

Can passive design strategies deliver successful classroom design in the climatic context of Lima?

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Abstract

The thermic condition of a building is one of the cornerstones of architectural design. This dissertation investigates whether applying passive design strategies can create a successful classroom design for a tropical climate.

The research questions were answered through a quantitative thesis. First, passive design strategies for heating, cooling and lighting were analysed, before selecting those with the potential to improve existing thermal and visual comfort. These strategies were then applied to the IES Virtual Environment 2021 model of an existing building to determine its performance and impact on the different rooms. The building used as the case study was the Faculty of Architecture, Arts and Urbanism in Lima.

The results demonstrated that the application of a double-skin façade or as simple a strategy as adding eaves had a significant impact on the thermal or visual conditions of the building. Therefore, the use of passive design strategies applied in a particular context is both possible and necessary to improve the thermal and visual requirements of a building.

Acknowledgements

Contents

Abstract	2
Acknowledgements.....	3
Contents	4
List of Figures	6
List of Tables	8
Chapter 1. Introduction	10
1.1 Background	10
1.2 Aims and objectives.....	11
1.3 Methodologies	12
Chapter 2. Overview and educational spaces in Peru	13
2.1. Climate of Lima.....	13
2.2. Education in Peru	14
2.3. Base case building	15
Chapter 3. Learning from what exists.....	19
3.1 Temperature and thermal comfort.....	19
3.2 Neutral temperature.....	20
3.3 Relative humidity	21
3.4 Air movement.	24
3.5 Lighting.....	26
Chapter 4. Benchmarks and the base case	27
4.1 Adaptive thermal comfort.....	27
4.2 Visual comfort.....	30
4.3 Characteristics of the existing building.....	31
4.3.1 Roof and slab	31
4.3.2 Walls	32
4.3.3 Windows.....	33

4.3.4	Louvres	34
4.4	Base case test	35
Chapter 5. Passive design approach		42
5.1	Passive cooling.....	42
5.2	Passive heating	44
5.3	Natural lighting and shading ratio.....	45
5.4	Passive design strategies applied in educational buildings in Peru.....	46
Chapter 6. Simulation		52
6.1	Passive design strategies	52
6.1.1	Roof insulation	52
6.1.2	Roof chamber	55
6.1.3	Wall.....	57
6.1.4	Glazing systems.....	60
6.1.5	Louvres	63
6.1.6	Double skin	70
6.2	Results and analysis.....	76
Chapter 7. Conclusion		79
Reference list.....		81
Appendix		85

List of Figures

Figure 1 Location of Lima	13
Figure 2 Aerial photograph of the FAUA building in 1955 (Hiromoto, 2016).	16
Figure 3 Ground floor.....	17
Figure 4 First floor.....	17
Figure 5 Second floor	18
Figure 6 Axonometry FAUA building	18
Figure 7 Olgyay bioclimatic chart of Lima.	22
Figure 8 Givoni-Milne psychrometric chart of Lima's hottest months.....	22
Figure 9 Givoni-Milne psychrometric chart of Lima's coldest months	23
Figure 10 Cooling effect of air movement (Khedari et al., 2000),.....	24
Figure 11 Existing windows in the classrooms, workshop and office.....	34
Figure 12 Existing windows in the library	34
Figure 13 Existing louvres in the classrooms, workshop, and office.....	35
Figure 14 Existing louvres in the library	35
Figure 15 Number of hours above 28 °C (operative temperature ASHRAE Standard 55).....	38
Figure 16 Uniformity ratio base case.....	39
Figure 17 Average daylight factor % in base cases.....	40
Figure 19 UDI average lux in the workshop	40
Figure 18 UDI average lux in classrooms	41
Figure 20 UDI average lux in library.....	41
Figure 21 UDI average lux in office.....	41
Figure 22 UTEC (Iwan Baan, 2016).....	47
Figure 23 Edificio E (Cristobal Palma, 2016).....	48
Figure 24 Plan Selva (The Curry Stone Foundation, 2018).....	49
Figure 25 School of the native community of Chuquibambilla (Costa Foundation, 2016)	50
Figure 26 Roof strategy performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5.....	53
Figure 27 Roof strategy performance compared with the base case (PMV ASHRAE55 Adaptive >0.5).....	54

Figure 28 Roof strategy overheating hours	54
Figure 29 Roof chamber performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5	55
Figure 30 Roof chamber performance compared with the base case, PMV ASHRAE55 Adaptive >0.5	56
Figure 31 Roof chamber strategy overheating hours	56
Figure 32 Wall strategy performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5	59
Figure 33 Wall strategy performance compared with the base case, PMV ASHRAE55 Adaptive >0.5	59
Figure 34 Wall strategy overheating hours.....	60
Figure 35 Glazing strategy performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5	61
Figure 36 Glazing strategy performance compared with the base case, PMV ASHRAE55 Adaptive >0.5	62
Figure 37 Double glazing strategy overheating hours	63
Figure 38 Louvre strategy performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5	65
Figure 39 Louvre strategy performance compared with the base case, PMV ASHRAE55 Adaptive >0.5	66
Figure 40 Louvre strategy overheating hours.....	66
Figure 41 Louvre strategy average daylight factor in percentage	69
Figure 42 Double skin types	70
Figure 43 Double skin performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5	71
Figure 44 Double skin performance compared with the base case, PMV ASHRAE55 Adaptive >0.5.....	72
Figure 45 Double skin strategy overheating hours	72
Figure 46 Double skin strategy average daylight factor %.....	76
Figure 47 Number of hours between -0.5 and 0.5 of PMV ASHRAE55 Adaptive ...	78
Figure 48 UDI Values Louvre strategy L1	87
Figure 49 UDI Values Louvre strategy L2	88
Figure 50 UDI Values Louvre strategy L3	88
Figure 51 UDI Values Louvre strategy L4	89

Figure 52 UDI Values double skin strategy DS40	89
Figure 53 UDI Values double skin strategy DS40L	90
Figure 54 UDI Values double skin strategy DS80	90
Figure 55 UDI Values double skin strategy DS80L	91
Figure 56 UDI Values double skin strategy DS120	91
Figure 57 UDI Values double skin strategy DS120L	92

List of Tables

Table 1 Monthly mean air temperature (°C)	14
Table 2 Monthly mean relative humidity (%)	14
Table 3 Neutral temperature in hot climates.....	21
Table 4 Air velocities and thermal comfort (Lechner, 2015)	25
Table 5 ISO Standard 7730 Building Classification	27
Table 6 CEN Standard EN15251 Building classification.....	28
Table 7 Lima monthly comfort temperature (CIBSE TM52).....	28
Table 8 Lima monthly upper and lower comfort temperature (ASHRAE 55).....	29
Table 9 Roof construction materials.....	32
Table 10 Exposed floor construction materials.....	32
Table 11 Slab construction materials	32
Table 12 Exterior wall construction 25 cm.....	33
Table 13 Interior wall construction 15 cm.....	33
Table 14 Predicted Percentage of Dissatisfied above 20% (ASHRAE55 Adaptive - % hours in range)	37
Table 15 Predicted Mean Vote above +0.5 (ASHRAE55 Adaptive - % hours in range).....	37
Table 16 Predicted Mean Vote above -0.5 (ASHRAE55 Adaptive - % hours in range).....	37
Table 17 Base case UDI	39
Table 20 Rules for estimating required thermal mass in the direct-gain system (Lechner, 2015)	44
Table 22 Roof insulation types.....	53

Table 23 Roof chamber types	55
Table 24 Wall types	58
Table 25 Glazed type.....	61
Table 26 Louvre type	64
Table 27 Louvre strategy UDI values	68
Table 28 Louvre strategy uniformity ratio	69
Table 30 UDI values in Classroom type A.....	73
Table 31 UDI values in Classroom type C.....	74
Table 32 UDI values in Classroom type E.....	74
Table 33 UDI values in office	75
Table 34 Double skin strategy uniformity ratio	75
Table 35 UDI values in Classroom type B.....	85
Table 36 UDI values in Classroom type D.....	85
Table 37 UDI values in Classroom type F	86
Table 38 UDI values in the workshop.....	86
Table 39 UDI values in the library	87

Chapter 1. Introduction

1.1 Background

One of the main issues of architectural design is the interior conditions of the buildings. However, in our daily lives, we do not notice the relationship between thermal comfort and our daily activities since the body has several involuntary mechanisms that regulate our temperature. This is because ambient temperature changes all the time, so our body has to counteract these changes. For this purpose, the body has many ways of regulating itself to maintain an optimal 'core temperature' of approximately 37 °C. Any slight changes to this core temperature can harm our bodies. However, although our body has ways of adapting to environmental conditions, it also has some limitations. Even when the changes are small, they can be underestimated. However, there is a range of ambient temperature and relative humidity levels in which we experience 'thermal comfort', which also allows us to be more efficient.

Lee Kuan Yew said that workers in Singapore increased their productivity when air conditioning was installed in offices. This allowed people to work during the day, and not only in the cool mornings or in the evenings. People became thermally comfortable, which allowed them to become more focused and **productive** (Yew, 2009). This hypothesis was confirmed as researchers found that thermal comfort in classrooms is essential. A paper titled *Thermal Comfort in Classroom: Constraints and Issues* suggested that thermal comfort in classrooms improves the quality and effectiveness of teaching (Marzita Puteh, Mohd Hairry Ibrahim, Mazlini Adnan, Che Nidzam Che Ahmad, Noraini Mohamed Noh, 2012).

Many studies have tried to get an exact definition of what could be the optimal temperature range for thermal comfort in tropical zones, although there are plenty of studies on thermal comfort in cold zones. However, the body's climate adaptation plays an essential role because it will change the temperature range in which we feel comfortable.

Thermal comfort in tropical zones was initially studied by Webb in 1949. Then in 1948, Hawker realised a studio in Singapore, finding a 26.4° C, as a balanced temperature. Busch found that in air conditions buildings this temperature is lower,

24.5° C, and for naturally ventilated buildings is 4° C more, 28.5° C, Kwok in Hawaii 26.8° C for air-conditioned buildings and 0.8 ° C more for naturally ventilated buildings. (Nyuk HienWong, Shan ShanKhoo, 2003).

One mistake I have had to face in my professional practice is that people unrelated to architecture typically think spaces with heating, ventilation and air conditioning (HVAC) systems are better; it is related to status in some cases. However, from personal experience, I found that some HVAC systems provide an inadequate level of thermal comfort. The most common type of HVAC in Lima recirculates and cools the air, meaning that it maintains the same level of pollutants, viruses, and bacteria. This can result in discomfort due to the high level of contaminants and, in the worst cases, can facilitate the spread of disease.

On the other hand, the tendency nowadays is to use more passive cooling or heating strategies as they use a great deal of energy otherwise. Since energy consumption is becoming a topic of global concern, now that awareness is increasing of the environmental impact of excessive energy consumption, increased efficiency in the HVAC equipment and how it is implemented is imperative.

Global warming is causing extreme weather to become more frequent. In other words, extremes of heat and cold in many areas are experienced more frequently and with increasing severity. Therefore, buildings must be designed to withstand a broader range of external environmental conditions.

This dissertation hopes to find ways to improve the quality of design projects by seeking to apply passive design strategies to an existing building and to compare its performance with existing conditions in buildings in the climatic context of Lima; consequently, testing ways to improve the thermal and visual space conditions.

1.2 Aims and objectives

This dissertation aims to investigate whether passive design strategies could be effectively incorporated in a university classroom building in a hot and arid climate and whether it can achieve better thermal comfort without increasing energy consumption or the building's carbon footprint.

The aims will be answered by the objectives below:

- 1 Identify critical aspects of the climate environment.
- 2 Examine passive strategies.
- 3 Investigate thermal performance in a classroom building.

1.3 Methodologies

This dissertation aims to confirm the hypothesis that passive design strategies can deliver successful classroom design in the climatic context of Lima through a quantitative thesis.

I will examine bioclimate strategies, such as passive strategies for heating, like roof insulation or wall insulation, and for cooling, like shading or double-skin façades. In order to determine how to improve thermal comfort without increasing either the building's energy consumption or its carbon footprint, I will measure the quality of the indoor air, temperature ranges, relative humidity levels, and CO₂ concentrations.

In Chapter Two, I will present the context of the dissertation and the physical characteristics of Lima, such as its location, climate, and the historical moment regarding the construction of the building. Chapter Three will explain the basic concepts of thermal comfort, and Chapter Four will define the benchmarks and the main case study (base case). From this point, a series of passive strategies will be explored. Once it is determined which of these design strategies are most relevant for the particular building in this climate, based on the thermal needs of the rooms and what these methods can do, I will then analyse these strategies using the IES Virtual Environment 2021 software to create a simulation model. The base model will be the Faculty of Architecture of the National University of Engineering in Lima, which is a university classroom building. Finally, the last chapter will summarise the design and the conclusion.

Chapter 2. Overview and educational spaces in Peru

This chapter explains the context of the dissertation by describing the unique characteristics of Lima's climate, the educational situation in Peru over the last few years, and the principal characteristics of the building that is used as the base case.

2.1. Climate of Lima

Lima is the capital city of Peru with a population of 9,674,755 inhabitants (INEI, 2021). It is located in the central coastal part of the country, overlooking the Pacific Ocean, and is also the political, cultural, financial and commercial centre of the country.



Figure 1 Location of Lima

Lima is located at 12°, 03' S latitude and 77°,02' W and longitude, at an average elevation of 180 metres above sea level. Due to its latitude and altitude, Lima should have a hot climate. However, the presence of the Humboldt Current cools the air, saturates the atmosphere, and creates the mists that cause temperatures to stay mild, or warm, all year round. The predominant seasons are summer and winter, with rapid

transitions between the two occurring in May and November. Summers are hot and muggy, with occasional rains, mainly in the afternoon or evening. In contrast, winters are cooler and characterised by grey skies, breezy conditions, higher humidity, and persistent morning drizzle. The predominance of clouds makes the Lima area one of the cloudiest on the entire Peruvian coast. Lima experiences surprisingly little sunshine for its latitude, with an annual average of 1,250 hours. Humidity is always high and morning mists are frequent.

Table 1 Monthly mean air temperature (°C)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean max	30	31	29	27	25	24	20	21	22	23	26	27
Monthly mean average	22	24	22	20	19	18	16	15	16	17	19	21
Monthly mean min	17	18	16	16	15	15	14	13	13	14	16	17

Table 2 Monthly mean relative humidity (%)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean max a.m.	81	98	98	99	95	99	99	99	99	99	97	98
Monthly mean average	80	80	82	87	87	89	92	92	90	87	86	85
Monthly mean min p.m.	50	48	42	60	65	60	69	74	68	60	60	55

According to Koppen, **climate classification** identifies 25 different climate types. Lima is categorised as BWh (B: Arid, W: Desert and h: Hot) (Kottek, 2006). The first letter is related to the type of vegetation. In this case, Lima is in the second group, the arid zone. The second letter considers the precipitation, which in the case of Lima is scarce, or completely absent. The third is related to air temperature, which for Lima is higher than 18 °C.

Lima experiences non-extreme temperature changes due to the difference of day and night is less than 10 °C, likewise between stations. However, due to Lima's relatively high humidity, temperature changes often feel more extreme.

2.2. Education in Peru

Over the last decade, Peru has been looking to improve the educational quality of its universities. In 2004, the government created the National Superintendence of Higher University Education (SUNEDU) programme, with the intention of achieving a minimum standard of university education. One selection criterion was that

universities had to have basic infrastructure in place, such as classrooms, laboratories, libraries, etc. Any universities that could not meet these minimum standards were shut down.

These universities often took advantage of the non-extreme weather conditions in some Peruvian cities, including Lima, and they used their spaces in a way that was not appropriate to their objective. The usual practice was that they would use any building type as a classroom, meaning that the spaces were often inadequate. Moreover, since they were designed for other uses, and for people other than students, it is difficult to comply with the minimum lighting and ventilation, noise and reverberation policies for optimal operation as a classroom.

Even though there are regulations in place regarding the minimum size of classrooms, the number of windows or the minimum height of the ceilings, there are no regulations regarding thermal comfort. These elements highlight the fact that the mild weather conditions in Lima mean that the issue of thermal comfort in its classrooms has barely been studied.

2.3. Base case building

The building analysed in this dissertation is the Architecture, Urbanism and Arts College (FAUA) in Lima, which was designed by the Italian architect Mario Bianco in 1951. It was one of the first 'modern-style' buildings in Peru. The design of the building is characterised by following the principles of modern style with open plans for flexible use, the simplicity and clarity in the shapes, the use of rectangular and cylindrical forms, and the visual expression of the structure – in this case, reinforced concrete.

'For early days, modern masters like Le Corbusier and Oscar Niemeyer understood that Modernism in architecture ought not be transplanted globally without some recognition of its changed context... unfortunately much of work that passes for architecture in tropics today are unadulterated transplants from temperate

countries... justified in the name of the International Style.' (Joo-Hwa Bay, Boon Lay Ong, 2006)

Despite the technologies and knowledge of the time, Mario Bianco's work was characterised as having a great sense of place. It is expected that when the analysis of the building is carried out, many of the passive design strategies will have already been fulfilled.



Figure 2 Aerial photograph of the FAUA building in 1955 (Hiromoto, 2016).

The building is a rotated, H-shaped structure (see Figures 2, 3 and 4) with the upper horizontal wing housing the classrooms. The ground floor has seven classrooms grouped together into four types, with one of each type selected for the analysis. On the upper floors, there are four workshops, all of them having the same configuration. The vertical edifice has the library on the first floor and the hall on the ground floor; on the horizontal bottom, a construction with a lower ceiling, the administration area, and complementary classrooms. The auditorium and art room are in adjacent constructions.

'One of the most important contributions to Lima's architecture of that time is the management of circulations through pergolas and covered spaces, inviting the user to tour the complex without being exposed to climatic variations' (Dede, 2008).

This allows for the creation of shaded areas and microclimates that interfere with the airflow of the ground floor.

The classrooms, the workshop, the library and the office were selected for analysis. Classroom types A, B, C and D on the ground floor have windows with 1 m embrasures facing north and high-level windows facing south, Classroom types E and F have windows facing north and south, as well as skylight windows. The workshops are on the first and second floors. All of them are similar in composition, with windows with 1 m embrasures facing north and south. The library is on the first floor, with high-level windows facing east-west, and a big window facing south. The office has high-level windows facing north and 1 m embrasures facing south.

