 times PH standards and still good by modern standards		
Treated floor area (TFA)	6,669.00	m²	TFA is about 90% of gross internal floor area, or 97% for a bungalow (as no stairs).
Internal volume of building	17,774.00	m³	
Likely infiltration rate at normal pressures	0.42	ach	This cells display the value if the justification for the chosen infiltration rate is given.
Time taken for infiltration to replace all the air in the building	2.38	h	
Average number of occupants (see end of commentary)	93.40	p	Suggestions: 0.014 * TFA for homes; 0.01 * TFA for offices; 0.072 * TFA for schools (fraction of an occupant is fine)
Ventilation rate	2,802.00	m³/h	
Ventilation rate	0.16	ach	

8.11 Space Conditioning

ZEBRA can model natural ventilation, mechanical ventilation and mechanical ventilation with heat recovery (MVHR). It also has the ability to account for cooling provided by the occupants opening the windows further if the building is overheating . We decide not to use this latter option as (1) we wish to see if the building might have an overheating issue if air conditioning proved to be too expensive for the occupants, and (2) in this location it can be so hot outside, more ventilation is likely to increase, not reduce, **overheating**.

Overheating can be described as discomfort to occupants caused by the accumulation of warmth within a building. It is considered to be a growing problem due to climate change, the urban heat island effect, electronic equipment, increasing amounts of glazing and so on.

The **Space conditioning** sheet has two tables: one for the heating calculations and one for the cooling calculations. In many ways these can be seen as representing the summer and winter operation of the building. Whatever you enter in the heating demand table is used also in the cooling calculations, unless you enter different numbers into the cooling demand table.

In our case, as this is a naturally ventilated building with the ventilation rate coming from the **Air** sheet as discussed above, we leave all input cells blank in the cooling table:

Parameters related to space heating demand	Value	Unit
Metabolic gains	1.12	W/m^2(TFA)
Electrical gains (e.g. lighting, computers etc.)	1.10	W/m^2(TFA)
Heat Recovery (HR)		-
Airchanges due to ventilation	0.16	ach
Sum of fan specific power		Wh/m^3

Ditto in the cooling table:

Space cooling demand				
Parameters related to space cooling demand	**Baseline value**	**Overwrite**	**Value**	**Unit**
Metabolic gains	1.12		1.12	W/m^2(TFA)
Electrical gains (e.g. lighting, computers etc.)	1.10		1.10	W/m^2(TFA)
Heat Recovery (HR)	0.00		0.00	-
Airchanges due to ventilation	0.16		0.16	ach
Sum of fan specific power	0.00		0.00	Wh/m^3
Non-permanent shading for window set 1			0.00	-
Non-permanent shading for window set 2			0.00	-
Non-permanent shading for window set 3			0.00	-
Non-permanent shading for window set 4			0.00	-

8.12 Systems

Here we set the fuel type to electricity for the space cooling and heating and the efficiency (CoP) to 2 (typical of an air-condition system), the fuel used for domestic hot water (electricity; efficiency = 1) and define the form of domestic hot water provision (on-spot with storage) and declare how much of the roof can be used for PV (60%). The sheet has the following completed tables:

Domestic hot water (DHW)	Value	Unit
Total daily hot water requirement of building	4,200.00	litres/day
Raw DHW energy demand	8.09	kWh/m^2(TFA)/a
DHW system type	On-spot, without storage	-

Main energy			
Units:	kWh/m^2(TFA)/a	-	-
System	Energy demand	Efficiency	Fuel
Ventilation	0.00		
Space heating	0.00	0.80	Mains gas
Space cooling	28.69	2.00	Electricity
DHW	8.21	1.00	Electricity

PV	Value	Unit
Total roof area	529.00	m²
Fraction of roof area suitable for PV	0.60	-
Final area for PV	317.40	m²

The fraction of roof area suitable for PV is something of a guess at this stage in the design cycle and will be dependent on roof space required for air conditioning system and other plant.

9 Results

Looking at each sheet in turn we can gather a lot of useful information to progress future iterations of the design. Not all will be of interest in each project or to each user. However, before you get excited about looking at the results, there are some important things you need to know:

- ZEBRA works left to right, sheet-by-sheet, with very little information flowing the other way. However, a few values do, for example the MVHR efficiency. We therefore recommend you complete the whole of ZEBRA, and only then look at the results.

- Once the whole workbook is complete, one can play with the values on a sheet and get instant feedback of the impact across all sheets. This is one of the most useful features of ZEBRA – there are no simulation or plot results phases to get in the way. It also encourages you to only change one variable at a time, hopefully helping you to get a better feel about many important aspects of low energy/carbon design.

- Too often there is a tendency to change a whole set of parameters and hence fail to get a visceral sense of how much difference each makes, and hence little is learnt about aspects of low energy building design that can be taken on to the next project. Hence, the most important aspect of any modelling is to **change one thing at a time**.

- **The location of input and results cells are fixed** on the worksheets and do not change if you change complexity level. At lower complexity levels this means large areas of blank space, so scroll to the right and down just to make sure you are not missing any results or inputs. On a slow machine some plots might take time, so again, it is worth slowly checking the whole **green area of cells** in case there are some interesting results just out of sight.

- **ZEBRA shows heat losses and gains and the heating or cooling needed** to maintain the set points on many of its sheets regardless of whether heating or cooling systems are fitted. This allows the user to think about where this heat or cooling might come from and whether incidental gains or ventilation might be able to provide all or much of it. This reflects ZEBRA's philosophy of trying to get design teams to reduce the need for heat or cooling, and only then to think about how this might be provided.

- In ZEBRA **most results are given in terms of per m² of treated floor area (TFA)**. This is known as the area-normalised result. This allows the user to compare the results more easily to previous iterations of the design and even other projects, where the floor area would have been very different.

- In fact, **to properly PLAY with ZEBRA** this is the only sensible thing to do. For example, if you decide to make one of the units on each floor larger than the other three, your total energy demand may go up but the per unit area demand (kWh/m^2) may remain static. So, a fair comparison between options is only enabled by the area-normalised result. To convert such values to whole building ones, just multiply by the TFA. You may well need this if you plan to meet a certain proportion of your demand from renewables, where the total energy demand is needed not the area-normalised one.

9.1 Summary sheet

This sheet summarises the performance of the building and, most importantly, compares this to the environmental requirements you set out on the **Requirements** sheet. The results are presented in three tables.

The first lists the building's headline parameters. At complexity level 1 this just shows the floor area, volume and surface area of the building, but if we switch briefly to complexity level 3 we see some other potentially useful values of interest to those that have been involved in low energy/carbon design before.

Summary

Key design parameters

Parameter	Value	Unit	Comment
Treated floor area (TFA)	6,669.00	m²	
Internal volume of building	17,774.00	m³	
Thermal envelope area	5,670.00	m²	Includes external walls, windows, roof and ground floor.
Compactness (envelope area / volume)	0.32	-	The smaller the value the more compact the building is.
Form factor (envelope area / tfa)	0.85	-	A low energy house would typically aim for a value ≤3.
Average U-Value	3.47	W/m²/K	
Heat Loss Coefficient	19,677.45	W/K	
Heat Loss Parameter	2.95	W/K/m²(TFA)	

The *compactness* is the ratio of the envelope area to the volume. The *form factor* is the ratio of the envelope area to the TFA. The average U-value is the area weighted *average U-value* of the building. As the building is quite large, we would expect the form factor to be low, which at 0.9 it is (for a low energy design this should be <3). The area weighted average U-value is 3.47 W/m^2/K. This might seem far from the 2.46 W/m^2/K used for the walls but is due to U-values for the roof and glazing. Too often we have found that people focus too much on just the wall U-value rather than on the average U-value - which is a much better predictor of the thermal performance of the whole building.

The heat loss coefficient is an overall statement about the heat loss of the building. The result, 21,114 W/kelvin, is the heat that is being gained or lost per degree centigrade of temperature difference between the inside and outside of the building. This value accounts for U-values, ventilation and infiltration, but not solar gains. Hence for this building, when it is 24°C inside and 30°C outside the heat gain = 21,114 W x (30 – 24) = 126 kW. The table also shows the Heat loss Parameter on a per m^2 TFA basis, which is ideal for making inter-building comparisons.

The next table shows the **operational intensities**:

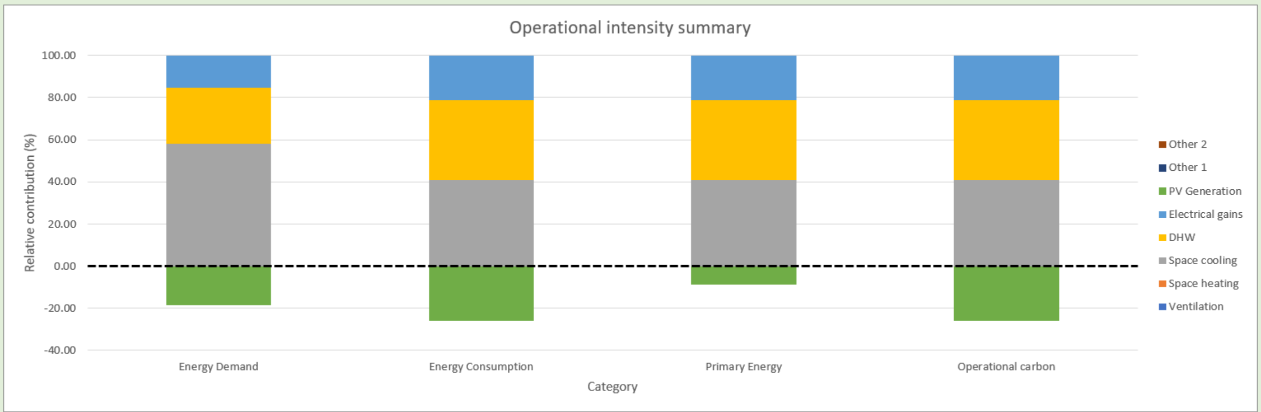
Operational intensity

Units:	kWh/m²(TFA)/a	kWh/m²(TFA)/a	kWh(primary)/m²(TFA)/a	$kgCO_2e$/m²(TFA)/a
System	Energy Demand	Energy Consumption	Primary Energy	Operational carbon
Ventilation	0.0	0.0		
Space heating	0.0	0.0		
Space cooling	27.7	13.9	20.8	1.9
DHW	7.8	7.8	11.7	1.1
Electrical gains	9.6	9.6	14.5	1.3
PV Generation	-10.9	-10.9	-5.5	-1.5
Other 1	0.0	0.0		
Other 2	0.0	0.0		

This shows that building has a space cooling *demand* of 27.7 kWh/m²/a. However, this is not the energy consumed, we must take into account the CoP of 2.0 for air conditioning system. This means that for every unit of electricity into the air-conditioning unit it will produce 2 units of cooling into the building. Therefore, the energy consumed will be half of the energy demand, i.e. 13.8 kWh/m²/a.

We also see that this very modest use of cooling is offset by the generation from the PV. Unsurprisingly in this location, there is no space heating requirement.

This information is echoed in graphical form to make it easier to see how the fractions change as the discussion focuses on demand, consumption, primary energy or operational energy. Note that ventilation in this context means energy use by fans, of which we have none.



The final table on the sheet is seen to contain some red highlighted text:

Parameter	Value	Unit	Comment
Space heating demand	0.0	kWh/m²(TFA)/a	Requirements = 15. Goal achieved.
Space cooling demand	27.7	kWh/m²(TFA)/a	Requirements = 30. Goal achieved.
Primary energy	47.0	kWh(primary)/m²(TFA)/a	Requirements = 120. Goal achieved.
Net primary energy	41.5	kWh(primary)/m²(TFA)/a	
Net operational carbon	2.8	$kgCO_2e$/m²(TFA)/a	Requirements = 0. Goal not achieved.

The red indicates values that were declared on the **Requirements** sheet, but have been failed to be met by the design. We set the Space cooling demand to 30 kWh/m^2/a, the current design is slightly lower than this- so this goal was achieved. We set the *net operational carbon* to an optimistic zero, so we are close, but not quite there. We set the *upfront carbon* to 500kgCO_{2e}/m^2 i.e. a low embodied carbon building, yet made no attempt to minimise embodied carbon, so this requirement failing isn't a surprise. However, we have hit our targets for space heating, cooling and primary energy.

9.2 Air sheet

From the **Air** sheet, we see that a pressure test infiltration rate of 6.0 ac/h at 50Pa equates to an infiltration rate at naturally occurring pressures of 0.42 ac/h. This might seem very low and not much of a heat loss/gain. However, ZEBRA also presents this result in terms of the time taken to replace all the air in the building, in this case 2.38 hours. So, over a day all the air in the building is replaced ten times, just by infiltration. As the internal volume of the building is 17,774 m^3, this is around 200,000 kg of air (volume × 1.1 {density of air in kg/m^3} × 10 changes) adding to the cooling load each day during the cooling season.

As we are running ZEBRA at complexity level 1, the ventilation rate is set to the default of 30 m^3/h per person. In most cases this rate ensures a very high air quality. Using a dynamic simulation package would allow you to more realistically know the ventilation rate from the opening and closing of windows – but only if you accurately know the likely opening schedule and likely opening angles and possibly the layout of internal partitions and internal door opening schedules that might change the flow across the space.

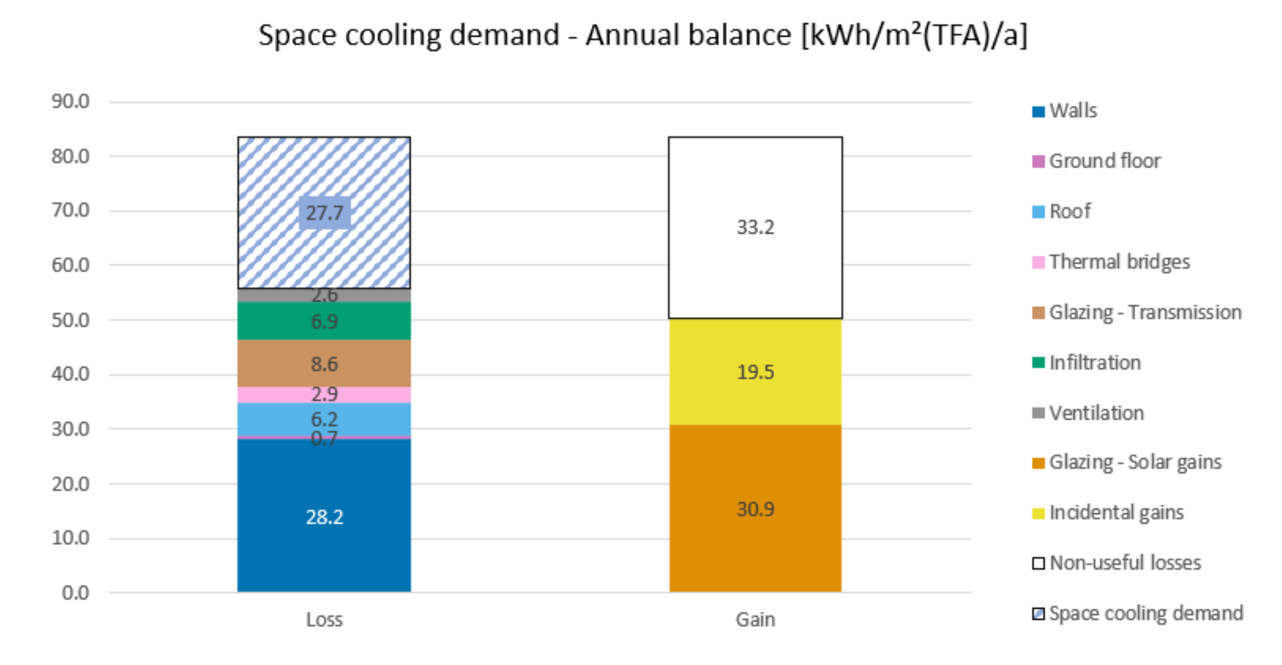
As you can imagine, getting this right in a model is very difficult, and as a starting point, needs a deep understanding of the culture in the location of the building and of the use of the relevant building type (schools, offices, homes etc.) in that culture, and of the window details – which might not be available at an early stage. Hence ZEBRA uses a set ventilation rate.

The results show the average ventilation rate to be 0.16 ac/h. This is time-averaged as it uses the time-averaged number of occupants; during occupied hours it will be higher. Note that this is less than the infiltration rate. This might be a surprising result to some, and in part arises from infiltration happening 24/7, whereas ventilation accounts for the intermittent occupation of spaces.

9.3 Space conditioning sheet

As there is no heating demand (see **Summary** sheet) we scroll straight down to the space cooling heat balance chart. These charts can be difficult to read on first acquaintance, so we recommend reading the document "**Reading the demand stacked bar charts**" on the ZEBRA website.

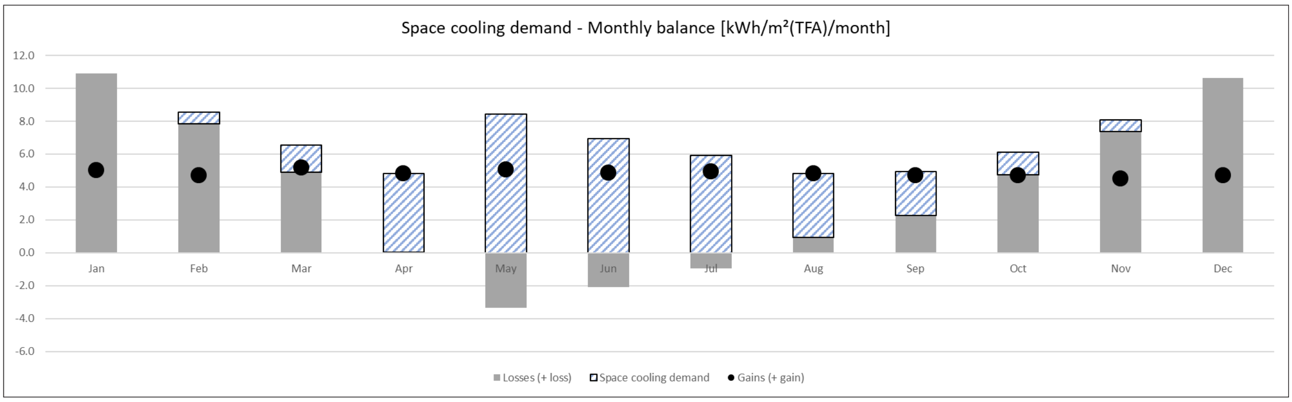
Note: As the **heating demand** = 0; we will be looking at only the space cooling graphs, you might have to scroll down on the ZEBRA page to see these.



From this we can see that:

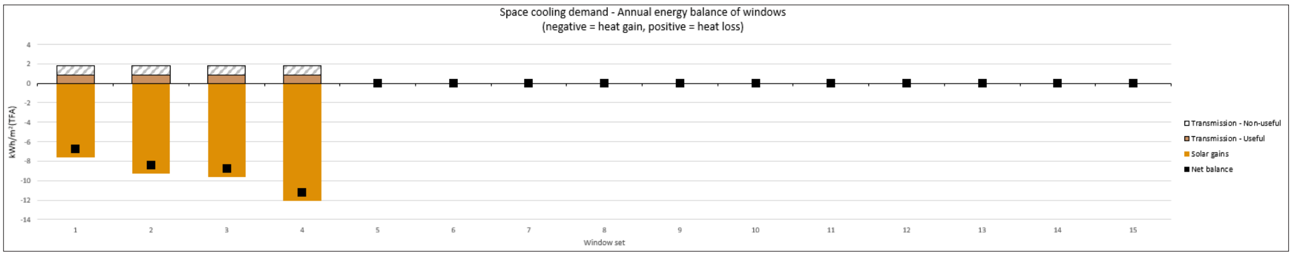
- The building, as probably used by the occupants, has a space cooling demand of 27.7 kWh/m^2/a. Note the consumption will be half this as the cooling units are assumed to have a CoP of 2. This load indicates that the building does need air conditioning if internal temperatures above 30°C are to be avoided.
- That the building is losing the greatest fraction of heat through the walls.
- However, 33.2 kWh/m^2(TFA) of the losses are not useful as they occur when the building does not require cooling.
- Therefore, the useful losses are 56.1 (the sum of the losses) – 33.2 = 22.9 kWh/m^2(TFA).

The next plot shows the space cooling demand load broken down by month (the space cooling demand is shown as blue hatched):



and allows us to see when in the year cooling might be useful in meeting the set point.

Looking at the individual window sets we see:



The windows (and particularly those on the west side) are a clear source of heat gain, suggesting this elevation would benefit from further shading.

9.4 Systems sheet

Here we see the PV system is delivering 76,766 kWh/a which equates to 10.94 kWh/m²(TFA)/a. The DHW including storage losses requires 7.8 kWh/m²(TFA)/a of electrical input. The other electrical loads add up to 9.64 kWh/m²(TFA)/a.

Domestic hot water (DHW)	Value	Unit
Total daily hot water requirement of building	4,200.00	litres/day
Raw DHW energy demand	7.80	kWh/m²(TFA)/a
DHW system type	On-spot, without storage	-
Total heat losses	0.00	kWh/m²(TFA)/a
Energy demand	7.80	kWh/m²(TFA)/a

Other electrical loads	Value	Unit
Energy demand	9.64	kWh/m²(TFA)/a

PV	Value	Unit
Total roof area	554.00	m²
Fraction of roof area suitable for PV	0.60	-
Final area for PV	332.40	m²
Available solar irradiation	2,052.85	kWh/m²(panel)/a
Generation	76,766.27	kWh/a
Generation per m² of TFA	10.94	kWh/m²(TFA)/a

If you switch to complexity level 3 you will see other data, particularly about the PV.

Also reported is the **overheating potential** (with respect to the cooling setpoint) of 8.29 thousand-**kelvin hours per annum**. This is a measure of how much the building would overheat if active cooling was not present. As ZEBRA is not an hourly model, it is impossible to know if this is general, but modest overheating, or short intense busts. However we can apply some logic as follows. From the graph above, the cooling demand seems to be focused on 6 months of the year. A quick search of the internet reveals a considerable diurnal cycle in summer of around 10°C for this location. Hence it would not be unreasonable to conclude that the overheating would mainly occur in summer and during the day. If we restrict ourselves to 8 hours in the middle of the day, during these months we have 8 hours × 6 months × 30.5 days per month = 1,464 hours. Dividing 8,290 by this gives just over 5.6°C. Since the cooling set point is high already at 30°C, regular temperatures of 36°C can be expected. This adds weight to our earlier conclusion that air conditioning will be needed.

Overheating potential and thousand Kelvin-hours: Overheating is a complex topic and there even exists a standard for it in the UK (search for CIBSE TM52)! But a simple way to think about this is the number of hours the building spends above the cooling setpoint weighted by the number of degrees above the setpoint. For example, if our setpoint is 26 °C and the building is at 27 °C for three hours, then we have 3 Kelvin-hours (1 Kelvin above for three hours). On the other hand, if the building is at 29 °C in the first hour and then 27 °C in the next two hours, we now have 3 Kelvin-hours for the first hour (3 °C up for one hour) plus 2 Kelvin-hours for the next two hours (1 °C up for two hours) for a total of 5 Kelvin-hours. As we go through the year, these hours can really add up so we need a unit of thousand Kelvin-hours, commonly written as kKh (kilo Kevin-hours).

ZEBRA displays many other results that are useful in focusing design discussions, but we now turn to the comparison with the monitored energy use.

9.5 Comparison to monitored energy use

As this is in fact a real building, we have the advantage of being able to monitor the energy use after construction and compare it to our predictions. Once constructed, the energy use of the apartments were monitored for a year and the annual energy consumption was found to average 28 kWh/m^2/a over the 24 apartments. This figure includes all energy use, so includes plug loads and DHW. This value is in modelling terms very close to the consumption estimated above (13.8 cooling (consumption), 9.6 other electrical loads (plugs and lighting), 7.8 DWH = 31.2 kWh/m^2/a).

Notes.

(i) A common level of heating energy use in the UK is 120 kWh/m^2/a, but varies greatly between buildings, even when they are in identical dwellings, so be careful about comparing a predicted energy use to modelling. Modelling is probably at its most useful when comparing the scale of impact from different strategies, rather than predicting the consumption of a particular building.

