A study of the three R-type thinking in sustainable designs: assessing the energy efficiency through simulation in Australia

ABDOLLAH BAGHAEI DAEMEI[1], **MOSTAFA KAZEMI**[2], **MAHSA MALEKFARNOUD**[3], **SEYED MOSTAFA TAVAKOLI**[4], AND **RONAK GERAVANDI**[5]

[1] *Young Researchers and Elite Club, Rasht Branch, Islamic Azad University, Rasht, Iran*
[2] *Department of Architecture and Urbanism, Tabriz Branch, Islamic Azad University, Tabriz, Iran*
[3,4] *Department of Architecture, Rasht Branch, Islamic Azad University, Rasht, Iran*
[5] *Department of Architecture, University of Tehran, Tehran, Iran*
[*] *Corresponding author: baghaei@iaurasht.ac.ir*

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Energy crises and the continuous fluctuation cost of fossil fuels have moved researchers' attention towards new sustainable and renewable energy sources. The three R-type thinking (i.e., reduce, reuse, and recycle), utilizes three great ways to protect the environment by saving money, energy, and natural resources. The Australian Building Codes Board is considered as a project for energy efficiency. BCA has also identified eight different climate zones within Australia. This paper discusses the climate conditions of the state capital cities of Sydney, Adelaide, and Perth that belong to the same climate zone 5 of the BCA. On this basis, the present paper covered three major aims. At first, we are doing to identifying the similarities and the differences in climate conditions in case studies, as a result of bioclimatic features. Then, the thermal performance of the "green roof" was evaluated in all three cases. The simulation was carried out on a residential building block for one year (four seasons) using the Design Builder software. Finally, based on the findings of this paper, building orientation strategy was chosen to assess natural ventilation through BEopt V. 2.8 software on a residential building in Sydney. The results showed that the green roof in Sydney could be an optimal thermal performance, in comparison with other cases. Also, it can be stated that the findings of natural ventilation simulation show the most optimal building orientation in Sydney is 45 degrees to the southeast in which this among included 17% has better performance to improve wind flow.

keywords: *Three R-type, Sustainable design, Passive techniques, Green roof, Energy efficiency, Building simulation, Natural ventilation.*

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1. INTRODUCTION

The Building Code of Australia (BCA) developed 'energy efficiency' regulations that require energy optimization for the extra heating and cooling. There are two conditions that set a house to be considered as an energy-efficient building. Either it covers the Deemed to Satisfy (DTS) plan, or it has been rated as 5-star by the National House Energy Rating Scheme [1, 2]. Construction standards in Australia improved after 1991 with the introduction of energy ratings and the integration of solar passive design principles. Solar passive design principles improve thermal and energy efficiency. They do this by orienting the home around correct sun angles and incorporating cross-flow ventilation. To create a comfortable and healthy home that does not rely heavily on mechanical heating or cooling, considering some principles is needed. Passive solar design is widely held in high esteem as a strategy for creating an internal environment that is as comfortable as possible for the climate. In the Perth climate, it is easy and inexpensive to build passive solar designed houses that may not need additional heating and cooling. The concept is not new, and it is supported by anecdotal and documented evidence that illustrates this, but apart from a few dedicated practitioners, it does not appear to have been widely adopted. In an ideal world, we might all live in passive solar designed houses [3]. However, in reality, site constraints such as overshadowing and orientation may not allow sun penetration in winter. In these cases, the passive solar design would be limited. To address this issue, solar passive design is not compulsory in all projects. Many companies embraced it during the ’90s, and most designers/architects are now familiar with the principles. However, there are still far too many homes built in Australia which ignore the basics [4]. It had an immediate impact on its effectiveness in creating a truly comfortable, energy-efficient internal environment [5, 6]. Passive House principles are primarily driven to create a completely air-tight environment, which then uses a ventilation system to control air quality, temperature, and humidity. Besides creating a genuinely comfortable and healthy environment, the other significant benefit is that ventilation systems are heat exchangers. They run on the difference between internal and external temperatures using almost no energy, which creates enormous energy efficiency and sustainability considering that heating and cooling are some of the most tremendous energy draws in many homes. Passive House has had such an impact that most European countries are currently considering making Passive House their national building standard. It has been estimated there are now over 50,000 Passive House buildings around the world. In Australia, the first certified Passive House was built in 2014. There are now several designers and builders who have embraced the future. They can now offer the experience and expertise to help them design and build a truly energy-efficient, comfortable and healthy Passive Home [7, 8]. One of the most related papers in this field was done with Baghaei Daemei et al., [9]. In this study, the researcher provided passive design strategies in eight cities around the world based on the Cfa Köppen climate classification. These strategies plotted from the Givoni chart and the Mahoney table. In fact, it can be obtained that passive solar strategies can be considered as a kind of renewable energy category. The use of such strategies is to design buildings based on the site and with local climatic potential and to consider climate as the main factor in architectural design. The key to designing a passive solar building is to best take advantage of the local climate by performing an accurate site analysis. Elements to be considered include window placement and size, and glazing type, thermal insulation, thermal mass, and shading. On the other hand, what we presented here is extracted from a more comprehensive study which aims to provide a framework for decision-makers, designers and the construction sector to select and plan for exploiting the available potential of our suggested designs and building elements which are appropriate for the existing environmental condition of their projects’ sites parallel to raising the energy efficiency with renewable energy. To do so, our study calculations include a wide range of cities and states. In other words, this study encompasses all the climates included in Australia’s weather conditions. Hence, we drew up a two-stage guideline for initiating our work. Firstly, it was crucial to analyze the climates and also, to develop suggestions for planning and designing buildings. Later on, simulating the green roof and comparing the results with a bare roof has been carried out to evaluate energy efficiency in all three cases of the study, which include Sydney, Adelaide, and Perth in order to determine how much the green roof can optimize energy consumption. The weather data of each location with their specific climate conditions are presented in a graph using EPW weather data file format. Building Bioclimatic charts are used to conceive the essential comfort level for each climate individually.

2. RESEARCH METHODOLOGY

This research has been conducted in three stages. In the first stage, climate data of the city of Sydney, Adelaide and Perth in Australia was collected and its climatic characteristics were identified. The study then required access to 3-hour relative humidity (RH) and temperature data for analysis with the Psychrometric chart. The method of carrying out this quantitative research was based on climatic studies, and meteorological data used as an EPW (Energy Plus Weather) file is extracted from the Energy Plus website [10]. The EPW data is provided by the US Department of Energy. The stages were carried out in such a way that at first the Givoni bioclimatic chart (Psychrometric chart) of case studies climate was presented and the comfort zone on a monthly basis was assessed. Then, passive design strategies were extracted and proposed in this diagram. The Climate Consultant V.6 software has been used to plot the Givoni bioclimatic chart and to draw up design strategies. The thermal comfort model used in this software was also selected as ASHRAE standard 55 and the current handbook of the fundamental model. Climate data throughout 10 years (2009–2018) has been used for this study. Climate Consultant was developed by Robin Liggett and Murray Milne of the UCLA Energy Design Tools Group [11, 12]. Psychrometric charts for specific climates could be utilized to gain the temperature and humidity data of the region, for instance, the wet bulb and dry bulb temperatures as well as relative or absolute humidity. To have an accurate perception of thermal comfort preparation together with implementing passive design strategies, the Psychrometric chart of the region stands as an essential tool. Building design with the consideration of local climate conditions has been done by Givoni (1976). Givoni developed a Building Bioclimatic chart to suggest means of achieving a climate-sensitive design at the end of the design progress [13]. In the second stage, simulating the "green roof" and comparing the results with a bare roof, has been carried out to evaluate energy efficiency in all three case studies to determine how much the "green roof" can optimize energy consumption. This simulation was carried out on a residential building block during a year. Design Builder Ver. 4.5 and Energy Plus, Version 8.3.0-6d97d074ea, YMD=2019.05.21 20:56 were also used for the simulation. Eventually, the city of Sydney was selected as a case study to evaluate natural ventilation. In this way, using a BEopt V. 2.8 software, a residential building was hypothetically modeled were evaluated which is have 2 stories. During the simulation whole of the HVAC system was turned off as well. The Building Energy Optimization Tool (BEopt) software provides capabilities to evaluate residential building designs and identify cost-optimal efficiency packages at various levels of whole-house energy savings along the path to zero net energy. BEopt has been developed by the National Renewable Energy Laboratory in support of the U. S. Department of Energy Building America. BEopt uses Energy Plus, the Department of Energy’s flagship simulation engine.