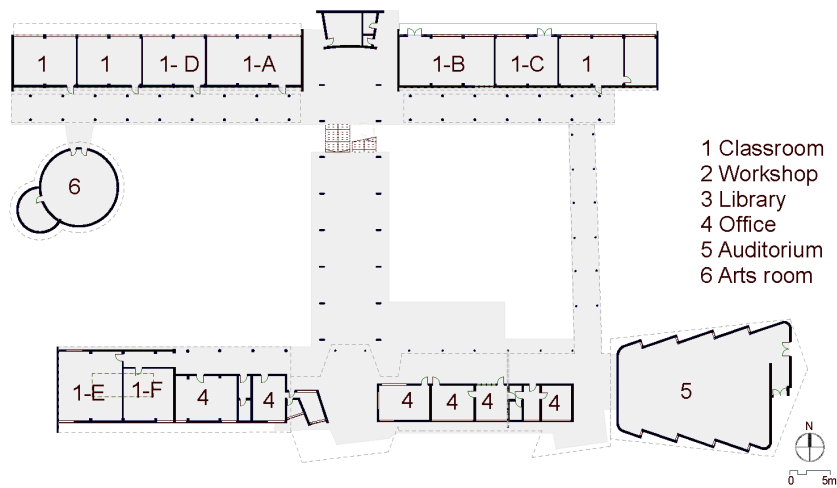


Figure 3 Ground floor

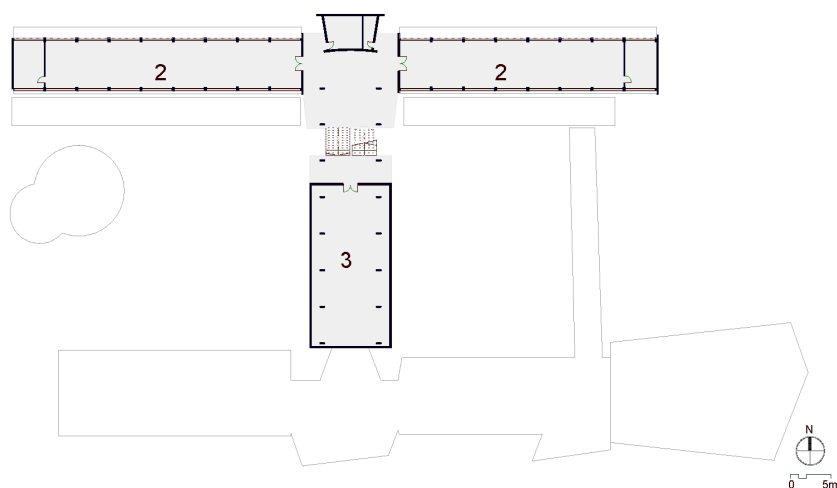


Figure 4 First floor

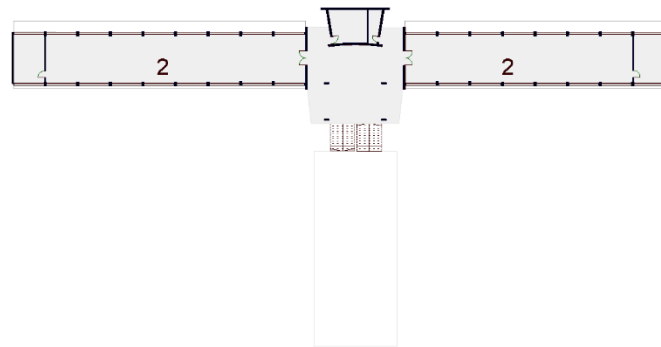


Figure 5 Second floor

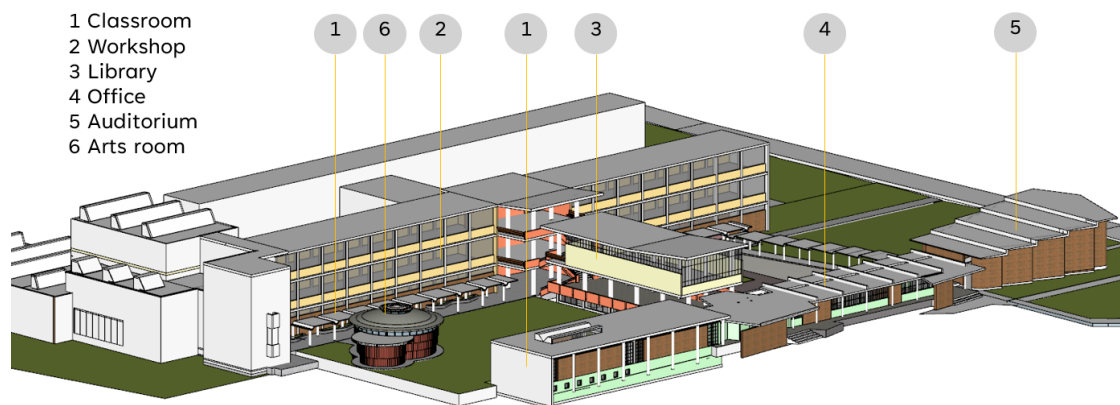


Figure 6 Axonometry FAUA building

Chapter 3. Learning from what exists

Over the last 50 years, there have been great improvements in the analysis of thermal comfort. These analyses have progressed from considering temperature, humidity, airspeed, and ambient temperature to considering more complex models, where sex, age, body constitution, menstrual cycle, ethnic grouping, light levels, etc. are also considered.

'In 1920... the use of fireplaces to control temperature was mandatory. In the second half of the nineteenth century, it was necessary to model the building as an open system and apply the laws of thermodynamics. Various electronic controllers were developed, which leads to the evolution of comfort monitoring. Fanger's comfort model introduced in the 1970s, based on physically based determinism and formulate comfort equation. The quality of air movement and sophisticated models which map both physics and physiology of the human body were also developed to build coherent, global thermal perception. These developments also are driven by energy efficiency. In the twentieth century, the focus goes to humans as the centre point of the design to improve the health and comfort of men and their homes' (Kanisius Karyono, Badr M. Abdullah, Alison J. Cotgrave, Ana Bras, 2020).

3.1 Temperature and thermal comfort

Our body cannot perceive temperature as an absolute number; the sensation of temperature is how quickly our body is losing or gaining heat. This gain or loss is related to the temperature and relative humidity, which are essential factors in thermal comfort.

According to Nicol et al. (2012), many authors in the 90s, such as Griffiths or Croome and Gan, found that the essential features regarding the user satisfaction of

buildings were the 'right temperature' and 'air freshness' (Fergus Nicol, Michael Humphreys, Susan Roaf, 2012).

By contrast, our body is continuously generating heat through two processes: one is metabolic generation, which assimilates and utilises energy from food, and which is unconscious, the second one is physical activity. The heat produced is lost to the environment by conduction (although very rarely, since we are covered by clothes and are not touching any large surfaces), convection, radiation or evaporation (Chitrarekha Kabre, 2018).

According to ASHRAE Standard 55, Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment (ASHRAE, 2020). Many authors have attempted to estimate a range in which the human being is in thermal comfort. However, as mentioned above, it depends on many factors. ASHRAE recommend a range between 19 °C and 28 °C for thermal comfort. Still, it depends on relative humidity and the Clo, which is the clothes value, which is also related to the season as summer and winter have different Clo values (1.0 Clo and 0.5 Clo, respectively).

The recommended temperature for a classroom, according to the ASHRAE Handbook - Heating, Ventilating, and Air Conditioning Applications for Teaching Spaces ranges from 21.87 °C to 25.3 °C in winter and from 23.8 °C to 26.7 °C in summer, with 60% relative humidity. (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, 2019), for CIBSE Guide A, this range is between 19 and 21 °C in winter and 21–25 °C in summer (CIBSE; Ken Butcher; Bonnie Craig, 2015). However, the temperature ranges of these guideline books are delineated for mostly cold climates, and is considered for spaces with HVAC.

3.2 Neutral temperature

Some researchers who focused their studies on tropical climates have found a temperature range beyond the values mentioned before. For example, Hien and Shan (2002) analysed several studies and found that the neutral temperatures for some countries with tropical climates are as follows.

Table 3 Neutral temperature in hot climates

Year	Research	Location	Temperature
1959	C.G. Webb	Singapore	25.94 ± 0.42°C
1978	K.R. Rao, J.C. Ho	Singapore	25°C
1986	M.R. Charm, S. Ali	India	28°C
1991	De Dear, Foo and Leow	Singapore	28.5°C
1992	J.F. Busch	Thailand	27.4°C
2002	N.H. Wong et al.	Singapore	28.9°C

3.3 Relative humidity

Relative humidity is the percentage relative to the moisture in the air and the amount of water vapour that it can hold. It is also related to the air temperature. For example, if the air temperature is 30 °C, the amount of water that can be held is 30.4 g/m³, while the amount for air at 20 °C is 17.3 g/m³. In a hot climate, relative humidity affects the evaporative heat loss from the human skin, thereby also affecting thermal sensation.

Some authors have developed climatic analysis tools, including Olgyay, Givoni-Milne and Mahoney. These tools are also related to temperature and relative humidity. Givoni and Milne also add 'wet bulb' temperature and absolute humidity, while Mahoney adds precipitation, intending to analyse the climatic conditions, and also gives some design recommendations (Santy, Hiroshi Matsumoto, Kazuyo Tsuzuki, Lusi Susanti, 2017).

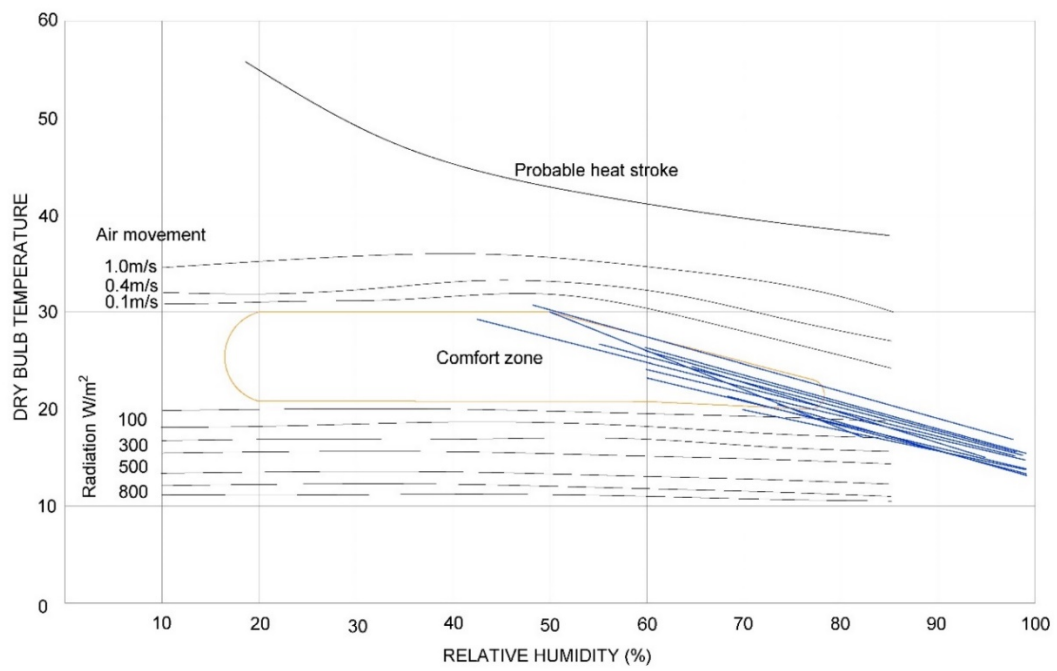


Figure 7 Olgyay bioclimatic chart of Lima.

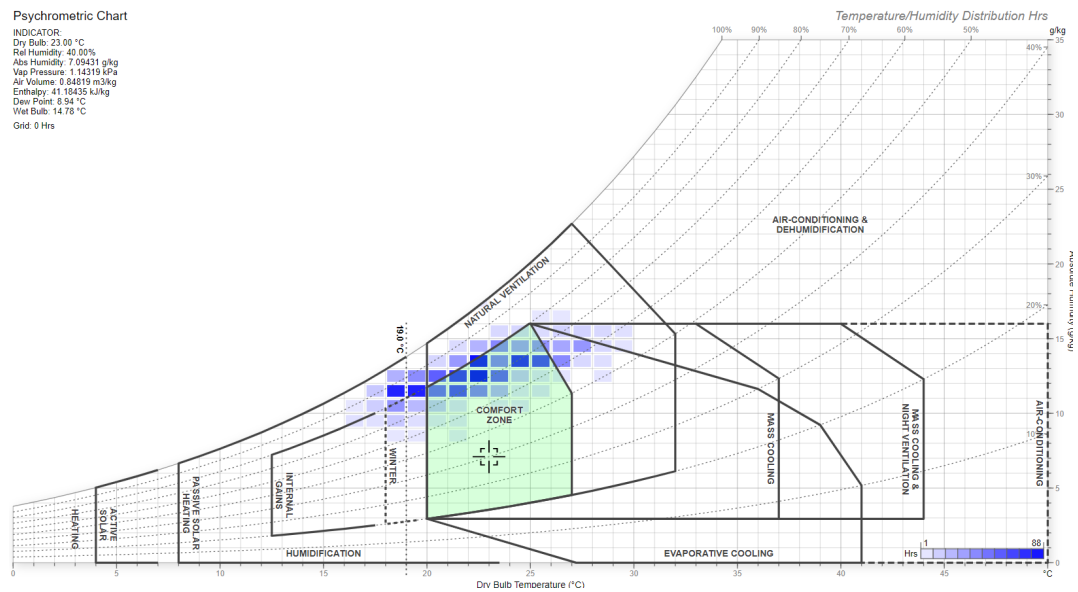


Figure 8 Givoni-Milne psychrometric chart of Lima's hottest months

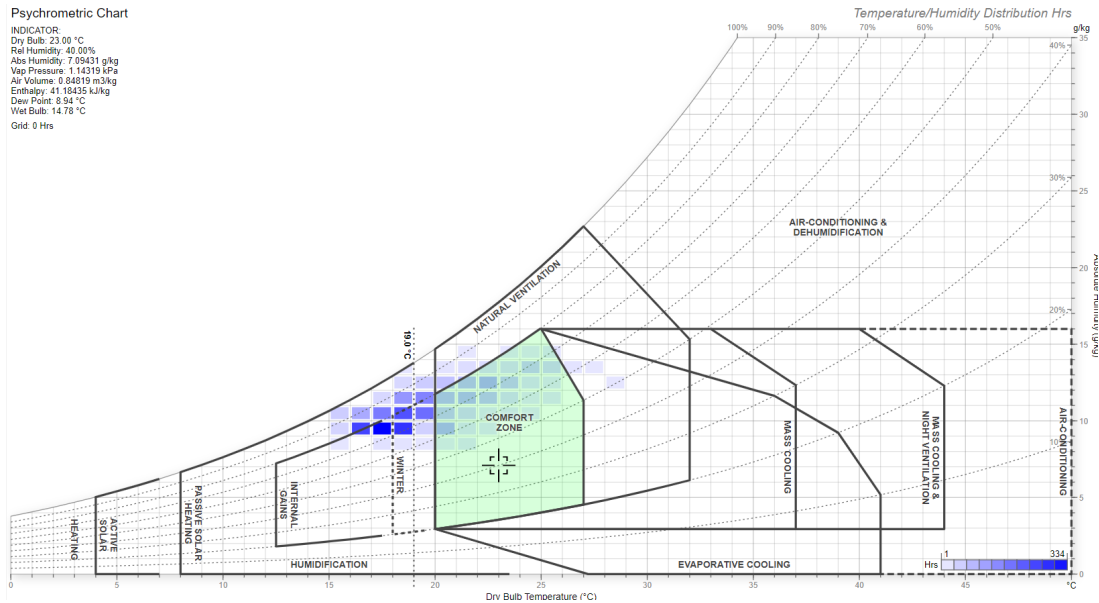


Figure 9 Givoni-Milne psychrometric chart of Lima's coldest months

In both cases, we can appreciate that Lima is significantly outside the 'comfort zone', and mainly rests in the area of lower temperatures and high rates of relative humidity. The Givoni-Milne and Olgyay recommendations are the same: natural ventilation in summer and internal gains and passive solar heating in the winter.

To reduce relative humidity rates, Paola Sassi, in her book *Strategies for Sustainable Architecture* (2006) outlines some suggestions.

Suggestions for avoiding excessively high RH.

- Provide adequate ventilation, focusing on areas that are sources of humidity, e.g., bathroom and kitchens.
- Insulate well and avoid cold-bridging.
- Avoid furnishings that are conducive to mould growth and the harbouring of dust mites (e.g., carpets).
- Considering using hygroscopic materials (e.g., unfired clay, timber, natural fibres, cork) and use permeable finishes (e.g., wax) to avoid sealing them.
- Considering using vapour-permeable wall constructions that allow excessive water vapour to escape the building (Sassi, 2006).

3.4 Air movement.

Our bodies produce heat constantly. In hot climates, one way to dissipate this heat is by the air movement around us (i.e., convection). The heat is removed by airflow from our bodies by turning our sweat from liquid to vapour. Still, the cooling effect is also dependent on other factors, such as humidity and temperature.

‘Precise relationships between increased airspeed and improved comfort have not been established. Under hot conditions 1 m/s is pleasant and indoor air velocities up to 1.5 m/s are acceptable. Above this, light objects may be blown... The skin is surrounded by a thin, still air layer that is close to skin temperature and insulates the body from its surroundings. Air movement decreases the thickness of this insulating layer and thus gives a cooling effect provided that the vapour pressure of air is lower than the skin vapour pressure’ (Chitrarekha Kabre, 2018).

A study was conducted in Bangkok, Thailand, a humid tropical condition, despite having different temperature conditions than Lima. Still, it gives an idea of the relationship between air movement and thermal acceptability. It also shows that the Thai people have a high-temperature tolerance compared to ASHRAE and ISO 7730. (Joseph Khedari, Nuparb Yamtraipat, NarisPratintong, JongjitHirunlabh, 2000).

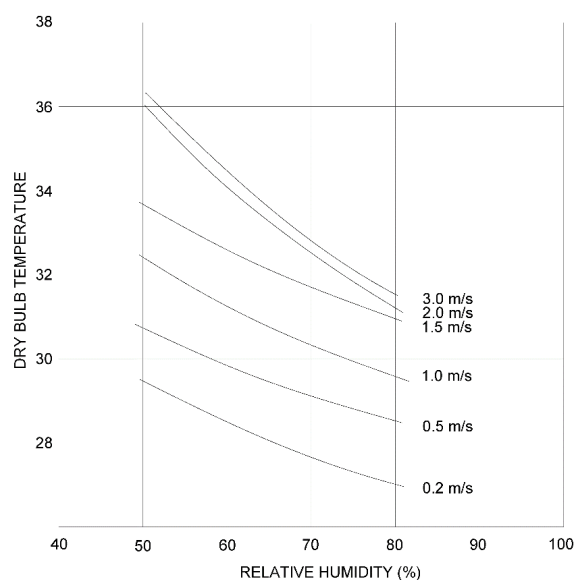


Figure 10 Cooling effect of air movement (Khedari et al., 2000),

Furthermore, Lechner (2015) provides us with a relationship between air movement and temperature reduction, and what it means for the human body.

Table 4 Air velocities and thermal comfort (Lechner, 2015)

Air velocity (m/s)	Equivalent temperature reduction (°C)	Effect on comfort
0.05	0.00	Slightly uncomfortable
0.20	1.10	Barely noticeable but comfortable
0.25	1.30	Design velocity for air outlets that are near occupants
0.40	1.90	Noticeable and comfortable
0.80	2.80	Very noticeable but acceptable in certain high-activity areas if air is warm
1.00	3.30	Upper limit for air-conditioned spaces, good air velocity for natural ventilation in hot and dry climates
2.00	3.90	Good air velocity for comfort ventilation in hot and humid climates
4.50	5.00	Considered a gentle breeze when felt outdoors

According to the CIBSE Guide, natural ventilation in a building must be designed to achieve two important aspects of the project.