(ii) A model that predicted that typical figure of 120 kWh/m^2 to 20%, i.e. +/- 25 kWh/m^2 would be seen as more than reasonable. If plug loads and domestic hot water use are added to the model the impact of occupant behaviour starts to play an even greater role. This can cause issues in the comparison of modelled and real energy use in low-energy designs, if you demand the model is accurate in terms of a percentage rather than a number of kWh/m^2/a. If your building only uses 15 kWh/m^2/a, then a 10% discrepancy between model and reality is only 1.5 kWh/m^2/a. This is a very small amount of energy, and an unrealistic measure of accuracy.

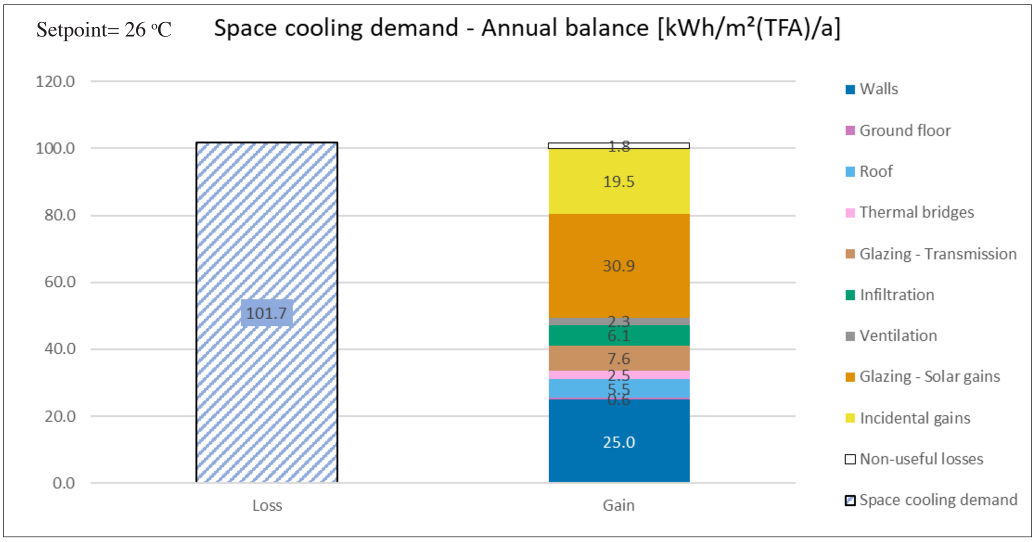
9.6 Parametric modelling: non-adiabatic lobby walls

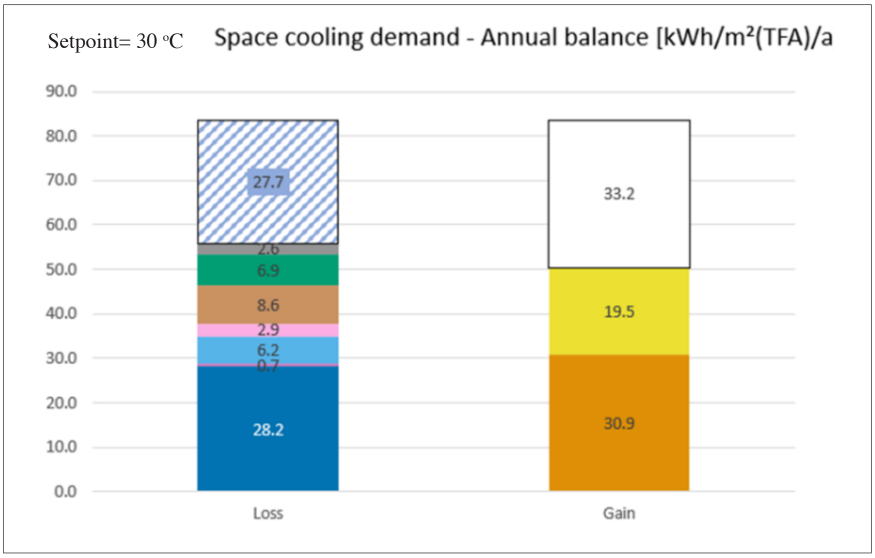
Re-running the calculations but setting the lobby walls to a realistic U-value (i.e. that used for the external walls, 2.46 W/m²/K) rather than 0 W/m²K, changes the cooling demand from 27.7 to 28.0 kWh/m²(TFA). This clearly shows that our initial simplification about the exposure of the walls was not a fatal error. We encourage you to always consider exploring any simplifications you make via this form of parametric modelling, just so you can ensure your results are robust and stand up to scrutiny.

9.7 Design adjustments

We have answered two of our initial design questions - yes, air conditioning is needed; and, yes, the overheating is likely to be considerable if the air conditioning was no longer affordable. We now turn to the remaining questions and consider what would happen if wealth increases such that the occupants can use air conditioning far more frequently and at a lower set point.

To do this we simply need to temporarily set the complexity level to 3, and reduce the setpoint to 26 °C. This produces the following heat balance chart, which can be compared to the situation when the set point was 30 °C by looking at the lower graph:





Space cooling demand (kWh/m²(TFA)/a): top with a setpoint of 26 °C; bottom with a setpoint of 30 °C

Looking at the two charts, we can see that the heat balance has completely changed, and this is another example of why it is a good idea to explore any assumptions via parametric modelling (in this case the set point). In the right hand chart we see that with a setpoint of 30 °C the building is generally losing heat to the external environment; at 26 °C the opposite is true, it is taking in heat from the outside, and hence the cooling demand is almost four times greater.

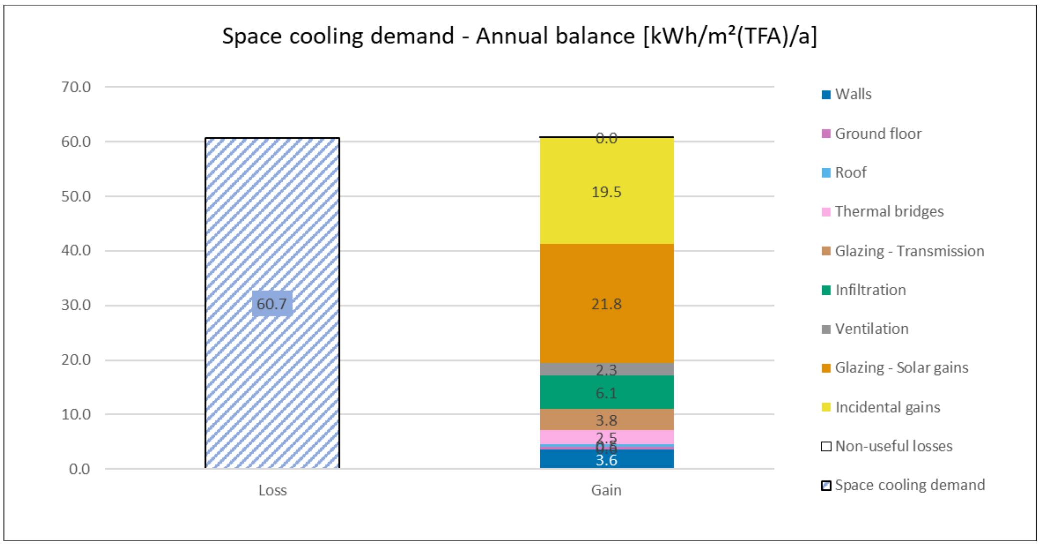
So yes, if the occupants do use a lower set point, the energy use is much greater. This result has implications for future carbon emissions and probably restricts the use of the cooling by the less wealthy.

Looking at the upper chart, we see that the main sources of heat getting into the building are: the walls, the glazing conductivity, incidental gains and solar transmission. In addition, the roof is a clear source of heat despite its small area (indicating the apartments directly below the roof might well be worth drawing out as a separate study).

Given this, our new strategy might be:

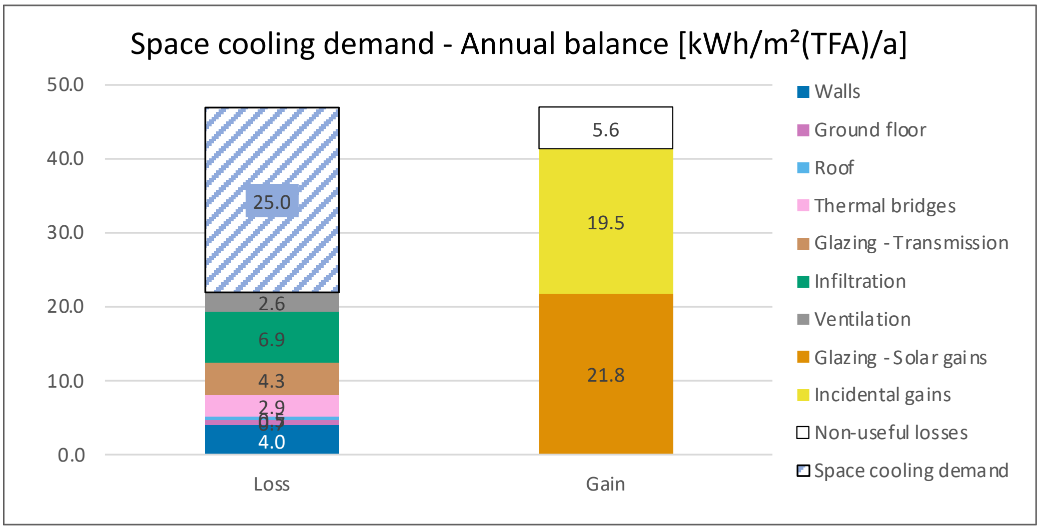
- adding insulation to the walls and roof give a U-value of 0.35 W/m²/K,
- using double glazing,
- offering the occupants external blinds.

If this were a real piece of design work, we would suggest you model with a series of possible U-values to see their impact and make only one change to the design at a time so you can see the impact of each in isolation, however this example is already quite long, so we instigate all the changes at once to give the following chart (we have set the lobby wall and door U-value back to 0 and assume the blinds are in use half the time (or to half the extent) in the cooling calculation by setting temporary shading (cooling) to 0.8):



Our strategy has been successful, in that we have halved the cooling demand and hence made the building more robust with respect to rising affluence. Whether this is enough of a reduction would be a question for the whole design team. It is also clear that to reduce the load much further we need to start thinking about infiltration and finding a way of reducing other incidental gains – which will not be easy.

This leaves the question of how much these changes might be useful to the current less well-off expected occupants? Returning the setpoint to 30 °C we obtain the following balance for the new design. It is clear that the reduction in cooling demand is quite small for these occupants, only around 3 kWh/m^2. And again we see the main driver of the demand is the incidental gains. This emphasises that controlling space heating and cooling demand is about much more than just U-values etc. This is often the case.



Part 2
Playing with ZEBRA

The most important thing you need to know about ZEBRA, or indeed any other model, is that the goal is to make a comparison between designs, not to make predictions about an unknowable future. In other words, do not treat the numbers you get back from ZEBRA as a "true" prediction of how your building will actually perform. Instead, see how those numbers change when you make changes. Once again, this means making one change at a time.

The tutorial has already shown you how to do this by playing with the set-point, adding temporary shading, improving some U-values etc.

In this part, we show you how to play in other ways. Accompanying ZEBRA files are available for every play in Part 2. However, we recommend you start fresh and use our files to check your work, or indeed, find mistakes in ours! Using a pre-filled sheet (or any other such model) always has the risk that you end up carrying someone else's mistakes with you.

1.0 Section 1: Residential

1.1 Hi Rise Apartment Block

1.1.1 Play 1: Playing with Weather Data?

In Part 1, our flat used the weather data for Cuddalore which, as we noted, is 170 km away from our site. In the UK, even a difference of about 30 km has been shown to cause a significant error (up to 2×) in the heating demand of a building. So, it seems sensible to ask whether using weather data more local to our site in Chennai might make a difference to our cooling demand calculation.

To do so, we have to first show you how to get new weather data into ZEBRA. While you can find all sorts of weather data on the web, ZEBRA requires data to be in a particular form and contain some important variables such as outdoor air temperature and solar radiation. The global community of building energy modellers uses the EnergyPlus Weather (.epw) file format which standardises the structure of data needed for more detailed simulators such as EnergyPlus (free and open-source), DesignBuilder (commercial soft-ware using EnergyPlus as an engine), IES Virtual Environment (A DesignBuilder competitor using its own proprietary engine) and many others. So, our converter also expects an .epw file as an input. While you can use any .epw file, their quality varies significantly by source. We hence recommend using files from known quality-controlled sources such as the ZED-i repository.

A key benefit of the ZED-i data over other data is that they have been specifically designed to overcome the limitations of existing data sets. For example, you can download a unique set of files for virtually every 25 km square over the Indian land surface: only locations with an elevation greater than 1,000 m are not supported. In addition, not only do you get data for "current" climate (defined as 1981 – 2010), you also get estimates of climate in the future (2060-2089) meaning that you can, for the first time, see how well your building will fare in a changed climate.

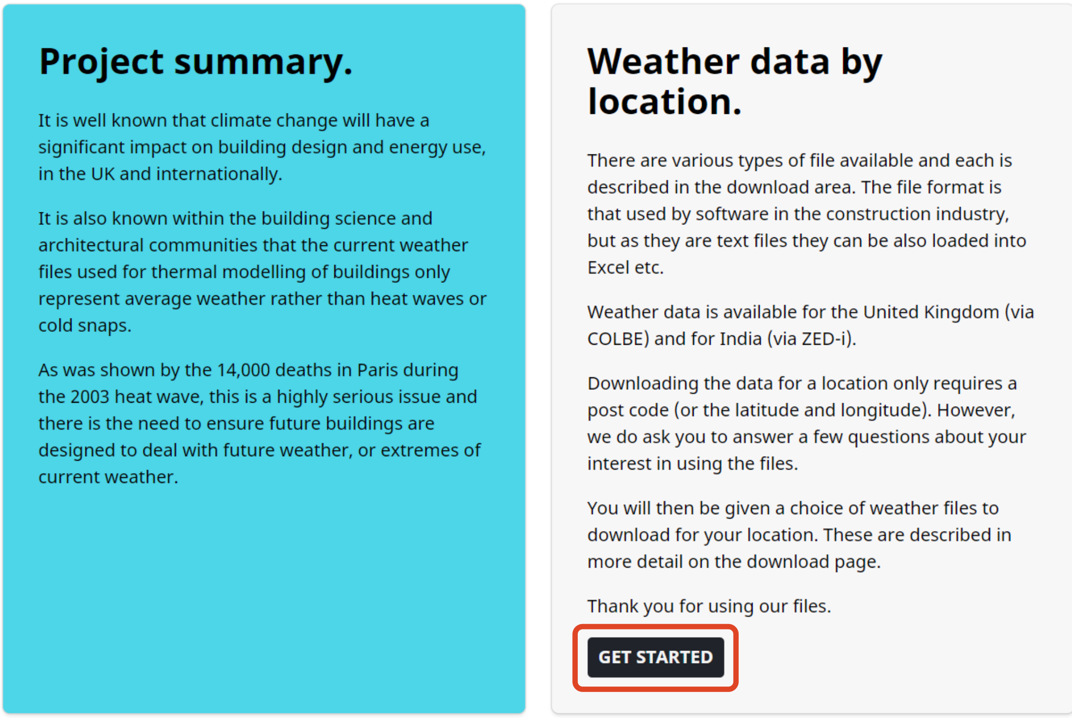
Here is how you get the site-local weather data for our 14 Story Apartment Block Chennai from the ZED-i repository into ZEBRA:

1. If you just got here, go to Part 1 and complete the example there using the nearest weather file in ZEBRA (Cuddalore). Keep a record of the output (space cooling, hot water, electrical etc) in a separate sheet for later comparison.

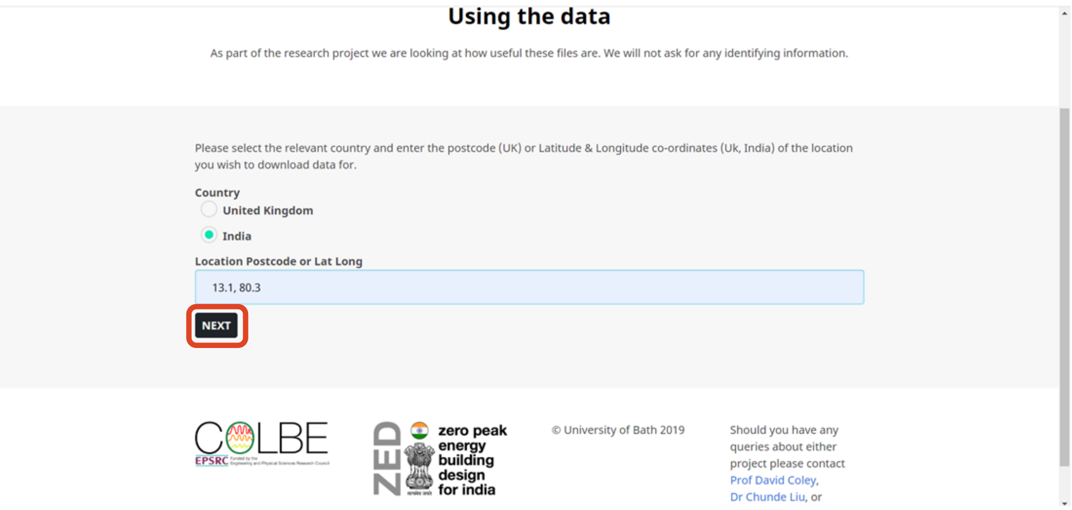
See Annex 2 for building parameters used

2. Next download the nearest weather file from: https://zed-i.bath.ac.uk/

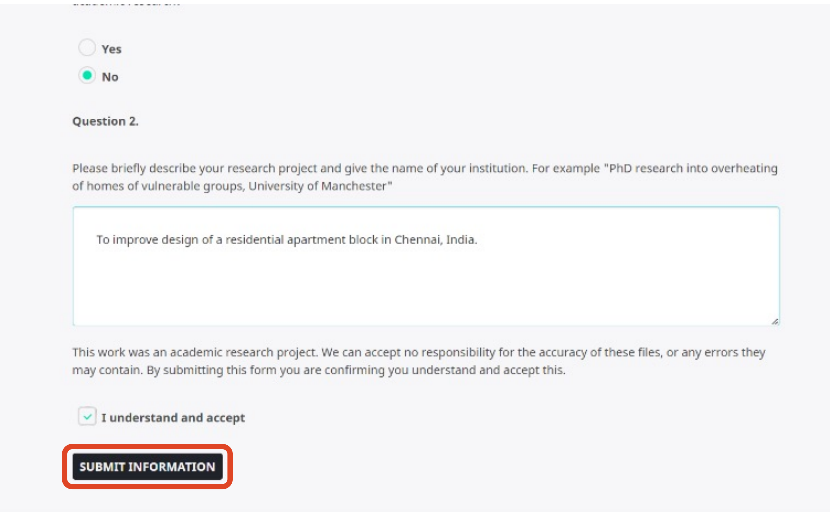
3. Click on “Get Started”.



4. The “Using the data” sheet asks for the latitude and longitude (separated by a comma) whose data is needed. This is **13.1, 80.3** for our site. Once you have entered the data as shown, click “Next”.

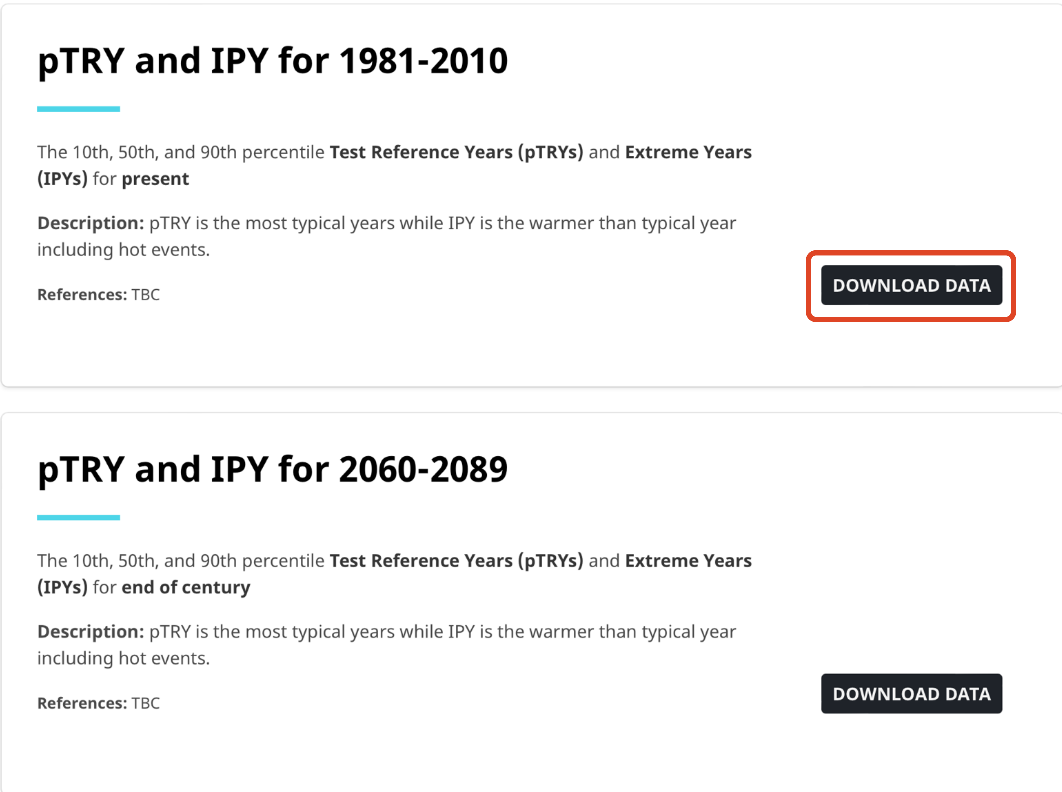


5. The next page requires some basic information to help us see how our data are being used. Complete the information on the next page and click “submit information”.



Please supply as much detail as you can when using our data for real projects as it helps us track the use of our work, which is funded using public money.

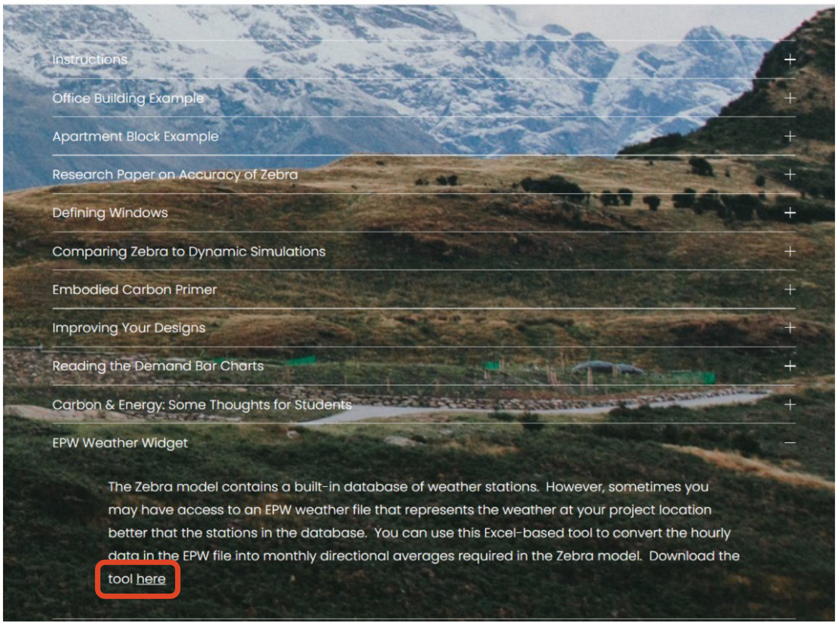
6. There is a choice of weather files to download. Click on the “download data” button in the “pTRY and IPY for 1981-2010” box. Here, we take 1981 – 2010 to represent current climate. Note that the download page might look different when you access the page.



This should download a zip-file containing several files. Unzip this file. Once unzipped, locate the file that has the words “50%” and “TRY” in the name. Save this file ready to use the next step.