3. CASE STUDIES

Australia has a varied climate, leading to different locations around the country having different heating and cooling requirements. To account for these differences the energy efficiency Deemed-to-Satisfy Provisions vary from location to location and for simplicity, locations with approximately similar climates have been combined into eight climate zones. The following provides a brief description of each NCC climate zone [14]:

- Climate zone 1 - High humidity summer, warm winter
- Climate zone 2 - Warm humid summer, mild winter
- Climate zone 3 - Hot dry summer, warm winter
- Climate zone 4 - Hot dry summer, cool winter

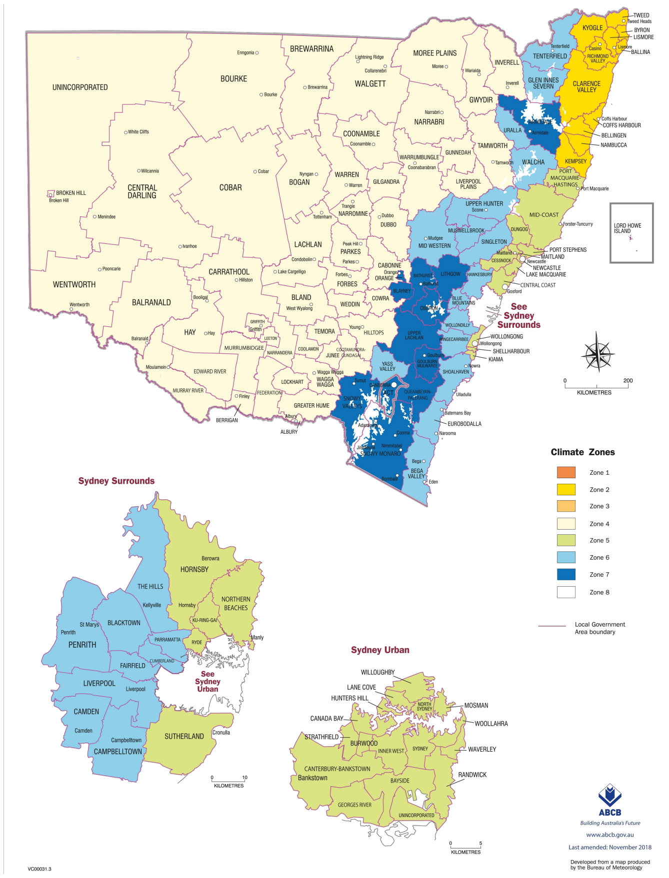


Fig. 1. Climate zone map: new south wales and the australian capital territory [14].

- Climate zone 5 - Warm temperate
- Climate zone 6 - Mild temperate
- Climate zone 7 - Cool temperate
- Climate zone 8 - Alpine

These eight climate zones are illustrated in the form of a climate zone map that was created using Bureau of Meteorology climatic data with two supplementary zones added to accommodate an additional temperate zone and alpine. The climate zone boundaries are also aligned with local government areas and are therefore subject to change from time to time (Fig. 1).

This study discusses the climate conditions of the state capital cities of Sydney, Adelaide, and Perth that belong to the same climate zone 5 of the BCA (Fig. 2). Also, climate data can be extracted from Table 1. as below:

A. Sydney's climate indicators

Sydney is the state capital of New South Wales and the most populous city in Australia and Oceania. According to the Köppen–Geiger classification, Sydney stands as a subtropical humid climate which means it has cool winters and warm summers and the high annual precipitation of this area leads to a homogeneous rainfall over a year. While Sydney CBD has a temperature higher than 30 °C for 14.9 days yearly, the metropolitan regions have it for 35 to 65 days including their suburbs. From Observatory Hill, recorded temperatures for the highest minimum temperatures and the lowest maximum temperature were 27.6 °C on February 2011 and 7.7 °C in July 1868. The weather condition is going to be moderate as the climate is along with the ocean and there would be more severe temperatures inside the western suburbs (Fig. 3).

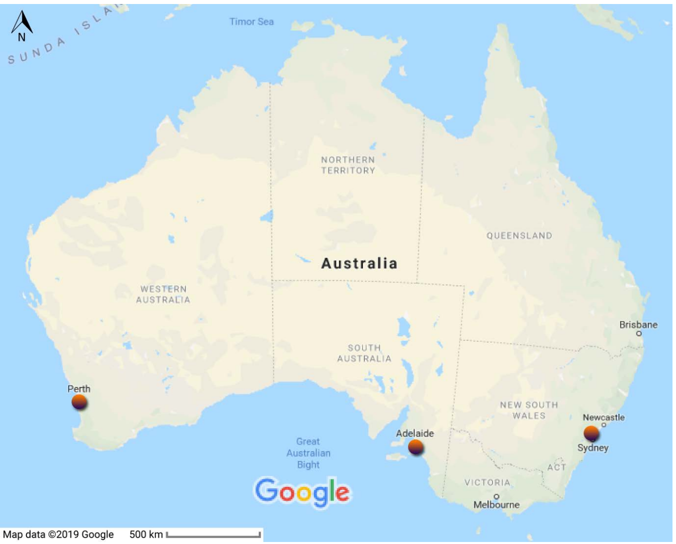
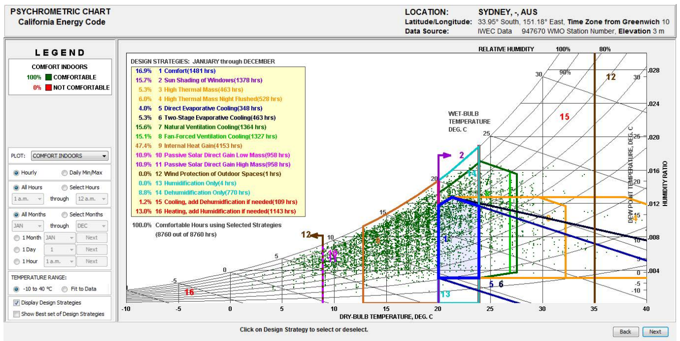


Fig. 2. The case studies' locations on the map.


PSYCHROMETRIC CHART
California Energy Code

LOCATION: SYDNEY, -, AUS
Latitude/Longitude: 33.95° South, 151.18° East, Time Zone from Greenwich 10
Data Source: IWEC Data 947670 WMO Station Number, Elevation 3 m

LEGEND
COMFORT INDOORS
100% 🟩 COMFORTABLE
0% 🟥 NOT COMFORTABLE

PLOT: COMFORT INDOORS
● Hourly ○ Daily Min/Max
● All Hours ○ Select Hours
1 a.m. through 12 a.m.
● All Months ○ Select Months
JAN through DEC
○ 1 Month JAN Next
○ 1 Day 1 Next
○ 1 Hour 1 a.m. Next
TEMPERATURE RANGE:
● -10 to 40 °C ○ Fit to Data
☑ Display Design Strategies
☐ Show Best set of Design Strategies

DESIGN STRATEGIES: JANUARY through DECEMBER

16.9%	1 Comfort(1481 hrs)
15.7%	2 Sun Shading of Windows(1378 hrs)
5.3%	3 High Thermal Mass(463 hrs)
6.0%	4 High Thermal Mass Night Flushed(528 hrs)
4.0%	5 Direct Evaporative Cooling(348 hrs)
5.3%	6 Two-Stage Evaporative Cooling(463 hrs)
15.6%	7 Natural Ventilation Cooling(1364 hrs)
15.1%	8 Fan-Forced Ventilation Cooling(1327 hrs)
47.4%	9 Internal Heat Gain(4153 hrs)
10.9%	10 Passive Solar Direct Gain Low Mass(958 hrs)
10.9%	11 Passive Solar Direct Gain High Mass(958 hrs)
0.0%	12 Wind Protection of Outdoor Spaces(1 hrs)
0.0%	13 Humidification Only(4 hrs)
8.8%	14 Dehumidification Only(770 hrs)
1.2%	15 Cooling, add Dehumidification if needed(109 hrs)
13.0%	16 Heating, add Humidification if needed(1143 hrs)

100.0% Comfortable Hours using Selected Strategies (8760 out of 8760 hrs)

Click on Design Strategy to select or deselect.