- In order to improve air quality:
 - Extract ventilation to remove pollutants
 - Provide whole-building ventilation to dilute other pollutants
 - Purge ventilation, to avoid high concentrations of pollutants
- Reduce overheating in summer.

Also, they mention that the recommended whole-building ventilation rate is 10 liters/s per person. Similarly, it is suggested that mechanical ventilation should be provided, since naturally ventilated buildings cannot provide a constant ventilation rate, meaning that in some cases, the CO₂ concentration could surpass the recommended level of 1,000 ppm.

3.5 Lighting

Lighting conditions are essential in any space, even more so in an educational building, and artificial lighting is responsible for a considerable percentage of energy consumption, furthermore:

‘Sensitive designers have always understood that what we see is a consequence of both the quality of the physical design and the quality of light falling on it.’ (Lechner, 2015).

One of the main characteristics of the modern architectural movement is to have large windows set in horizontal bands as it facilitates the use of natural light in classrooms.

‘Daylighting was considered to be an important factor in the design of schools rather than in the design of any other building. The positive impact of daylighting in the performance of, the creation of a pleasant environment, the promotion of healthier conditions as well as the provision of energy saving’ (Aimilios Michael, Chryso Heracleous, 2017).

On the other hand, during the design process, it is necessary to be aware of the amount of natural light, as an excess can cause glare, which can cause serious problems. Moreover, according to Norbert Lechner (2015), visual performance is related to the amount of light. However, at around 500 lux there is a considerable increase in visual performance as light increases, while for light sources above 1000 lux, this performance improvement is diminished. In general, he mentions 300 lux for ambient lighting and overhead lighting for specific tasks (Lechner, 2015).

Chapter 4. Benchmarks and the base case

This chapter provides the background for the reference points that guide this thesis. First, the optimal ranges for temperature and light levels need to be established. For this, I will be using international regulations because thermal or visual comfort norms in Peru are scarce or non-existent. In addition, the base case for the analysis will be discussed.

4.1 Adaptive thermal comfort

To measure whether people are comfortable, the Predicted Mean Vote (PMV) index, which is a scale that goes from -3 (Cold) to 3 (Hot), will be used. It is calculated based on four measurable quantities: air velocity, air temperature, mean radiant temperature and relative humidity, and two expected parameters: clothing and metabolism.

The Predicted Percentage of Dissatisfied (PPD) index provides a quantitative prediction of the number of thermally dissatisfied people. When these two indexes are cross-referenced, because of individual differences, it is impossible to obtain a thermal environment in which everyone is satisfied; even in the 0 (Comfort) range, 5% of people are still dissatisfied. For this reason, the PPD ranges from 5% to 100%.

Three standards are used internationally to quantify comfort: ISO 7730, the ASHRAE Standard 55 (2010), and the Comité Européen de Normalisation Standard EN15251 (2007) (Fergus Nicol, Michael Humphreys, Susan Roaf, 2012).

ISO Standard 7730 uses PMV/PPD index and categorises buildings into three groups.

Table 5 ISO Standard 7730 Building Classification

Category	PPD	PMV
A	<6%	$-0.2 < \text{PMV} < 0.2$
B	<10%	$-0.5 < \text{PMV} < 0.5$
C	<15%	$-0.7 < \text{PMV} < 0.7$

ASHRAE Standard 55 divides buildings into two categories, of which 80–90% of the building occupants might expect to find the conditions acceptable.

The European standard (CEN) has three categories.

Table 6 CEN Standard EN15251 Building classification

Category	Description	PMV
I	High levels of expectation	$-0.2 < PMV < 0.2$
II	Normal level of expectation	$-0.5 < PMV < 0.5$
III	Acceptable	$-0.7 < PMV < 0.7$

Overheating in buildings is a problem with significant consequences and one that needs to be addressed due to the rising temperatures caused by global warming. CIBSE Guideline TM52 (2013) relates to air temperature, radiant temperature, humidity and air movement, as well as information about clothing and activity.

Moreover, it uses the equation suggested by ANSI/ASHRAE Standard 55.

$$T_{comf} = 0.31 T_{om} + 18.8$$

where T_{comf} is the comfort temperature and T_{om} is the mean monthly outdoor temperature.

Table 7 Lima monthly comfort temperature (CIBSE TM52)

Month	Mean (°C)	T_{comf} (°C)
January	22.00	24.62
February	24.00	25.24
March	22.00	24.62
April	20.00	24.00
May	19.00	23.69
June	18.00	23.38
July	16.00	22.76
August	15.00	22.45
September	16.00	22.76
October	17.00	23.07
November	19.00	23.69
December	21.00	24.31

CIBSE TM52 has three ways of measuring overheating.

Criteria 1: Sets a limit of hours that operative temperature can exceed the comfort temperature by 1 K.

Criteria 2: Establishes a daily limit of acceptability by measuring the frequency and duration of periods of overheating.

Criteria 3: Sets a maximum daily temperature for a room.

(CIBSE TM52, 2013)

ASHARE Standard 55 (2020) suggest the limits of acceptable operative temperature with the following equations.

$$\text{Upper 80\% operative limit } (^{\circ}\text{C}) = 0.31 T_{pma(out)} + 21.3$$

$$\text{Lower 80\% operative limit } (^{\circ}\text{C}) = 0.31 T_{pma(out)} + 14.3$$

where $T_{pma(out)}$ is the mean outdoor air temperature or prevailing mean, and the published meteorological monthly means for each calendar month (ASHRAE, 2020).

For Lima, these are the limits of operative temperature.

Table 8 Lima monthly upper and lower comfort temperature (ASHRAE 55)

Month	Mean (°C)	T _{upper} (°C)	T _{lower} (°C)
January	22.00	28.12	21.12
February	24.00	28.74	21.74
March	22.00	28.12	21.12
April	20.00	27.50	20.50
May	19.00	27.19	20.19
June	18.00	26.88	19.88
July	16.00	26.26	19.26
August	15.00	25.95	18.95
September	16.00	26.26	19.26
October	17.00	26.57	19.57
November	19.00	27.19	20.19
December	21.00	27.81	20.81

The Peruvian standard does not have a reference regarding thermal comfort. It does have the Technical Standard for Educational Infrastructure NTIE 001-2017 General Design Criteria (2017), which is a guideline on recommendations for educational space and has a chapter related to comfort, Chapter IV, which addresses issues such as thermal, visual and acoustic comfort. However, on the subject of thermal comfort, it only gives general design recommendations on ventilation, air renewal, UV-B radiation measures, etc. (MINEDU, 2017).

4.2 Visual comfort

There are several criteria used to measure natural lighting that are based on UK guidelines such as CIBSE or UK Department of Education guidelines and Peruvian MINEDU guidelines. For this analysis, I used the following: Useful Daylight Illuminance (UDI), Spatial Daylight Autonomy (SDA), uniformity ratio and daylight factor.

UDI 'is a daylight availability metric that corresponds to the percentage of the occupied time when a target range of illuminances at a point in space is met by daylight' (Azza Nabil, John Mardaljevic, 2006). This tool has some parameters regarding the percentages that we can obtain.

- Less than 100 lux is considered inefficient.
- A range of 100–500 lux is considered effective. However, for this report, I will be more accurate and consider a range of 200–500 lux as the CIBSE reconditions for office as a minimum lux parameter.
- Lux levels of 500–2000 are also desirable.
- More than 2000 lux, however, will cause thermal discomfort (Azza Nabil, John Mardaljevic, 2006).

Daylight Autonomy (DA) is the percentage of the annual daytime hours in which a given point in space is above a specific illumination level.

For the UK Department of Education, in the Output Specification Generic Design Brief, the recommendations for teaching spaces are 80% for UDI ranging from 100 to 3000 lux, and 50% for DA at 300 lux for the teaching spaces (Department for Education, 2020).

For the measurement of homogeneity in lighting conditions, the uniformity ratio is used, according to CIBSE Guide F, which is the ratio of the minimum illuminance to the average illuminance over the specified task area (CIBSE, 2012). Although this parameter focuses on measuring artificial illumination, it is also why CIBSE Lighting Guide 5: Lighting for Education (2011) recommended a uniformity ratio above 0.7 (CIBSE, 2011). It will help measure the homogeneity of the illumination in a room to ensure that there is no glare.

Daylight factor is the ratio of the light level inside the room to the light level outside, in relation to an unobstructed, overcast sky. It does have limitations, as it does not consider the building's location or the orientation of the façade and does not provide any indication of glare or visual comfort. After applying the strategies, however, the results must be above the limit recommended by the Peruvian norm.

According to Peruvian norms, it is recommended that the daylight factor should be above 2%. The range of lux values are as follows:

- Classroom : minimum 250 lux, recommended 500 lux.
- Workshops: minimum 300 lux, recommended 500 lux.
- Libraries: minimum 300 lux, recommended 350 lux.
- Offices and administration: minimum 250 lux, recommended 300 lux (MINEDU, 2017).

4.3 Characteristics of the existing building

The College of Architecture, Arts and Urbanism building has the following elements.

4.3.1 Roof and slab

The architecture of Lima is characterised by the use of lightweight materials in the roofs, which is mainly due to the general absence of rain or extreme weather. These weather conditions are also conducive to the building of flat roofs.

The roof is used only to generate shade and protect from the outdoor elements. Before the 1940s, the material used was *quincha*, which is made of reeds covered with mud. However, the building was built in the 1950s, meaning that the roof is constructed with modern materials such as bricks with reinforced concrete.

Table 9 Roof construction materials

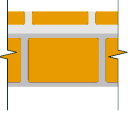
	Material layer	Conductivity W/(m*k)	Specific heat capacity J/(kg*k)	U Value W/m²k
	Cast concrete (10)	0.38	1000	1.4706
	Common brick (200)	0.62	837	
	Cast concrete (50)	0.38	1000	
	Brickwork (50)	0.84	837	

Table 10 Exposed floor construction materials

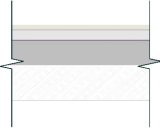
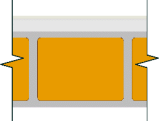
	Material layer	Conductivity W/(m*k)	Specific heat capacity J/(kg*k)	U Value W/m²k
	Gravel (150)	0.36	840	1.2248
	Cast concrete medium	1.4	840	
	Cast concrete light (35)	0.38	1000	
	Clay tile (15)	0.571	837	

Table 11 Slab construction materials

	Material layer	Conductivity W/(m*k)	Specific heat capacity J/(kg*k)	U Value W/m²k
	Cast concrete (10)	0.38	1000	1.4986
	Common brick (200)	0.727	837	
	Cast concrete (35)	0.38	1000	
	Clay tile (15)	0.571	837	

4.3.2 Walls

The walls of the architecture of Lima, like the roofs, are composed of lightweight materials; before the extensive use of bricks and reinforced concrete, it was customary to find buildings with adobe on the first floor and *quincha* on the second floor.

In the building, there is no difference between the interior and exterior walls except for the width; due to the way the brick is laid; on the exterior walls, it is used on the widest side and the interior on the thinner side, resulting in the two widths of the walls, 25 and 15 centimetres.

Table 12 Exterior wall construction 25 cm


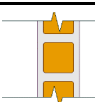
	Material layer	Conductivity W/(m*k)	Specific heat capacity J/(kg*k)	U Value W/m ² k
	Cast concrete (15)	0.38	1000	1.813
	Common brick (220)	0.727	837	
	Cast concrete (15)	0.38	1000	

Table 13 Interior wall construction 15 cm

	Material layer	Conductivity W/(m*k)	Specific heat capacity J/(kg*k)	U Value W/m ² k
	Cast concrete (15)	0.38	1000	2.4154
	Common brick (120)	0.727	837	
	Cast concrete (15)	0.38	1000	

4.3.3 Windows

Following the modern movement principles, windows are prominent in all the rooms. They are situated in the south and north, except for the library, which has windows on each side, a big window facing the south, and windows located high up on the other three sides. In addition, the classrooms and workshops have a ratio of 1:2 in width and height, the office has a ratio of 1:1.25 and the library is 1:2.5, which facilitates the airflow.

The section windows are made up of three panels – the lower and upper panels are top-hinged, and the middle one is fixed. This design allows for variable airflow: in winter, a stronger airflow removes pollutants from the air without cooling the occupants. However, in summer, the airflow can be increased so that it passes across the occupants.

The windows are composed of an iron frame and simple glass panels.

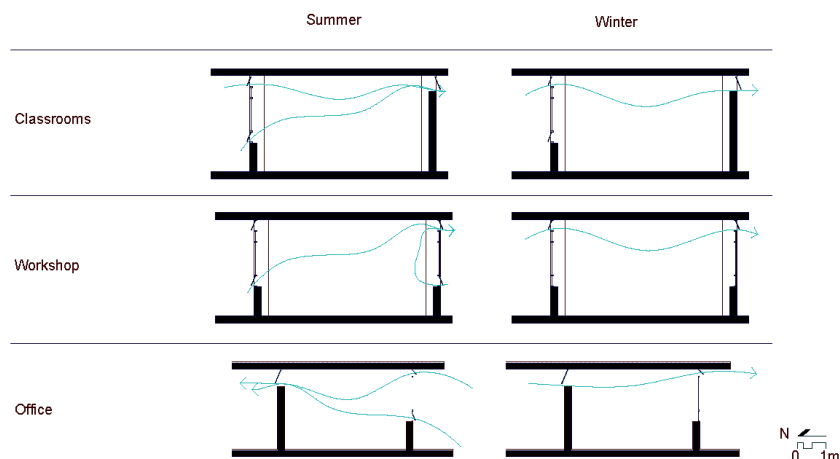


Figure 11 Existing windows in the classrooms, workshop and office

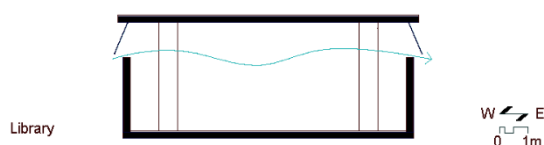


Figure 12 Existing windows in the library

4.3.4 Louvres

The windows have louvres to protect from direct sunlight in almost all cases; the only exception is Classroom type F.

The workshops and Classroom types A, B, C have this protection to the north and south, while the north-facing windows have a 65-cm horizontal louvred overhang designed to completely protect the windows from the summer sun. The same goes for the south-facing windows, which has a horizontal louvred overhang of 30 cm for winter.

Classroom type F only has protection from the south; the horizontal louvred overhand has 120 cm, enough to afford complete protection from sunlight in winter. However, the north façade has no protection, so the summer sunshine can enter the room. Classroom type E has similar characteristics, but the area is shared with a reception on the north side.

The office is protected from the sunlight on both sides. To the south, it has a horizontal louvred overhang of 100 cm, and in the north, is about 370 cm, which protects from the sun's rays throughout the summer.

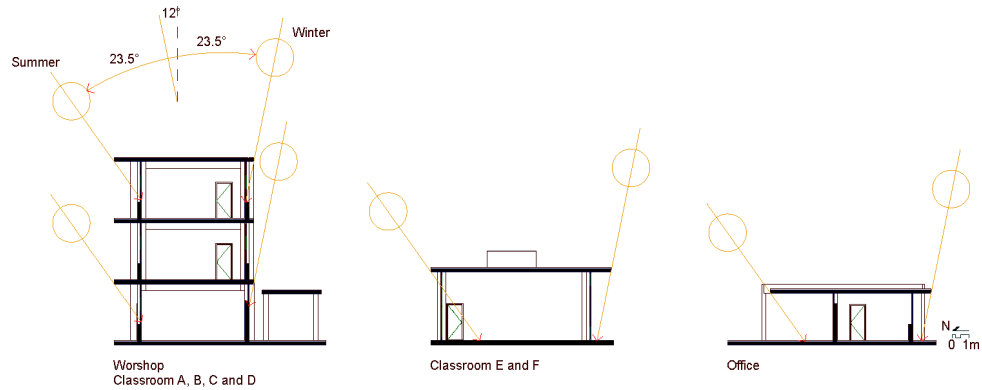


Figure 13 Existing louvres in the classrooms, workshop, and office

The library is the only space with windows on all sides. However, it only has protection in the south and north; on the south side, the horizontal louvred overhang is 100 cm, which protects the whole wall; on the north side, the protection is through the stair hall, and is 435 cm.

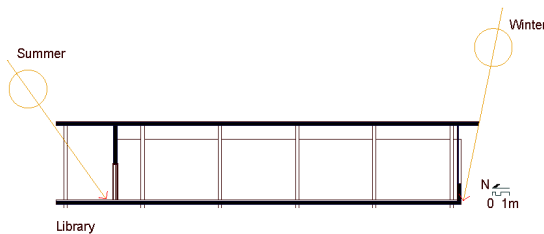


Figure 14 Existing louvres in the library

4.4 Base case test

The base case model in IES VE has the following configuration: as the windows are manually operated, the windows profile was configured to open when the temperature is 24 °C or the amount of CO₂ is higher than 800 ppm, in addition, in

order to simulate reality as much as possible, the HVAC, heating, or auxiliary ventilation systems were turned off in all the rooms.

As all mechanical elements that require energy for their operation were turned off, the EUI or energy consumed is not compared for the analysis. The factors to measure the performance of the strategies are thermal and visual comfort.

Thermal comfort was measured using the following tools.

Predicted Percentage of Dissatisfied (PPD). Between 5% and 20% of people were dissatisfied during occupied hours. The room with the lowest rate was the workshop with 36%, and the room with the highest percentage was Classroom type F with 41.8%. The following tools are complementary and explain the reasons for these percentages.

Predicted mean vote (PMV). This tool can show which people are above and below the comfort zone. For example, when the values are below -0.5, the room is too cold. The office, with 580 hours, had the worst value for this parameter. However, the rest of the room is not far away from this value.

On the other hand, when the values are above 0.5, the room is too hot. The building is in a humid desert, so it is understandable that the most significant number of hours is in this segment. The ambient temperature which has the highest number of hours, is the workshop with 2,222, which corroborates the PPD index.

As mentioned before, the PMV index is calculated on a base of six parameters. However, the temperature has a critical incidence. The following table confirms this since the temperature and the PVM index is correlated because the highest values are for the same rooms: the office and the workshop.