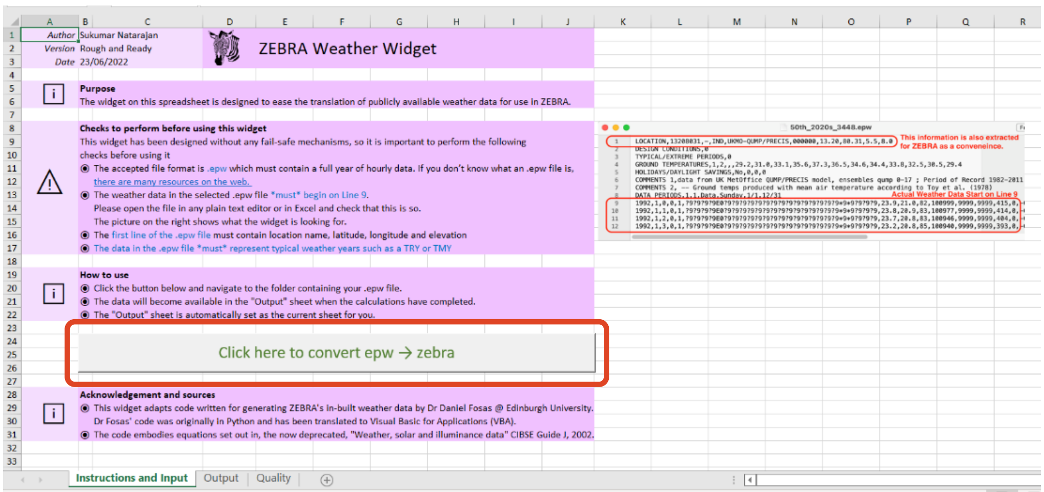
Residential

7. Next you will need to download the “ZEBRA weather widget”.



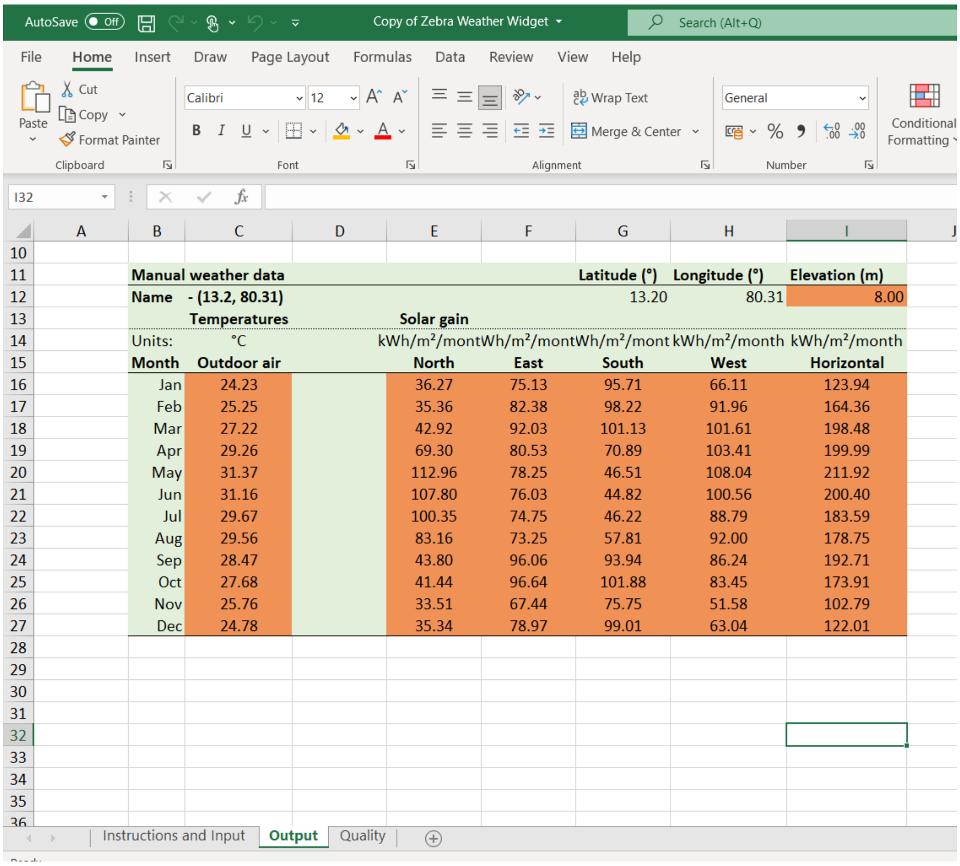
Download Weather Widget from ZEBRA Webpage with the QR Code:

8. Now open the **ZEBRA Weather Widget** to convert the above EPW weather file into a format that ZEBRA can use. Once opened, click on “Click here to convert .epw to ZEBRA”. This will ask you to locate the above weather file. Once you have located and loaded the file, the widget may ask you to name the location, after which it will take a short while to convert the file. When we name the location, we also add the time frame (e.g. “Chennai present” or “Chennai 1981 - 2010”) to keep an audit of what we have done. We recommend you do this too! Also, don’t panic if the widget looks like it has frozen - it hasn’t! The conversion calculations are complex and take some time to execute.



Once the data has been processed, the widget will change to its “Output” sheet and the area you need to copy will be pre-selected. Simply hit CTRL-C (or ⌘-C on a Mac) and copy over the data in brown into the **Weather** sheet.

Residential



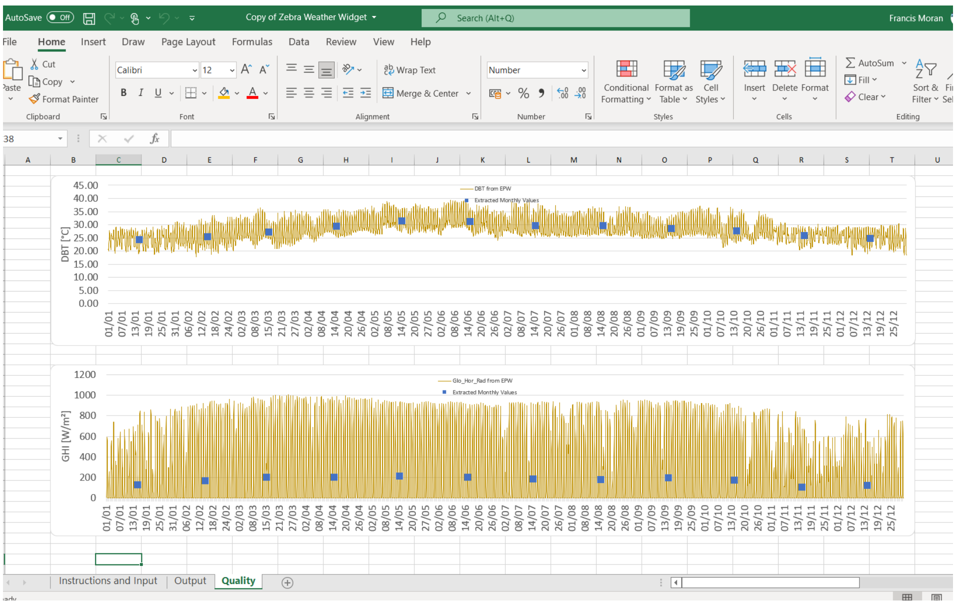
Manual weather data

Name - (13.2, 80.31)		Latitude (°)	Longitude (°)	Elevation (m)		
		13.20	80.31	8.00		

Month	Outdoor air (°C)	North (kWh/m²/mont)	East (kWh/m²/mont)	South (kWh/m²/mont)	West (kWh/m²/month)	Horizontal (kWh/m²/month)
Jan	24.23	36.27	75.13	95.71	66.11	123.94
Feb	25.25	35.36	82.38	98.22	91.96	164.36
Mar	27.22	42.92	92.03	101.13	101.61	198.48
Apr	29.26	69.30	80.53	70.89	103.41	199.99
May	31.37	112.96	78.25	46.51	108.04	211.92
Jun	31.16	107.80	76.03	44.82	100.56	200.40
Jul	29.67	100.35	74.75	46.22	88.79	183.59
Aug	29.56	83.16	73.25	57.81	92.00	178.75
Sep	28.47	43.80	96.06	93.94	86.24	192.71
Oct	27.68	41.44	96.64	101.88	83.45	173.91
Nov	25.76	33.51	67.44	75.75	51.58	102.79
Dec	24.78	35.34	78.97	99.01	63.04	122.01

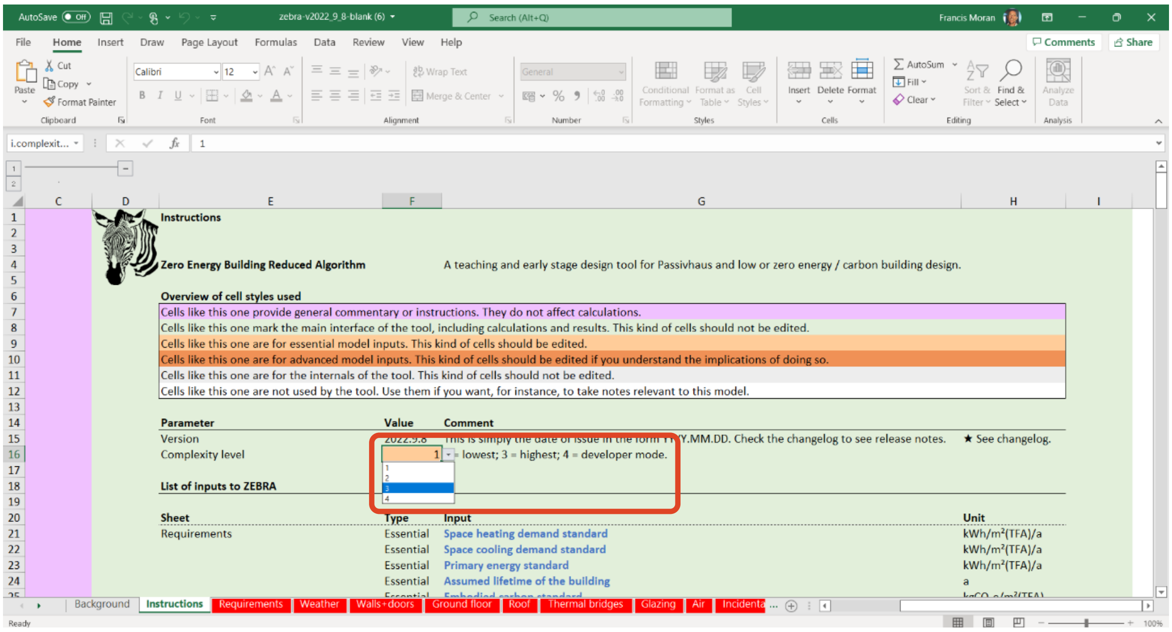
Temperatures: Outdoor air. Solar gain: North, East, South, West, Horizontal.

However, before you do so, there is another sheet labelled "Quality", that is worth looking at. This is part of any good practice when dealing with data and is designed to give you a "sense check" on the data. For the file from ZED-i it looks like this:

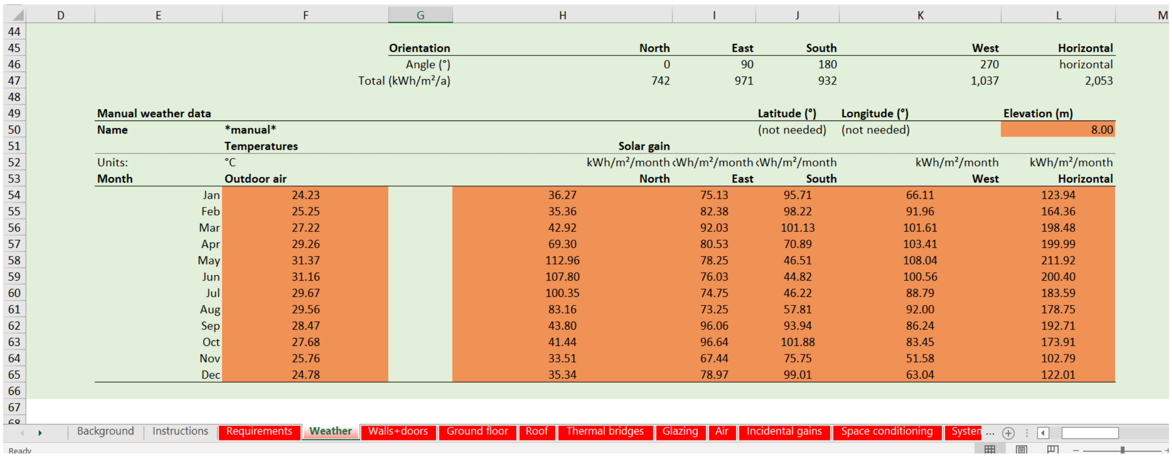


The orange data in the graphs are the raw data contained in the .epw file you loaded into the widget and the blue dots represent the values that the widget has converted for use in ZEBRA. We can see that the orange data show that temperatures touch 40 °C in June and transition to slightly cooler months in either direction with no significant “monsoon” effect as one might expect in hot and dry cities such as New Delhi. Solar radiation is uniformly high in the summer months with lower values and greater variability between November and January. The blue dots for both temperature and solar radiation lie satisfyingly in the “middle” of the orange data and are not easily biased by extremes. Having briefly checked this, we return to the “Output” sheet and copy our data.

9. In the ZEBRA workbook change to **Complexity Level 3** on the **Instructions** sheet:



10. Then go to the Weather sheet and scroll down to Row 50 and paste the copied data from the widget into the ZEBRA weather sheet (be sure to include copying and pasting the site elevation). This should look like this:



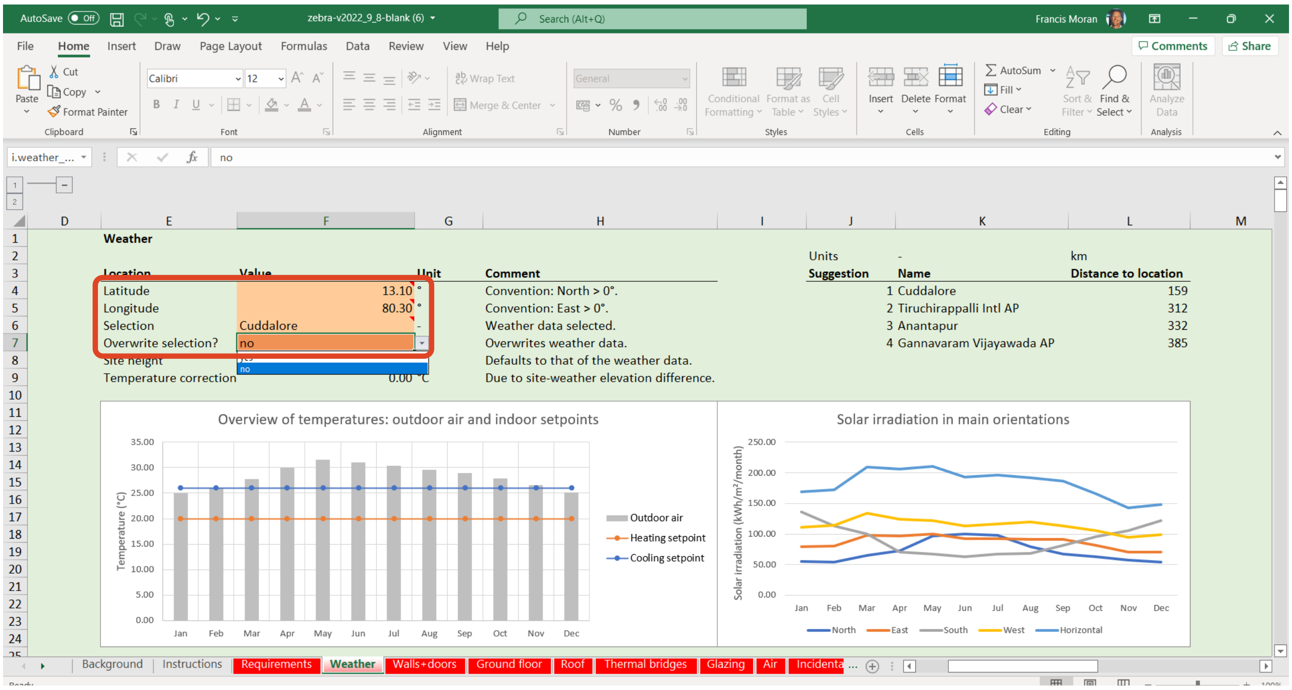
	Orientation	North	East	South	West	Horizontal
	Angle (°)	0	90	180	270	horizontal
	Total (kWh/m²/a)	742	971	932	1,037	2,053

Manual weather data

Name	*manual*	Latitude (°)	Longitude (°)	Elevation (m)
		(not needed)	(not needed)	8.00

	Temperatures	Solar gain				
Units:	°C	kWh/m²/month	kWh/m²/month	kWh/m²/month	kWh/m²/month	kWh/m²/month
Month	Outdoor air	North	East	South	West	Horizontal
Jan	24.23	36.27	75.13	95.71	66.11	123.94
Feb	25.25	35.36	82.38	98.22	91.96	164.36
Mar	27.22	42.92	92.03	101.13	101.61	198.48
Apr	29.26	69.30	80.53	70.89	103.41	199.99
May	31.37	112.96	78.25	46.51	108.04	211.92
Jun	31.16	107.80	76.03	44.82	100.56	200.40
Jul	29.67	100.35	74.75	46.22	88.79	183.59
Aug	29.56	83.16	73.25	57.81	92.00	178.75
Sep	28.47	43.80	96.06	93.94	86.24	192.71
Oct	27.68	41.44	96.64	101.88	83.45	173.91
Nov	25.76	33.51	67.44	75.75	51.58	102.79
Dec	24.78	35.34	78.97	99.01	63.04	122.01

11. Next scroll up to **Row 7** and select "**yes**" in the "**over-write selection**" drop down box, now change back to **Complexity Level 1**.



There is one more thing to change and that is the cooling set point. This defaults to 26 °C in ZEBRA along with a heating set point of 20 °C:

See the ZEBRA website's "Docs" tab for information on set points.

Based on the guidance provided in 8.4 and Annex 1 we have set the cooling set point to 30 °C, this of course can be raised and lowered as ZEBRA is used in different climates. We hope to release further guidance on how to determine setpoints, so please check the ZEBRA website in due course.

We now get to the interesting bit. In the table below, the left-hand column shows the result of using the data for Cuddalore built into ZEBRA. The right-hand column is the new data from ZED-i that is local to our site. There is a clear drop in space cooling demand using the more local data. Remember, the utility of this approach does not necessarily lie in the "truth value" of the results, but rather that they are meaningfully different. Thus, from this point on in Part 2, we will only be using the highly-local weather file from the ZED-i repository (unless otherwise noted). Note that the final row in the table shows **PV (photovoltaic)** electricity generation using 60% of the available roof area.

Photovoltaic (PV) cells, convert sunlight directly into electricity, for more information see:

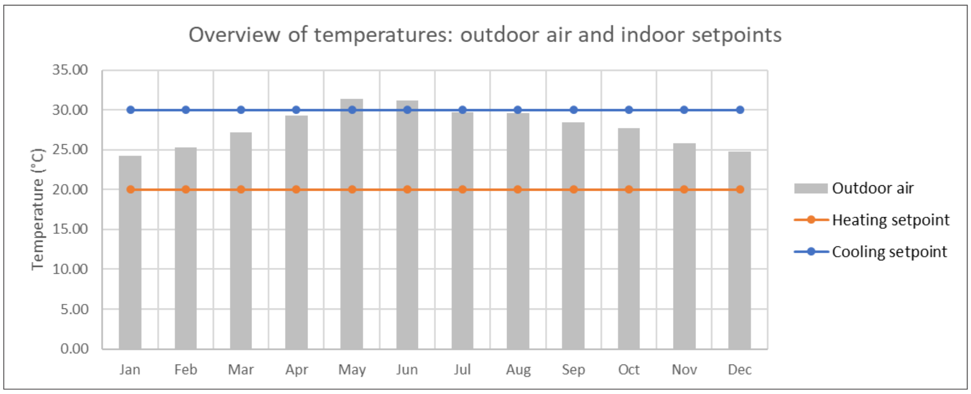
	Play 1	
	14 storey apartment block	
	Chennai – Energy Demand kWh/m²/a	
	ZEBRA built-in	ZED-i epw present
Ventilation	0.0	0.0
Space Heating	0.0	0.0
Space Cooling	37.0	28.7
Hot Water (HW)	8.1	8.2
Electrical Gains	9.6	9.6
Total	**54.7**	**46.5**
PV gen	-11.7	-11.0
Net of PV	**43.0**	**35.5**

Electrical Gains
ZEBRA presently uses the term "electrical gains" in the Summary sheet which can be potentially confusing. Think of this as the electricity demand from lighting, computers etc.

1.1.2 Play 2: What happens if I use future weather files?

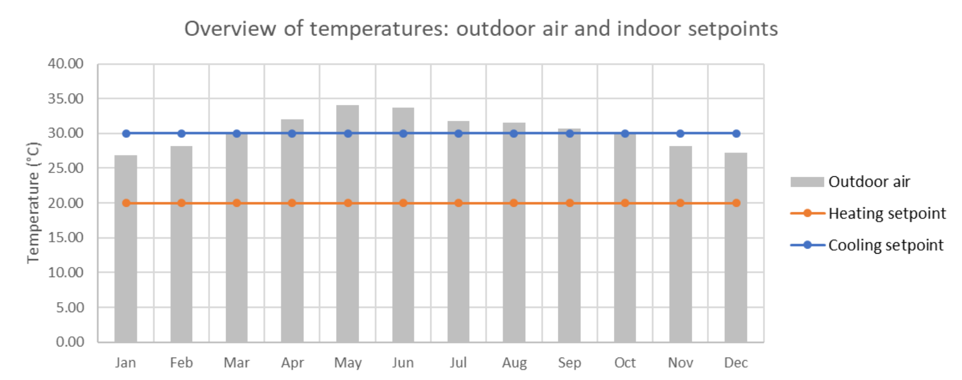
Comparing present and future weather files we observe the following:

- When the present weather file data from ZED-i are loaded into ZEBRA, we observe that monthly average temperatures in May (the hottest month) are around 32 °C falling to about 24 °C in January (the coldest month).



- When we load the future weather files from ZED-i into ZEBRA, we can immediately see that not only has the average temperature in May gone up to about 34 °C (i.e. a 2 °C increase on average) but that the average temperature in January has also gone up to about 26 °C, again a rise of 2 °C. That the rise seems to be 2 °C in both months is somewhat coincidental as in other locations it may be more – or even less – in different months. Remember that these are monthly average temperatures converted from hourly data. That is, we have gone from having 8,760 data points in a year to just 12, so there is a lot of more detailed weather information contained in the ZED-i epw file than ZEBRA needs.

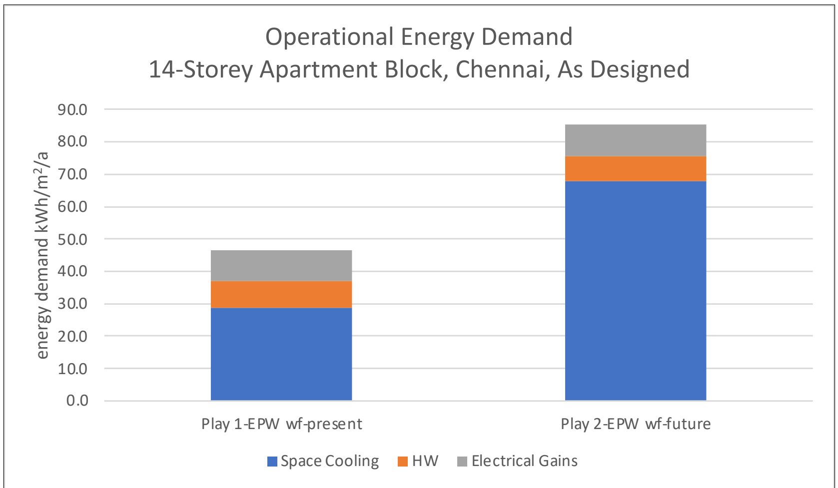
Residential



Leaving the set point unchanged for now we can observe an increased annual space cooling demand: ZED-i repository.