Fig. 3. Psychrometric chart of Sydney (Plotted by the Climate Consultant Software).

B. Adelaide's climate indicators

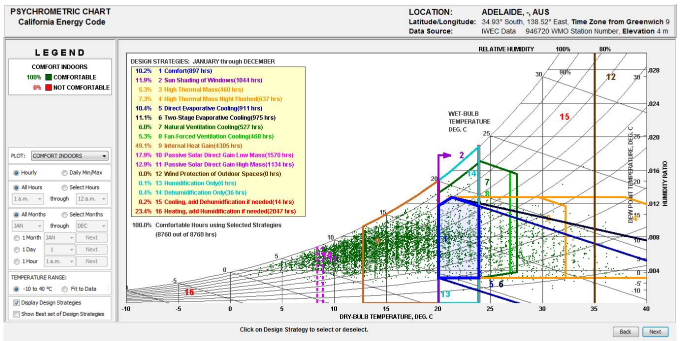
Adelaide is the capital city of the state of South Australia, and the fifth-most populous city of Australia. In the summer (December to February) the average maximum temperature is around 29 °C, but there is considerable variation and Adelaide can usually expect several days a year in which the daytime temperature is 39 °C and there are generally two or more days in which the maximum is 40 °C or slightly above. In the winter (June to August) the average maximum is around 15–16 °C and the average minimum around 7–8 °C. In the winter, Adelaide experiences quite a significant wind chill, which makes the apparent temperature seem cooler than it actually is. Rainfall is unreliable, light and infrequent throughout the summer. The average in January and February is around (0.8 inches), but completely rainless months are by no means uncommon, and in 1893 sixty-nine days passed without measurable rainfall. In contrast, the winter has fairly reliable rainfall with June being the wettest month of the year, averaging around 80 mm (Fig. 4).

C. Perth's climate indicators

Perth is the capital and largest city of the Australian state of Western Australia (WA). Perth receives a moderate though highly

Table 1. Annual climatic data for each case study

	Humidity (%)	Temperature record high (°C)	Temperature record low (°C)	Average rainy days (mm)	Wind speed (m/s)
Sydney	56	46	2.1	1200	6.7
Adelaide	47	47	−0.4	548	7.3
Perth	47	46	−0.7	733	8.4


PSYCHROMETRIC CHART
California Energy Code

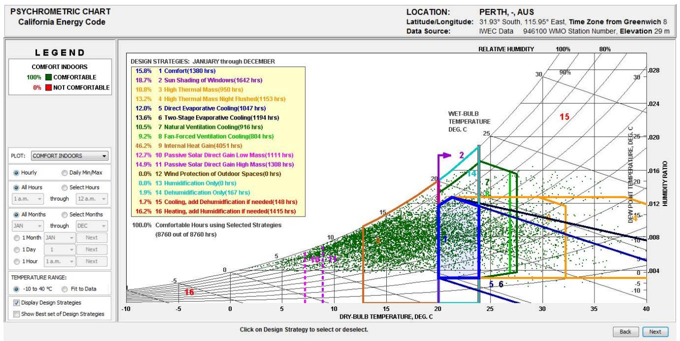
LOCATION: ADELAIDE, -, AUS
Latitude/Longitude: 34.93° South, 138.52° East, Time Zone from Greenwich 9
Data Source: IWEC Data 946720 WMO Station Number, Elevation 4 m

DESIGN STRATEGIES: JANUARY through DECEMBER

10.2%	1	Comfort(897 hrs)
11.9%	2	Sun Shading of Windows(1044 hrs)
5.3%	3	High Thermal Mass(460 hrs)
7.3%	4	High Thermal Mass Night Flushed(637 hrs)
10.4%	5	Direct Evaporative Cooling(911 hrs)
11.1%	6	Two-Stage Evaporative Cooling(975 hrs)
6.0%	7	Natural Ventilation Cooling(527 hrs)
5.3%	8	Fan-Forced Ventilation Cooling(468 hrs)
49.1%	9	Internal Heat Gain(4305 hrs)
17.9%	10	Passive Solar Direct Gain Low Mass(1570 hrs)
12.9%	11	Passive Solar Direct Gain High Mass(1134 hrs)
0.0%	12	Wind Protection of Outdoor Spaces(0 hrs)
0.1%	13	Humidification Only(6 hrs)
0.4%	14	Dehumidification Only(36 hrs)
0.2%	15	Cooling, add Dehumidfication if needed(14 hrs)
23.4%	16	Heating, add Humidification if needed(2047 hrs)

100.0% Comfortable Hours using Selected Strategies (8760 out of 8760 hrs)

Fig. 4. Psychrometric chart of Adelaide (Plotted by the Climate Consultant Software).


PSYCHROMETRIC CHART
California Energy Code

LOCATION: PERTH, -, AUS
Latitude/Longitude: 31.93° South, 115.95° East, Time Zone from Greenwich 8
Data Source: IWEC Data 946100 WMO Station Number, Elevation 29 m

DESIGN STRATEGIES: JANUARY through DECEMBER

15.8%	1	Comfort(1380 hrs)
18.7%	2	Sun Shading of Windows(1642 hrs)
10.8%	3	High Thermal Mass(950 hrs)
13.2%	4	High Thermal Mass Night Flushed(1153 hrs)
12.0%	5	Direct Evaporative Cooling(1047 hrs)
13.6%	6	Two-Stage Evaporative Cooling(1194 hrs)
10.5%	7	Natural Ventilation Cooling(916 hrs)
9.2%	8	Fan-Forced Ventilation Cooling(804 hrs)
46.2%	9	Internal Heat Gain(4051 hrs)
12.7%	10	Passive Solar Direct Gain Low Mass(1111 hrs)
14.9%	11	Passive Solar Direct Gain High Mass(1308 hrs)
0.0%	12	Wind Protection of Outdoor Spaces(0 hrs)
0.0%	13	Humidification Only(0 hrs)
1.9%	14	Dehumidification Only(167 hrs)
1.7%	15	Cooling, add Dehumidfication if needed(148 hrs)
16.2%	16	Heating, add Humidification if needed(1415 hrs)

100.0% Comfortable Hours using Selected Strategies (8760 out of 8760 hrs)

Fig. 5. Psychrometric chart of Perth (Plotted by the Climate Consultant Software).

seasonal, winter-based rainfall. Summers are generally hot and dry, lasting from December to March, with February generally being the hottest month of the year. Winters are cool and wet, giving Perth a hot-summer Mediterranean climate (Köppen climate classification Csa). Perth has an average of 8.8 hours of sunshine per day, which equates to around 3200 hours of annual sunshine, and 138.7 clear days annually, making it the sunniest capital city in Australia. Summers are dry but not completely devoid of rain, with sporadic rainfall in the form of short-lived thunderstorms, cold fronts and on occasions decaying tropical cyclones from Western Australia's north-west, which can bring heavy rain. Winters see significant rainfall as frontal systems move across the region, interspersed with clear and sunny days. The highest temperature recorded in Perth was 46.2 °C on February 23rd 2018, although Perth Airport recorded 46.7 °C on the same day. On most summer afternoons a sea breeze, known locally as the "Fremantle Doctor", blows from the southwest, providing relief from the hot north-easterly winds. Temperatures often fall below 30 °C a few hours after the arrival of the wind change. In the summer, the 3 pm dew point averages at around 12 °C (Fig. 5).