Table 14 Predicted Percentage of Dissatisfied above 20% (ASHRAE55 Adaptive - % hours in range)

Location	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Classroom type A	12.7	24	33.9	0.3	0	0	0	0	0	0	0	2.6
Classroom type B	7.1	16.7	23.1	0	0	0	0	0	0	0	0	0.9
Classroom type C	5.3	15.7	20.8	0	0	0	0	0	0	0	0	0.3
Classroom type D	13.6	24	31.3	0	0	0	0	0	0	0	0	2
Classroom type E	6.8	17.6	25.4	0.3	0.3	0	0	0	0	0	0	0.9
Classroom type F	7.1	17.3	22.2	0	0	0	0	0	0	0	0	0.6
Library	6.8	15.4	20.5	0	0	0	0	0	0	0	0	0.6
Office	2.7	7.7	10.5	0	0	0	0	0	0	0	0	0
Workshop	30.5	38.5	47.3	2.1	0.3	0	0	0	0	0	0.9	10.5

Table 15 Predicted Mean Vote above +0.5 (ASHRAE55 Adaptive - % hours in range)

Location	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Classroom type A	44.1	54.2	66.1	5.9	0.9	0	0	0	0	0	1.8	16.2
Classroom type B	33.7	48.7	56.4	3.6	0.3	0	0	0	0	0	0.3	9.1
Classroom type C	33.1	46.5	55.6	2.7	0.3	0	0	0	0	0	0	8.5
Classroom type D	44.1	53.8	65	6.2	0.3	0	0	0	0	0	1.2	15.4
Classroom type E	34.9	49.4	56.1	6.2	0.6	0	0	0	0	0	0	10.3
Classroom type F	38.8	51.6	59.8	4.1	0.3	0	0	0	0	0	0	11.7
Library	31.7	44.9	48.7	3.3	0.3	0	0	0	0	0	0.3	9.7
Office	21	35.6	38.7	0.6	0.3	0	0	0	0	0	0	5.1
Workshop	63.9	63.5	72.1	15.1	4.7	0.9	0	0	0	0	5.3	39.3

Table 16 Predicted Mean Vote above -0.5 (ASHRAE55 Adaptive - % hours in range)

Location	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Classroom type A	0	0	0	0	1.8	8.3	15.7	16	15.1	13.9	3.6	0
Classroom type B	0	0	0	0	1.5	10.4	14.8	9.5	19.8	17.8	4.4	0
Classroom type C	0	0	0	0	0.9	12.4	17.1	11.5	20.7	15.1	2.7	0
Classroom type D	0	0	0	0	1.5	8.9	16.2	16	15.4	12.1	3.8	0
Classroom type E	0	0	0	0	2.7	11.2	14	14.5	14.2	12.4	3.6	0
Classroom type F	0	0	0	0	0.9	6.8	20.8	21.3	15.1	10.1	1.2	0
Library	0	0	0	0.3	2.1	12.1	13.7	17.5	14.2	9.8	2.4	0
Office	0	0	0	0	7.7	19.8	9.4	7.1	19.2	12.7	4.4	0
Workshop	0	0	0	0	0.9	5.6	12.5	11.2	14.2	8.3	1.5	0

In contrast to the PPD and PMV index, which shows that the building performs poorly in thermal comfort, it performs excellently in the UDI index – far exceeding the benchmarks. All rooms were between 100 and 3000 lux over 80% of the time; however, most also had very high values – in the range of 500 lux and above.

According to the operating temperature limits of ASHRAE Standard 55, the number of hours that the rooms were at 28 °C are as follows.

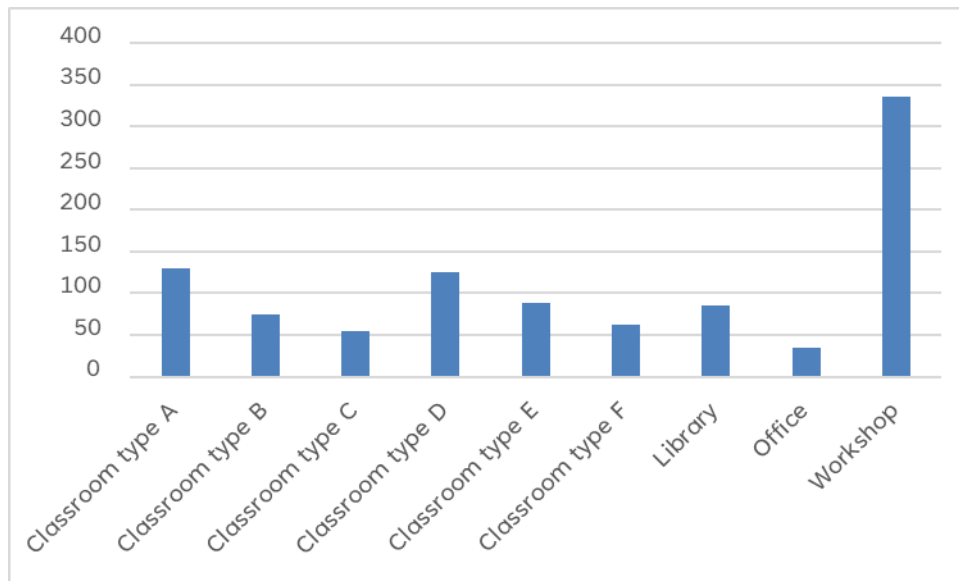


Figure 15 Number of hours above 28 °C (operative temperature ASHRAE Standard 55)

The workshop has the highest number of hours above the 80% limit suggested by the ASHRAE Standard 55 for naturally conditioned spaces. Presumably, this is because the space has a higher proportion of windows, which allows a significant amount of light, and therefore heat, to enter. The rest of the rooms have a similar number of hours, typically between 50 and 120.

It was also found that none of the rooms had temperatures below 19 °C, which is the lowest operative temperature.

A limitation found in IES VE 2021 is the overheating tool related to CIBSE TM52. The software tested the model between May and September, which are winter months in the southern hemisphere, reporting that all the rooms passed all three criteria.

Table 17 Base case UDI

Location	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
Classroom type A	0.0%	0.0%	100.0%	0.0%
Classroom type B	0.0%	61.0%	38.0%	0.0%
Classroom type C	0.0%	65.0%	34.0%	0.0%
Classroom type D	0.0%	14.0%	85.0%	0.0%
Classroom type E	0.0%	0.0%	93.0%	6.0%
Classroom type F	0.0%	0.0%	100.0%	0.0%
Workshop	0.0%	0.0%	100.0%	0.0%
Library	0.0%	0.0%	94.0%	5.0%
Office	0.0%	0.0%	100.0%	0.0%

All rooms are within 80% of between 100 and 3000 lux, as suggested by the UK Department of Education (2020). However, spaces such as Classroom type E and the library had a percentage of areas above 3000 lux. This can be seen more clearly in the following lux contour diagrams. This phenomenon occurs because there is a lack of solar protection in these spaces. On the other hand, Classroom types B and C had the lowest average lux, mainly because these spaces have fewer large windows facing north compared with the other classrooms.

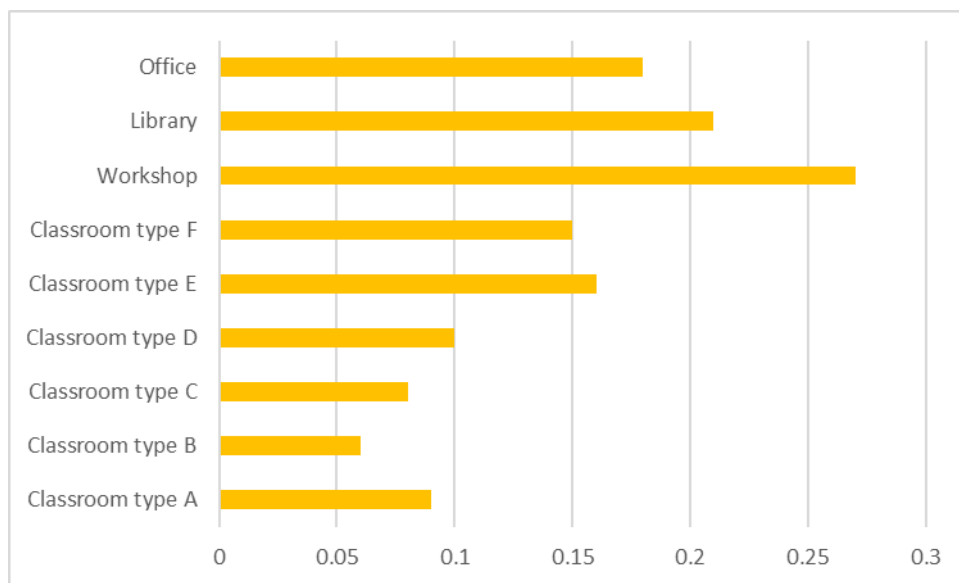


Figure 16 Uniformity ratio base case

As expected, the uniformity values are far from the reference value of 0.7. However, the spaces with the highest percentage of windows have the best results. By contrast, Classroom types B and C have the worst outcomes, as these spaces are irregular in terms of the location of windows and doors, which means they have fewer illuminated areas around the doors on the north side. Classroom types E and F also have irregular windows, but their uniformity values are approaching the mean since they have skylights.

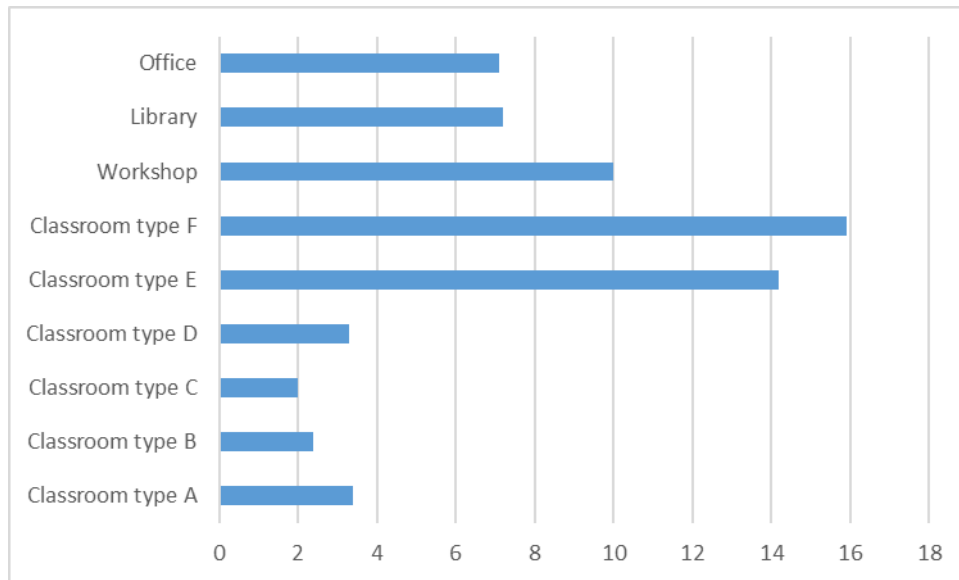


Figure 17 Average daylight factor % in base cases

In the average daylight factor test, all the rooms successfully reached the limits recommended by the Peruvian norm. However, Classroom types A, B, C and D were slightly above this benchmark because the proportion of windows in the other rooms are lower since these rooms only have a big window on the north side.

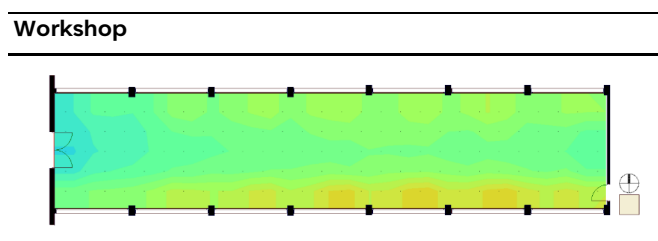


Figure 18 UDI average lux in the workshop

Classrooms

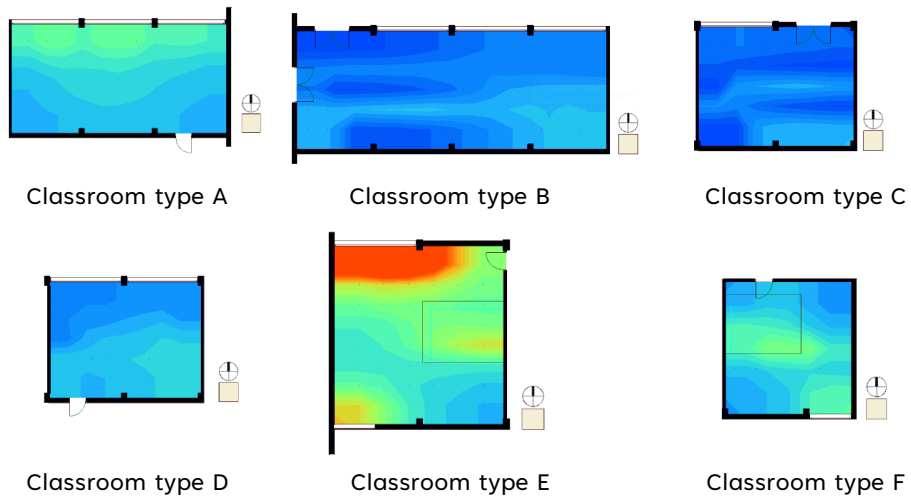


Figure 19 UDI average lux in classrooms

Library

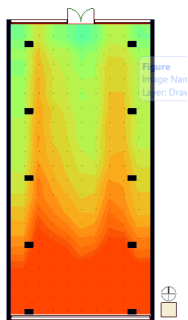


Figure 20 UDI average lux in library

Office

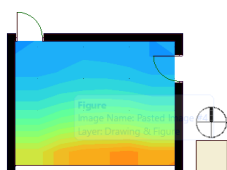


Figure 21 UDI average lux in office

Chapter 5. Passive design approach

The graphic of Givoni-Milne shows that buildings in Lima need to be warmer in winter and cooler in summer. This is corroborated by the building base case test. In summer, people experienced discomfort in approximately 50% of the hours, while this percentage dropped to about 15% in winter.

In this chapter, concepts related to passive design are explored. Lechner divided the concepts into three groups: cooling, heating, and lighting. Although he makes a distinction of what constitutes a tropical climate, this segment will be helpful in understanding how it will be applied in the buildings. Furthermore, it must be mentioned that passive strategies are not a new concept, as they have always been used. That is why there are many passive design studies that focus on vernacular architecture. Through trial and error, the people who inhabited them have found which one is best for each climate type.

5.1 Passive cooling

Passive cooling is the technique of maximising heat loss and minimising heat gain to keep the building interior comfortable, thus controlling the inside temperature.

According to Lechner, the first stage of cooling a building is heat avoidance; the building receives sunlight during the day. We can control these gains, by transferring the energy to the interior using shading devices, creating cool microclimates, or designing appropriate walls, ceilings, and floors. The second stage is passive cooling, using air movement, evaporating cooling, a reflection of radiation. This is recommended for hot and humid climates in particular. To maximise wind in this type of climate is imperative, so high canopy trees can be planted to provide shade. Additionally, solar chimneys can be used to augment the wind (Lechner, 2015).

A strategy to minimise heat gain is the use of double-skin façades, where air flows between the two layers, improves thermal comfort and works as an acoustic barrier. Indoor air can move naturally or be mechanically blown.

Advantages:

- Diffused lighting inside.
- Reduction in radiation.
- Reduces heat loss in winter and improves air circulation in summer.

Disadvantages:

- Costly to install.
- Requires a high level of maintenance.

On the other hand, using air movement, evaporation cooling and radiation reflection are all design strategies to maximise heat loss.

There are two types of ventilation: comfort ventilation and night flush cooling. Comfort ventilation draws in the outside air in order to pass it directly over the people. Night flushing, by contrast, consists of hot air being flushed out of the building during the night and is prevented from re-entering during the day. However, this method is not recommended in hot and humid climates such as Lima, because the differences between the night and day temperatures are not extreme enough to allow the building to be cooled sufficiently.

If the airflow generated by the pressure difference in the environment is insufficient, it is possible to apply the following strategies:

- Ventilated air chambers to avoid solar gains from the roof to the interior. The airflow stimulates heat loss by convection.
- The use of vegetation, where the shade produced by these elements generate cool areas, which cool the air from outside that enters the rooms.
- The chimney effect (Lechner, 2015).

Another strategy is to create a double roof layer, generating an air chamber, this strategy is also mentioned in the Peruvian norm (MINEDU, 2017). This is a similar principle to the double skin, with the goal of reducing the solar gains in the roof so that the space will create shade and increase the airflow around the building.

5.2 Passive heating

According to the Givoni-Milne psychrometric chart, internal gains are not enough during the coldest months due to the low temperatures and high humidity, moreover, this is corroborated in the base model test, where winter months have between 5 and 20% of hours below -0.5 in the PMV adaptive range. Consequently, passive solar heating is also necessary. This strategy consists of solar gains harnessing, using methods such as insulation of the building envelope, highly efficient glass layers, and building systems to avoid thermal bridging and filtration.

Insulation and thermal mass are typically utilised to reduce indoor temperature fluctuations. Furthermore, in cold climates, insulation is essential to prevent heat transfer from the inside to the outside, while thermal mass is necessary to store heat during the day and dissipate it at night. However, in a climate like Lima's, in which the temperature is both above and below the comfort zone, this method can be helpful in the colder months but detrimental during the warmer months.

According to Lechner (2015), the mass surface area is more important than the mass thickness. Furthermore, the thermal mass material must consist of dark colours, while the reflected material must be light in colour.

Table 18 Rules for estimating required thermal mass in the direct-gain system (Lechner, 2015)

Thermal mass	Thickness	Surface area to glazing area ratio
Masonry or concrete exposed to direct solar radiation	10- 15cm	3
Masonry or concrete exposed to reflected solar radiation	5 - 10 cm	6
Water exposed to direct solar radiation	15-30 cm	0.5
Phase change material exposed to direct solar radiation	2.4-10 cm	1

Lechner also mentions that there are three types of solar gain.

- Direct gain, for mild and cold climates.
- Indirect gain, for mild to very cold climates.
- Isolated gain, for cold to very cold climates.

Direct gain is a design strategy closely related to thermal mass. Usually, the sun warms the slab, which stores heat during the day and releases it at night. Therefore, it is crucial to analyse the shading elements in order to prevent this process from continuing in the summer.

5.3 Natural lighting and shading ratio

In tropical zones, direct sunlight must be blocked from every direction. It is also recommended that classroom buildings have north- and south-facing windows to protect from direct sunlight, and that reflected radiation is blocked. However, natural light provides a pleasant environment and promotes healthier working conditions, so making sure there is a decent view from the window is essential.

According to the Peruvian norms, the recommended window ratio for classrooms is 7–10% of the floor area (MINEDU, 2017).

Goals in daylight:

- Collect just enough light in summer.
- Reduce or prevent strong direct glare.
- Prevent excessive brightness ratios.
- Prevent or minimise veiling reflections from skylights.
- Diffuse the light.

One of the essential strategies for sustainable design is providing adequate shading because it decreases solar gain, which is a problem in almost every building, and much more so in a hot tropical climate. Using louvres can reduce a building's energy consumption.

Many types of glass are manufactured for use in buildings. However, those related to minimising solar energy gain and maximising natural light transmission are classified as follows.

'With fixed performance:

- *Heat absorbing glass,*
- *Solar reflecting glass,*

- *Solar control reflective polyester coated film glass,*
- *Low emittance coating glass.*

With variable performance (smart glasses):

- *Electrochromic glass,*
- *Thermochromic glass,*
- *Photochromic glass.’ (Chitrarekha Kabre, 2018).*

In the case of glazing, to ensure the best result in the design process, both the U-value and the shading heat gain coefficient must be taken into consideration.

5.4 Passive design strategies applied in educational buildings in Peru.

In the last thirty years, there was an expansion of the university education offer in Peru. Consequently, many universities buildings were constructed, and most of them are classroom buildings that fulfil their purpose but do not transcend beyond the proposed assignment. However, it is possible to find a couple of exceptions, Universidad de Ingeniería y Tecnología (UTEC) in Lima by Grafton Architects, winner of RIBA International Prize 2016, and Edificio E, the University of Piura in Piura by Barclay & Crousse Architecture, winner of The Mies Crown Hall Americas Prize in 2018. Furthermore, there are a couple of exceptional educational school projects, Plan Selva in 2016 and the school of the native community of Chuquibambilla in 2018.