	Play 1		
	14 storey apartment block		
	Chennai – Energy Demand kWh/m²/a		
	ZEBRA built-in	**ZED-i epw present**	**ZED-i epw future**
Ventilation	0.0	0.0	0.0
Space Heating	0.0	0.0	0.0
Space Cooling	37.0	28.7	68.0
Hot Water (HW)	8.1	8.2	7.6
Electrical Gains	9.6	9.6	9.6
Total	**54.7**	**46.5**	**85.2**
PV gen	-11.7	-11.0	-10.6
Net of PV	**43.0**	**35.5**	**74.6**

Sometimes tabular data can get rather dull, so it is worth reminding ourselves just how profound a change this is by seeing the same data in a graph. It now becomes clear that a seemingly small 2 °C rise in average temperatures means more than a doubling (2.4× to be precise) of cooling energy demand in the future.



It may be that this scale of increase may not occur in practice as there is a school of thought suggesting that we will adjust our expectations of indoor temperatures as the climate changes, i.e. the "adaptive model" for which there is an India-specific version called IMAC. So, it may be worth reassessing the cooling set point (see Annex 1).

1.1.3 Play 3: What happens if I add an extra bedroom?

Continuing from the same building as above (i.e. using localised present weather data for the site), we now play with the question of what happens when one of the four units in plan increases in area, for ex-ample, by getting an extra bedroom. Here are the steps:

1. Let us assume we are adding a 5m × 5m bedroom to the South façade on every floor.

   a. Envelope increase: of 420 m² from 3,905 m² to **4,325** m².

Walls+doors

Units:	-	m	W/m²/K	W/m²/K	W/m²/K	m²
External wall+door name (optional)	**Construction**	**Insulation thickness**	**U-value from construction**	**U-value from other**	**U-value final**	**Area**
a	Other - Wall			2.46	2.46	4,325.00
b Lobby Doors				0.00		[illegible]
c Lobby Walls				0.00		1,674.00
d						
e						
f						
Summary					2.46	4,325.00

   b. TFA increase of 350 m² from 6,669 m² to **7,019** m²:

D	E	F	G	
	Requirements			
	Energy and carbon philosophy	**Value**	**Unit**	**Comment**
	Space heating demand standard	15	kWh/m²(TFA)/a	The Passiv
	Space cooling demand standard	30	kWh/m²(TFA)/a	The Passiv
	Primary energy standard	120	kWh/m²(TFA)/a	The Passiv
	Assumed lifetime of the building	60	a	Sets a fram
	Embodied carbon [A1-A5]	500	kgCO₂e/m²(TFA)	500 is best
	Operational carbon	0	kgCO₂e/m²(TFA)/a	0 is the asp
	Key characteristics	**Value**	**Unit**	**Comment**
	Treated floor area (TFA)	7,019.00	m²	TFA is abo

c. See calculator for increased thermal bridges due to additional floor area to 1,086.6 W/K and paste result into the Thermal Bridge sheet:

Calculator screenshot:

Thermal bridges - Estimation (based on SAP 10.2, equation K2)			
Unit:	m²	W/m²/K	W/K
Element	**Area**	**Estimate**	
Walls	4,325.00	0.20	865.00
Ground floor	554.00	0.20	110.80
Roof	554.00	0.20	110.80
Total			**1,086.60**

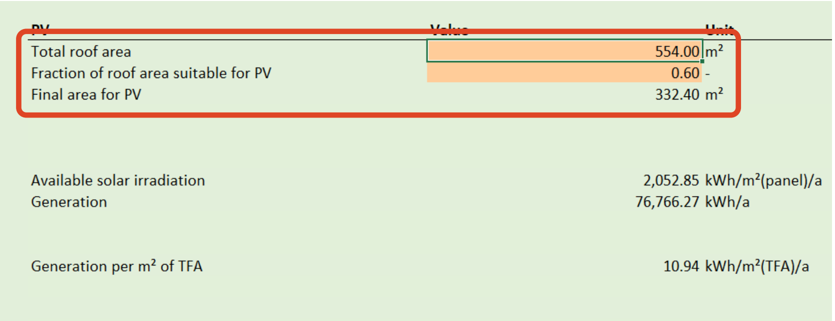
Thermal Bridge sheet screenshot:

Thermal bridges	Value	Unit	Comment
Is the design free of linear thermal bridges?	no	-	Depends on detailing.
Linear thermal bridge coefficient		W/m/K	Ignored if thermal bridge free.
Total length of thermal bridge		m	Ignored if thermal bridge free.
Is the design free of point thermal bridges?	no	-	Depends on detailing.
Point thermal bridge coefficient	1,086.60	W/K	Ignored if thermal bridge free. ★ See calculator for basic estimate.
Number of point thermal bridges	1.00		Ignored if thermal bridge free. If using the calculator, use 1 point thermal bridge.

d. On the **Air** sheet add an additional volume increase of 1,050 m³ from 17,774 m³ to **18,824** m³ and an increase of average number of occupants from 93.4 occupants to **98.3** occupants:

E	F	G
Air		
Parameter	**Value**	**Unit**
Assumed infiltration rate	6.00	ach@50Pa
Justification for the chosen infiltration rate	Architect-10 times PH stan	
Treated floor area (TFA)	7,019.00	m²
Internal volume of building	18,824.00	m³
Likely infiltration rate at normal pressures	0.42	ach
Time taken for infiltration to replace all the air in the building	2.38	h
Average number of occupants (see end of commentary)	98.30	p
Ventilation rate	2,949.00	m³/h
Ventilation rate	0.16	ach

On the **System** sheet we also need to increase the area of roof available to receive PV from 529 to **554** m², leaving the fraction of roof available for PV at 60%:

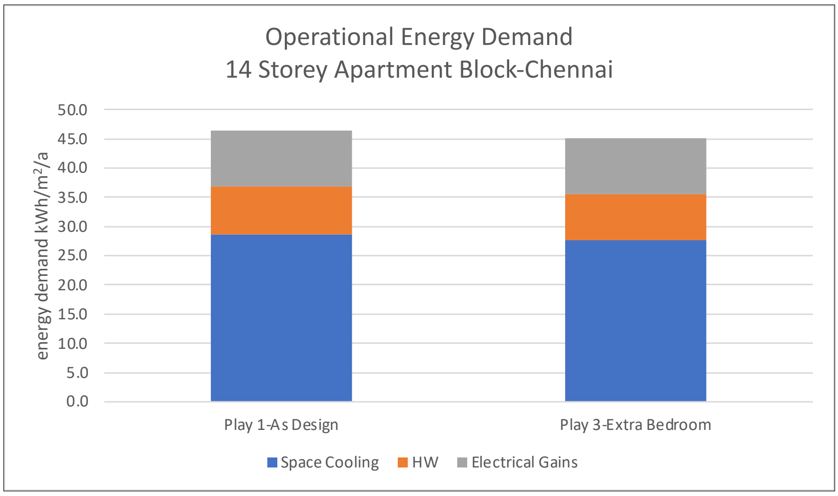


2. If we now add our new results into the table we obtained at the end of the last play, we get this following new table:

	Play 3	
	14 storey apartment block	
	Chennai – Energy Demand kWh/m²/a	
	As Design ZED-i epw present	Additional Bedroom ZED-i epw present
Ventilation	0.0	0.0
Space Heating	0.0	0.0
Space Cooling	28.7	27.7
Hot Water (HW)	8.2	7.8
Electrical Gains	9.6	9.6
Total	46.5	45.1
PV gen	-11.0	-10.9
Net of PV	35.5	34.2

We observe that there is small reduction in annual energy demand of 1.4 kWh/m². This is primarily due to an increase in the ratio of TFA to envelope area.

If you are wondering why adding an entire room doesn't seem to have moved the needle very much, especially when compared to the change between weather files, this is because all our comparisons are normalised against floor area. That is, we are looking at kWh/m² not kWh. If you multiply the kWh/m² numbers by the actual TFA, you will find that the building with the extra room now consumes 3,026 kWh more than our starting building, i.e. 216 kWh per annum more for a single flat. Using normalised floor area values allows us to keep comparing like for like – a very important aspect of any modelling exercise.



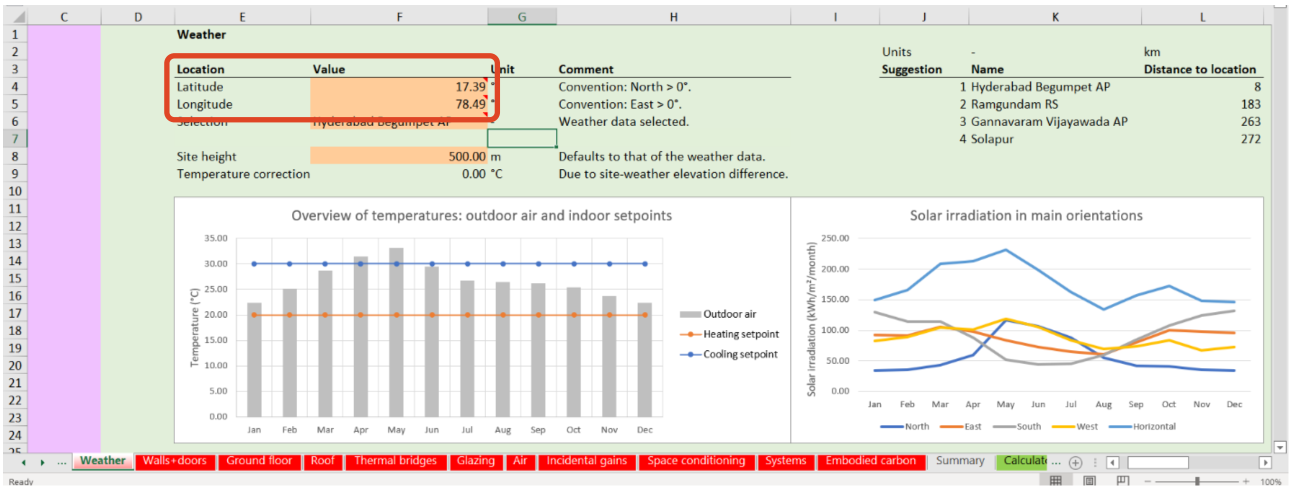
1.1.4 Plays 4 and 5: What happens if I'm not in Chennai?

You already know that the answer to this question is that the energy demand is likely to change. So, the real questions we want to play with are: by how much and in what direction? Let us see what happens as we move inland and further north from Chennai to Hyderabad and then Jaipur.

To test this, you will need to enter the new co-ordinates as follows:

Play 4-: **Hyderabad**: Latitude 17.38 and Longitude 78.49 (so, enter **17.38, 78.49** on the ZED-i website).

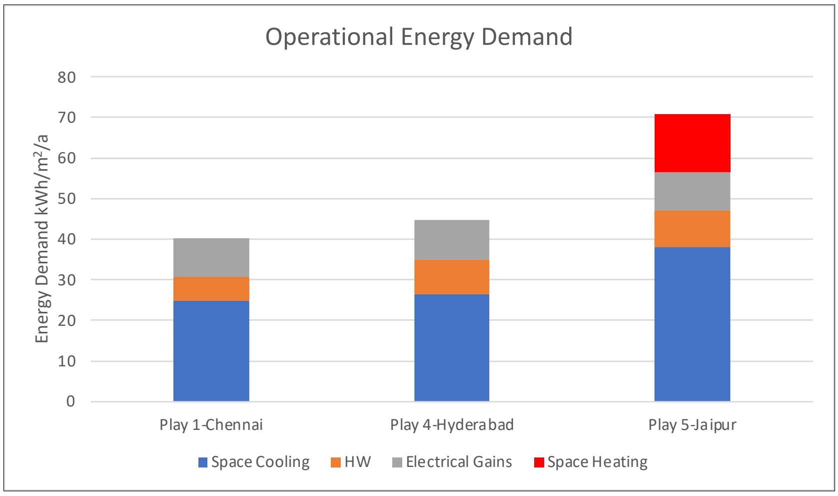
Play 5-: **Jaipur**: Latitude 26.91 and Longitude 75.79 (so, enter **26.91, 75.78** on the ZED-i website).



Having obtained the EPW weather files for these locations, use the "weather widget" results to paste into the **Weather** sheet and then select "**over-write selection?**".

	Plays 4 and 5 compared to Play 1		
	14 storey apartment block - Energy Demand kWh/m²/a		
	Play 1 - Chennai	Play 4 - Hyderabad	Play 5-Jaipur
	ZED-i epw present	ZED-i epw present	ZED-i epw present
Ventilation	0.0	0.0	0.0
Space Heating	0.0	0.0	14.2
Space Cooling	24.7	26.6	38.2
Hot Water (HW)	5.8	8.5	8.9
Electrical Gains	9.6	9.6	9.6
Total	**40.1**	**44.7**	**70.9**
PV gen	-11.0	-11.2	-10.9
	29.1	33.5	60.0

We now have answers to our questions: operational energy demand goes up, marginally in Hyderabad but rather dramatically in the desert environment of Jaipur where it is sufficiently cold in the winter to require heating energy demand.



Residential

1.1.5 Plays 6-10: What happens if I change fabric efficiency?

Fabric efficiency refers to the rate at which your walls, window, roof and floor gain or lose heat through coming into contact with the warm air outside or the cooler ground underneath. You already know these as the U-value of these elements. Improving U-values can result in a reduction in the infiltration rate (see Section 8.10 for an explanation of this term, in case you have forgotten) if better quality fixtures, materials and construction are used. We will also see how this affects our results. We will do all of this playing with our apartment block which has been magicked to Jaipur. Part 3 contains a library of useful U-value data which we are using below.

1. This is a parametric analysis: ***after each parameter alteration undo the change and return to original worksheet data.***

2. **Play 6:** Our original flat used **15 mm external plaster + 200 mm brick + 12 mm internal plaster** (from SP-41 (1987)) as the wall material with a U-value of 2.46 W/m²K. What if we were building with **15 mm external plaster + 50 mm foam concrete + 100 mm concrete block + 12 mm internal plaster** (from SP-41 (1987)) instead? Looking at Part 3 data for **15 mm external plaster + 50 mm foam concrete + 100 mm concrete block + 12 mm internal plaster** (from SP-41 (1987)), we see that it has a U-value of 1.2 W/m²K. Put this into your sheet, then record the result. Undo and return to the original data now – you have been reminded!

	E	F	G	H	I	J	K
1	Walls+doors						
2							
3	Units:	-	m	W/m²/K	W/m²/K	W/m²/K	m²
4	External wall+door	Construction	Insulation thickness	U-value	U-value	U-value	Area
5	name (optional)			from construction	from other	final	
6	a	Other - Wall			1.20	1.20	3,905.00
7	b Lobby Doors				0.00		1,055.80
8	c Lobby Walls				0.00		1,674.00
9	d						
10	e						
11	f						
12	Summary					1.20	3,905.00

3. **Play 7:** Our original flat used a **10% framed single-glazed window** with a mid-pane U-value of 5.0 W/m²K and g-value (this is the same as the Solar Heat Gain Coefficient, SHGC) of 0.45. What if we improved our window to a **10% framed double-glazed window** with a mid-pane U-value of **2.0** and g-value of **0.6**? Let us change this and record the result.

	E	F	G	H–K
1	Glazing			
2				
3	Parameter	Value	Unit	Comment
4	Mid pane U-value	2.000	W/m²/K	Reasonable defaults are: 0.85 (triple glazing); 2 (double glazing); 5 (single glazing).
5				
6				
7				
8	Glazing g-value	0.600	-	0-1. Reasonable defaults are: 0.45 (triple glazing); 0.60 (double glazing); 0.85 (single glazing).
9				
10				

4. **Play 8:** Our original apartment block used **50 mm lime concrete using brick ballast aggregate + 100 mm RCC slab + bitumen wash on top surface** (from SP-41 (1987)) as the roof material with a U-value of 4.20 W/m²K. What if we were building with 2**0 mm roof finish (tile) + 30 mm PCC + 25 mm XPS insulation + 150 mm RCC slab + 10 mm Plaster** (adapted from ECBC Design Guidelines) instead? Looking at Part 3, we see that it has a U-value of **1.0** W/m²K. Change and record result.

XPS stands for Extruded Polystyrene which usually has much lower thermal conductivity than the other popular insulation material Expanded Polystyrene (EPS). The lower the conductivity of the insulating material, the better the insulation it offers.

	Roof		
	Units:	m²	W/m²/K
	Roof name (optional)	**Area**	**U-value**
	a Flat Roof	529.00	1.00
	b		
	c		
	Summary	529.00	1.00

5. **Play 9:** What if we don't get the level of ventilation we thought we might? This may happen for many reasons: noise or smells outside and occupants behaving in a manner we did not expect. We test this by changing assumed infiltration rate of 6.0 ACH to **2.0** ACH – record result.

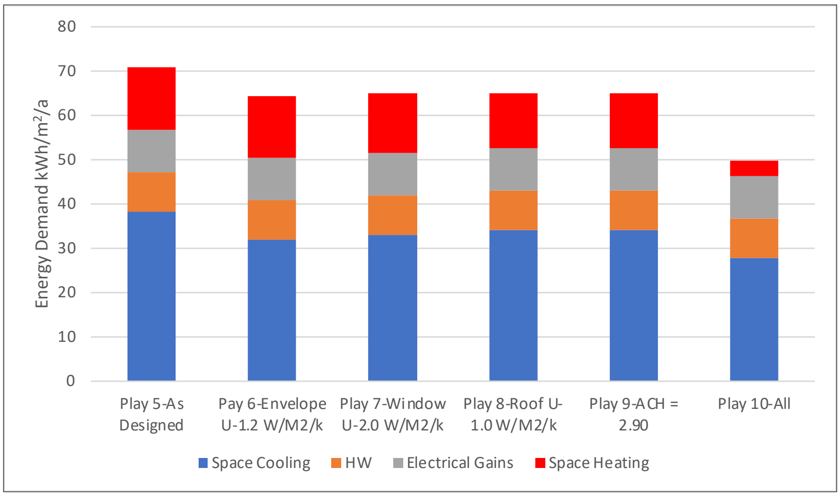
Air

Parameter	**Value**	**Unit**	**Comment**
Assumed infiltration rate	2.00	ach@50Pa	0.6 or better to be a Passivhaus, the average value in the UK is probably 6 for a small building.
Justification for the chosen infiltration rate	Architect-10 times PH standards and still good by modern standards		
Treated floor area (TFA)	6,669.00	m²	TFA is about 90% of gross internal floor area, or 97% for a bungalow (as no stairs).
Internal volume of building	17,774.00	m³	
Likely infiltration rate at normal pressures	0.14	ach	This cells display the value if the justification for the chosen infiltration rate is given.
Time taken for infiltration to replace all the air in the building	7.14	h	
Average number of occupants (see end of commentary)	93.40	p	Suggestions: 0.014 * TFA for homes; 0.01 * TFA for offices; 0.072 * TFA for schools (fraction of an occupant is fine).
Ventilation rate	2,802.00	m³/h	
Ventilation rate	0.16	ach	

6. **Play 10:** For the final run incorporate all the above parameters, the results are:

	Plays 5 to 10 using present weather file for Jaipur from ZED-i					
	14 storey apartment block - Energy Demand kWh/m²/a					
	Play 5	**Play 6**	**Play 7**	**Play 8**	**Play 9**	**Play 10**
	As Designed	Wall U=1.2 W/m²/K	Window U=2.0 W/m²/K	Roof U = 1.0 W/m²/K	ACH = 2.0	*All as Plays 6 - 9*
Space Heating	14.2	13.8	13.5	12.4	12.2	3.6
Space Cooling	38.2	32.0	33.1	34.2	37.8	27.9
Hot Water (HW)	8.9	8.9	8.9	8.9	8.9	8.9
Electrical Gains	9.6	9.6	9.6	9.6	9.6	9.6
Total	**70.9**	**64.3**	**55.5**	**65.1**	**68.5**	**46.6**

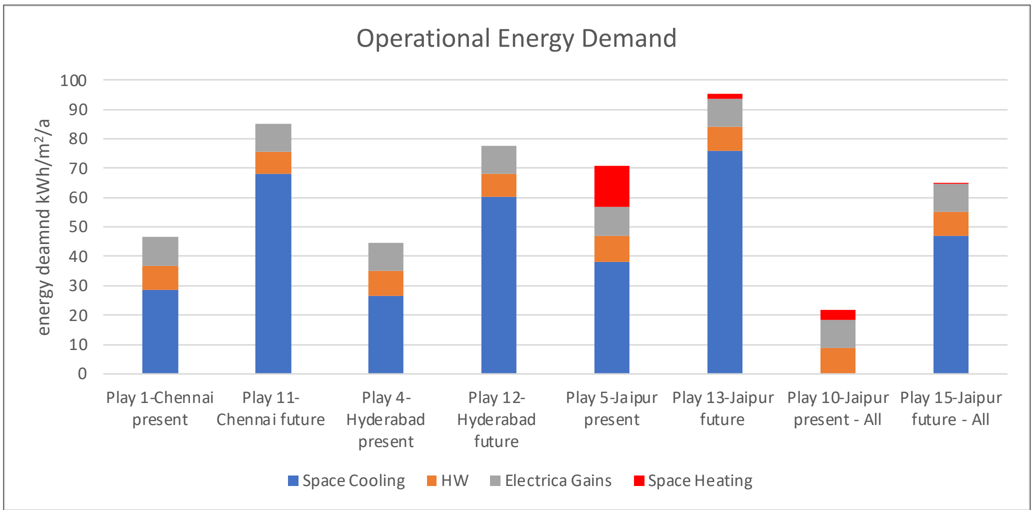
Residential



Residential

1.1.6 Plays 11-15: What happens to our "more efficient" building in the future?

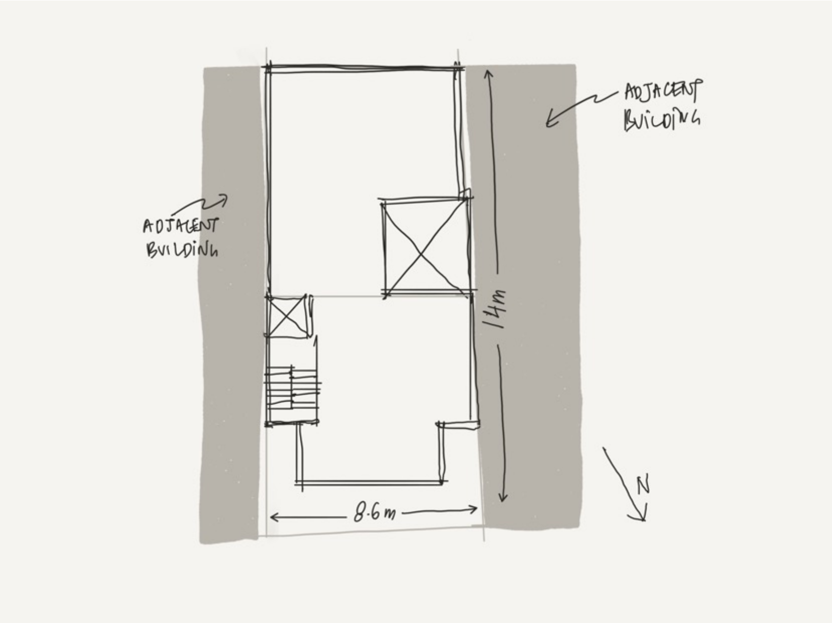
Using the process shown in Part 2 1.1.1, we import Jaipur's 2060-2089 epw weather data into ZEBRA's **Weather** sheet. For interest, we have kept our other two locations here too. As expected, the future is going to be warmer than now and this is likely to significantly increase cooling energy demand. The most interesting data here are the two columns for the apartment block in Jaipur with and without the fabric efficiency improvements (i.e. Play 13 and Play 15). It is rather obvious that investing in more efficient fabric and airtightness – even the modest amounts we have used here – is very much needed to ensure a climate resilient and energy secure future.