4. PASSIVE TECHNIQUES

Energy efficiency is probably the topic that first comes to mind when discussing the eco-design of buildings, and with good reason. The energy demands of constructed environments are huge, and increasing the energy efficiency of buildings is perhaps the single most effective step we can take in reducing our environmental footprints. Regarding energy efficiency, there are two general approaches: passive and active techniques. As could be expected, passive techniques consist of simpler, usually non-mechanical approaches, while active techniques tend to involve more advanced technologies. As it could not be expected, the passive/active distinction is not really about human involvement. Some passive approaches require active participation (such as opening and closing windows or vents), while specific active approaches (such as photovoltaic panels or automated lighting controls) may not need a human hand at all [15] Another difference between passive and active energy efficiency is that most passive concepts are not new. They often utilize tools or methods that are centuries old, ideas that have been in continuous use or that were left along the wayside when design in the Industrial Age seemed to make them unnecessary or superfluous. Many of these temporarily lost or forgotten techniques are now being rediscovered. Since they are not new, most passive techniques are mature, time-tested concepts and not cutting-edge technologies in the way that active approaches such as photovoltaic or light-emitting diodes (LEDs) are. That means there are fewer unknowns and fewer things to go wrong. Passive tools also typically have fewer moving parts, so they require less repair or maintenance. Taken together, this makes passive energy efficiency simpler, more reliable, and usually less expensive than active energy efficiency [16]. Many Eco designers believe that passive tools are the first steps to be taken because they tend to yield the most bang for the buck. We can start understanding passive energy efficiency by looking at local designs. Most types of domestic architecture derived from necessity. In the days before heating and air-conditioning systems, for example, how were buildings cooled in the hot and humid Southeast? How were they heated during the New England winters? How did buildings take advantage of breezes in Iran or sun angles in New Mexico? That historic relationship between design and local conditions changed when the Industrial Age combined with modern architecture. No longer was building design at the mercy of nature. The same curtain-wall tower or wood-framed house could be inserted virtually anywhere in the world. Moreover, the design of each side of a building could be the same, regardless of the direction it faced. Not only could a suburban development house look the same in different parts of the country, but it could also look the same no matter it's orientation [17].

A. Thermal mass

The combination of latitude and seasonal changes in sun angle results in varying amounts of insolation the amount of solar

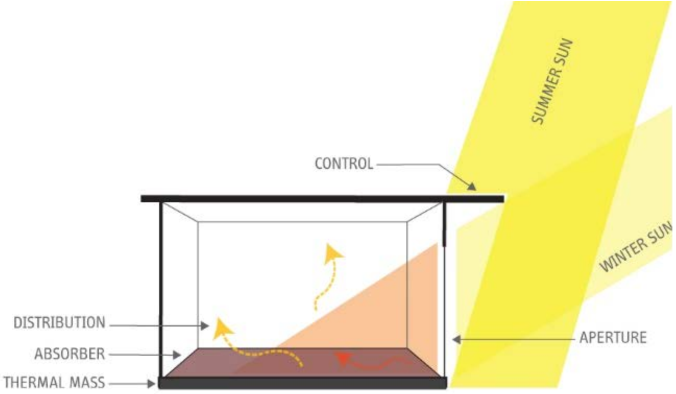


Fig. 6. The five basic components of passive solar heating.

radiation received. Insolation is an essential factor in active solar projects (as discussed in the following chapter), but it is also a critical component of passive solar design. The design for a passive solar building has to take into account the amount and angle of solar gain throughout the seasons and during each day. When these are combined, building forms optimized regarding footprint, massing, orientation, facade, and fenestration can be generated. To get there, it is necessary to break down the components of the passive solar design [18]. The U.S. Department of Energy (DOE) has a straightforward outline explaining the five elements that collect and distribute solar radiation within a building, condensed here (Fig. 6).

1. Aperture: A window glass as the entrance of solar radiation
2. Absorber: Black or dark surface for the thermal absorption
3. Thermal mass: preservation of solar heat gains by specific materials
4. Distribution: Means delivering stored solar thermal energy to the building's zones. A strictly passive design will not use mechanical methods.
5. Control: Roof overhangs and other means that can be used as shading for the aperture area during hot seasons.

Overhangs, when appropriately designed, can do that. Window blinds can too, but they require either user interaction or automated systems. Nature provides us with another method: deciduous trees can function as controls by having leaves in the summer and dropping the leaves in the winter. Moreover, they accomplish this with a negative carbon footprint. The solution is to create a building element that can absorb and retain solar gain so that the heating and cooling cycle of the day can be evened out. This involves two parts. First, a visible surface is needed to absorb solar radiation. Appropriately, this surface is called an absorber. Since lighter colors reflect radiation and darker colors absorb it, a basic rule is that the absorber should be fairly dark in order to be effective (Fig. 7).

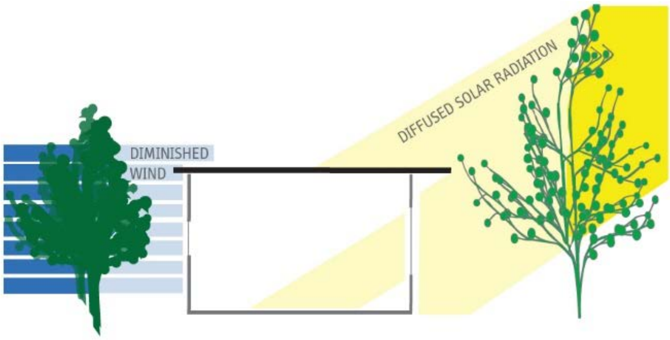


Fig. 7. Deciduous trees provide natural summer shading and allow needed winter sunlight.

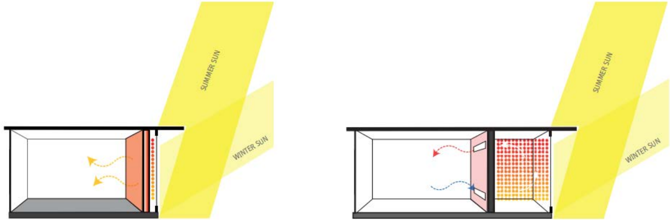


Fig. 8. (a) A Trombe wall can be thought of as a passive thermal mass turned vertical, (b) Trombe wall with operable vents and space for a sunroom.

The absorbed radiation then has to be retained. This is handled by thermal mass: materials such as concrete, stone, or earth, which can store and then slowly reradiate the energy. A dark wood floor over concrete is a good pairing of the absorber and thermal mass. The materials do not have to be separate, however. Dark-tinted concrete, for example, can serve as both. The remaining element in the passive solar design diagram is distribution. In many passive systems, distribution is the gradual reradiation of stored heat from the thermal mass. However, it can also be augmented by mechanical means, such as fans and blowers, or joined with passive ventilation systems [19, 20]. Trombe walls can be thought of as a variation on the five passive solar elements described above. In a Trombe wall, the aperture becomes a larger area, and the absorber and thermal mass are placed parallel to the aperture with an air space in between. The air trapped between the aperture and the thermal mass serves to insulate the mass so that it does not lose its heat to the outdoors. Instead, the heat moves through the thermal mass towards the interior. Depending on the density and thickness of the mass, it arrives at the interior sooner or later. For example, if the mass is an eight-inch-thick concrete wall and heat travel through it at a rate of one inch per hour, then the heat will arrive indoors eight hours later or approximately at sundown when the outdoor air temperature starts to fall. By adding operable vents to a Trombe wall, even more control over heat dissipation can be gained. And by adding extra depth between the aperture and the mass, space can become useful as a greenhouse or sunroom [21]. A Trombe wall can be thought of as combining a type of solar thermal collector with added insulation. In fact, there are versions of the concept in which the thermal mass takes the form of vertical tubes of water. Essentially, a Trombe wall creates an intermediate layer that buffers the internal space from the external climate while moderating temperature swings (Fig. 8).