Figure 22 UTEC (Iwan Baan, 2016)

UTEC was a contest where many offices around the world participated. Won by the Irish firm, Yvonne Farrell, co-founded Grafton Architects, in 2006 in an interview to CNN:

'It's an artificial cliff face hollowed out as if from solid concrete. It's a challenging building. Its beauty isn't skin deep. It's not a pretty package with a fancy ribbon around it. It's a framework for life that shakes beauty up a little.' (CNN, Glancey, Jonathan, 2016)

The UTEC, building have mainly four passive design strategies, the orientation, the form, the shading elements, and the use of thermal mass material.

The first strategy is the orientation of the building; it follows the shape of the land because it has a high-density program. Occupying the entire land, it has laboratories, classrooms, libraries, auditoriums, and offices. Then, as the architects say it is an artificial cliff, which follows the site's shape, it puts the essential rooms facing south as a strategy to keep them away from the noise of the adjacent highway.

The classrooms and laboratories facing south also allow eaves with a significant distance between them, which is favourable in the summer months, when the sun is on the opposite side of these rooms, allowing to enter more indirect light.

The second strategy is thermal mass; the complete building is in exposed concrete, far away from the conceptual idea. The purpose of this material is to be used as

thermal mass, and it will be used for cooling and retard heat transfer during the hottest days.

The third strategy is protection from direct sunlight; the form of the building helps to avoid direct sunlight since it is protected from the sun in summer with a big roof. Also, the classrooms face south since the louvres must be shorter, allowing a more flexible design without comprising the sunlight protection.

The fourth strategy is breakout rooms; the building has open spaces between the classrooms and laboratories that allow all of them to have cross-ventilation. Furthermore, the roof that protects the building from the north also protects these spaces, increasing the temperature and pressure difference, favouring air currents.



Figure 23 Edificio E (Cristobal Palma, 2016)

On the other hand, Edificio E was a direct order; the University of Piura needs to build a lecture hall to accommodate an increase in students expected to arrive, mainly due to the government's encouragement of students through undergraduate scholarships. The building was completed in 2016. Piura is on the north coast of Peru, near to Lima, in a hot desert. However, it is warmer with a maximum temperature of 34C, the building also have four manly passive design strategies, Location, thermal mass, sunlight protection and Landscape.

The first strategy is building distribution. It is located in an extensive land surrounded by carob trees. In the plans, it is an exact square with irregular forms in the interior. The classrooms and laboratories face north and south, while the circulation and offices face east and west, respectively. This distribution allows having a better location for classrooms. Furthermore, the circulation location also

protects the classrooms, creating an intermediate space that receives the morning sun.

The second strategy is the use of thermal mass, as in the UTEC building, they used exposed concrete as a thermal regulator to cool and retard heat transfer during the hottest days, especially in this place which is warmer so that in winter only slight protection from the weather is required.

The third strategy is direct sunlight protection. This protection is designed as a large roof that accommodates social interactions rather than just a classroom building. Consequently, this building also has breakout spaces between the main program, which facilitates the creation of different temperatures and low-pressure, creating air currents. Also, the windows have eaves that protect from direct sunlight.

The fourth strategy is the use of landscape. The building benefits from the existing vegetation that creates shade and cool currents entering the building.



Figure 24 Plan Selva (The Curry Stone Foundation, 2018)

Plan Selva is a Peruvian government program that provides for the modular and systematic construction of 1,000 schools in remote jungle areas where native cultures live. To these exceptional circumstances, the developed program required management and pedagogical innovation as pillars. In 2016 he won the highest award given by the Peruvian architecture society, Hexagon de Oro (Golden Hexagon).

The floor is raised above the natural terrain to protect the usable area from ground moisture.

Walls are designed to promote ventilation and diversify and organize interior spaces as they are practical surfaces that can be used as furniture.

The project was conceived to use wood as a local sustainable material. However, due to the lack of local certification, which would lead to encouraging illegal logging due to the amount it would require, it has switched to metal as the structure material.



Figure 25 School of the native community of Chuquibambilla (Costa Foundation, 2016)

The school of the native community of Chuquibambilla was designed by Marta Maccaglia, from Asociación Semillas, and AMA + Bosch Arquitectos. In 2018 Marta Maccaglia won the Global Award for Sustainable Architecture, this prize is under the Patronage of UNESCO. This project is characterized by the sensitivity of its conception, since it involves the community in the design and construction process. In addition, the school is not only used by children but also by the population in general. And following the practices of sustainable design, the passive design was applied in the project.

Located in a hot climate in the jungle of Peru, this place has an average temperature throughout the year of 34 °C as a maximum and 19 °C as a minimum, with an average relative humidity of 77%. The passive strategies of the project are as follows.

Use 30° pitched roofs to protect from the high rainfall. And, the difference of height is used to install high windows to increase cross ventilation. The roof has overhangs to protect from direct sunlight, which in turn generates the circulation space.

The surrounding vegetation is used to create microclimates and shading to reduce the temperature of the air entering the rooms.

Having higher temperatures than the previous projects, the thermal strategy is different. Ventilated bricks are used as masonry, which also increases air flow, and the project uses solar panels to power the computer lab.

Both university buildings share the primary strategy, a big roof that allocates social interactions, spaces between core programs, and spaces that result from their irregularity. It should be noted that both buildings have asymmetrical shapes as a design principle, since according to Peruvian regulations, due to the occurrence of earthquakes, these structures are essential for society in case of the manifestation of these and must meet the highest structural standards, one of them being symmetry and homogeneity. Still, these anomalies in the forms create the spaces of socialization which in turn generate microclimates that benefit thermal comfort.

On the other hand, both projects of schools in the Peruvian jungle are separate structures with a freer organization, united by the roofed circulation to promote ventilation using ventilated walls. However, they share with the university classrooms the strategy of the cantilevered roof to protect the classrooms from direct sunlight.

Chapter 6. Simulation

In this chapter, several passive design strategies are analysed and applied to the existing building model in IES VE.

6.1 Passive design strategies

The passive design strategies were selected according to the base case analysis and the passive design approach. It should be noted that the building already has passive design strategies implemented, including orientation and louvres.

Additionally, the primary strategy suggested by Lechner (2014). The building's classrooms are oriented in an east-west direction, which is the recommended location for classrooms in tropical climates. Also, as mentioned in the previous chapter, horizontal louvred overhangs are designed according to the sun's pathway. In addition, dissertations were reviewed in which passive systems were applied in tropical climates.

6.1.1 Roof insulation

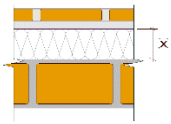
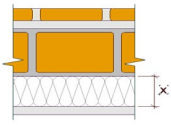
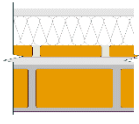
Alvarado and Martínez (2008) showed that a simple passive strategy, aluminium with polyurethane insulation over a concrete slab, had a reduction of the thermal load by 70% and successfully controlled thermal fluctuations on residential buildings in a hot climate such as Puerto Rico (Jorge L. Alvarado, Edgard Martínez, 2008).

Another passive roof strategy is the use of planted roofs. Hodo-Abalo et al. (2012) studied planted roofs in a tropical climate and demonstrated that foliage density and, therefore, choice of canopy type, greatly influences thermal efficiency because leaves reduce the solar flux penetration (Samah Hodo-Abalo, Magolmèèna Banna, Belkacem Zeghamati, 2012). However, planted roofs could be problematic in Lima, as it does not experience significant rainfall.

Insulation will be applied to a roof to reduce heat transfer from solar gains, and our analysis will test different widths of this element. In addition, the insulation will be placed above and below the slab. Group A has insulation above the slab, Group B has insulation below. These two first groups have elements with insulation thicknesses of 100, 300 and 500 mm. Finally, Group C will have a layer of insulation

which is then covered with a thin layer of aluminium. In recent years, this method has become popular in Peru due to its thermal properties.

Table 19 Roof insulation types

Type		Insulation thickness	U Value W/m ² k
	RIA1	100	0.2384
	RIA2	300	0.0921
	RIA3	500	0.0571
	RIB1	100	0.2384
	RIB2	300	0.0921
	RIB3	500	0.0571
	RIC1	150	0.151

For the performance analysis, only rooms in direct contact with the roof were chosen. During the winter, Group B was observed to have a better performance in almost all the rooms. It was observed that insulation is a progression in the reduction of the hours of thermal discomfort. However, there is not a significant difference between 300 and 500 mm of insulation (RIB2 and RIB3). On the other hand, the addition of aluminium does not have a differentiated impact.

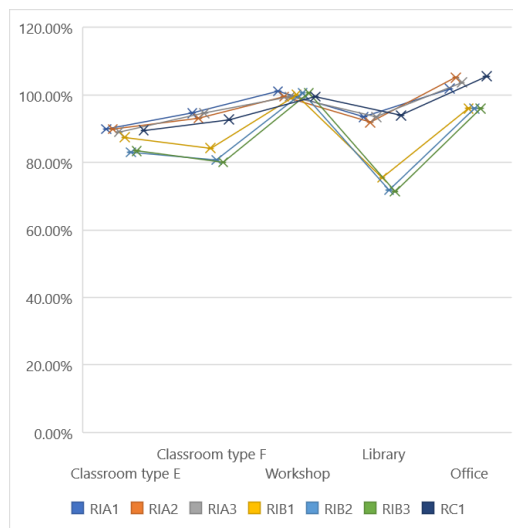


Figure 26 Roof strategy performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5

In summer, the opposite was observed, with Group B having the worst performance. However, no significant relationship was observed between the thickness of the insulation and the diminution of hours of thermal discomfort for either group. Furthermore, the RIC1 option has the same performance as group A. In these months, it also has a similar impact on the thermal comfort of the rooms.

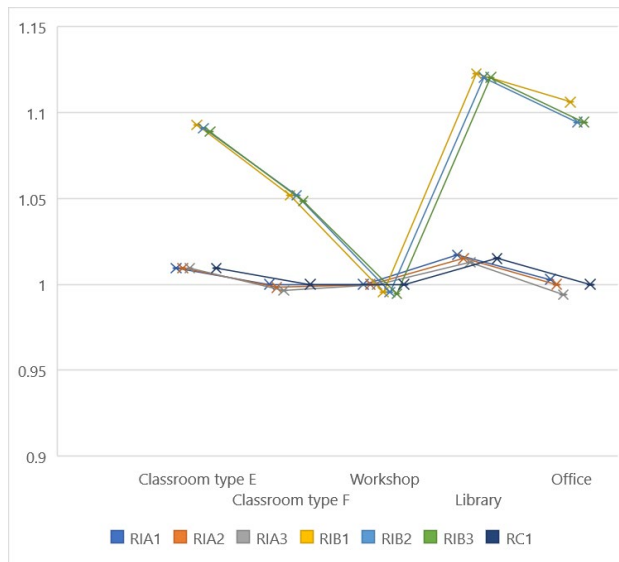


Figure 27 Roof strategy performance compared with the base case (PMV ASHRAE55 Adaptive >0.5)

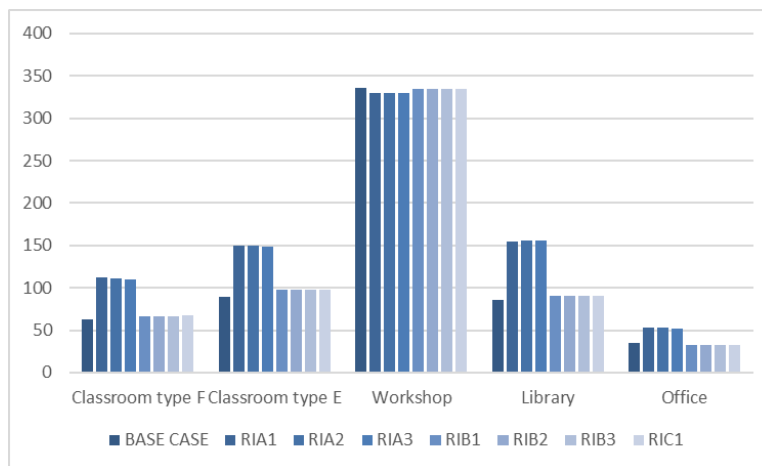


Figure 28 Roof strategy overheating hours

Almost none of the strategies have a positive impact on reducing the number of overheating hours. There was a slight improvement of about 10% in the office with the insulation below the slab, Group B, and the RIC1 strategy. In contrast, the most

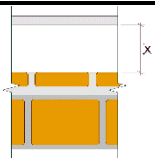
striking increment in overheating hours is the insulation using the ‘above the slab strategy’, Group A, with about 80% in the library, and in Classroom types E and F.

6.1.2 Roof chamber

The guideline Technical Standard for Educational Infrastructure NTIE 001-2017 General Design Criteria (2017) recommends in the case of pressure differences between the exterior and interior or in the incident winds do not generate enough air movement, the use of ventilated roof chambers.

Three ventilated roof chambers will be analysed, differing in height.

Table 20 Roof chamber types

Type	Cavity (cm)	
	DR1	50
	DR2	100
	DR3	150

In winter, almost all the typologies have an excellent performance with a direct relationship between the height and the reduction in the number of hours of thermal discomfort seen. The typology with the greatest amount of air between the roofs achieves the best result, especially in classroom F, with a 44% reduction in the number of hours of thermal discomfort.

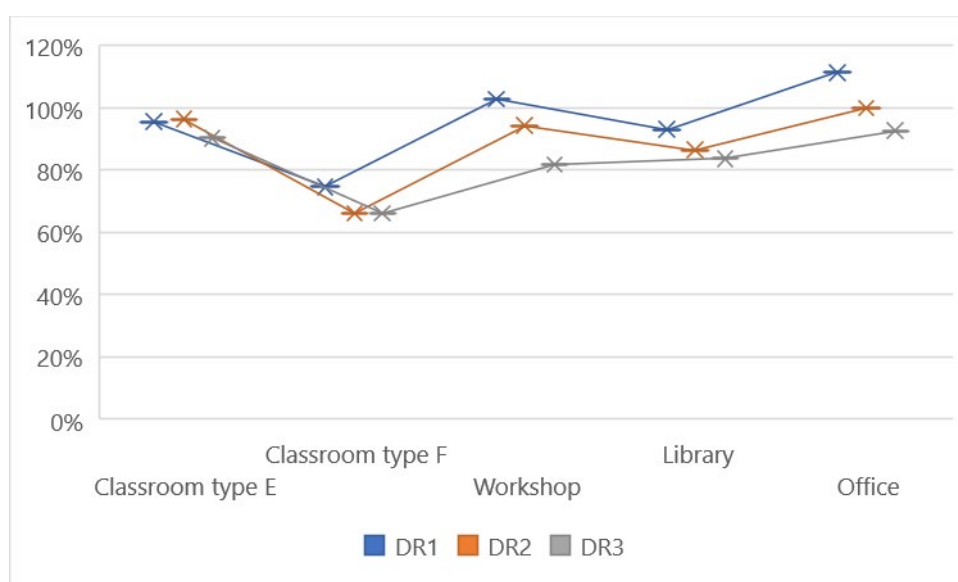


Figure 29 Roof chamber performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5

On the other hand, in summer, all have similar performance, around 2% improvement, except in classroom F where all have a 13% negative impact. Due to the small difference between their performances, it is not possible to discern a pattern in height and performance.

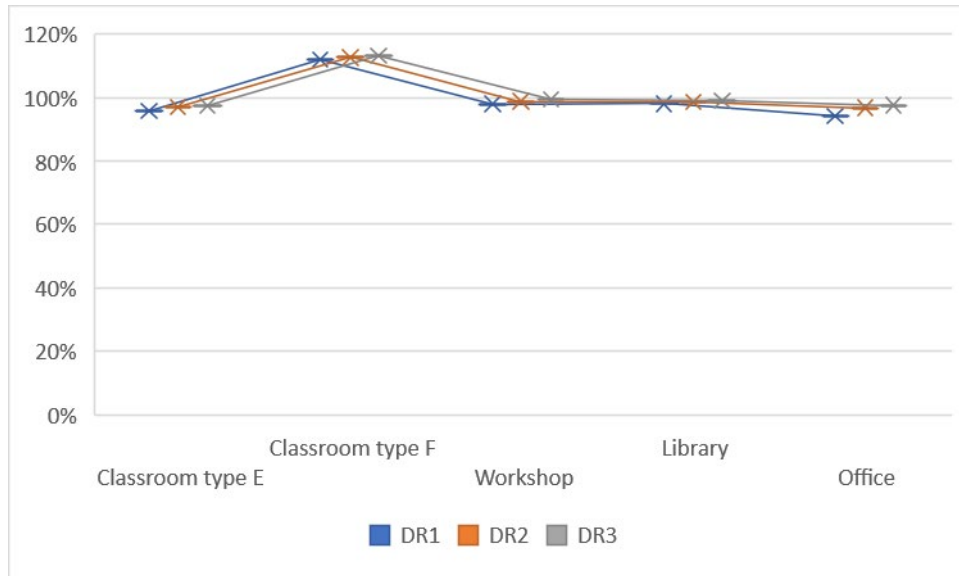


Figure 30 Roof chamber performance compared with the base case, PMV ASHRAE55 Adaptive >0.5

All the typologies reduced the overheating hours, except in the library where the improvement is almost zero. The DS5 type performs better, especially in the office and classroom F with 17% and the workshop with 6%.

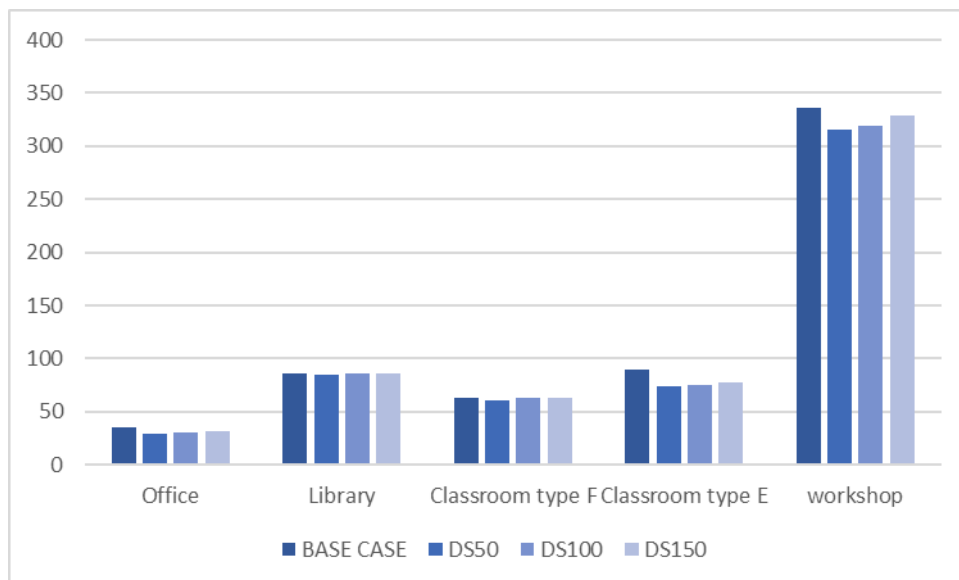


Figure 31 Roof chamber strategy overheating hours

6.1.3 Wall

A similar strategy will be applied to the walls, with the insulation being placed in the interior cavity of the wall. Aside from their thermal properties, this will help with soundproofing. Again, the test will consist of different widths of insulation.