1.2 Ummm, I am designing a house not a flat?

Luckily, we also have a house to show you how to put one through ZEBRA. The house is built over five storeys and is on a constrained site with party walls along its length. This is important because less heat will move between these adjoining houses and our house, so much of the heat gains will really be from the front + back elevations and the roof. Also, the picture of the actual house reveals to us that there are lots of "sticky out" bits in concrete each of which has a continuous connection to the floor plate. This is important because, as we saw in Section 8.7, this continuous connection will create thermal bridges allowing heat from the outside air to be conducted via the concrete into the house, raising its cooling load, or vice versa.

Figure 2: (a) (above) The actual building and
(b) (overleaf) an early-stage sketch plan.



The process of entering data for the house is not dissimilar to that for a flat. The main points to remember for the house are:

- The walls are made from **230 mm wire-cut bricks + 12 mm internal plaster** (adapted from SP-41 (1987)) with U_{wall} = **2.15** W/m²K (see Part 3 for U-value data).

- The party walls, i.e. the shared walls between homes will have a U-value of **zero**. This is because most people keep their homes to similar temperatures, so it is not unreasonable to assume at this early stage of the design that no heat is gained across such walls.

- The house has an underground parking area so the ground slab is in contact with the outdoor air. No guidance presently exists in India for ground slab U-values but ZEBRA contains a built-in calculator designed to aid in calculating this. There are two options, one for ground floors in contact with the ground and another for **suspended floors**, i.e. where the outdoor air may come in contact with the underside of the floor, which is the case here. As this is a multi-storey house, the ground U-value will have a lower impact on heat gains and losses compared to other elements such as the walls and windows, compared to a single or double storey house. By assuming a highly conductive **U-value** (**unadjusted**) of the floor slab of 2 W/m²K (**Cell U8** in the **Calculators** sheet) we get U_{ground} = **1.57** W/m²K.

- The roof is made from **25 mm roof finish (tiles) + 50 mm Mud Phuska + 50 mm brick tile + 115 mm RCC + 10 mm internal plaster** (adapted from SP-41 (1987)) with U_{roof} = **2.5** W/m²K.

- We use the thermal bridge calculator to work out that the gains/losses are **130.25** W/K. At this stage the calculator assumes "standard" thermal bridging from elements such as window lintels, sills and metal ties. So, the exaggerated effect of the projecting floor plates etc has not yet been taken into account, which we will do separately.

- Windows are **double-glazed** so have a double-pane U_{window} = **2.0** W/m^2K and gwindow = **0.6**.

- As earlier, we are assuming high levels of infiltration so ACH = **6.0**.

- Incidental Gains = **1.1** W/m^2 (of TFA).

- Hot Water = **25** l/person/day. Unlike the UK, this use is highly seasonal in India. At present ZEBRA calculates this uniformly across the months and will therefore overestimate use. When using in real projects, we recommend scaling the result by the number of months of expected use. For example, if you are expecting hot water use in three out of twelve months only, then take 25% (3/12ths) of ZEBRA's predicted value. One has to be careful with this, of course, as experience suggests humans get accustomed to things that were once thought of unnecessary, or even luxuries. Hence, in the rest of this report, we continue with ZEBRA's output.

1.2.1 Plays 16-20: House in Kolkata & Tezpur, orientation, thermal bridging and ECBC(R)

We will make several plays now:

- **Play 16:** We begin by modelling our house in Kolkata (Latitude **22.57**, Longitude **88.36**) with the appropriate ZED-i weather file for present climate. This uses the same procedure as Section 1.1.

- **Play 17:** We look at the effect of more thermal bridges (arising from floor slabs penetrating the envelope). All details as Play 7 except thermal bridges have been set to **1302.50** W/K (×10 to reflect all floor slabs exposed to external at perimeter).

- **Play 18:** The house as modelled has its front façade facing North East. So, we now ask what happens if the house were instead facing South East (i.e., a clockwise rotation of 90°) to see the effect of orientation. In ZEBRA, orientation only affects solar gains through the windows. So, changing orientation for the house simply involves changing the angle that each window set faces in the **Glazing** sheet. The original house had **Window Set 1**, which represents the front façade, facing North East by setting orientation to **45°**. As this house does not have any side elevations, we need only worry about the rear elevation which is defined as **Window Set 3** with an orientation of South West and angle of **225°**. Why not use Window Set 2? Well, we decided to create another pair of windows: **Window Set 2** and **Window Set 4** in the 90° rotated orientations of **135°** and **225°**. Now, if we put the areas 84.0 m^2 and 82.7 m^2 in Window Sets 1 and 3 (setting areas for sets 2 and 4 to zero) we model the house in its original orientation. Swapping the area information, i.e. Sets 1 and 3 to zero area and Sets 2 and 4 to 84.0 m^2 and 82.7 m^2 gives us the answer for the rotated orientation! Clever!

Orientation is measured in angles from due North. This means, for example, that East is 90° and South East is 135°. The main impact of orientation on any building is the impact that varying levels of solar radiation have on heat coming into the building. At present, ZEBRA works on the basis that the window is the "weakest" part of this heat gain. In reality, walls will also transmit solar heat gain though to a lesser extent, and especially lesser when insulation is used. It is possible that later versions of ZEBRA also account for this effect, so it is important to keep up-to-date with ZEBRA's ongoing development by downloading more recent versions when they are released.

- **Play 19:** Kolkata is about 6 m above mean sea level. Let's travel North and East from here to Tezpur (Latitude **26.65**, Longitude **92.79**), which is nearly 100 m above mean sea level to see the effect of elevation (i.e. the **environmental lapse rate**), again using ZED-i weather data for present climate. All other details as Play 7.

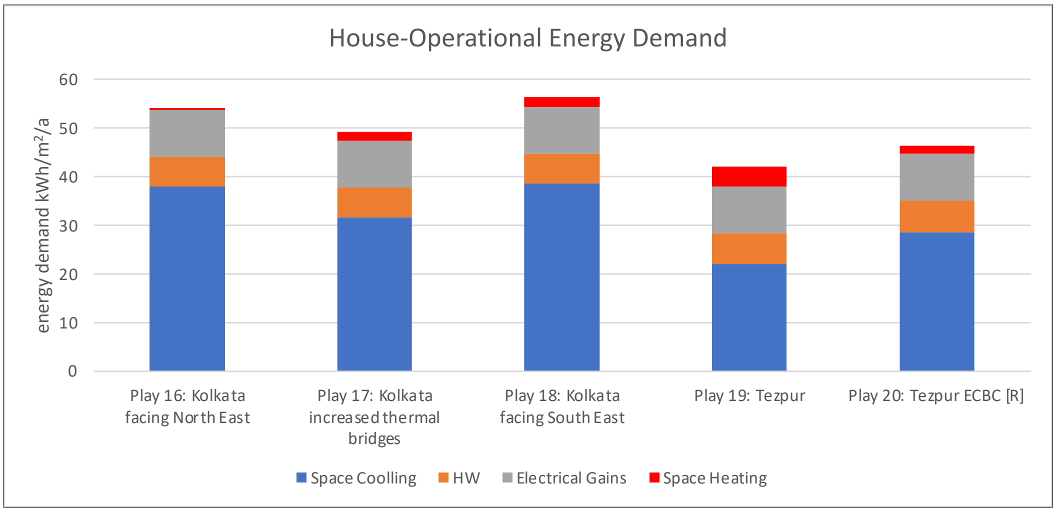
Environmental Lapse Rate: as elevation increases, temperature drops by around 0.6 °C for every 100 m increase in elevation.

ECBC-R
The proper name for ECBC-R is the Eco-Niwas Samhita. The website is detailed and it has its own tools. You can read more about the code here:

- **Play 20:** So far, we have discussed Passivhaus and GRIHA in this manual. What if we want to see if the house can meet ECBC (R) targets? This would imply:

  – U_{wall} = **0.75** W/m²K.
  – Party wall U_{party} = **0.0** W/m²K.
  – Ground Slab (not specified in ECBC(R) so remains unchanged as Uground = **1.57** W/m²K.
  – Roof U_{roof} = **1.2** W/m²K.
  – Thermal bridges (not specified in ECBC(R) so remains unchanged = **130.25** W/K
  – Our glazing is unchanged so U_{window} = **2.0** W/m²K and also unchanged is gwindow = **0.6**.
  – Orientation, unchanged = NE (**45°**).
  – Airtightness is presently not used as a metric in ECBC(R), however blower door tests are being increasingly used in India, so this is likely to evolve. For now, our infiltration value remains unchanged at ACH = **6.0**.
  – Incidental Gains (not specified in ECBC(R) so remains unchanged = **1.1** W/m²(TFA).
  – Hot Water, unchanged = **25 l**/person/day.

The results of Plays 16 – 20 are shown in the graph below.



Looking at the graph, there are several features of interest. Rather than reading it from left to right as you might expect, let us begin from the right-most pair of results relating to our house in Tezpur and its "ECBC upgraded" twin (Plays 10 and 11). We observe that when the envelope is upgraded to a tighter standard to meet ECBC regulations, heating demand decreases from 4.0 to 1.2 kWh/m²/a but the **cooling demand increases** from 21.0 to 27.2 kWh/m²/a. Why is this?

The answer is both subtle and interesting and to do with an interplay of the weather of this location and our chosen setpoint of 30 °C. Look at the graph of external weather and our cooling temperature setpoint. We see that the average outdoor air temperature is never above the cooling setpoint of 30 °C. This means that all of the cooling energy demand of 21.0 kWh/m²/a is due to solar and incidental heat gains, i.e. the heat that is *inside the building*. Hence, when we add insulation, less of this heat escapes to the outside and our cooling system has to work harder to deliver the same temperature of 30 °C. Remember from Part 1 that we have chosen this seemingly high setpoint to account for the fact that the air-conditioning may not always be turned on and not in all rooms as ZEBRA assumes.

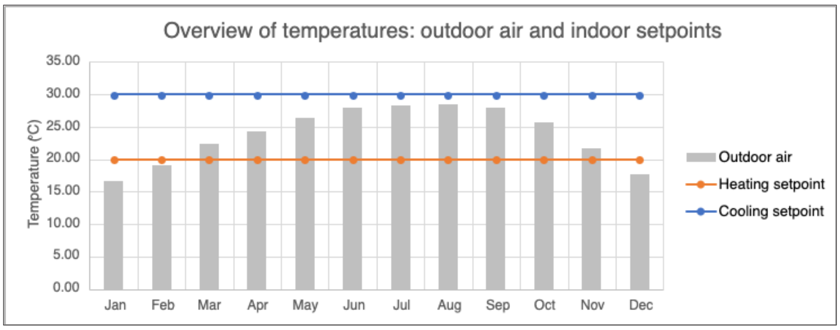


Figure 3: ZEBRA's plot of weather data and setpoints for Tezpur.

But we are playing, so there is no reason to see what happens at a different setpoint of, say, 25 °C. We can easily see that the months May to October all have average temperatures above 25 °C. Before we move to **Complexity Level 3** and change our setpoint, **it is worth thinking about what we expect to happen**. The solar and internal gains will remain the same, but the building's envelope which is in contact with the external air will now see an inward heat flow because the indoors are now cooler than the outdoors. In such a situation, increasing the envelope's insulation should restrict heat flow from outside to inside, reducing cooling energy demand. Simultaneously, the internal gains that caused an increase earlier continue to have an effect because not only is this heat no longer escaping outside, but the cooling system is also working harder to bring the indoor temperature down to 25 °C instead of 30 °C. Which do you think will "win"?

thinking about what we expect to happen
This is an important part of any modelling process. We must try and imagine what we expect to happen and then see to what extent our expectation was met. A more scientific term for such a process is called "hypothesis testing".

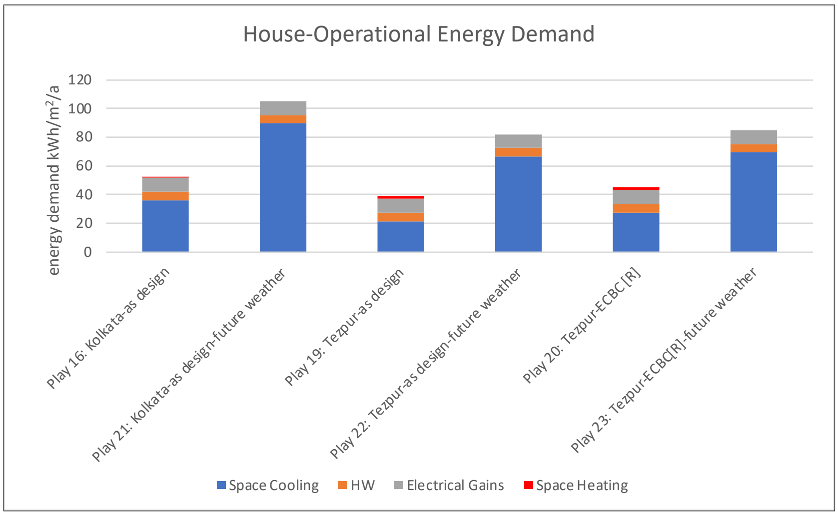
Changing our setpoint in the vanilla uninsulated and ECBC insulated cases to 25 °C (by changing to **Complexity Level 3** and filling in the setpoint box in the **Requirements** sheet) tells us that the ECBC version produces a net reduction in cooling energy demand. Without worrying too much about the size of the increase at 30 °C or the reduction at 25 °C, we simply note that this is an excellent demonstration that your assumptions matter and will produce different results in different weather or other conditions.

	Cooling energy demand [kWh/m²/a]		
	Tezpur vanilla	Tezpur ECBC	Change (ECBC - Vanilla)
30 °C	21.02	27.22	+6.20
25 °C	95.27	89.12	-6.15

Returning to our results graph, we can now understand the result of Play 8 more easily. The cooling energy demand decreases because at a setpoint of 30 °C the outdoor air is cooler and the building can lose the heat due to internal gains (incidental + solar) more effectively to the outside through the exposed concrete which is a good conductor of heat. Play 9's result is fairly straightforward. As we turn our building to the South East (i.e. compared to the North East orientation of Play 7), we get a slightly higher cooling energy demand, due to the fact that the glazing is admitting more solar heat gains. The heating energy demand is negligible and can be ignored in all except perhaps Tezpur (Play 10).

1.2.2 Plays 21-23 House in Kolkata & Tezpur under Future Weather

Once again, we examine what happens to each of the above plays in a future climate using the ZED-i weather files for 2060 – 2089. As expected, a future warmed climate will significantly increase energy demand, either doubling or tripling over the coming decades. This is summarised in:



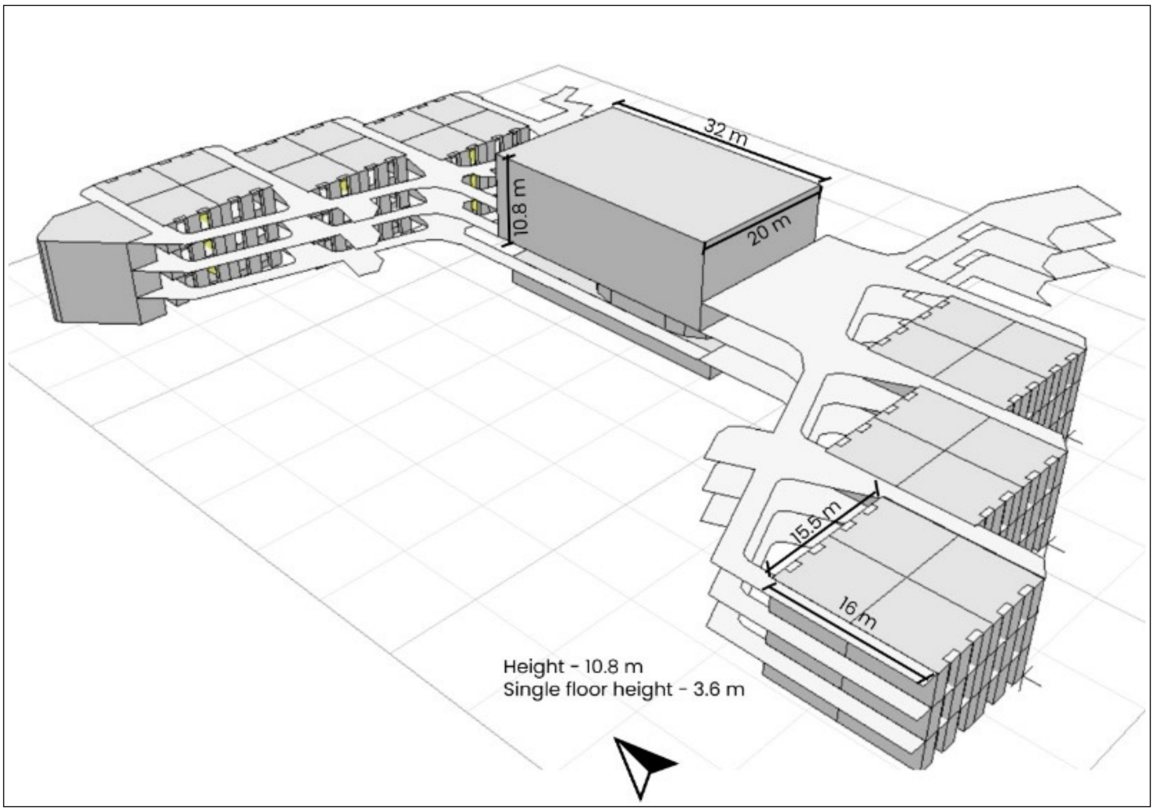
2.0 Section 2: Schools

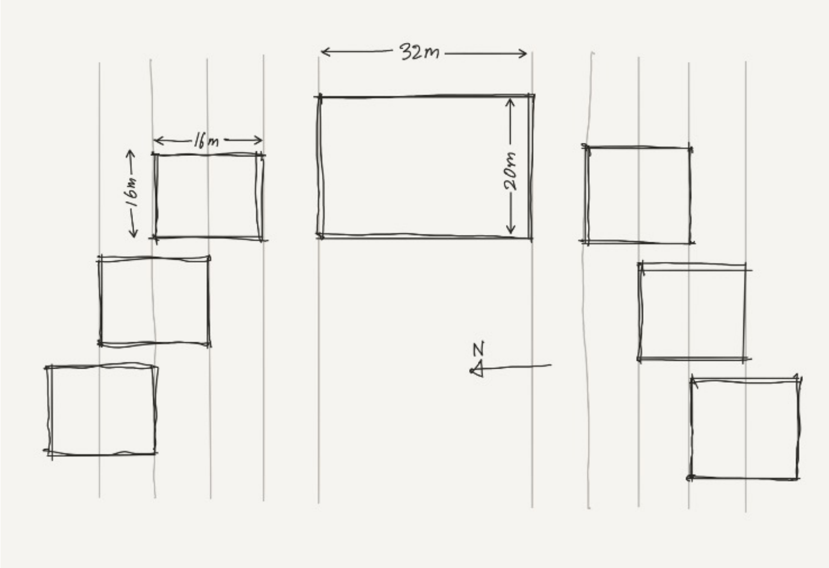
So far in the manual we have dealt exclusively with residential typologies, i.e., a flat and a house. Of course, the power of ZEBRA and ZED-i are not limited to residential buildings and so we now turn our gaze towards two types of non-residential buildings: schools and offices.

This section covers schools. Schools and homes have rather different occupancy both within a day (with schools often ending late afternoon) and in the year with extended closures during summer holidays. This change in occupancy influences the energy consumption of the building with much greater heat gains from people due to the large number of children and the varying, and usually greater, use of computers and lights.

2.1 State School

Our first school is a state (government) school located in Ashoknagar which is in Madhya Pradesh state (Latitude **24.58**, Longitude **77.73**). The school is spread over seven interconnected three-storey buildings in a splayed layout. The length of the central building faces due West, so there is risk of overheating. To mitigate this, the designers have inset the main structure by approximately 0.12 m from a terracotta exo-skin. This skin is designed to provide a level of permanent shading without significantly affecting daylight availability. This is modelled in ZEBRA by inserting an appropriate "permanent shading" factor of 0.46 (more than heavy shading), for each set of glazing this applies to (**Column K Row 83** onwards in the **Glazing** sheet). The other buildings are nearly square in plan with dimensions of 16 × 15.5 × 10.8 m. These house the classrooms and have a North / South aspect with some degree of southern shading offered by the access corridors for those on the northern side of the site. Classrooms are single aspect with two windows.





Schools

The fact that this school is located in Ashoknagar, once again demonstrates the power and utility of using ZED-i weather data. The nearest weather data in ZEBRA would be Guna, 43 km away, which is not too distant, but the nearest file from an independent source such as **ISHRAE**, the usual source for India, is Bhopal, about 200 km away. So, we are working, once again with the ZED-i weather file for Ashoknagar by inputting the latitude and longitude into ZED-i's website which will return data within 25 km of Ashoknagar. The key inputs for this school are:

ISHRAE is the The Indian Society of Heating, Refrigerating and Air Conditioning Engineers. You can find out more about their weather files here:

- The areas A_{ground} = A_{roof} = main building 32 x 20 + six classroom buildings (16 x 15.5) x 6 = 2,128 m^2.

- We assume that the façade glazing ratio is 20%. So, we can get the wall area by multiplying the nominal wall area (i.e. width × height) by **0.8**. Since not all facades are glazed, we split this as follows (asterisks have been used here instead of × to be consistent with Excel's syntax for multiplication):

Classroom buildings N/S	Glazed	(15.5 * 10.8) * 12 * **0.8**	= 1,607.64 m^2.
Classroom buildings E/W		(16m * 10.8) * 12	= 2,073.60 m^2.
Main building E/W	Glazed	(32 * 2) *14.4 * **0.8**	= 737.28 m^2.
Main building N/S		(20 * 2) * 14.4	= 576 m^2.
(Sum) A_{wall}			= **4,993.92** m^2.

We now enter **4,993.92** into **Cell K6** in sheet **Walls+Doors**.

- We simply reverse this process by now multiplying by **0.2** to obtain the area of the glazing "hole" in the different orientations:

Classroom buildings N/S	Glazed	(15.5 * 10.8) * 12 * **0.2**	= 401.76 m^2.
Main building E/W	Glazed	(32 * 2) *14.4 * **0.2**	= 184.32 m^2.

To save ourselves the trouble of doing ZEBRA's slightly tedious glazing **calculations**, we head to the Calculators sheet. As the area above will be split between opposing orientations (N/S or E/W), we only need half the area per orientation. So, we enter **200.88** into **Cell AC24** of **Calculators** for the N/S glazing. Then following the guidance in the "Defining windows in ZEBRA" document on ZEBRA's website, we copy **Cells AD24:AK24** and use **Paste Special > Values** into **Cell G:83** of the Glazing sheet for North. Repeat for the other orientations.

- The wall is made from **15 mm external plaster + 200 mm Light Weight Concrete Block (2 holes) + 12 mm Plaster** (adapted from SP-41 (1987)) with U_{wall} = 2.0 W/m^2K (see Part 3 for U-value data).

- Using the technique we used for the house earlier, we use ZEBRA's calculator to find that U_{ground} = **0.34** W/m^2K.

- The school has roof consisting of 80 mm **Brick Bat Coba + 30mm PCC + 100 mm EPS insulation + 150 mm RCC Slab + 10 mm internal plaster** (from ECBC Design Guideline) with U_{roof} = 0.4 W/m^2K.

- Thermal bridges are **1,849.98** W/K.

- Windows are **single glazed** so have a single-pane U_{window} = **5.0** W/m^2K and g_{window} = **0.85**.

- Infiltration remains leaky at ACH = **6.0**.

- Schools are in operation for fewer hours than homes and offices, so ZEBRA suggests lower incidental gains of **0.71** W/m²(TFA) compared to the 1.1 W/m²(TFA) we used for homes.

- ZEBRA does not give guidance on hot water demand for schools. The suggested value for homes is 25 l/person/day and that for offices is 2.5 l/person/day. Given that schools are likely to require slightly higher requirements from an office if shower rooms or catering is present, we have chosen to use a slightly higher value of 3 l/person/day as our input for schools. With an assumed occupancy of 3,264, this gets us **9,792** l/day.

Insert these data into a new ZEBRA workbook.

2.1.1 Plays 15-21: State School in different locations, improved walls, natural ventilation and net-zero energy

Here are the plays for this building:

- **Play 15:** this is the school as built in Ashoknagar.