B. Solar orientation

For a building to effectively use thermal mass for solar gain or insulation, it has to be oriented advantageously. In practice, this means that the best orientation for a building is with its major axis running east-west so that it can have passive solar apertures facing south and offer an insulated barrier with fewer openings to the north. In a residential building example, the most efficient layout would locate frequently used daytime spaces to the south and more utilitarian or night-occupied spaces, such as bedrooms, to the north. South-facing windows, of course, are also subject to summer heat gain (as are east- and west-facing windows) unless they are shaded, as described earlier. North-facing windows, especially at high latitudes, should be smaller or high quality (or both) to minimize both heat loss and infiltration by cold northern winds. Solar orientation is not the only factor. Prevailing winds and natural or artificial obstructions figure into the equation as well. For instance, a cliff (or a high-rise building) to the south may undermine all your otherwise accurate planning [22–24].

C. Surface-to-volume ratio

A factor as fundamental as a building's overall mass and shape can be significant as well. Since heat loss and heat gain occur through the building's envelope, it follows that a building that has less exterior exposure will be more efficient. This means that multistory buildings-to a point-are more efficient than single-floor structures (assuming similar types of construction). This is one of the reasons why people living in cities have lower Eco-footprints than rural and suburban denizens. In general, the goal is to have a low surface-to-volume ratio, that is, as little exposed surface relative to the amount of interior space as possible. This is a bit at odds with some other design goals, especially daylighting. A large floor plate, for instance, may be more efficient for heating and cooling, but it means deeper, darker spaces farther removed from daylight, views, and natural ventilation [25–27].

D. Windows and glazing

Creating a sizeable southern exposure does not mean that an elevation should have as many windows as possible. There's a point of diminishing returns, determined by the size of the windows, their thermal qualities, the thermal qualities of the floor or walls that the sunlight falls on, and, of course, the climate patterns. A building in a hot region with a low-thermal-mass floor would not be a good candidate for a vast expanse of south-facing windows (unless it incorporated effective daylight controls). On the other hand, a building sited farther north with a stone floor and insulating windows might make great use of southern windows (provided that these windows are well-engineered). Window terminology has become a lot more involved than it used to be. In the 1960s, architects had a fundamental choice between single-pane and insulated, or thermal-pane, glass. In all but the most comfortable climates, insulated glass is now the minimum standard. The excellent choices include triple-pane, thermal-break, gas-filled, low-emissivity, and other options. To simplify decision making, Energy Star and the National Fenestration Research Council have devised a label that lists five qualities:

- U-factor is the inverse of the better-known R-value. It is a measure of a window's ability to prevent heat from escaping. A lower U-factor means less heat will escape. The ratings generally fall between 0.20 and 1.20.
- Solar heat gain coefficient (SHGC) is a measure of the window's ability to block incoming heat from sunlight. SHGC numbers are between 0 and 1, with a lower number indicating less heat transmission. In most cases, a lower number is therefore better.
- Visible transmittance is an indicator of how much light comes through the glass. Like SHGC, it has ratings between 0 and 1, with 1 indicating greater transmittance.
- Air leakage is an indicator of how much air passes by infiltration relative to the size of the window. It is expressed in cubic feet per minute per square foot of window (cfm/sq. ft.) As you might expect, less infiltration is better.
- Condensation resistance is how well the window resists the formation of condensation on the interior surface. Ratings are between 0 and 100, with a higher number indicating better resistance.

E. Insulation

Those yellow or fluffy pink strips of insulation, stuffed between studs and rafters, have become a ubiquitous symbol of increasing energy efficiency. Indeed, from a thermal barrier point of view, a frame wall without insulation is hardly better than no wall at all. Standard fiberglass insulation, however, has some significant drawbacks. It typically contains formaldehyde, and its fibers can be irritating or even dangerous, as anyone who has installed this type of insulation can attest. Furthermore, it is not good at filling gaps, particularly those around pipes and wiring. Although versions of it have improved (a few no longer contain formaldehyde, and some are made with recycled content), the issues with the fibers themselves and the difficulty of achieving a quality thermal barrier remain. There are alternatives to fiberglass. A predecessor is mineral wool, a humanmade fiber made from either mineral (called rock wool) or from blast-furnace slag (called slag wool). It is generally thought to be safer than fiberglass but is more expensive. A newer substitute is made from cotton or recycled denim. Its great advantage is that you do not have to wear a hazmat-type suit to install it, and since it is made from plants (unlike fiberglass), it is biodegradable [28]. Early versions of this material had a tendency to settle within the walls, resulting in less insulation at the top, but newer formulations and blowing techniques have minimized this problem. A significant advantage of loose fill over batt insulation is that it is better at filling gaps and less-accessible areas, such as those around intersections, electrical boxes, and pipes. Foamed-in-place insulation is even better at this. The installation involves spraying the foam, which then expands, filling gaps in the process [29]. There are two basic types of spray-foam insulations: open-cell and closed-cell. Open-cell foams expand much more than closed-cell, growing to as much as one hundred times their initial volume and yielding R-values of close to four per inch. Closed-cell expands comparatively less but is denser and creates a higher R-value per inch, as much as twice the open-cell R-value (Table 2).

F. Cool roofs

With thermal mass, the objective is to gather and absorb heat. On roofs, though, the goal is reversed. For a few reasons, especially in the summer, heat should be reflected away. One is to minimize heat gain inside the building. The typical dark-colored roof, whether asphalt shingle or a flat bituminous roof, is a great absorber useful in our thermal mass diagram, but not at the top of a building, where heat tends to accumulate. Another reason to reflect heat away is to address a phenomenon known as the heat island effect [30]. Typically, built-up areas are several degrees warmer than surrounding less dense neighborhoods. To a great extent, this is due to the percentage of surface area, especially for pavements and roofs that are covered with dark materials. Making roofs in light colors reflects much of that solar radiation and helps to alleviate both interior and exterior heat buildup. There are several rating systems for roofing materials. The most common gauge is albedo. It rates the degree of reflectivity of material, running from zero (for total absorption) to one (for total reflectivity). Energy Star–rated buildings with flat roofs must use roofing with an albedo of at least 0.65; those with sloped roofs require a material with an albedo of at least 0.25. A

Table 2. Comparison of R-values for some popular types of insulation

Common Types of Insulation	Fiberglass Batt	Rock Wool Batt	Cotton Batt	Cellulose Blown	Open-Cell Foam	Closed-Cell Foam
R/inch	3.1–4.30	3.1–4.00	3.1–3.70	3.7	3.6–3.8	5.8–6.8

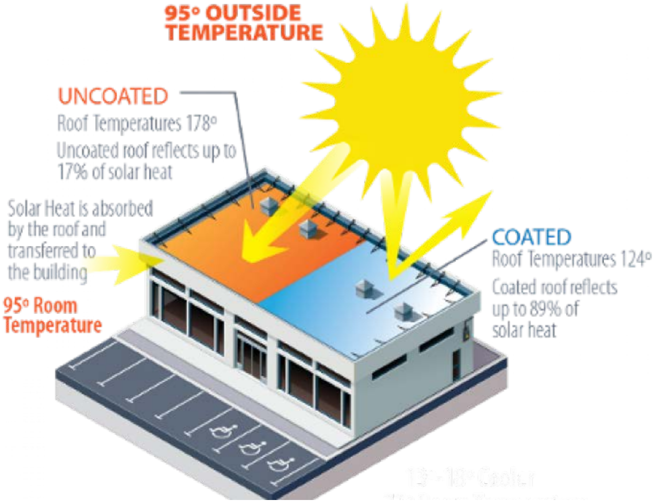


Fig. 9. Cool roofing diagram.

material's albedo may not adequately describe its heat-absorbing properties. A metal roof, for instance, may be highly reflective but also have low emissivity, causing it to heat up more than a nonmetal material with the same albedo (Fig. 9) [31].