Although Kalua's (2016) focused on residential buildings, it showed that moderate insulation is very beneficial in hot and humid climates, as excessive building insulation could adversely affect indoor thermal comfort (Kalua, 2016). Another study indicated that cavity wall insulation performs better in offices and educational buildings (Pooya Lotfabadi, Polat Hançer, 2019).

Furthermore, the selection of the walls for the analysis followed Jannat et al.'s (2020) study, which found that a double layer of breaks separated by a cavity plus insulation has better performance (Nusrat Jannat, Aseel Hussien, Badr Abdullah, Alison Cotgrave, 2020).

The walls are divided into three groups. Group A walls consist of light materials, which are of a typical construction type in Peru. Group B walls contain insulation, and in Group C, the wall has the same layers as in the base case but reducing the total depth of the bricks, thus reducing the wall thickness by 10 cm.

Table 21 Wall types


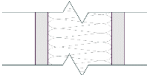
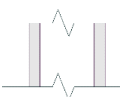

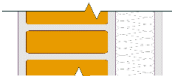

Type	Description	Layers	U Value W/m ² k
	WA1 P10	Cast concrete (100)	2.3086
	WA2 Drywall and insulation	Plasterboard (15) Insulation (90) Plasterboard (15)	0.2527
	WA3 Drywall	Plasterboard (15) Cavity (90) Plasterboard (15)	2.029
	WB1 Double brick and insulation	Concrete tyles (30) Cast concrete (15) Common brick (120) Cavity (50) Common brick (120) Insulation (120) Plasterboard (15)	0.1134
	WB2 Single brick and insulation	Cast concrete (15) Common brick (120) Insulation (120) Plasterboard (15)	0.1184
	WC1 Single brick 12cm	Cast concrete (15) Common brick (120) Cast concrete (15)	2.4154

Figure 32 shows the performance compared to the base case in the winter months, with Group B showing a significant improvement in thermal comfort in all the rooms. In Group A, a correlation between the U-value and performance is observed, with the one with the lowest U-value performing better. Group C walls have a mixed performance: a slight improvement in Classroom types A, B, D, F and the office, no change in Classroom types C and D, and poor performance in the workshop and library, the two largest rooms in the building.

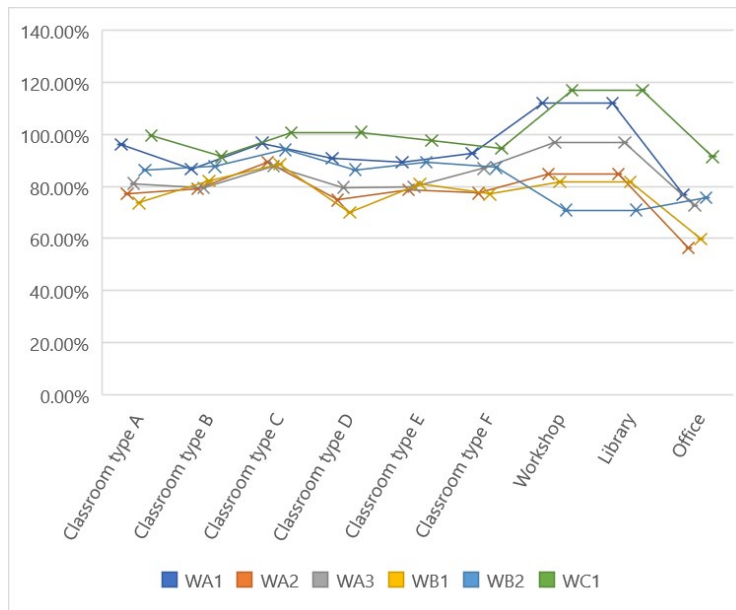


Figure 32 Wall strategy performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5

In the summer months, almost all the wall types show a deterioration in the thermal conditions of the building. The exception is the WC1 type in the workshop, which shows a marginal improvement. It can also be observed that this type has a minor impact on thermal comfort throughout the whole building.

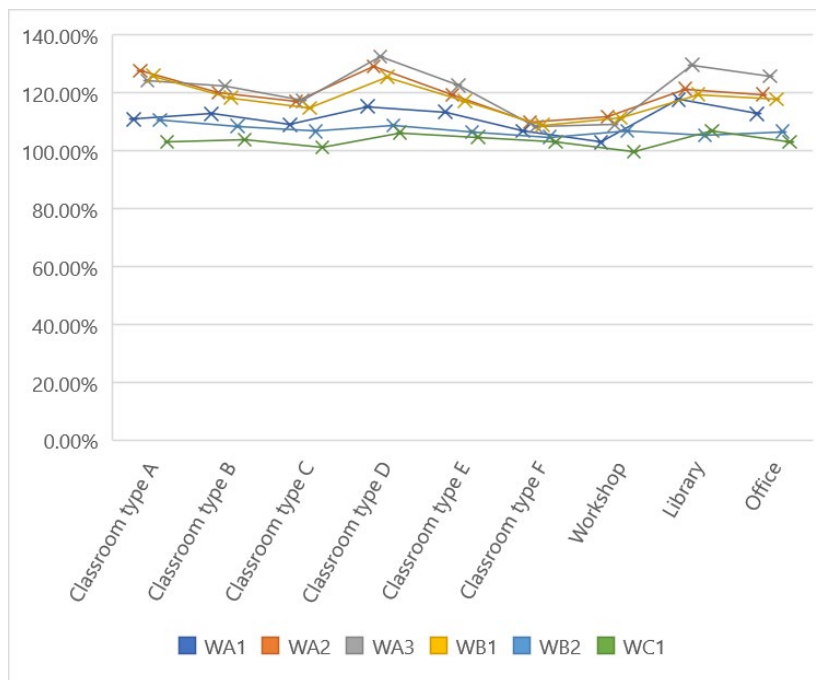


Figure 33 Wall strategy performance compared with the base case, PMV ASHRAE55 Adaptive >0.5

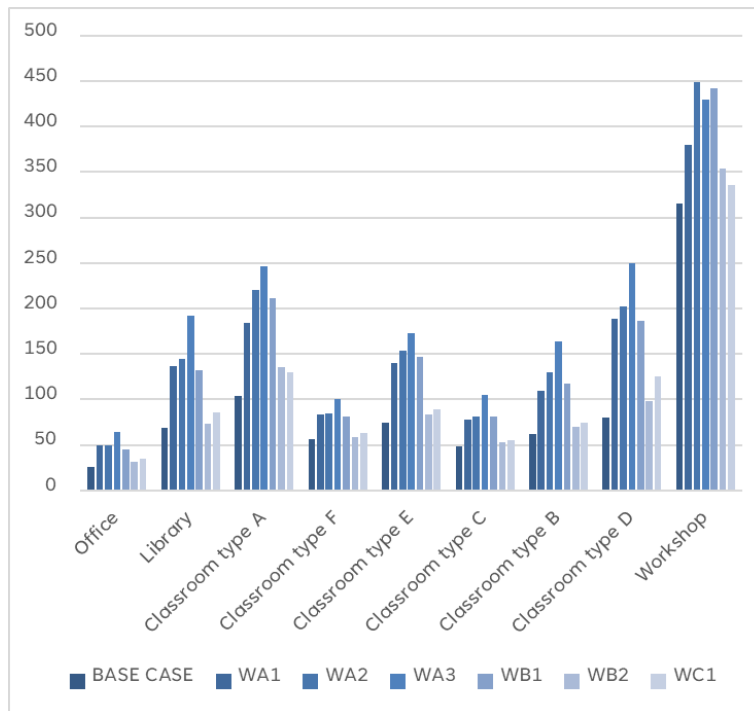


Figure 34 Wall strategy overheating hours

As with the roof strategies, the wall strategies were designed to counteract the cold in winter, meaning that they increase the overheating hours as a consequence. The most extreme example of this is WA3, the plasterboard wall, which showed approximately twice as many overheating hours in all circumstances. The most favourable strategy is WB2, single brick with insulation, which only showed an approximate 15% increase in overheating hours.

6.1.4 Glazing systems

Although the windows are protected from direct sunlight, the fact that they are in a tropical area means that significant levels of sunlight still enter the interior. The use of double glazing will reduce the amount of light that enters, so it should be expected to have a more stable illumination and to mitigate temperature increase.

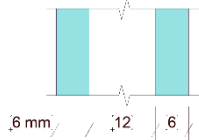
There are various glazing systems, such as double glazing, triple glazing, Low-E coating, and vacuum insulating glazing. However, all these different types are not always available in emerging markets such as South America. Therefore, for the test, the most basic and common variant, double glazing was analysed, along with

its air and argon interior variants. Also, another option was tinted glass on the exterior.

Two variants were selected: Group A with air and Group B with argon.

Table 22 Glazed type

Type	Cavity	External panel
GLA1	AIR	laminated
GLA2		Antisun
GLA3		Suncool
GLB1	ARGON	laminated
GLB2		Antisun
GLB3		Suncool



In the winter months, the best performance was observed in the options that had laminated glass with air and argon, GLA1 and GLB1. The most positive impact was seen in the workshop and the library, which have the largest glass windows. However, these rooms are the only ones that show an improvement compared with the base case. In all the other rooms, the thermal conditions deteriorated.

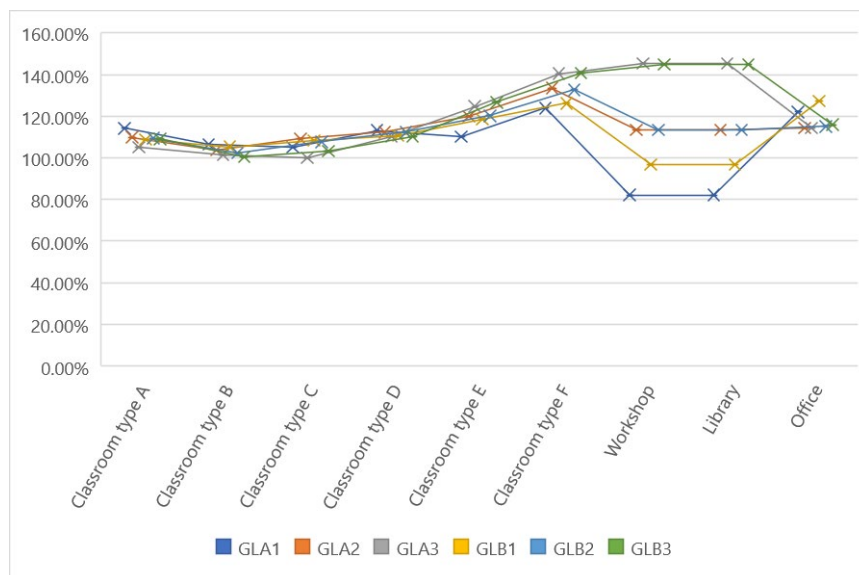


Figure 35 Glazing strategy performance compared with the base case, PMV ASHRAE55 Adaptive <- 0.5

By contrast, a significant improvement was seen in all cases during the summer months, with the options with Suncool showing the best performance. There were no significant differences between the performances of the air and argon glazing.

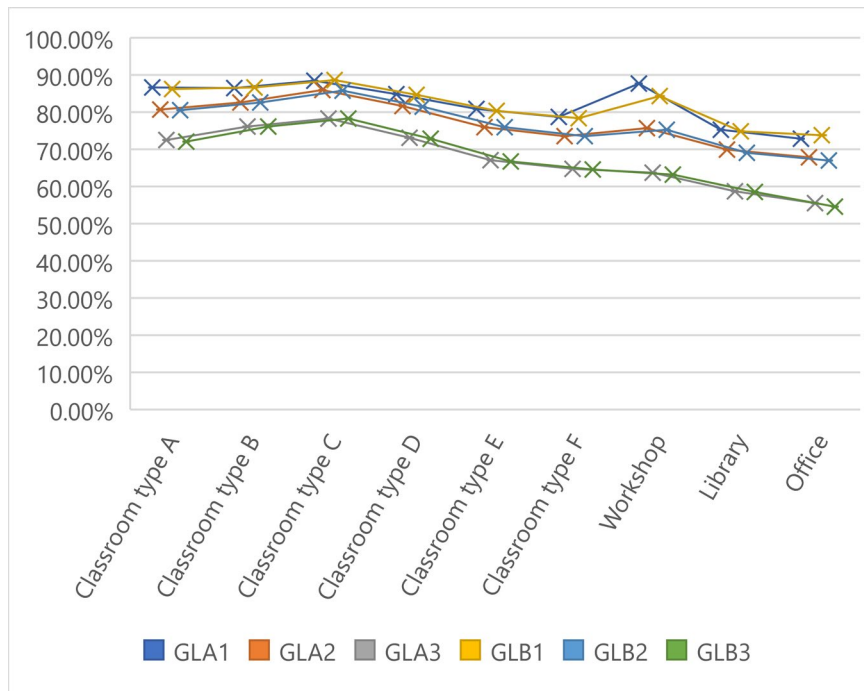


Figure 36 Glazing strategy performance compared with the base case, PMV ASHRAE55 Adaptive >0.5

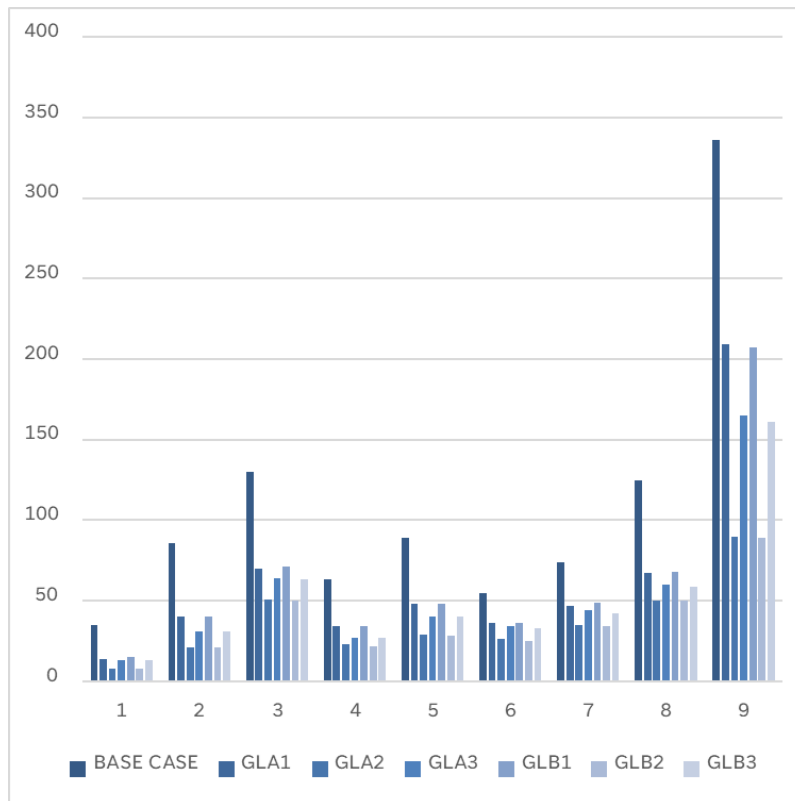


Figure 37 Double glazing strategy overheating hours

All double-glazing strategies significantly reduced overheating hours. The most striking pattern was shown in the Antisun panel. In both cases, with air and argon inside the glass, it showed the best result, with an approximately 60% reduction. By contrast, the laminated board showed the least improvement with an approximately 30% reduction.

6.1.5 Louvres

Louvres are also used to reduce the amount of light that enters the interior.

Like the existing horizontal louvred overhang, the proposed eaves have dimensions that limit the solar inclination in winter and summer, the difference being that the eaves will the entire wall as well as the windows.

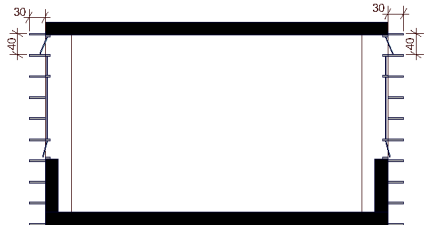
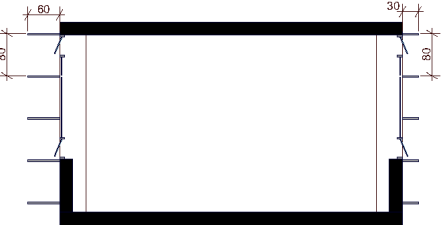


Uribe et al. (2018) analysed the performance of louvres in different climates and found that applying louvres in a tropical environment can lead to a 55% reduction in energy consumption. They compared two configurations of louvres, 12 and 24 cm, and found that the former was more efficient (Daniel Uribe, Waldo Bustamante, Sergio Vera, 2018).

Ming-Chin et al. (2008) found that a double-layer sunscreen device with vertical eaves in a subtropical climate is able to significantly increase the uniformity ratio. It also helped to reduce the energy consumption in the classrooms they tested (Ming-Chin Ho, Che-Ming Chiang, Po-Cheng Chou, Kuei-Feng Chang, Chia-Yen Lee, 2008).

Although previous research suggests that 12-cm louvres showed a more significant reduction in energy consumption for the test, slat spacing of 40 and 80 cm was selected for types L1 and L2. Because exterior views are considered essential in this dissertation, types L3 and L4 follow the double-layer sun shading strategy used by Ming-chin et al. (2008). L3 consists of double-layer sun shading and L4 consists of double-layer sun shading plus a vertical eave.

In the case of the library, the only room with east-west facing windows, the proposed louvres are as follows. Vertical louvres of 30 cm and 60 cm separated by the same magnitude, for L1 and L2 respectively, for options L3 and L4, the same option as L1.

Table 23 Louvre type

Louvre type	
 <p>L1</p>	 <p>L2</p>
 <p>L3</p>	 <p>L4</p>

During the winter months, all options showed a deterioration in the level of thermal comfort in Classroom types E and F. In addition, in types, L1 and L2, a deterioration

in thermal condition was observed in all rooms, except Classroom types A and C. On the other hand, L3 and L4 showed similar performance, with either a slight or no increase in the hours of thermal comfort in all rooms except for Classroom types E and F. However, the worst results were found for the L1 typology in Classroom types E and F, since these classrooms did not have grilles in the base case, meaning that the impact was more significant in these classrooms.