- **Play 16:** We magic the building to Rourkela, Odisha (Latitude **22.26**, Longitude **84.85**). Rourkela despite being an important town in Odisha is, at present, served only by an ISHRAE weather file in Bhubaneswar about 300 km away as the crow flies and on the other side of the Eastern Ghats! ZEBRA's in-built data betters this by offering data from Jharsuguda, which is 91 km away. But ZED-i's data are within 25 km. All other design elements remain unchanged.

- **Play 17:** Once again, we see what improving U-values does, this time for our school in Rourkela. The building as designed is specified with 15 mm external plaster + 200 mm Light Weight Concrete Block (2 holes) + 12 mm internal plaster (adapted from SP-41 (1987)) walls with a U-value of 2.0 W/m²K. We ask what if the school designers had instead chosen **15 mm external plaster + 115 mm brick + 50 mm air cavity + 115 mm brick + 12 mm internal plaster** (adapted from SP-41 (1987)), a locally available material with a U-value of 1.5 W/m²K instead?

- **Play 18:** As it is likely that a state school may either not have access to air-conditioning or, if it did, is perhaps in a location with intermittent electricity supply. In such situations, it may be that the building has to rely a lot more on natural cross ventilation to provide comfort for its occupants. To test this using the design in Play 16 in Rourkela we alter the air changes for **ventilation from 0.6 to 4.0 in Cell G70** in the **Space Conditioning** sheet:

	D	E	F	G	H	I
61		-9 1 2 3 4 5	6	7		8
62						Window s
63						
64						
65		**Space cooling demand**				
66		**Parameters related to space cooling demand**	**Baseline value**	**Overwrite**	**Value**	**Unit**
67		Metabolic gains	5.76		5.76	W/m²(TFA)
68		Electrical gains (e.g. lighting, computers etc.)	0.71		0.71	W/m²(TFA)
69		Heat Recovery (HR)	0.00		0.00	-
70		Airchanges due to ventilation	0.60	4.00	4.00	ach
71		Sum of fan specific power	0.00		0.00	Wh/m³
72		Non-permanent shading for window set 1			0.00	-

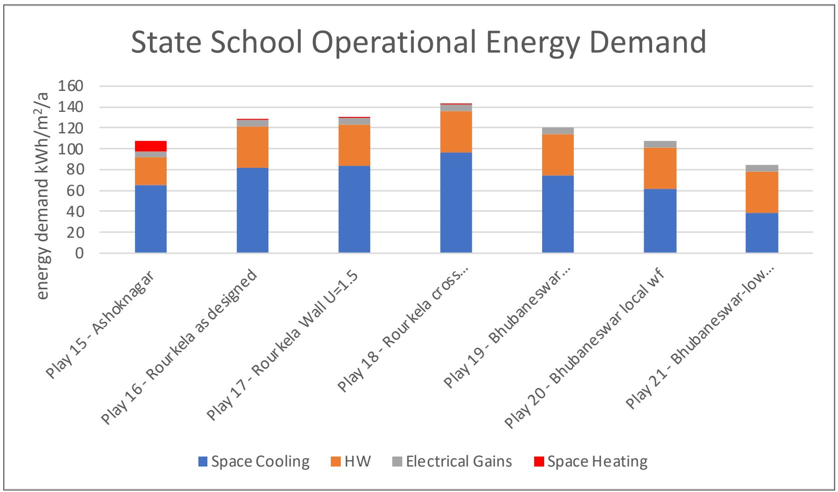
Ventilation from 0.6 to 4.0
Note that this now means the total air changes for this building are now 6.0 (due to infiltration) + 4.0 (due to natural ventilation) = 10.0 air changes. This is approximately a 50% increase compared to the original building which had a total of 6.0 + 0.6 = 6.6 air changes.

Schools

- **Play 19:** Like our Cuddalore to Chennai example earlier, we will move the building as it existed in Play 15 to Bhubaneswar (Latitude 20.29, Longitude 85.82) to see what effect a non-local weather file does to ZEBRA's prediction for our school. Entering these coordinates into ZEBRA's built in weather file gives us weather from "nearby" Balasore, 179 km away.

- **Play 20:** Same as Play 19 but using a local weather file for Bhubaneswar from ZED-i and the weather widget (section 1.1.1).

- **Play 21:** Finally, we use Play 20 with the local weather file to model a low-energy design (U_{wall} = 1.0 W/m^{2}K, U_{roof} = 0.2 W/m^{2}K, U_{ground} = 0.2 W/m^{2}K, U_{glass} = 2.0 W/m^{2}K), air changes for ventilation from 0.6 to 4.0 to ask if a zero-energy building is possible. There are many definitions of "zero-energy" and here we use a simple one of "net-zero operational energy demand at site". That is, minimising demand to a level (through low U-values) that all residual needs can be met from on-site generation. Comparison with our earlier cases will also show to what extent the demand reduction actually helps in getting to net zero.



From these results we can make several observations:

a. Ashoknagar (Play 15) is the only climate with a small predicted heating energy demand. Cooling energy demand, like all the other plays here is the most dominant requirement. In reality, this school has no air-conditioning installed so the cooling energy demand is notional and indicative of the magnitude of energy that would be demanded in a future where air-conditioning becomes more ubiquitous.

b. The difference between Play 16 and Play 17 is small. Play 17 with more insulated walls has only a marginal effect, actually increasing the cooling load by 1.3 kWh/m^2/a. See the results from Plays 16 – 20 for a possible explanation.

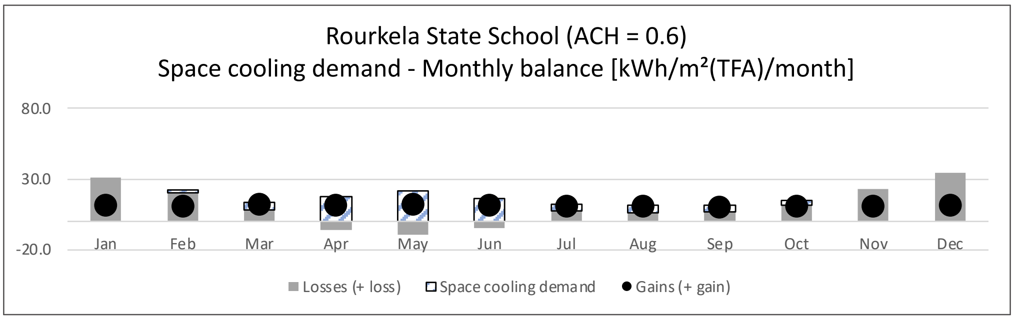
c. In Play 18 with increased ventilation, the cooling load goes up significantly. This is because the outdoor air has a **temperature that is above the cooling set point** in many summer months except April – June, the hottest months of the year requiring space cooling. It is instructive to compare the month-by-month effect of this increased ventilation in

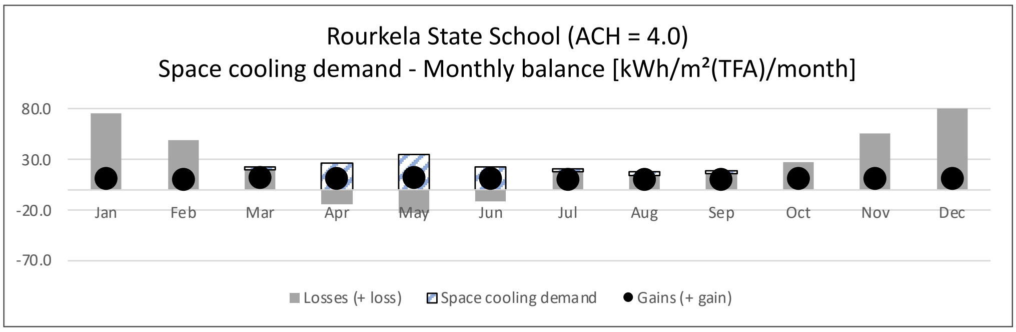
temperature that is above the cooling set point
Compare this with our discussion of results from Plays 7 – 11.

Schools

the "Space Cooling Demand – monthly balance" graphs in the **Space Conditioning** sheet (the graph is located near **Cell H88**). In these graphs, the grey bars relate to heat lost (+) or gained (-) due to the envelope being in contact with the outside air whereas the black dots represent heat gained (+) or lost (-) from solar and internal heat. The results from both sheets are shown here, with the only modification being that the y-axis for both as been set to a max of 60 to enhance **visual comparability**. We can now see that more heat is lost in the cooler months when ACH = 4.0 and *more heat is gained* (grey bars below zero) in the warm months. The extra heat loss does not end up increasing heating demand because it is not enough to trigger the heating set point. In the summer, however, the extra heat gained from the outdoors was already above the cooling set point and so we see a dramatic increase in demand. It is really important to remember that when ZEBRA indicates "demand" it simply indicates a potential need to meet it. If our building is purely naturally ventilated, then obviously no cooling is being supplied.

Visual comparability
Graphs that are meant to be looked at side by side should always have the same "extents". This makes them easier to read visually.





d. Plays 19 & 20 again emphasise the importance of using local weather data with a measurable difference.

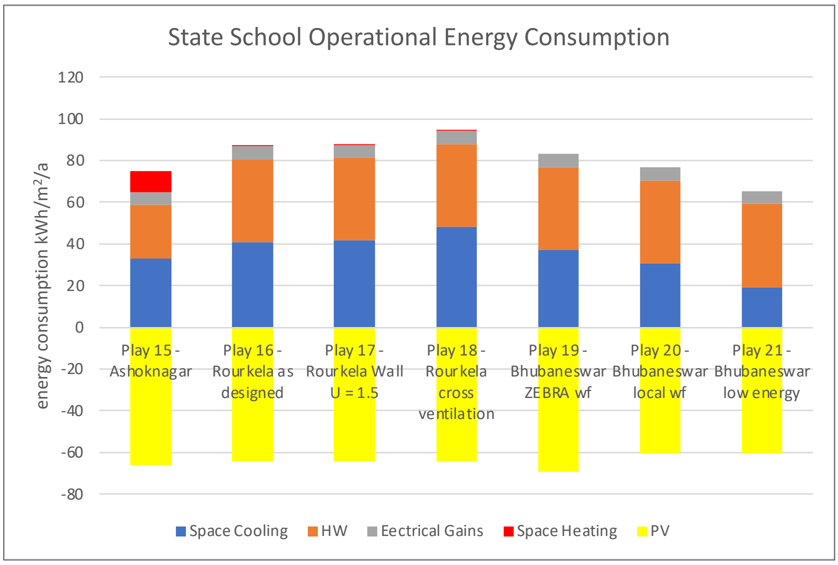
e. Play 21 uses the local weather file from ZED-i and then improves the envelope and increases ventilation to investigate how low our energy demand can get. We find that cooling energy demand drops to 58.3 kWh/m^2/a. So, we did not get to zero, and the hot water demand and plug-load requirement remains. Before we proceed, let us briefly think about the 4.0 air changes of natural ventilation.
When our building was in Rourkela, we saw that increasing natural ventilation seemed to create greater demand for cooling. However, in Bhubaneswar, the uninsulated building shows a space cooling energy demand of 61.5 kWh/m^2/a when natural ventilation is at 0.6 air changes. It drops to 38.7 kWh/m^2/a when the air changes are set to 4.0. So, unlike in Rourkela, increasing natural ventilation works to lower cooling demand in Bhubaneswar. We can check this by resetting the air changes in the low-energy version of this building back to the default of 0.6 by deleting the

4.0 in **Cell G70** in sheet **Space conditioning**. If you do this, you will see that the cooling energy demand increases to 58.3 kWh/m²/a compared to 38.7 kWh/m²/a earlier. **This demonstrates the importance of using this type of modelling with local weather and not relying on intuition or falling prey to our biases from previous experience.**

2.1.2 Well, can we get to net-zero or not?

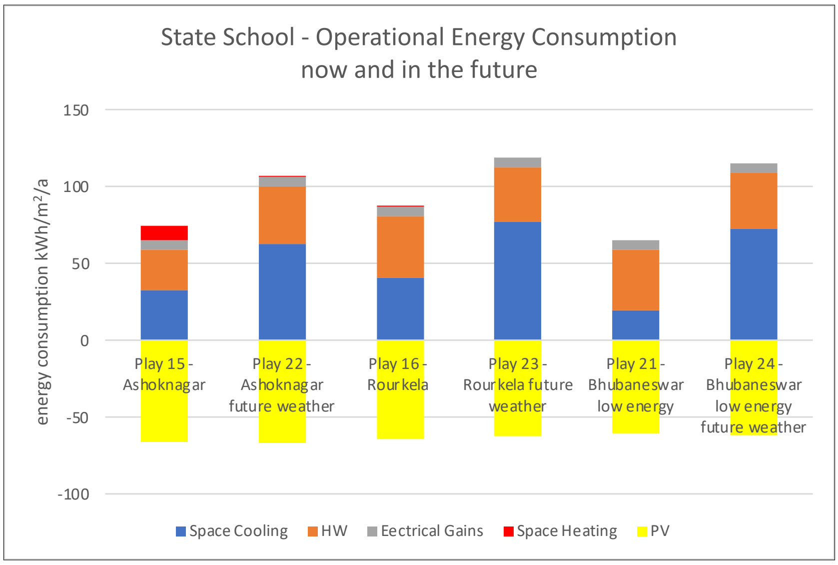
Having spent the effort to reduce demand, it now makes sense to see if any on-site needs can be met with renewables. This can be seen in the graph below. We find that the PV generation potential varies between these locations. The one to look out for is Play 19 where we find that the use of ZEBRA's built-in weather file might have given us a more optimistic estimate of generation than is the case when using the more local ZED-i weather data.

Warning! This graph looks like the others but the y-axis now reads "energy consumption" and not "energy demand". This is because the PV generation *includes* the efficiency of the PV system and any conversion losses, so we can only make a fair comparison by including the efficiency of the cooling and heating systems. For simplicity, we have assumed a cooling system efficiency (i.e. CoP) of 2 throughout and a heating efficiency of 1. We find that PV can offset quite a lot of our requirements and all of our needs when using the local weather file and the low-energy version of our building in Bhubaneswar. Some of the consumption shown, e.g. hot water, may never be needed suggesting significant potential for many of these buildings to be self-sustaining.



2.1.3 Plays 22-24: State School is it low-energy in a future climate?

While the last result seems rather satisfying, we need to consider the impact of future weather to check whether our buildings will continue to be low-energy in a changed climate. The answer, unfortunately, seems to be “no”, assuming hot water is needed. If we continue to supply cooling with a CoP of 2, even our low-energy building from Play 21 which seemed self-sustaining will find it very difficult to keep cool in the future and will most likely not be able to meet its energy requirements from on-site renewables as the deficit is 53.2 kWh/m^2/a. However, an improvement in air-conditioning CoP to **3.5** (**Cell L8** on the **Systems** sheet) reduces this deficit to 22.3 kWh/m^2/a and, additionally, an improvement in PV panel efficiency from 15% to **25%** (**Cell F41** on the **Systems** sheet) would once again make us net-zero. Both these improvements are well within the realm of possibility in today’s market. Of course, none of these improvements are needed if hot water demand is reduced or removed.



2.2 Private School

For our privately run school, we turn to Greater Noida to the East of Delhi (latitude **28.56**, longitude **77.45**). Note that this won’t be the same weather file as central or other parts of Delhi. For example, if the school were in Najafgarh, about 60 km away on the Western side of Delhi, then ZED-i will produce a different weather file because the data change every 25 km.

The school has an adventurous shape, but for now we will look at the main block rather than the whole complex. This block has a total occupancy expectation of 930 students and staff. Other key things to note are:

- The wall is made from **15 mm PL + 200 mm Light Weight Concrete Block (2 holes) + 12 mm PL** with U_{wall} = **2.0** W/m^{2}K (see Part 3 for U-value data).

- Unlike the state school which had Uground = **0.4** W/m^{2}K, our private school has a U_{ground} = **1.0** W/m^{2}K. This will increase heat transfer between the slab and the ground underneath.

Schools

- The school has an **80 mm Brick Bat Coba + 30 mm Cement Mortar + 75 mm EPS + 150 mm RCC Slab + 20 mm PL** roof with U_{roof} = **0.46** W/m²K.

- The total thermal bridges for this school are less than a third of the state school at **705.68** W/K.

- Unlike the state school which used ‡, this private school has opted for ‡ resulting in a lower $U_{glazing}$ of **2.0** W/m²K with $g_{glazing}$ = **0.6**.

- We continue to assume poor levels of airtightness with infiltration set to ACH = **6.0**.

- Incidental Gains are set to the ZEBRA recommended **0.71** W/m²(TFA).

- Hot water consumption is taken as **3** l/person/day (930 occupants).

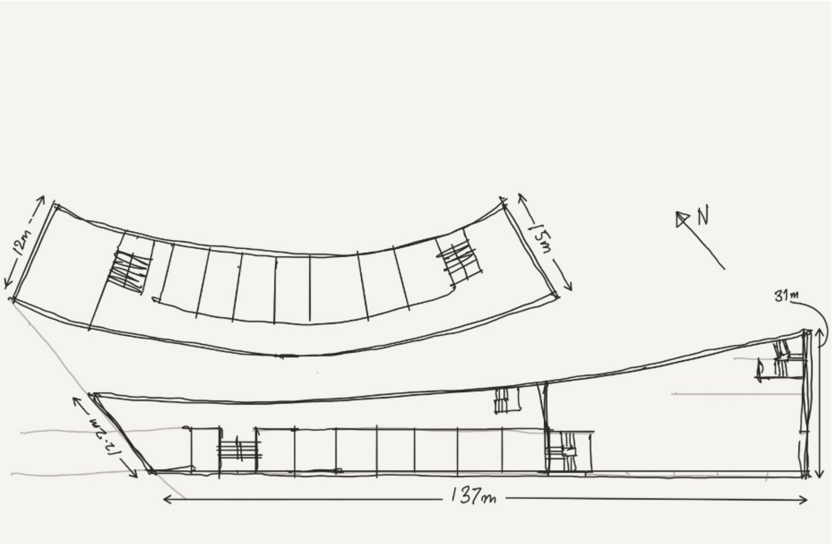


Figure x; An early stage sketch of the private school and the school under construction in March 2023.

2.2.1 Plays 25-32: Private School in Greater Noida, ECBC, larger windows, zero lifetime-carbon

As before, we undertake a series of plays as follows:

- **Play 25:** the private school as designed.

- **Play 26:** What happens if we keep the same building geometry but built to ECBC standard? This implies the following inputs:

  - We now build the wall using **15 mm external plaster + 50 mm foam concrete + 150 mm concrete block + 12 mm Plaster** (adapted from SP-41 (1987)) to get a lower U_{wall} = 1.0 W/m²K.

  - Ground Slab - no change

  - We now build the roof using **100 mm Brick Bat Coba + 30 mm PCC + 150 mm RCC Slab + 100 mm Bonded Mineral Wool + 10 mm PL** (adapted from ECBC Design Guideline) to get a lower U_{roof} = **0.33** W/m²K.

  - Even though we are improving aspects of the envelope, we expect the same level of thermal bridges to remain as it is usually difficult to significantly reduce them using standard construction techniques. Hence, no change.

  - The ECBC standard suggests $U_{glazing}$ = **2.5** W/m²K, $g_{glazing}$ = **0.6**. The base case had already bettered this with a $U_{glazing}$ = 2.0 W/m²K. It is usual, however, that buildings are usually specified to the prescribed minimum standard as there is often seen to be little incentive in bettering this. Hence, we choose to use the minimum standard required for standard compliance.

  - As with thermal bridging, we keep infiltration to the same standard (ACH = **6.0**) as it is difficult to control this using standard construction techniques.

  - Incidental Gains and Hot Water don’t change.

- **Play 27:** We make a relatively simple change to the façade glazing ratio from 22% as currently designed to roughly double at 40%, to see what effect this has on performance. We do this by increasing the hole area in the appropriate cells of **Column F** in the **Glazing** Sheet (remembering to reduce wall area by the same amount).

- **Plays 28 and 29:** We examine what it would take to make this a zero-carbon building over its lifetime. Here, by “zero” carbon we mean only the carbon emissions resulting from the operation of the building. We are not only interested in whether the goal can be met but also whether it is sustainable into the future. We imagine that the following could help reduce the cooling and heating demand, changed from Play 25 (assuming these are the ones most controllable at this stage):

  - We decide to build the roof using **80 mm Brick Bat Coba + 30mm PCC + 100 mm EPS + 150 mm RCC Slab + 10 mm Plaster** (adapted from ECBC Design Guideline) to deliver U_{roof} = 0.4 W/m²K.

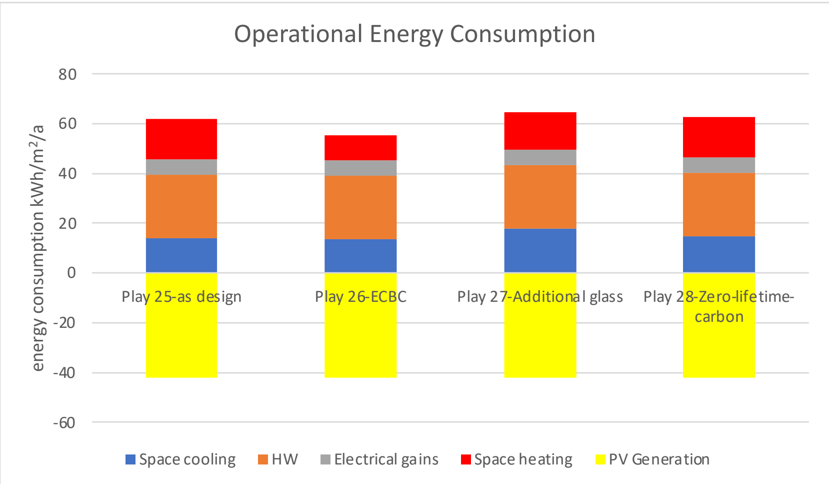
- To control heat gains from the windows, we use UPVC-framed double-glazed windows with a mid-pane $U_{glazing}$ = 1.0 W/m^2K. However, remembering that reducing heat gains from the outdoors through contact with the external air is not enough, we also reduce $g_{glazing}$ from 0.6 to 0.45. One thing to remember when reducing g-values is that this can also result in a reduction in the visible light transmittance (VLT) – that is, light in the visible spectrum which we need as humans for visual comfort. ZEBRA does not account for this at present so it will need separate consideration, possibly through consultation with an expert. In addition to reducing g-values, we decide to go the whole hog and add on temporary shading for cooling through a roller-blind system by setting **0.8** in the relevant cells in **Column R** in the **Glazing** sheet.

- Air changes for ventilation from 0.6 to **4.0**, as we did in Plays 18 and 21, earlier.

- A key input we have not discussed so far in this manual is the **carbon intensity of electricity generation**. India's per capita emissions are very low due to the large population base, but carbon intensity of generation is the third largest in the world due to the use of inefficient generation and low-quality coal. At present, it is 0.725 kgCO_2/kWh/a compared to a global average of 0.510 kgCO_2/kWh/a according to the **International Energy Agency**. Hence, we enter the value **0.725** into **Cells F61:F62** in the **Systems** sheet. However, as India decarbonises its electricity supply through, for example, increased solar and wind generation which already constitute 20% of all generation, we can expect this figure to drop significantly in the future. As ZED-i's future weather files are for the 2060 – 2089 period, we feel confident in assuming an inversion of the current 20:80 renewables to fossil fuel mix, to 80:20 in favour of renewables by this date. This suggests a carbon intensity in the future of about 0.150 kgCO_2/kWh/a – still higher than the ZEBRA default of 0.136 kgCO_2/kWh/a, and hence not unrealistic.

Carbon intensity of electricity generation
This is the amount of Carbon emissions released to produce a single unit (i.e. kWh) of electricity. In ZEBRA it is expressed in kilograms CO_2-equivalent per kWh per annum (kgCO_2e/kWh/a). In some sources, such as the IEA report we cite, it is given in gCO_2e/kWh/a.