G. Radiant barriers

Another method of reducing summer heat gain from roofs is to install a radiant barrier. This is a reflective surface- placed below the roofing and rafters or at the attic floor-that reduces the amount of solar heat that penetrates the attic or the upper story of the building. It can also help contain heat loss in the winter. For a radiant barrier to work, it needs to have an air space of at least $\frac{3}{4}$ inch adjacent to the reflective side of the barrier (which can face in or out). It is debatable whether it makes sense to use a radiant barrier in conjunction with a cool roof since the cool roof will already reflect much of the solar heat gain. It cannot hurt and will still assist with winter heat loss, but the cost may not be justified by the savings in air-conditioning. Radiant barriers do not help reduce the heat island effect; they are primarily for reducing internal heat gain and the resulting air-conditioning loads and generally affect only the upper story of a building. So, in a high-rise structure, the reduction of cooling will be less significant relative to the overall load. Similarly, the reduction in heat gain resulting from a cool roof (as with a green or vegetated roof) is felt only at the top of the building, whereas the reduction of the heat island effect is tied more to the ratio of the roofed area to open space and is unrelated to the height of the building (Fig. 10).

H. Ventilation and circulation

To this point, we have looked primarily at building envelopes regarding how to store heat or keep it in or out. That would be fine if our sole intention were to control the inside temperature and the building was in a climate where the outdoor temperature was not comfortable. Except perhaps for an arctic research lab, this is usually not the case. In most locations, there are times of the year or day when the outside air is pleasant, and it makes sense, if for no other reason than to save energy, to ventilate a building with that air rather than with mechanically conditioned air. Beyond that, there are periods when we can utilize natural ventilation in place of mechanical cooling, even when the outside air is less than ideal though it requires relearning some older, perhaps forgotten, techniques, as well as a better understanding of alternative natural systems [32]. The first rule of air movement (at least for this discussion) is that hot air rises. Over the ages, building designs have made use of this fact to enable air circulation, typically by creating chimneys or tall spaces in which rising hot air generates a draft, pulling air from the lower parts of the building. The process is referred to as a stack or chimney effect. This explains why open-front fireplaces make buildings colder: the movement of air up the chimney requires that outside air is drawn into the room to replace it. The hot air from the fire is sent up and out the chimney, while cold outdoor air is brought into the room. The only place that is warmer, aside from the chimney itself, is the area directly in front of the fireplace (Fig. 11).

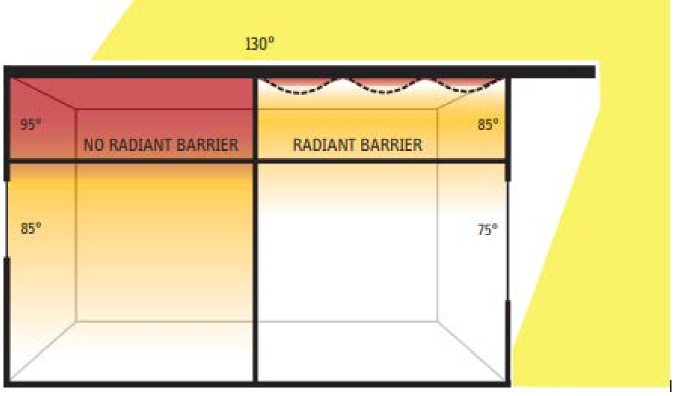


Fig. 10. The cooling effect of a radiant barrier.

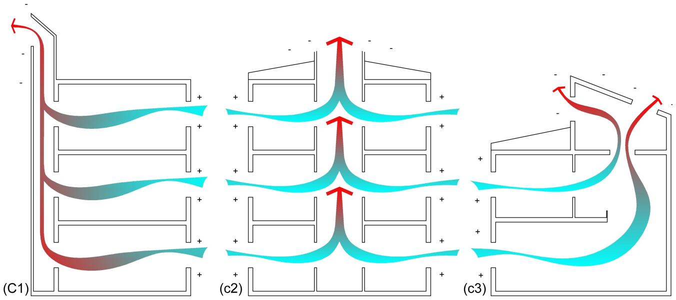
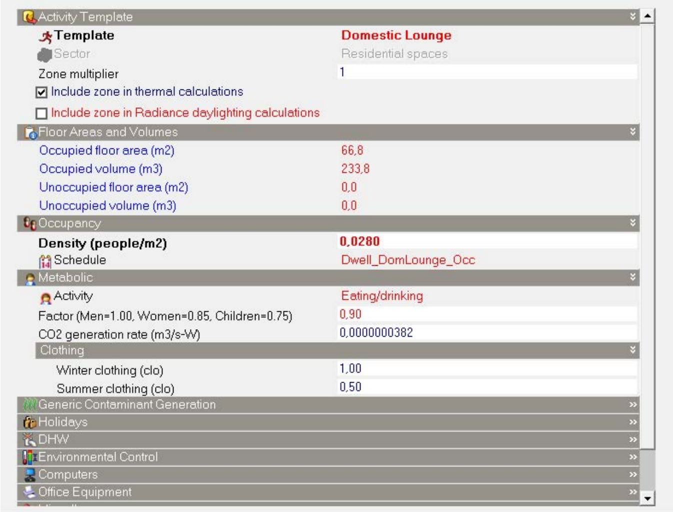


Fig. 11. Illustration of natural ventilation combining prevailing wind with the chimney effect [20].



Template: Domestic Lounge
Sector: Residential spaces
Zone multiplier: 1
☑ Include zone in thermal calculations
☐ Include zone in Radiance daylighting calculations
Occupied floor area (m2): 66,8
Occupied volume (m3): 233,8
Unoccupied floor area (m2): 0,0
Unoccupied volume (m3): 0,0
Density (people/m2): 0,0280
Schedule: Dwell_DomLounge_Occ
Activity: Eating/drinking
Factor (Men=1.00, Women=0.85, Children=0.75): 0,90
CO2 generation rate (m3/s-W): 0,0000000382
Winter clothing (clo): 1,00
Summer clothing (clo): 0,50

Fig. 12. Details of activities (Extracted from Design Builder).

5. SIMULATION AND DATA ANALYSIS

A. Energy optimisation of the "Green Roof"

Design Builder Ver. 4.5 was selected to carry out the green roof simulation and assess its thermal performance in this paper. In order to obtain the energy performance, two unreal residential building blocks with actual specifications (the dimensions of $11 * 7m$ with a floor area of $70m^2$ considering a 20 cm wall thickness) were modeled in the size of residential building blocks in each of the three studied cases. The thickness and types of layers in the bare and green roof are depicted in (Table 3).

According to Table 3, it can be said that a bare roof has five layers including gravel, bitumen, slab (concrete), cement mortar and plaster from the outside to the inside, and a green roof has seven layers including the vegetation layer, mud, natural rubber, bitumen, cement mortar, slab (concrete) and plaster from the surface to the inside, respectively. Furthermore, the Leaf Area Index (LAI) and other key green roof parameters used in the building models were based on the CIBSE Guide A [33] presented in Table 4. Also, Details of activities such as building function, occupancy, and metabolic rate can be observed in Fig. 12 and Table 5 as well.

Later on, in the study, the thermal performance of the bare and green roof was extracted in the simulation module of the Design Builder software and was placed in Fig. 13. It should be noted that all heating and cooling systems were shut down during the simulation. The purpose of this simulation is to evaluate the reduction of heat transfer from the roof to the exterior and vice-versa. Thermal properties of the bare roof layers such as U-Value ($0.447W/m^2 - K$), R-Value ($2.239\ W/m^2 - K$) and also thermal properties of the green roof layers including U-Value ($0.578\ W/m^2 - K$), R-Value ($1.731\ W/m^2 - K$).