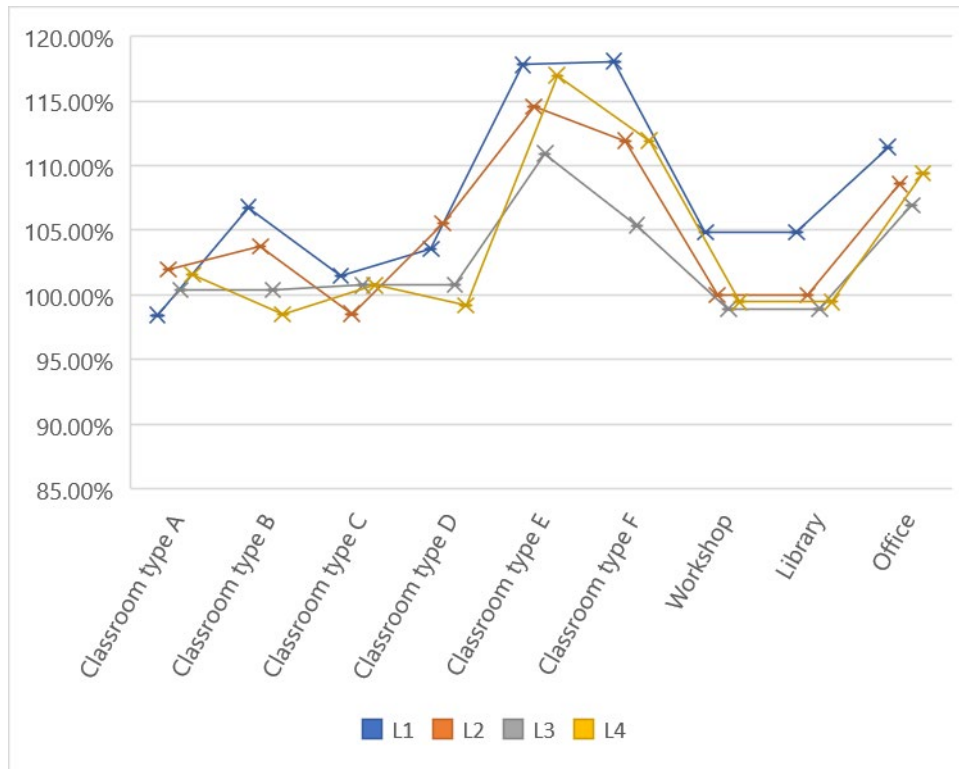


Figure 38 Louvre strategy performance compared with the base case, PMV ASHRAE55 Adaptive < 0.5

By contrast, improvements in thermal comfort were seen in all the rooms during the summer months, except for Classrooms A, B and C with L3 and L4 types, which showed a slight decrease. Furthermore, during these months, L1 and L2 performed better than L3 and L4. As expected, and reaffirming Uribe et al.'s (2018) research, small spacings between the louvres gave a better performance. The best improvement was found in the library, which had east-west-facing windows.

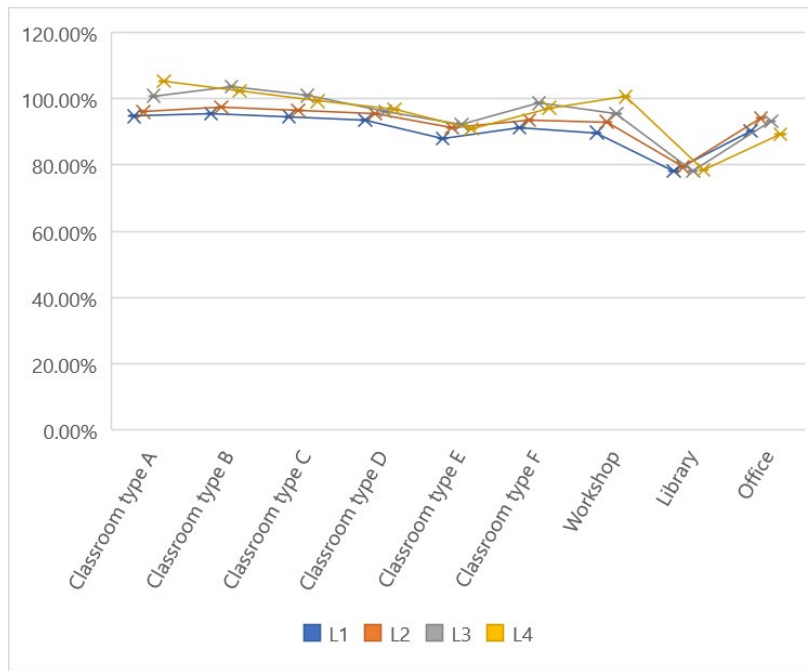


Figure 39 Louvre strategy performance compared with the base case, PMV ASHRAE55 Adaptive >0.5

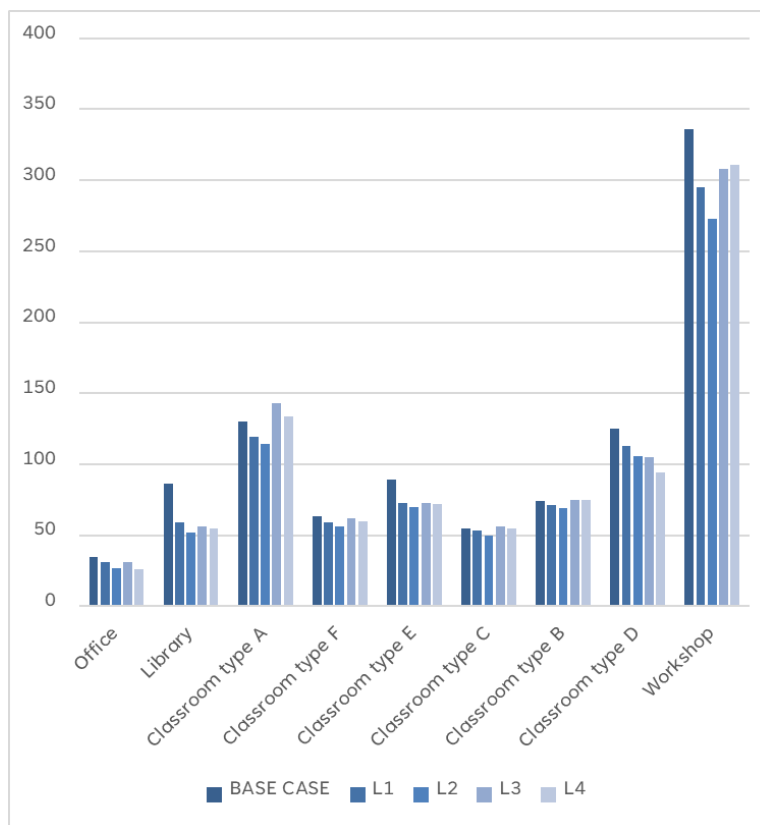


Figure 40 Louvre strategy overheating hours

As expected, the louvre strategies reduced the overall number of overheating hours. In almost all cases, this reduction was around 15%, although type L1 in the library showed a decrease of 30%. On the other hand, options L3 and L4 increased the number of overheating hours in Classroom type A by 10% and 8%, respectively; these were the only cases that were disadvantageous. Because these strategies increased the amount the light entering the room, this will be corroborated in the light and uniformity ratio graphics.

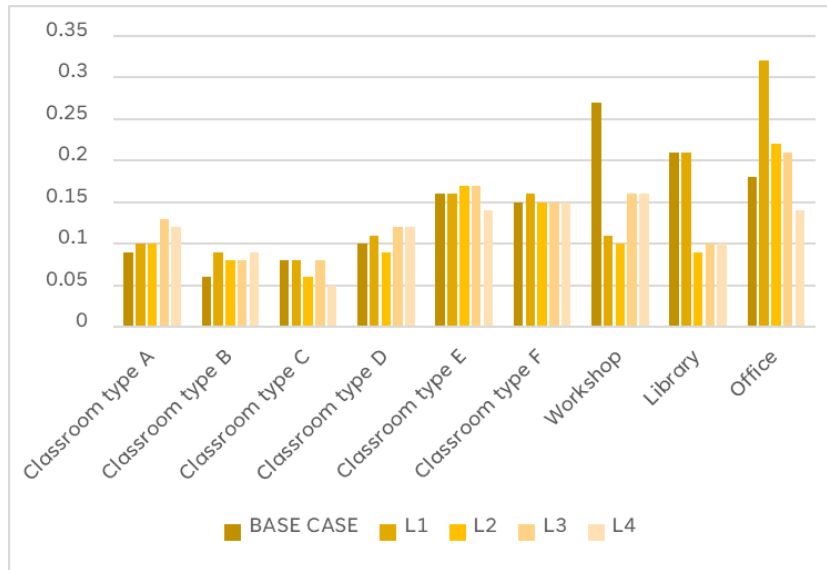
As expected, the amount of light decreases, with the major decreases observed in the L1 and L4 types because L1 has only a small distance between the eaves and L4 has vertical louvres. However, it does not compromise the quality of the space because in almost all cases the reduction is not substantial; they are still in the range of 100–3000 lux. Nevertheless, there are some exceptions in the base case. Classroom type E and the library had some areas above 3000 lux. However, once louvres were incorporated, the lux levels decreased to an acceptable level.

The rooms showing the most significant changes were Classroom types A, B, C and D, the application of louvre strategies results in these rooms having the highest percentage of lux in the 100-500 lux range, which is still acceptable. However, electric lighting would not be necessary throughout most of the day. Even the L1 and L4 options in Classroom type C that have areas below 100 lux are still in the recommended value of 80% in the range of 100–3000 lux and 50% for DA for 300 lux.

Table 24 Louvre strategy UDI values

Location	Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
Classroom type A	BASE CASE	0.0%	0.0%	100.0%	0.0%
	L1	0.0%	100.0%	0.0%	0.0%
	L2	0.0%	21.0%	78.0%	0.0%
	L3	0.0%	0.0%	100.0%	0.0%
	L4	0.0%	21.0%	78.0%	0.0%
Classroom type B	BASE CASE	0.0%	61.0%	38.0%	0.0%
	L1	0.0%	100.0%	0.0%	0.0%
	L2	0.0%	56.0%	44.0%	0.0%
	L3	0.0%	61.0%	38.0%	0.0%
	L4	0.0%	100.0%	0.0%	0.0%
Classroom type C	BASE CASE	0.0%	65.0%	34.0%	0.0%
	L1	2.0%	98.0%	0.0%	0.0%
	L2	0.0%	94.0%	5.0%	0.0%
	L3	0.0%	100.0%	0.0%	0.0%
	L4	2.0%	97.0%		0.0%
Classroom type D	BASE CASE	0.0%	14.0%	85.0%	0.0%
	L1	0.0%	100.0%	0.0%	0.0%
	L2	0.0%	37.0%	62.0%	0.0%
	L3	0.0%	88.0%	11.0%	0.0%
	L4	0.0%	100.0%	0.0%	0.0%
Classroom type E	BASE CASE	0.0%	0.0%	93.0%	6.0%
	L1	0.0%	8.0%	92.0%	0.0%
	L2	0.0%	0.0%	100.0%	0.0%
	L3	0.0%	0.0%	100.0%	0.0%
	L4		2.0%	97.0%	
Classroom type F	BASE CASE	0.0%	0.0%	100.0%	0.0%
	L1	0.0%	8.0%	92.0%	0.0%
	L2	0.0%	4.0%	96.0%	0.0%
	L3	0.0%	0.0%	100.0%	0.0%
	L4	0.0%	4.0%	96.0%	0.0%
Workshop	BASE CASE	0.0%	0.0%	100.0%	0.0%
	L1	0.0%	3.0%	96.0%	0.0%
	L2	0.0%	0.0%	100.0%	0.0%
	L3	0.0%	0.0%	100.0%	0.0%
	L4	0.0%	3.0%	96.0%	0.0%
Library	BASE CASE	0.0%	0.0%	94.0%	5.0%
	L1	0.0%	48.0%	51.0%	0.0%
	L2	0.0%	36.0%	63.0%	0.0%
	L3	0.0%	33.0%	66.0%	0.0%
	L4	0.0%	40.0%	59.0%	0.0%
Office	BASE CASE	0.0%	0.0%	100.0%	0.0%
	L1	0.0%	21.0%	78.0%	0.0%
	L2	0.0%	2.0%	97.0%	0.0%
	L3	0.0%	2.0%	97.0%	0.0%
	L4	0.0%	28.0%	72.0%	0.0%

Table 25 Louvre strategy uniformity ratio



For options L1 and L2, which are eaves only, L1 has better performance and increases uniformity in all rooms except for the workshop. On the other hand, for the options with double eaves, the one without vertical eaves, L3, has a slightly better performance. However, of all the possibilities, L1 has a more homogenous performance and has a significantly increased performance for the office.

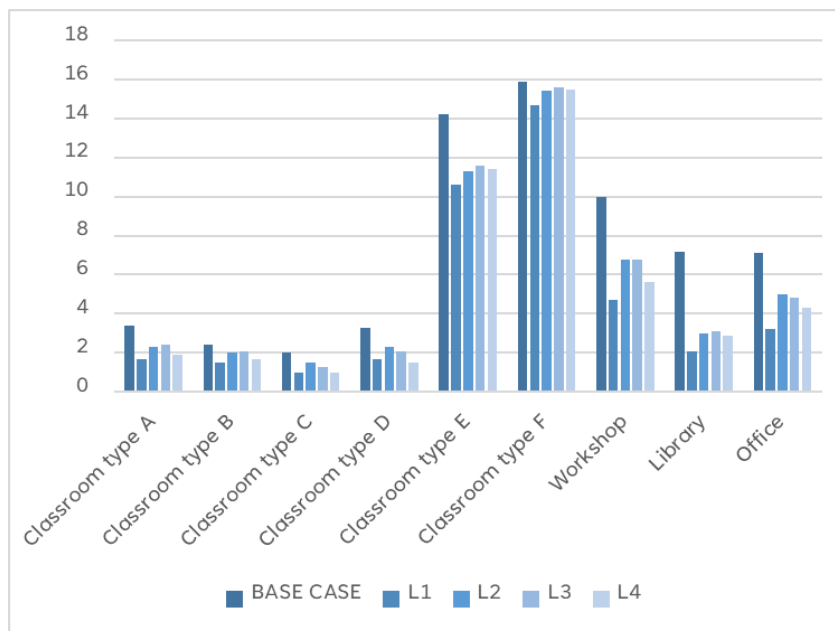


Figure 41 Louvre strategy average daylight factor in percentage

As expected, the rooms in the base test were slightly above the limit recommended by the Peruvian norms, after applying the louvre strategies, these rooms had a large percentage of daylight factor below 2%, all rooms without exception. The greatest reduction of daylight factor is observed in the L1 type, with reductions of 70% in the library and around 50% in the rest of the rooms. On the other hand, the options with the best performance were L2 and L3, with a reduction of 60% for the library and 20% for the rest of the rooms.

6.1.6 Double skin

The double-skin technique is used in a variety of climates depending on the materials. Above all, how the inside airflow is managed can reduce or increase the indoor temperature.

A double skin with opaque materials should be used to reduce the temperature in the building. It will be tested in three dimensions for the double skin, and then one with eaves, as suggested by Barbosa et al. (2015), in which they tested different double-façade options for an office building in Rio de Janeiro (Sabrina Barbosa, Kenneth Ip, Ryan Southall, 2015).

The test consists of the addition of opaque double glazing. Two group types were used, with the difference between them being the incorporation of eaves. All the types had one window at the bottom and one at the top.

Double skin type

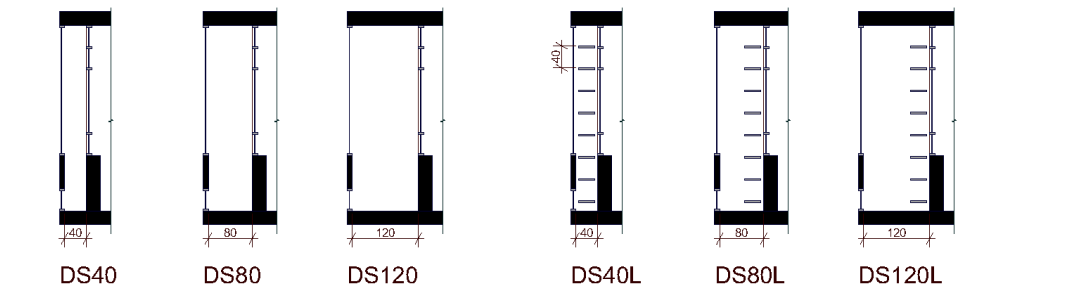


Figure 42 Double skin types

In the colder months, there were improvements in the thermal conditions in most rooms, particularly in the workshop. However, the offices and the library did not

show any improvement. It was observed that the presence of eaves is not advantageous.

Furthermore, in Classroom types B, C and D, a greater cavity distance was preferable, while in Classroom types A and E, the best performance had the DS40 option, which had the shortest cavity distance.

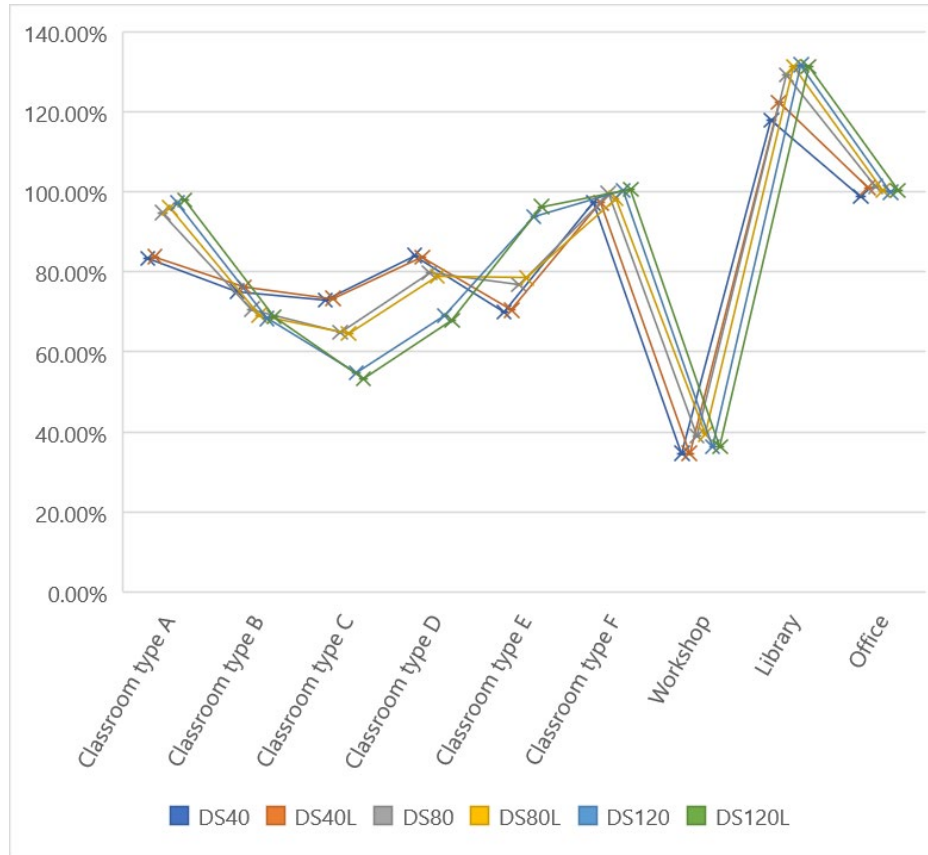


Figure 43 Double skin performance compared with the base case, PMV ASHRAE55 Adaptive <-0.5

There were improvements in thermal conditions in almost all cases during the hottest months, except for types DS40 and DS40L in the office. In this case, the presence of the eaves does not show any improvement either. However, a pattern can be seen in all the rooms, in that the greater the distance from the cavity, the better the performance.