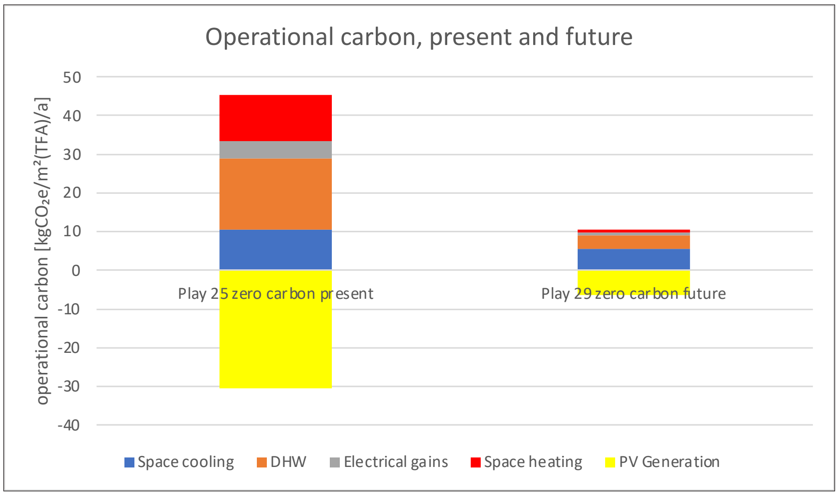
See Figure 1.22 in IEA (2021), India Energy Outlook 2021, IEA, Paris https://www.iea.org/reports/india-energy-outlook-2021, License: CC BY 4.0



After reminding ourselves that we are once again looking at consumption (i.e. after accounting for air-conditioning efficiency) and not demand, our first observation is that the most dominant load is for hot water – so the assumption of 3 l/person/day for 930 occupants is critical and could be looked at more carefully. Next, the ECBC version of the school results in marginally lower (0.3 kWh/m²/a) cooling energy consumption than the building as designed. This difference is small enough to be ignored. However, the impact on heating energy consumption is more pronounced with a reduction of 6.1 kWh/m²/a.

Taking the PV generation into account, the ECBC case gets us a fairly low-energy building with only 13.4 kWh/m²/a remaining to be drawn from the electricity grid compared to 19.8 kWh/m²/a as designed. The addition of glass to the existing design immediately puts any chance of low or zero energy out of reach as both heating and cooling energy consumption increase, needing a total of 22.6 kWh/m²/a to be drawn from the grid.

Turning to our lifetime zero carbon question, we find that at present (Play 28), our building is far from being net zero carbon given that emissions net of PV generation are 14.7 kgCO_2e/m²/a (you can read this in **Cell F53** of the **Summary** sheet). While this drops significantly to 4.0 kgCO_2e/m²/a in the future (Play 32), it is quite likely this is due to the changing carbon intensity of generation which we assumed would fall by 80% in the 2070s compared to today. We can verify this by temporarily setting the carbon intensity in the future weather model to 0.725 kgCO_2/kWh/a (**Cells F61:F62** in the **Systems** sheet), thus enabling a direct comparison with our starting case with the only change being the weather. We find that net operational carbon would actually go up to 19.4 kgCO_2e/m²/a, i.e. a rise of 19.4 – 14.7 = 4.7 kgCO_2e/m²/a. So, the decarbonisation of the grid is so substantial that it significantly reverses the increase in emissions caused by warming weather.



Schools

3.0 Section 3: Offices

In modelling terms, schools and offices differ from one another by the type of occupants, the density of this occupation and the length of use both in a single day and across the year. In this section, we look at a simple low-rise office common in many Indian cities as well as a highly glazed, and so-called “premium”, high-rise office.

3.1 Low-rise office

Our low-rise office is located in Karnal, Haryana (Latitude **29.69**, Longitude **76.99**). The office is three-storeyed with a deep plan of 40 m and a width of 30 m. Such deep plan buildings usually mandate significant artificial lighting and ventilation to functionalise the central part of the building. To mitigate this, several full-height punctures have been introduced as the sketch plan indicates. Considerable shading on the southern façade has been introduced partly using an extended overhang on the ground floor and the rest through a series of tilted PV panels. The key things to note for this office are:

- The wall is made from **15 mm Plaster + 250 mm Cement Stabilized Brick + 50 mm Internal Bonded Mineral Wool + 10 mm Plaster** with U_{wall} = **0.50** W/m^{2}K (see Part 3 for U-value data).

- Once again, we have slab on ground and, using the technique illustrated earlier, we get U_{ground} = **0.42** W/m^{2}K.

- The office has an **80 mm Brick Bat Coba + 30mm PCC + 100 mm EPS + 150 mm RCC Slab + 10 mm Plaster** roof with U_{roof} = **0.42** W/m^{2}K.

- ZEBRA’s calculators sheet estimates thermal bridges at **982.00** W/K.

- The office has opted for **double-glazing** resulting in a $U_{glazing}$ of **2.5** W/m^{2}K with $g_{glazing}$ = 0.6.

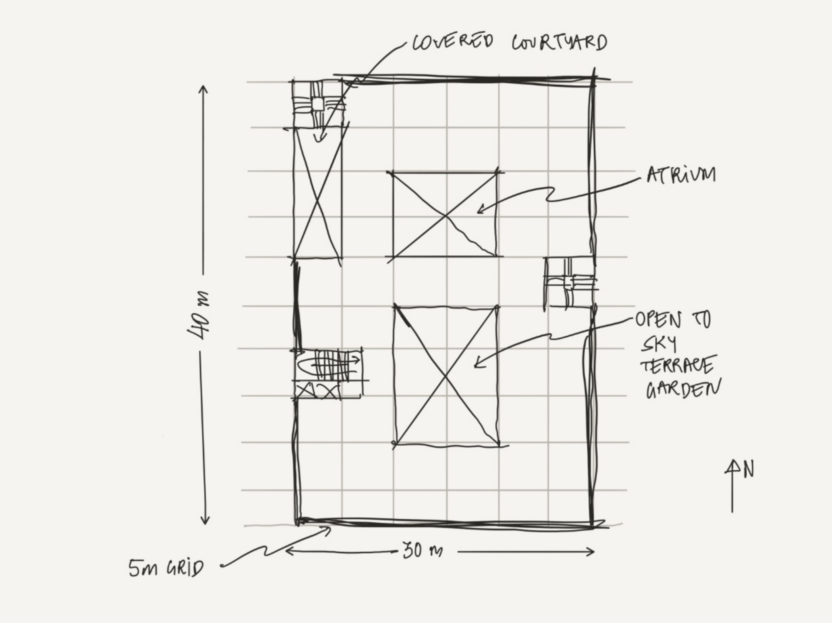
- The building has considerable shading on the south and ZEBRA recommends a **Permanent Shading** value of 0.7 for heavy shading (**Cell K119** on the **Glazing** sheet). The other facades do not have any shading on the façade though the 3D renders suggest there may be some trees shading the ground floor. To keep things simple for now and because we wish to model obstructions later, we set all other facades to the nominal value of **0.23** permanent shading.

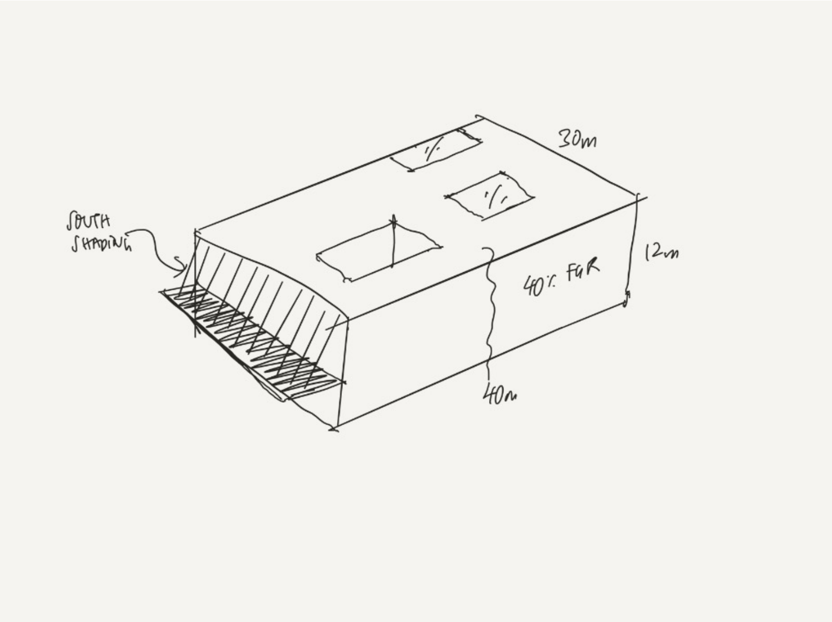
- We continue to assume poor levels of airtightness with infiltration set to ACH = **6.0**.

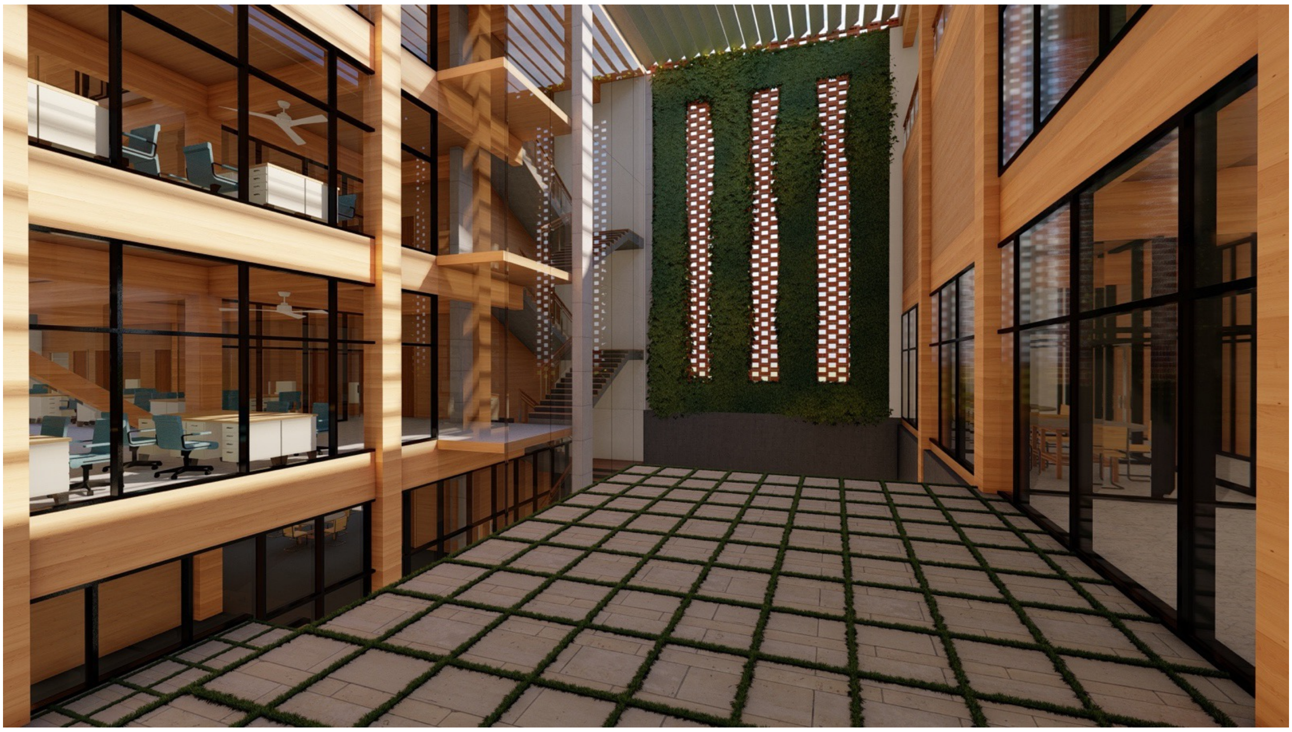
- Incidental Gains are set to the ZEBRA recommended **1.4** W/m^2(TFA) for offices.

- Hot water consumption is taken at the ZEBRA recommended **2.5** l/person/day for 270 occupants.

Offices


COVERED COURTYARD
ATRIUM
OPEN TO SKY TERRACE GARDEN
40 m
30 m
5m GRID
N


30m
SOUTH SHADING
12m
40% FAR
40m



9.7.1 Plays 29-31: Low Rise Office - the effect of permanent shading.

One of the most common things that can affect such low-rise buildings is the presence or absence of shading in the form of trees or buildings. Indeed, it is possible that a building starts out in a fairly open setting and shading occurs around it over time as the area grows and develops. Hence, we consider the effect of two alternative shading scenarios: one surrounded only by trees and other buildings of a similar height to our case study versus another surrounded by much taller buildings.

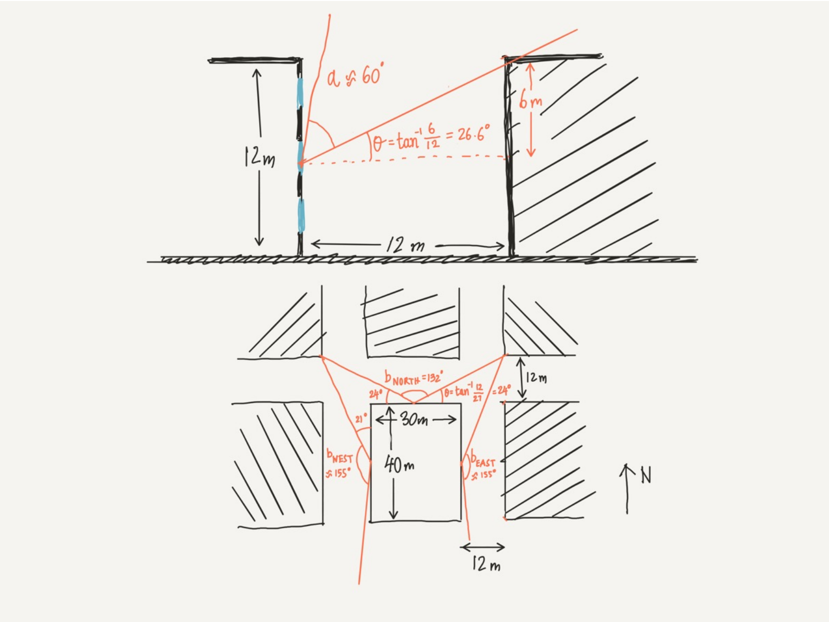
1. **Play 29:** The low-rise building as designed.

2. **Play 30:** To cater for a building being shaded by obstructions of a similar height to itself, such as trees or other buildings, we can change the permanent shading for all window sets from the original input of 0.23 to **0.5**, which is ZEBRA's suggested value for average shading.

76								
77								
78	**Window set 1 - Window breakdown**		See calculator for properties ★ General		★ Simpler version		★ See shading calculator	
79	Window set name (optional)	north	-					
80	Orientation	0.00	°					
81	Units:	m²	m²	m²	m	m	-	
82	**Window name (optional)**	**Hole area**	**Glazing area**	**Frame area**	**Perimeter**	**Length glass-{frame/divider}**	**Permanent shading**	**Tempor**
83	north	92.90	69.60	23.30	50.20	20.00	0.50	
84		0.00						
85		0.00						
86		0.00						
87		0.00						
88		0.00						
89		0.00						
90		0.00						
91		0.00						
92		0.00						
93	**Equivalent window set (aggregated):**	**92.90**	**69.60**	**23.30**	**50.20**	**20.00**	**0.23**	
94								

Roof | Thermal bridges | Glazing | Air | Incidental gains | Space conditioning | Systems | Embodied carbon | Summary | Calculators

To check how good this assumption is, we can perform an assessment using ZEBRA's **Calculator** sheet and the shading calculator starting at **Cell N7**. Let us assume that all the surrounding buildings are the same height of 12 m and also set back from our building by 12m. Using the diagram below, and inputting the angles a (**60°**) and **b** (East = West = **155°** and North = **132°**) we get shading values of East = West = 0.43 and North = 0.51. So, an assumption of 0.5 does not seem unreasonable.

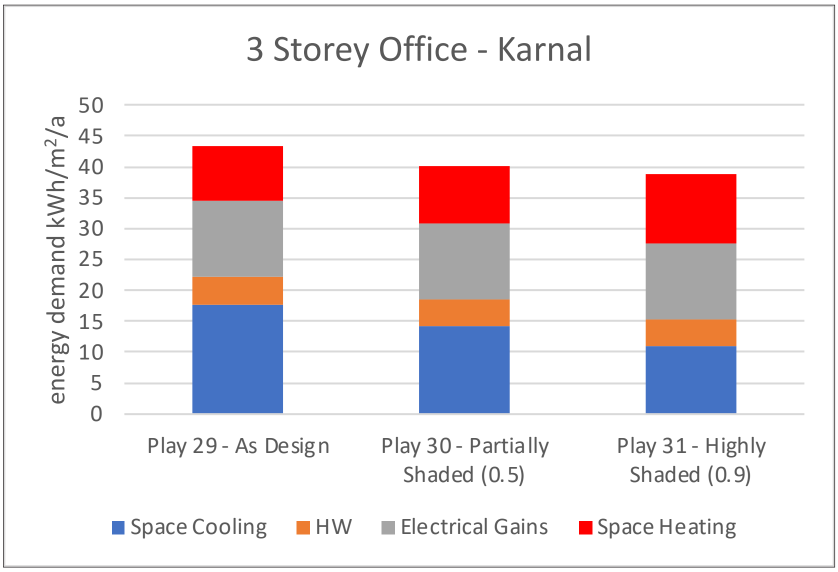


3. **Play 31:** To reflect almost complete shading from adjacent tall buildings, we repeat the above but change permanent shading from 0.5 to 0.9 – to reflect more than average shading:

131								
132	**Window set 4 - Window breakdown**		★ See calculator for properties		★ See simpler calculator		★ See shading calculator	
133	Window set name (optional)	west -						
134	Orientation	270.00 °						
135	Units:	m²	m²	m²	m	m		
136	**Window name (optional)**	**Hole area**	**Glazing area**	**Frame area**	**Perimeter**	**Length glass-{frame/divider}**	**Permanent shading**	**Temporary sh**
137	west	21.70	16.30	5.40	24.20	6.00	0.90	
138		0.00						
139		0.00						
140		0.00						
141		0.00						
142		0.00						
143		0.00						

Offices

We are now in a position to see what impact these changes to adjacent shading have had on energy demand:



As you might expect, shading has a significant impact on cooling energy demand as it reduces solar gain. A moderate amount of shading (0.5 in ZEBRA) brings our cooling energy demand down from 17.7 kWh/m²/a to 14.2 kWh/m²/a, a reduction of 20%. This goes down even further to 10.9 kWh/m²/a (38%) with significant quantities of shading (0.9 in ZEBRA). However, you will have no doubt noticed that the drop in cooling is associated with an increase in heating demand. Karnal has fairly cool winters with monthly mean temperatures between 12 and 15 °C. A more shaded site therefore suggests that improving fabric U-values could help protect against an increased space heating demand while also ensuring low cooling energy demand in the hot summer months.

As shown earlier, ZEBRA allows you to alter the shading for each façade separately. So, by knowing the current surroundings and estimating the future situation for each façade will enable you to get to an even better estimate of how your building will perform, now and in the future. In fact, most modellers often fail to properly account for site shading in their work resulting in over-sizing of systems, increasing cost and carbon. A mistake easily avoided and well-worth the small effort.

9.7.2 Plays 32-35: Low Rise Office – AC, GSHP, temporary shading, PV and the future.

So far, all our cooling energy demand has been met by the most common means of delivering cooling, the humble air-conditioning (AC) system. While ACs can have a range of efficiencies, CoPs normally range between 2 to 2.5. In Japan and Korea, CoPs of 4 have been in place for a few years so it is conceivable such efficiencies will become commonplace in India too. However, there are other ways to deliver cooling and a ground-source heat pump (GSHP) can usually offer a CoP of 3.5 without difficulty.

1. **Play 32:** We want to look at the energy consumption (remember this is different from demand!) of our building as designed with an air-conditioning system of CoP 2.0 versus a low-energy cooling system with a CoP of 3.5. As heat pumps can be reversible, the same system can supply both cooling and heating, often not the case with air-conditioning.

   We change our cooling and heating system rather simply by altering the CoP on **Cells L8:L9** of the **Systems** sheet as follows:

Main energy				
Units:	kWh/m²(TFA)/a		-	-
System	Energy demand		Efficiency	Fuel
Ventilation		0.00	1.00	Electricity
Space heating		8.89	3.50	Electricity
Space cooling		32.20	3.50	Electricity
DHW		4.38	1.00	Electricity
Plug loads		12.26	1.00	Electricity
PV Generation		-14.35	1.00	Electricity PV export
Other 1		0.00	1.00	Electricity
Other 2		0.00	1.00	Electricity

2. **Play 33:** Now we ask what the effect of better shading is in both situations and if it changes our thinking in any way. This time we alter shading through the concept of '**temporary shading**' in ZEBRA which is different from the permanent shading we saw earlier because, unlike permanent shading – which is of course permanent! – we can now account for a level of occupant behaviour in different seasons (this was also covered in Part 1 in 8.8). This is because temporary shading is set differently for heating and cooling conditions allowing ZEBRA to calculate their effects separately. In our case, we assume this shading is applied only for cooling during the hot months. This could be implemented by allowing occupants to manage their shading device or even an automated system. As the image shows, temporary shading is changed in the **Glazing** sheet where we have set a value of **0.8** (1.0 is fully shaded, 0 is no shading). We do this for all orientations.

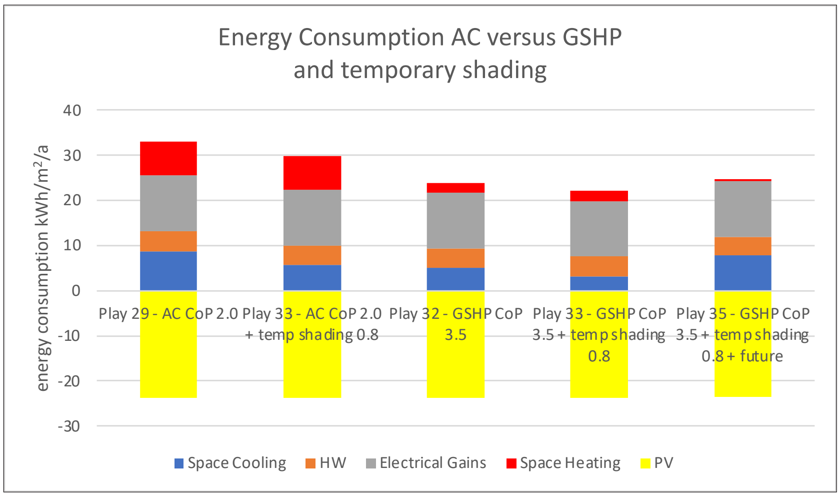
115	south	-						
116	180.00	°						
117	m²	m²	m²	m	m	-	-	
118	**Hole area**	**Glazing area**	**Frame area**	**Perimeter**	**Length glass-{frame/divider}**	**Permanent shading**	**Temporary shading (heating)**	**Temporary shading (cooling)**
119	134.50	100.90	33.60	60.30	30.00	0.23		0.80
120	0.00							
121	0.00							
122	0.00							
123	0.00							
124	0.00							
125	0.00							
126	0.00							
127	0.00							
128	0.00							
129	**134.50**	**100.90**	**33.60**	**60.30**	**30.00**	**0.23**	**0.00**	**0.80**
130								

Offices

3. **Play 34:** We now add PV to 60% of our roof area to see if our design approaches low carbon emissions. ZEBRA does not compute PV on vertical surfaces at the moment. If the top half of the front elevation of this building were covered in PV this would be an area of approximately 180 m^2. The roof area used by ZEBRA for PV works out to 525 m^2 (**Cell F40** in the **Systems** sheet). So, we are generating far more electricity than might be the case in the actual building. Note that to keep things on a single graph, this play is shown for all cases in the graph.

4. **Play 35:** As usual, we ask what the future will bring, but we select only our best performing version from the previous set – i.e. the one with the lowest energy consumption.

We are ready to see our results now: remember this is consumption not demand!