Following the results obtained in Fig. 13, it can be expressed that the average bare roof heat transfer rate for Sydney was 0.21 in April, 0.13 in July and 0.06 in October; and the lost heat was -0.16 in January. Also, the amount of green roof heat transfer for Sydney was 0.10 in April and 0.09 in July, and heat loss in October and January was -0.12 and -0.32, respectively. Then, the average heat transfer rate for the bare roof for Adelaide was -0.11 in April, -0.25 in July and -0.50 in October and -1.56 in January was lost. Also, the amount of green roof heat transfer for Adelaide was -1.19 in April, -0.51 in July, and -0.41 in October and the heat lost in January was -2.26. The average heat transfer rate for Perth in April, July, October, and January were -0.07, -0.03, -0.05 and -0.4 of the lost heat, respectively. Also, the amount of green roof heating for Perth in April, July, October, and January were -0.48, -0.27, -0.27, and -0.9, respectively. Moreover, Fig. 14 shows the amount of heat transferred and received in one year on average for bare and green roofs in each month.

Table 4. Green roof model materials data on the software (Energy Plus)

Green Roof Plant	
Grass/straw materials - straw thatch (m)	0.1
Thermal Bulk Properties	
Conductivity ($W/m - K$)	0.4
Specific heat ($J/kg - K$)	11
Density (kg/m^3)	641
Height of plants (m)	0.6
Green Roof Thermal Parameters	
LAI	2.7
Leaf reflectivity	0.22
Leaf emissivity	0.95
Minimum stomatal resistance (s/m)	180
Max volumetric moisture content at saturation	0.5
Min residual volumetric moisture content	0.01
Initial volumetric moisture content	0.15
Surface properties	
Thermal absorptance (emissivity)	0.78
Solar absorptance	0.6
Visible absorptance	0.6

According to Fig. 5, it can be stated that the heat transfers and receptions for bare and green roofs in Sydney over a period of one year has been 0.06 and -0.025, respectively. However, this value for bare and green roofs is -0.605 and -1.89 in Adelaide, and -0.13 and -0.48 in Perth, respectively.

B. Natural ventilation evaluation of sydney

This simulation evaluated in Sydney as a case study. The residential building has 2 stories in which included the kitchen, living room, toilet and study room on the first floor and 3 bedrooms, toilet and small pantry with total 220 m^2 (Fig. 15). Natural ventilation was evaluated by orientation the building in three conditions included SSW 22.5, Southwest 45 and WSW 67.5 azimuth (degree). In the following the characterize of wind was provided.

Averaging at 13.8 km/h, November is the windiest month, whilst March is the calmest at 11.3 km/h. The prevailing wind annually is northeasterly. In the warm months, only 40% of the time Sydney would get wind directions from the northwest or southwest, which are the dry winds flown from the heated interior of Australia. Fig. 16 shows the wind rose diagram of Sydney from 2009 to 2018.

On this basis, the weather data (EPW) of Sydney imported to the BEopt software, and the site condition was set by that EPW file. After that, with the optimization module from the software, the simulation was run (Fig. 17).

Table 3. Conventional layers of bare and green roof (Energy Plus)

<table>
<tr><td rowspan="6">Outside</td><td colspan="7">Bare roof</td><td rowspan="6">Inside</td></tr>
<tr><td>Gravel</td><td colspan="2">Bitumen</td><td>Slab</td><td colspan="2">Cement mortar</td><td>Plaster</td></tr>
<tr><td>0.07 cm</td><td colspan="2">0.01 cm</td><td>0.2 cm</td><td colspan="2">0.02 cm</td><td>0.015 cm</td></tr>
<tr><td colspan="7">Green roof</td></tr>
<tr><td>Vegetation</td><td>Mud</td><td>Natural rubber</td><td>Bitumen, pure</td><td>Cement mortar</td><td>Slab</td><td>Plaster</td></tr>
<tr><td>0.1 cm</td><td>0.1 cm</td><td>0.04 cm</td><td>0.01 cm</td><td>0.02 cm</td><td>0.2 cm</td><td>0.015 cm</td></tr>
</table>

Table 5. Zone summary (Simulation Input Data)

	Area $[m^2]$	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume $[m^3]$	Gross Wall Area $[m^2]$	Window Glass Area $[m^2]$	Lighting $[W/m^2]$	People $[m^2$ per person$]$	Plug and Process $[W/m^2]$
Block	66.8	Yes	Yes	233.78	1	117.8	25	35.71	0
Total	66.8			233.78		117.8	25	35.71	0
Conditioned Total	66.8			233.78		117.8	25	35.71	0
Unconditioned Total	0			0		0			
Not Part of Total	0			0		0			

Based on Fig. 17, can be observed that the flow rate of natural ventilation for each sample separately. In this regard, the flow rate in the base model was 457 cfm which other three samples were compared with the base model. The flow rate of Sample 1 to 3 is 495, 551, and 519 cfm respectively which in Fig. 17 highlighted with blue color. On this basis, for results of the simulation can be said that sample 2 oriented with 45 degrees to Southwest it can be an exceeding optimal behavior on natural ventilation.

6. RESULTS AND DISCUSSION

A. Passive design techniques based on the findings

Considering only the Design Strategies that were selected on the Psychrometric Chart, 100.0% of the hours will be Comfortable. This list of passive Design techniques applies specifically to this particular climate, starting with the most critical first. These Passive design techniques are achieved by climate consultant:

- For temperate climates, lightweight construction, slab-on-grade, movable walls, and outdoor shading lead to traditional passive homes.
- Porches and patios with screening stand as a useful approach to face insect problems, passive comfort cooling is resulted by free ventilation for warm climates.
- Appropriate natural ventilation can minimize reliance on air conditioning systems in warm climates. Perfect shading and considering the best orientation to exploit from breezes.
- Hence, for the relatively comfortable climates, implementing shading as an answer to overheating and considering apertures and open surfaces for breezes in summer and providing heat gains from the sun as a passive heating strategy in winter are suggested.
- In hot and humid climates as well as in temperate climates, designing the building plan shaped to be a long narrow floor, can be advantageous since it provides maximum possible cross ventilation.
- In temperate weather conditions, wide overhangs on low-pitched roofs will also be beneficial.
- Cool or white-colored roof materials helps to minimize incident heat gains, and elimination of the glazing faced to the west reduces heat gains in the afternoon for the summer and fall seasons.
- To get the highest advantage of natural cross-ventilation, utilization of louvered doors with an open plan is reasonable, although if privacy is needed, jump ducts can act in a similar way.
- Another strategic action is to provide air movement and air circulation in the hot days of summer using fans, since it makes occupants feel about 2.8°C cooler and consequently, reduction in air conditioning demands occurs.
- Air conditioning could be eliminated by affixing overhangs and moveable sunshades (extending in the summer) on windows.
- The most efficient mass walls are the ones accompanying exterior insulations such as EIFS foam and putting the mass on the internal sections. Also, plaster and direct contact drywalls could be added.
- To produce stack ventilation, even when wind speeds are low, maximize the vertical height between the air inlet and outlet (open stairwells, two-story spaces, roof monitors).
- Arranging green materials such as trees, plants, bushes, and ivy-covered walls to minimize heat gains especially from the west side. The rain availability in the region for plant endurance should also be considered.
- Energy-efficient air conditioning systems like heat pumps have to be assessed to find out about the feasibility of having such systems in this climate.
- To have a passive solar heating concept in the building, windows have to face north in order to gain the possible sun radiation in winter. The windows were equipped with overhangs to prevent extra heating in the summer is also crucial.

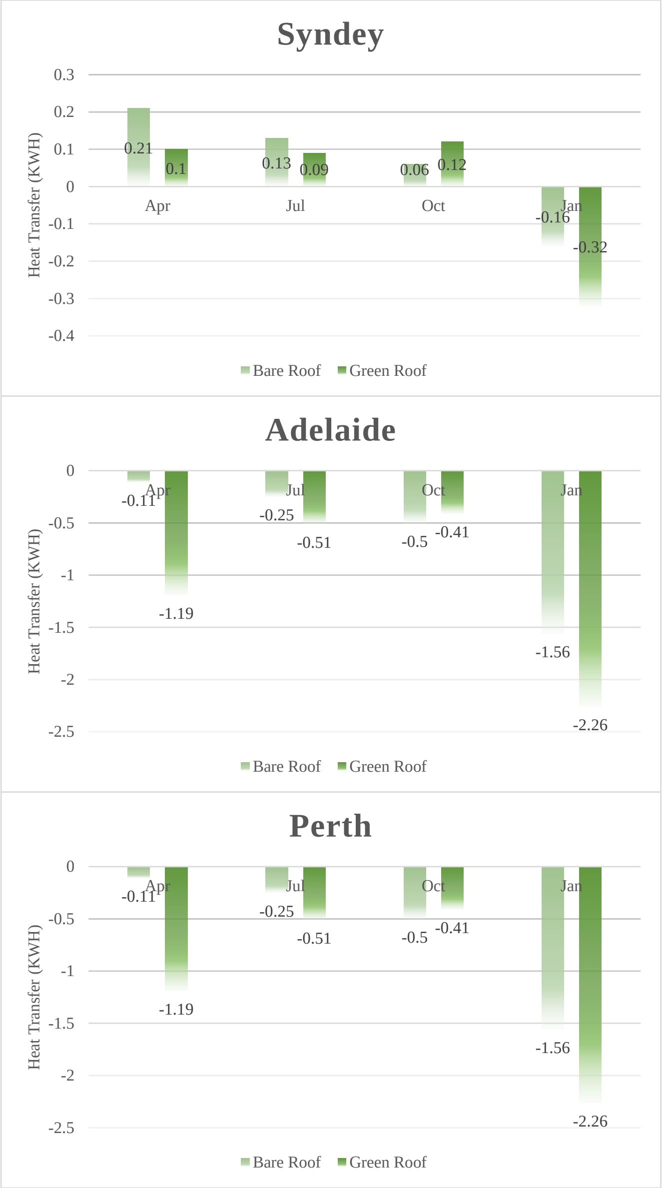


Fig. 13. Heat transfer of bare and green roof for each city in different months.

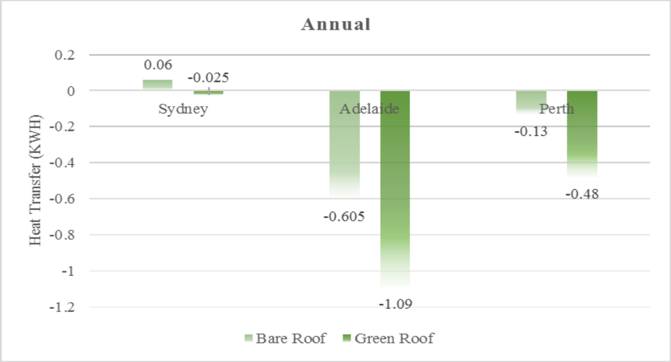


Fig. 14. Comparison of the heat transfer and reception of each city during a year.

Fig. 15. A case study in Sydney (Plotted by BEopt Software).

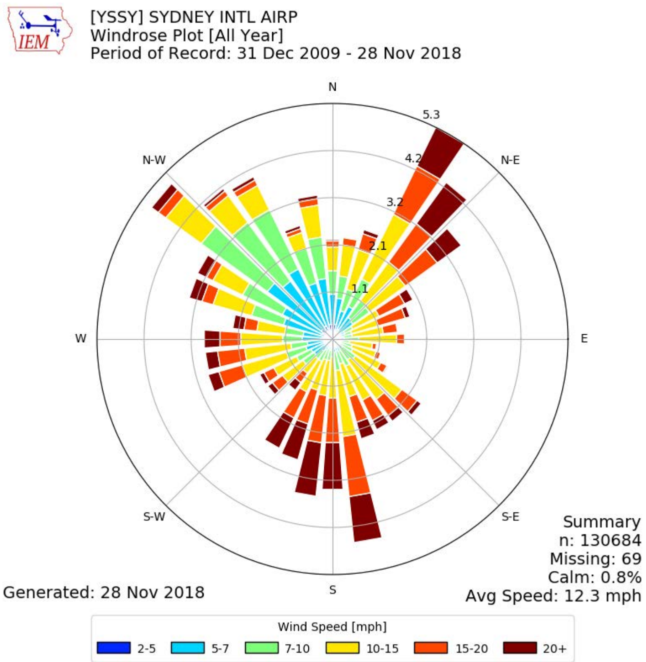


Fig. 16. The wind rose diagram of Sydney [34].

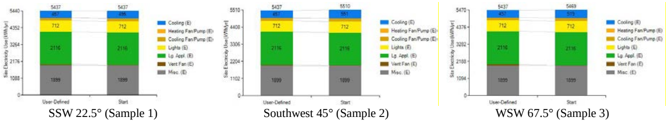


Fig. 17. Results of natural simulation.

- Utilizing large openings facing upwind and door and window openings on opposite sides of the building facilitate cross ventilation.
- Well ventilated attics and pitched roofs have a good impact on shedding rain. In an extended model, it protects porches and all the outdoor spaces of the building.

This study proposes to investigate the thermal performance and reduce the heat transfer of green roofs in four different climatic zones of Australia. Also, the second aim of current study was to evaluate the natural ventilation in Sydney with the various orientations of building.

7. CONCLUSION

The climate of a place is influenced by various micro-climatic features. The climate classification of the Bureau of Meteorology Australia has Sydney, Adelaide, and Perth in the same temperate climate zone. Similarly, the Building Code of Australia has them grouped together in zone 5. However, rigorous climate analysis of these locations revealed differences in climate conditions between these locations. This study identified the differences in temperature, humidity, sky condition, and wind intensity and its direction. All these features are major, considering climate as an integer parameter in urban planning and building design. Winter heating and summer cooling requirements together with available solar radiation and wind suggest different orientations of buildings and streets in all three locations. High heating degree hours for all the locations suggest securing sunshine in site and lot planning. Wind directions in different seasons and times are crucial to planning the outdoor open space for the summer and winter months. Thus, the variation in summer and winter open space is observed in all the cities. The higher summer temperature along with the higher diurnal temperature range means that in Perth, special attention is required in comparison to Sydney and Adelaide. Sydney has got warm and humid summers while it is hot and dry in Perth and Adelaide. The larger area of thermal mass in buildings is required in Perth and Adelaide along with evening or night ventilation which can ensure comfortable indoor conditions. The winter clear sky conditions in Sydney encourage the use of passive solar heating techniques while this is not the case in Adelaide and Perth due to overcast conditions. Finally, the research findings show that green roofs in Sydney can help reduce heat transfer in April and July. Also, the city of Sydney had the lowest heat transfer through the "green roof" on a yearly basis too. It is recommended to consider green roofs in the cities of Adelaide and Perth to improve buildings' thermal performances in terms of reducing heat transfer in these climates too. In fact, the main focus of the present paper was the thermal impact of green roofs as a suitable passive technique. Measurements are also compared for a bare and green roof with simulations for the various climatic conditions in Australia. Also, an annual evaluation of the thermal performance and heat transfer of extensive green roofs was performed. In the end, the simulation results of wind flow rate on Sydney showed that the building with 45 degrees orientation to Southeast could be optimal behavior on natural ventilation in compared that the other samples in which this among included 17% have better performance of the based model. In the following, compared with samples 1 and 3, also 10% and 6% respectively.

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