The overall trend for this set of graphs seems obvious: improving CoP helps as does temporary shading. However, the real story is in the middle two graphs. Shading can deliver as much of a reduction in cooling energy consumption (36%) as shifting to a GSHP (43%). Since we assumed people are unlikely to shade their windows in the cold months, we do not see an equivalent increase in space heating consumption. While it is tempting to follow a system or technology approach to reducing emissions or energy consumption (e.g. "look how much wonderful PV I have on the roof!") the graph illustrates what is possible using sensible design alone. For example, a key challenge in using a GSHP is usually the access to the horizontal ground area to install the system.

The value of PV here is evident as the majority of our consumption comes from the electricity required to run lights, computers and other plug loads in the office. The PV allows us to get to net-zero as we have a positive deficit of 0.2 kWh/m^2/a – that is, the building is now energy positive. If the roof is not used for PV and instead we use PV on the front elevation, it would not be possible to be this close to net zero due to the lower area and usually lower efficiency from a non-optimal angle and shading from surroundings.

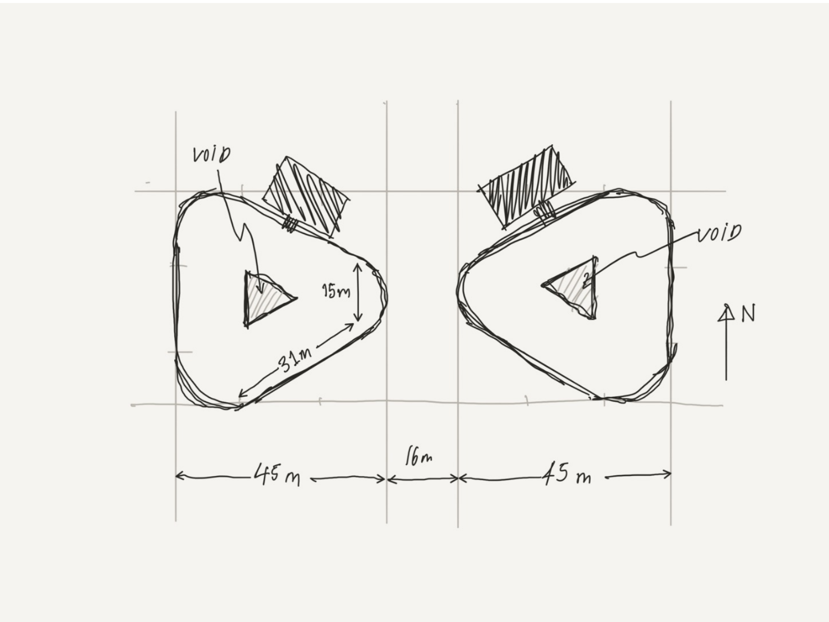
In a future climate, our building turns slight energy negative again (but only to 0.1 kWh/m^2/a, which is negligible). This is because heating demand has all but disappeared, somewhat mitigating the increase in cooling, plus a small decrease in hot water consumption. This result suggests that the building is likely to continue to perform well into the future.

3.2 High Rise Office

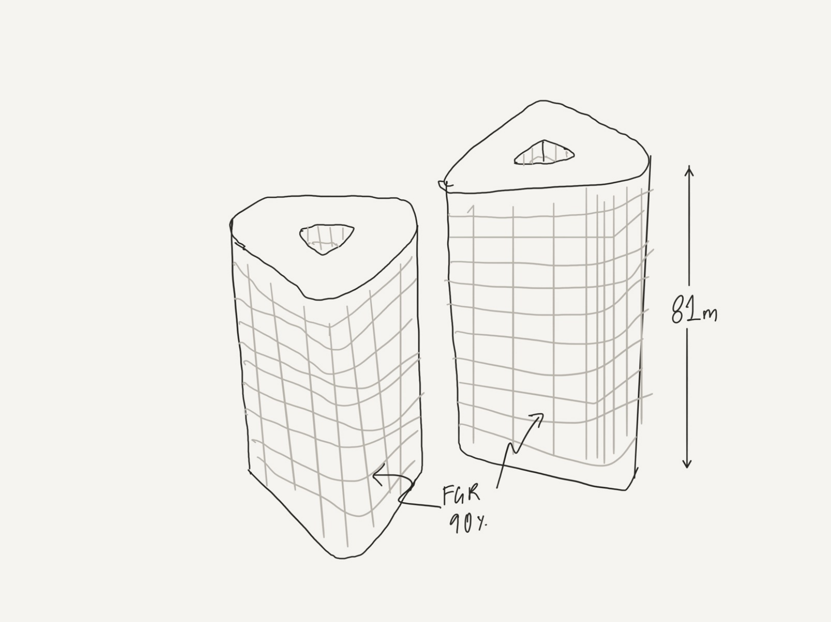
We now turn our attention to a building one might find almost anywhere in the world: a highly glazed high-rise building, used as an office here but we have seen the same approach being used for almost any kind of building. Our goal with this building is to firstly ask what ZEBRA predicts its energy consumption to be. Our guess is this is likely to be rather high given that glazing will cause significant solar heat gains and is, at the same time, very poor at keeping the coolth produced by the air-conditioning system indoors.

Here we have a pair of omni-glazed triangular-in-plan 21-storey towers in Varanasi, Uttar Pradesh (Latitude **25.32**, Longitude **82.97**). A key difference between this building and the others is our choice of set-point. Offices in general have long occupancies and sealed glass towers like this usually operate centralised conditioning with the set-point in the hands of a facility manager. This means that our need to keep setpoints at 30 °C so far to account for a degree of variability in use and access no longer applies. Hence, for all cases here, our chosen set-point is the ZEBRA default of **26 °C** (**Cell F15** in the **Requirements** sheet). In some ways, this in itself could be seen as conservative due to the fact that overcooling, i.e. the delivery of conditioned air to such a low setpoint that it causes cold discomfort in a warm climate, is prevalent in many such buildings.

Note how the orientation of these buildings does not matter as there is little effort made here to respect the different solar positions that will occur in the four cardinal directions.



Offices



As we have restricted ourselves to not altering the amount of glazing, we have decided to play with cross ventilation, solar control glass, shading, each separately and in combination.

1. **Play 36:** high-rise office as designed.

2. **Play 37:** We start with adding more ventilation. Note that ZEBRA only sees this as extra air changes and does not pretend to model actual airflow. To add in **cross ventilation**, change to complexity level 3 and then go to the **Space Conditioning** sheet and insert **4.0** in cell **G70**:

Cross ventilation
Ventilation through natural means is difficult to estimate without more detailed modelling. As an example, a detached house may have between 2 (single-sided) to 6 (cross-ventilation) ach.

64					
65	**Space cooling demand**				
66	**Parameters related to space cooling demand**	**Baseline value**	**Overwrite**	**Value**	**Unit**
67	Metabolic gains	0.80		0.80	W/m²(TFA)
68	Electrical gains (e.g. lighting, computers etc.)	1.40		1.40	W/m²(TFA)
69	Heat Recovery (HR)	0.00		0.00	-
70	Airchanges due to ventilation	0.10	4.00	4.00	ach
71	Sum of fan specific power	0.00		0.00	Wh/m³
72	Non-permanent shading for window set 1			0.00	-
73	Non-permanent shading for window set 2			0.00	-
74	Non-permanent shading for window set 3			0.00	-
75	Non-permanent shading for window set 4			0.00	-
76	Non-permanent shading for window set 5			0.00	-
77	Non-permanent shading for window set 6			0.00	-
78	Non-permanent shading for window set 7			0.00	

Weather | Walls+doors | Ground floor | Roof | Thermal bridges | Glazing | Air | Incidental gains | Space conditioning | Systems | Em…

3. **Play 38:** Solar control through glass is complex as there are different aspects of transmission, reflection and absorption that can be controlled. ZEBRA looks purely at the net effect of all these technologies in terms of what proportion of the solar irradiance hitting the outside gets through to the inside, given by the g-value. This is adjusted in the **Glazing** sheet. Our original building used a double glazed system with a g-value of 0.60 and we are now specifying double glazing with a g-value of 0.42. Note that this new value is very much at the low-end of what is practical. Lower g-values are possible but maintaining high levels of visible transmittance to let in daylight might be expensive.

Offices

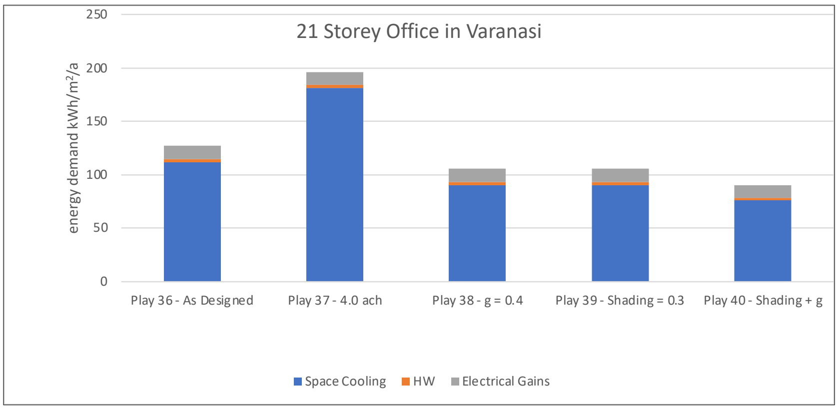
Parameter	Value	Unit	Comment
Mid pane U-value	2.500	W/m²/K	Reasonable de
Glazing g-value	0.600	-	0-1. Reasonabl

Parameter	Value	Unit	Comment
Mid pane U-value	2.500	W/m²/K	Reasonable d
Glazing g-value	0.420	-	0-1. Reasonal

4. **Play 39:** As with the State School building, for each window set introduce "Temporary shading (cooling)" to 0.3 to reflect a small amount of occupant-controlled shading:

-	-	ud
porary shading (heating)	Temporary shading (cooling)	N repeat
	0.30	1
		1
		1
		1
		1
		1
		1
		1
		1
		1
0.00	**0.30**	**10.00**

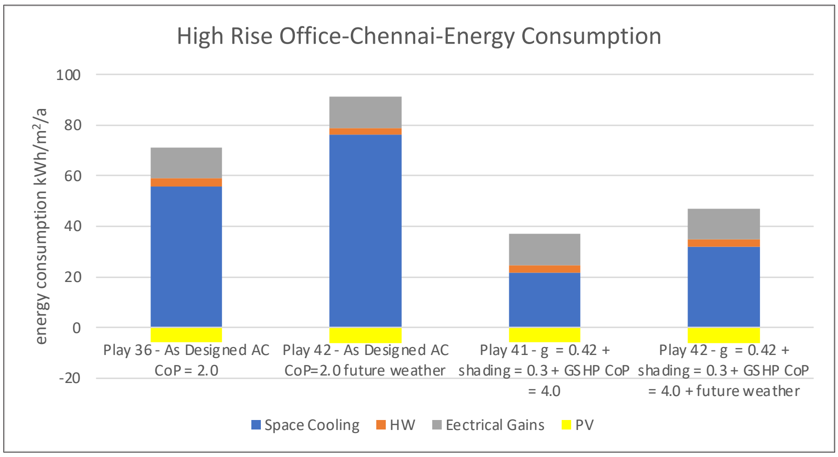
5. **Play 40:** The best performing of the above, together. Also known as the kitchen sink option



The biggest positive difference is made by the g-value which drops cooling energy demand from 111.8 kWh/m²/a in the original design to 90.2 kWh/m²/a, a reduction of 19%. Temporary shading of 0.3 has virtually no effect demonstrating the futility of trying to solve the problem of over-glazing through "band-aid" fixes. The added ventilation makes things much worse. Remember that most high-rise glazed buildings don't offer operable windows for reasons of structural integrity and safety, so this is neither seen to perform well nor particularly feasible. So, our best case might be to try combining low g-value with shading (Play 40). Here, shading clearly has an effect on top of the g-value. It is worth comparing this optimised space cooling energy performance at 76.1 kWh/m²/a to the most optimal low-rise office case (Play 30) of 26.8 kWh/m²/a. A dramatic difference. Should we compare them? Probably not. This is because even though they are the same type of building and we are comparing energy data normalised by floor area, the chosen setpoints in the two are different, so it is not apples-to-apples. Why don't you try changing the setpoint in the low-rise building to 26 °C and see what happens?

9.7.3 Plays 41 to 42: High Rise Office, the real kitchen sink (PV, GSHP, future)

Well, you are now thinking that surely the way to solve our problem is to get some PV on to the roof. OK, let's do this for all the cases here. Why stop there? Let's get a highly efficient air-conditioning system or even a GSHP, assuming we have plenty of ground area to meet demand (**Play 41**). We need to also look at how such a building will do in the future, so let's do that too (**Play 42**). We will assume 60% of the roof is available for PV and employ a GSHP with a CoP of 4.0 and apply all our changes to Play 40. We also switch to energy consumption instead of demand for our graph.



It turns out that adding PV to 60% of the roof area, which would accommodate a 277 **kWp** PV array, would generate about 6 kWh/m²/a. So we learn that as the ratio of roof area to total TFA in the design is low, PV can only make a very small contribution to onsite energy demand.

kWp (kilo watt peak) is the peak power of a PV system or panel. Solar panel systems are given a rating in kilowatts peak (kWp) which is the rate at which they generate energy at peak performance, such as on a sunny day.

We can also see in the above graph that with future weather files the contribution of PV to reducing carbon emissions is reduced further. Contrast these results against the low-rise office which not only has a much better roof area to TFA ratio, but also started off with lower demand due to not being highly-glazed. While not an option in ZEBRA, a back of the paper calculation suggests that to meet the sort of demand we are seeing here would require a 1-2 MWp array covering around 500 m² of surface area. A useful demonstration of what it means to have a highly glazed building like this in terms of energy demand.

Part 3
Constructions Library

In this part, we have assembled a library of constructions from which to choose from and use in ZEBRA. These are derived and adapted from:

- The venerable **SP 41 handbook** (marked with ☆).
- The more recent **Thermal performance of walling material and wall technology** (marked with ●). This provides detailed drawings and manufacturer source and is therefore worth checking for more information.
- ECBC design guidelines (marked with ✦).

SP 41 (1987)
Handbook on Functional Requirements of Buildings (Other than Industrial Buildings) [CED 12:Functional Requirements in Buildings]

Thermal performance of walling material and wall technology, Part-1. Rawal, R., Maithel, S., Shukla, Y., Rana, S., Gowri, G., Patel, J., & Kumar, S. (2020, June). Retrieved from carbse.org, www.beepindia.org, www.gkspl.in/publications

Some things to consider as you select and use the U-values in these tables:

- A key thing to remember about using any of the U-values here is that it is virtually certain that *no* actual wall or roof built to these configurations will produce these exact values. In fact, you can safely assume the actual U-value will be worse (i.e. larger) than you see. So, use with care and apply safety factors if you are likely to be working with less-skilled labour.
- U-values are usually written to three decimal places but SP 41 reports to only two. We have maintained these without adding trailing zeros.
- We have grouped constructions by type and then sorted them by increasing U-value to make reading them, and using them, easier. Where a particular construction has been used in the manual, we have marked it in green as usual and indicated which case study building the construction features in.

10.1 Walls

	Configuration Note: PL = plaster	U-value [W/m²K]	Source	Used in this manual for
Brick based constructions				
01	**15 mm PL + 50 mm PU + 230 mm Brick + 12 mm PL**	**0.40**	✦	Private school
02	**15 mm Plaster + 250 mm Cement Stabilized Brick + 50 mm Internal Bonded Mineral Wool + 10 mm PL**	**0.50**	✦	Private school
03	**12 mm PL + 30 mm XPS + 230 mm brick + 12 mm PL**	**0.75**	✦	House
04	12.5 mm PL + 114 mm brick wall + 50.8 mm reed board + 38 mm cement concrete PL	0.80	☆	
05	12.5 mm PL + 25 mm expanded polystyrene + 225 mm brick + 12.5 mm PL	0.85	☆	
06	12.5 mm PL + 225 mm brick + 25 mm expanded polystyrene + 12.5 mm PL	0.85	☆	
07	12.5 mm PL + 25 mm expanded polystyrene + 112.5 mm brick + 12.5 mm PL	0.97	☆	
08	12.5 mm PL + 112.5 mm brick + 25 mm expanded polystyrene + 12.5 mm PL	0.97	☆	
09	12.5 mm PL + 450 mm brick + 12.5 mm PL	1.35	☆	
10	**15 mm PL + 115 mm brick + 50 mm air gap + 115 mm brick + 12 mm PL**	**1.50**	☆	State school
11	12.5 mm PL + 112.5 mm brick + 50 mm air gap + 112.5 mm brick + 12.5 mm PL	1.55	☆	
12	12.5 mm PL + 337.5 mm brick + 12.5 mm PL	1.65	☆	
13	Rattrap bond wall (230 mm burnt clay bricks)	1.673	●	
14	Brick Wall (12.55 mm cement plaster + 230 mm solid brick + 12.5 mm cement plaster)	1.670	●	
15	225 mm cavity brick wall	1.69	☆	

Constructions Library

	Configuration Note: PL = plaster	U-value [W/m²K]	Source	Used in this manual for
16	12.5 mm PL + 75 mm brick + 50 mm air gap + 75 mm brick + 12.5 mm PL	1.80	☆	
17	12.5 mm PL + 225 mm brick + 12.5 mm PL	2.13	☆	
18	**12 mm PL + 230 mm brick + 12 mm PL**	**2.15**	☆	House
19	**12.5 mm PL + 200 mm brick + 12.5 mm PL**	**2.28**	☆	Apartment
20	12.5 mm PL + 112.5 mm brick + 12.5 mm PL	3.00	☆	
Concrete based constructions				
21	**15 mm PL + 200 mm AAC Block + 100 mm Air Gap + 100 mm AAC Block + 10 mm PL**	**0.45**	✦	Private school
22	Structural stay-in-place formwork system (Coffor) - Insulated panel (230 mm)	0.520	●	
23	Reinforced EPS core Panel system (150 mm)	0.907	●	
24	12.5 mm PL + 50 mm foam concrete + 112.5 mm concrete + 12.5 mm PL	0.99	☆	
25	**15 mm PL + 50 mm foam concrete + 150 mm concrete block + 12 mm PL**	**1.00**	☆	State School
26	**15 mm PL + 50 mm foam concrete + 100 mm concrete block + 12 mm PL**	**1.20**	☆	Apartment
27	Glass fibre reinforced Gypsum Panel - with RCC filling (124 mm)	1.534	●	
28	Glass fibre reinforced Gypsum Panel - Unfilled (124 mm)	1.559	●	
29	Glass fibre reinforced Gypsum Panel - with RCC and non-structural filling (124 mm)	1.715	●	
30	200 mm light weight concrete-block (3 holes)	1.93	☆	
31	**15 mm PL + 200 mm Light Weight Concrete Block (2 holes) + 12 mm PL**	**2.00**	☆	State and private School, High-rise office
32	200 mm light weight concrete-block (2 holes)	2.07	☆	
33	12.5 mm PL + 200 mm cinder concrete block + 12.5 mm PL	2.09	☆	
34	100 mm cellular concrete	2.12	☆	
35	150 mm hollow pan	2.56	☆	
36	200 mm dense concrete-hollow block (3 holes)	2.79	☆	
37	100 mm light weight concrete-block	2.90	☆	
38	**200 mm dense concrete-hollow block (2 holes)**	**3.01**	☆	State School
39	100 mm hollow pan	3.27	☆	
40	150 mm concrete block	3.29	☆	
41	100 mm concrete block	4.12	☆	
Steel based constructions				
42	Light Gauge framed steel structure with EPS (150 mm)	1.188	●	
43	Light Gauge framed steel structure with pre-painted galvanized iron sheet (PPGI) sheet and vapour barrier (150 mm)	1.629	●	
Other constructions				
44	76.2 × 76.2 mm wooden studs + 38.1 mm wooden boarding with fireproof paint spray on each side	1.03	☆	
45	254 mm rubble wall + 12.5 mm PL	3.47	☆	
46	Mud wall based on wooden lacings	4.88 to 6.28	☆	

10.2 Roofs

	Configuration Note: PL = plaster	U-value [W/m²K]	Source	Used in this manual for
Reinforced Cement Concrete (RCC) based constructions				
01	**100 mm Brick Bat Coba + 30 mm PCC + 150 mm RCC Slab + 125 mm PU + 10 mm PL**	**0.20**	✦	
02	**100 mm Brick Bat Coba + 30 mm PCC + 150 mm RCC Slab + 100 mm Bonded Mineral Wool + 10 mm PL**	**0.33**	✦	
03	**80 mm Brick Bat Coba + 30mm PCC + 100 mm EPS + 150 mm RCC Slab + 10 mm PL**	**0.40**	✦	State school, High-rise and low rise offices
04	**80 mm Brick Bat Coba + 75 mm EPS + 30 mm Cement Mortar + 150 mm RCC Slab + 20 mm PL**	**0.46**	✦	House, Private School
05	50 mm expanded polystyrene + 50 mm RCC + waterproofing	0.62	☆	
06	**20 mm roof finish (tile) + 30 mm PCC + 25 mm XPS insulation + 150 mm RCC slab + 10 mm PL**	**1.00**	✦	Apartment
07	100 mm RCC + 50 mm foam concrete + waterproofing	1.08	☆	
08	50 mm RCC + 25 mm expanded polystyrene	1.08	☆	
09	25 mm expanded polystyrene + 50 mm RCC	1.09	☆	
10	**20 mm roof tiles + 30 mm PCC + 25 mm EPS + 150 mm RCC slab**	**1.20**	✦	House
11	100 mm RCC + 75 mm cinder + 50 mm brick tile	1.76	☆	
12	115 mm RCC + 75 mm Mud Phuska + 50 mm brick tile	2.01	☆	
13	100 mm RCC + 50 mm cinder + 50 mm brick tile	2.07	☆	
14	115 mm RCC + 50 mm Mud Phuska + 50 mm brick tile	2.31	☆	
15	**25 mm roof finish (tiles) + 50 mm Mud Phuska + 50 mm brick tile + 115 mm RCC + 10 mm PL**	**2.50**	☆	House
16	100 mm RCC + 100 mm lime concrete	2.78	☆	
17	100 mm RCC	3.59	☆	
18	88.9 mm concrete using brick aggregate + 25.4 mm Kota stone slab on each side	3.65	☆	
Lime concrete based constructions				
19	125 mm cord unit + 85 mm lime concrete	2.13	☆	
20	137.5 mm clay unit + 100 mm lime concrete	2.14	☆	
21	150 mm clay unit + 100 mm lime concrete	2.21	☆	
22	100 mm cellular unit + 85 mm lime concrete	2.27	☆	
23	50.8 mm lime concrete using ballast aggregate + 114 mm reinforced brick and bitumen wash on top	2.45	☆	
24	154 mm lime concrete using stone aggregate + 76 mm stone slab	3.07	☆	
25	**50.8 mm lime concrete using brick ballast aggregate + 50.8 mm RCC slab + bitumen wash on top surface**	**4.02**	☆	Apartment
Clay based constructions				
26	137.5 mm clay unit	2.99	☆	
27	150 mm clay unit	3.15	☆	

Annex 1 GRIHA Benchmark data

Here, we reproduce some benchmark data from GRIHA to give you an idea of the sorts of numbers you might expect to see when using ZEBRA or when measuring performance in the real world. The numbers in the table are those the standard expects you to achieve for compliance.

These numbers are directly comparable to ZEBRA's output due to the use of kWh/m^2/a, but you will need to sum the numbers in Cells **G19:G23** in the **Summary** sheet as these are the total energy consumption (not demand). In modern versions of Excel this is very easy – simply select those cells and read the sum in the bottom right of Excel's window (near the zoom buttons). The key takeaway is the size of the number: most are either high double digits or low triple digits.

[kWh/m2/a]	Daytime Occupancy 5 days a week		24-hour occupancy 7 days a week					
Climate	Institutional	Office	Healthcare Facility	Hospitality	Office	Residential	Residential	Transit Terminal
Composite	90	90	250	275	225	70	225	300
Hot and Dry	90	90	250	275	225	70	225	300
Warm and Humid	90	90	275	275	225	70	225	300
Moderate	75	75	250	250	210	50	210	300
Cold	90	120	275	300	275	100	225	275

Notes

Notes

ISBN 978-0-86197-206-7
9 780861 972067