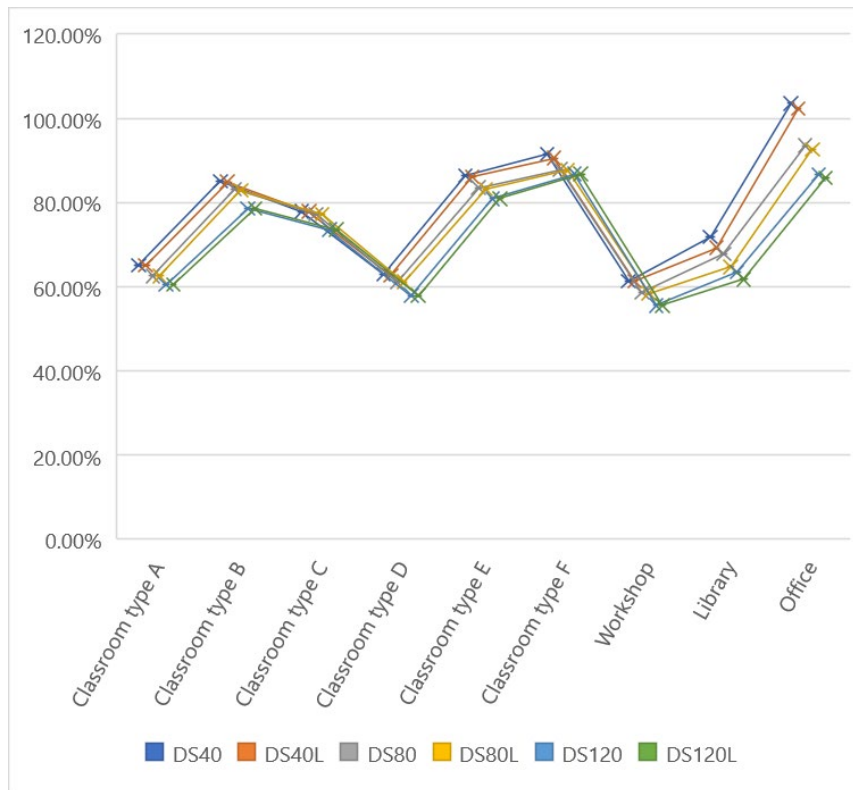


Figure 44 Double skin performance compared with the base case, PMV ASHRAE55 Adaptive >0.5

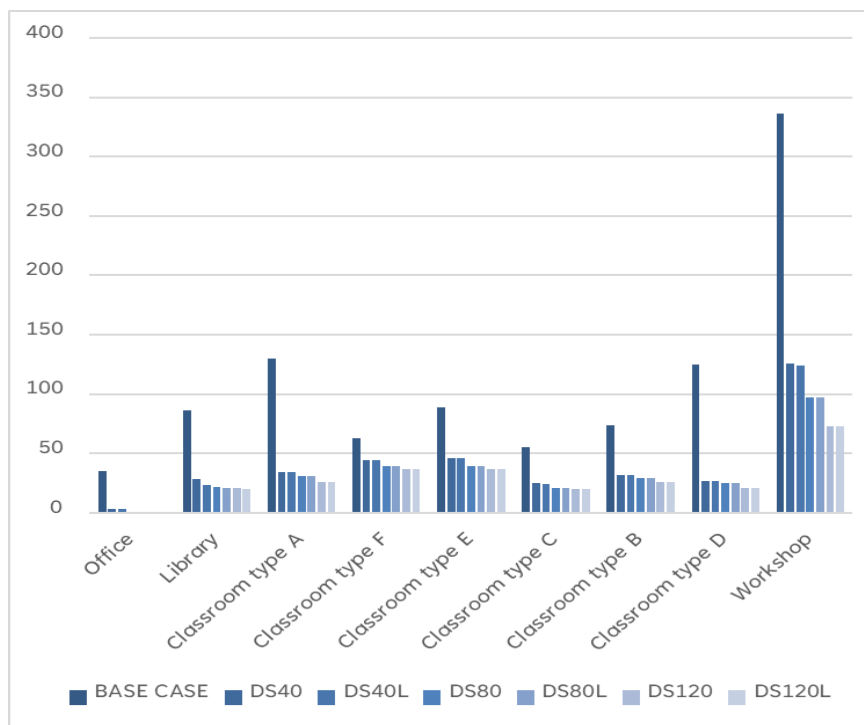


Figure 45 Double skin strategy overheating hours

All the double-skin types showed exceptional performance in reducing overheating hours and were more successful than any of the previous strategies. As expected, the typology with the best result was the wider double skin with eaves in the interior, which allowed less light to enter, and led to a decrease in overheating hours of around 80%. On the other hand, this strategy was less successful in Classroom type F, which showed a 35% reduction in overheating hours for all types. However, it should be mentioned that this room type is the only one with a double-skin façade face.

Classroom types A, B, and D showed similar patterns in the observed changes. There were no significant reductions in the average amount of light in the double-skin options without eaves, while for the options with inside eaves, there are zones of space below 100 lux. Even the DS80L and DS120L had less than 80% in the recommended range.

Table 26 UDI values in Classroom type A

Classroom type A				
Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
BASE CASE	0.0%	0.0%	100.0%	0.0%
DS40	0.0%	100.0%	0.0%	0.0%
DS80	0.0%	100.0%	0.0%	0.0%
DS120	0.0%	100.0%	0.0%	0.0%
DS40L	20.0%	80.0%	0.0%	0.0%
DS80L	36.0%	63.0%	0.0%	0.0%
DS120L	21.0%	78.0%	0.0%	0.0%

Classroom type C shows a substantial decrease in the amount of light, and all the double-skin types applied decreased the values below the recommended level.

Table 27 UDI values in Classroom type C

Classroom type C

Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
BASE CASE	0.0%	65.0%	34.0%	0.0%
DS40	34.0%	66.0%	0.0%	0.0%
DS80	45.0%	54.0%	0.0%	0.0%
DS120	57.0%	42.0%	0.0%	0.0%
DS40L	88.0%	11.0%	0.0%	0.0%
DS80L	100.0%	0.0%	0.0%	0.0%
DS120L	100.0%	0.0%	0.0%	0.0%

The library, workshop and Classroom types E and F all showed the same changes. In all cases, average light levels were reduced but were still in the 100–3000 lux range. As expected, the options with eaves showed a greater decrease.

Table 28 UDI values in Classroom type E

Classroom type E

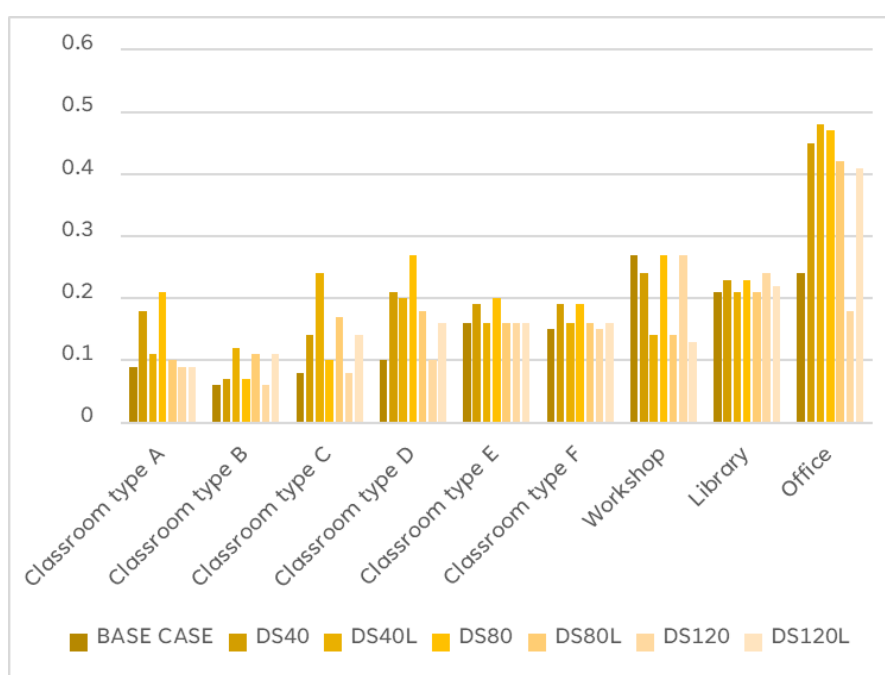
Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
BASE CASE	0.0%	0.0%	93.0%	6.0%
DS40	0.0%	58.0%	41.0%	0.0%
DS80	0.0%	66.0%	33.0%	0.0%
DS120	0.0%	75.0%	25.0%	0.0%
DS40L	0.0%	81.0%	18.0%	0.0%
DS80L	0.0%	85.0%	14.0%	0.0%
DS120L	0.0%	85.0%	14.0%	0.0%

On the other hand, all the changes had a significantly detrimental impact on the office. The light levels fell below 100 lux, which is not recommended

Table 29 UDI values in office

Office				
Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
BASE CASE	0.0%	0.0%	100.0%	0.0%
DS40	100.0%	0.0%	0.0%	0.0%
DS80	100.0%	0.0%	0.0%	0.0%
DS120	100.0%	0.0%	0.0%	0.0%
DS40L	100.0%	0.0%	0.0%	0.0%
DS80L	100.0%	0.0%	0.0%	0.0%
DS120L	100.0%	0.0%	0.0%	0.0%

Table 30 Double skin strategy uniformity ratio



A pattern can be seen in the spaces with more light, such as Classroom types E and F, the library, and the workshop; the options without eaves gave a better performance. On the other hand, in the rooms with less light, the types with less separation between walls have better performance DS40, DS40L, DS80 and DS80L, but there is no clear pattern between the options with or without eaves.

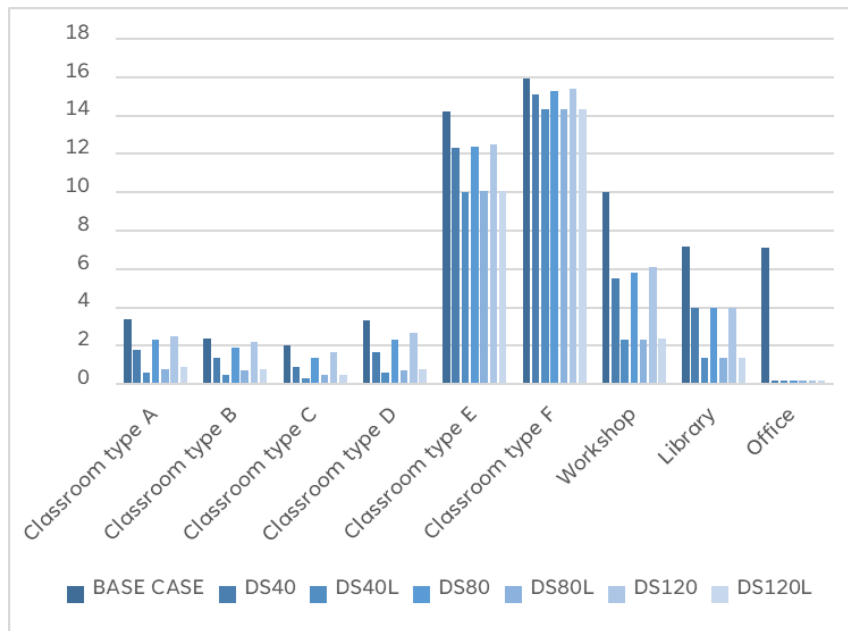


Figure 46 Double skin strategy average daylight factor %

As was the case with the louvre strategy, the rooms that in the base case had daylight factors slightly above 2%. However, when the strategy was applied, these rooms fell below the reference values. The results also showed that the options with louvres in the interior can significantly affect the daylight factor, with reductions of 20% in Classroom types D and F and 80% in the rest of the rooms. In contrast, the option with the best performance was the DS120, which showed a 10% reduction in Classroom types E and F and 20% in the rest of the rooms.

The double-skin strategy gave a good performance in both summer and winter; however, they negatively impact upon visual comfort. In addition, although the types with eaves present a slight variation in performance to the types without eaves, the presence of eaves significantly decreased the amount of light.

6.2 Results and analysis

For the figure 47, a type for each strategy was selected, for which the following was considered. Since no one type had a positive impact on all the criteria, Those that gave average results and above all that did not increase the hours of overheating

were selected, for which the typologies that did not have a marked adverse effect were selected, from this group, those with the best performance were chosen.

The roof insulation strategies all had a positive impact on thermal comfort in winter; however, they had a negative impact in almost all cases during the summer. The group with no increase in overheating hours, RIB1, RIB2, RIB3 and RIC1, were selected; from this group, RIC1 was selected as it was the only one that had only a marginally negative impact in summer.

Contrary to expectations, the ventilated air chamber strategy works better in winter than in summer. Because this system is designed to cool the upper slab through the air currents generated in the chamber, a more in-depth study is needed to analyse these airflows. The highest-height alternative, DR3, obtained the best results, and since it did not present an increase in overheating hours, this typology was chosen for the final comparison.

Similar to the roof insulation strategy, the wall strategies also had a positive impact in winter. Furthermore, the results showed that insulation strongly influences thermal comfort in these months. However, in summer, options without insulation worked better, although all the different types increased the number of overheating hours. The type that was ultimately chosen was the one with the least impact, WB2, which is also the one that gave a relatively stable performance in both winter and summer.

Double glazing strategies showed exceptional results during the summer. However, the options with an external panel of Suncool had a severely detrimental impact during winter. Furthermore, there was no significant difference in performance between the air and argon options, with the biggest determinant being the outer panel. In this strategy, all options reduced the number of overheating hours, but GLA2 and GLB2 were ultimately chosen because they have the most significant impact, although GLB2 had the most consistent performance throughout the year.

The louvres strategies also showed excellent results during summer. Furthermore, they helped reduce glare since they made the light in all the rooms except the workshop more homogeneous. L1 and L2 were selected as they were most successful in reducing the number of overheating hours. From these, L2 had the most consistent performance throughout the year.

The double-skin strategy also gave good results in both summer and winter, although it had a negative impact on visual comfort. The types with eaves significantly decreased the amount of light, with only slight variations in thermal comfort. For this reason, the options with eaves were discarded. From the group of double skin without eaves, DS120 had the greatest positive impact on thermal comfort. It was also the most homogeneous and the one that reduced the number of overheating hours to the greatest extent.

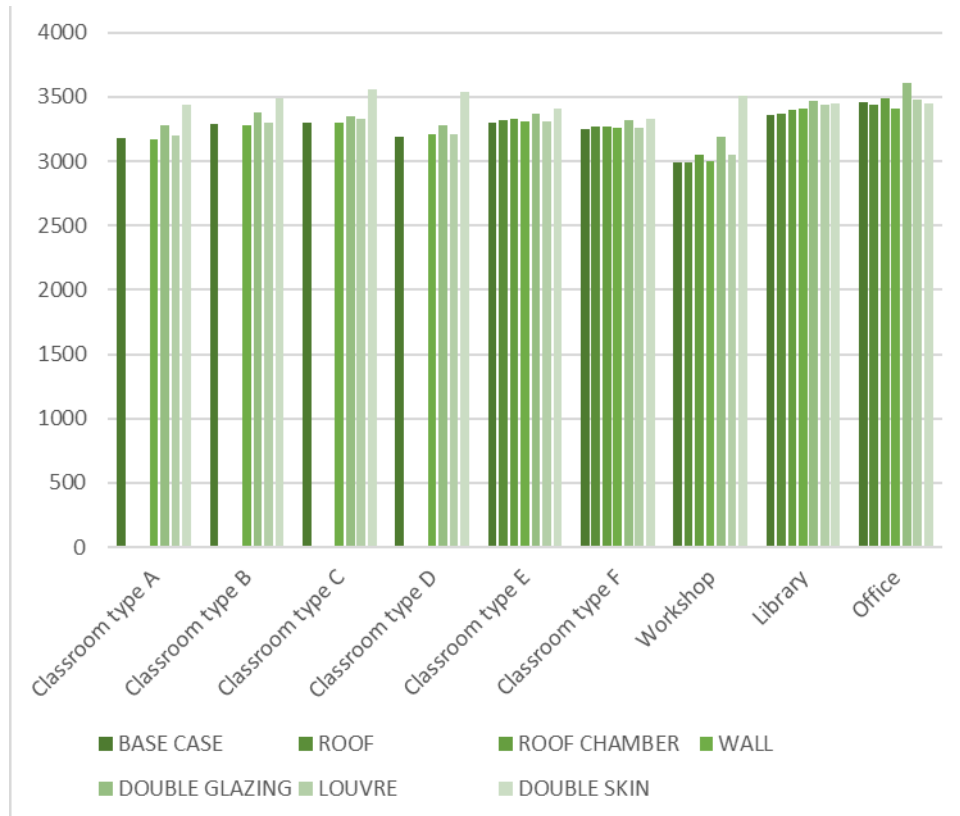


Figure 47 Number of hours between -0.5 and 0.5 of PMV ASHRAE55 Adaptive

It can also be seen that the options with double glazing and double-skin façades have the most significant positive impact on the hours of thermal comfort, with the double-skin strategy having a positive effect of about 8% for all the rooms, and 17% for the workshop. On the other hand, the wall and roof strategies had the most negligible impact, with variations between 0 and 1%.

Chapter 7. Conclusion

This dissertation began with the idea of increasing the architectural design quality by improving the internal conditions of the rooms using passive strategies without negatively impacting energy consumption. By determining that applying passive design strategies can be applied in the climatic context of Lima, it is possible to achieve a successful classroom design.

Passive design strategies were explored and applied in an existing building to improve thermal and visual comfort, with all of them having a mainly positive impact. However, it should be understood that not all approaches will be beneficial throughout the year. Therefore, knowing each strategy's pros and cons will make a difference in the design process.

It has shown that it is possible to improve the internal conditions of rooms by applying passive strategies. Through computational advances, it is now possible to simulate complex models that show the effects of these strategies. However, further analysis is required in cases where airflows are an essential part in the approach.

Based on the tests, it was found that the double-skin strategy has a significant impact on the thermal conditions of the room due to having the best percentages, and in addition is one of the few that show an improvement in both spring and summer, a factor that was a priority in this analysis. On the other hand, the performance of double glazing depends on the season, as it is particularly beneficial during summer but severely detrimental during winter.

This dissertation has also shown that due to the climatic conditions of the tropics and the uniqueness of Lima's climate, there was no significant impact on thermal comfort levels produced by insulation in walls or ceilings since the improvements are much lower when compared with other strategies.

As expected, all the strategies improved the thermal or visual comfort conditions of the room. In addition, it should be noted that simple approaches, such as installing louvres, can significantly improve lighting levels, particularly in rooms with extreme lighting conditions. On the other hand, adding louvres to a double-skin façade will block too much light.

The strategies met the expectations to a significant degree since, as expected, they increase or decrease the temperature inside depending on their properties. Consequently, they have a positive impact on either thermal or visual comfort. Nevertheless, it should be noted that some designs, such as double skin with eaves, significantly improve thermal comfort conditions. Still, they had the most negative impact on visual comfort, as some rooms fell below the recommended light levels, this was mainly observed in rooms with small windows.

Based on these conclusions, architects and designers should pay particular attention to this part of the design process because it is essential to analyse the project's circumstances. Firstly, they should look at the conditions of the place; secondly, they should determine the needs of the project; and thirdly, they should determine the ideal strategy, as not all strategies will work perfectly throughout the year. Therefore, knowing each strategy's pros and cons will make a significant difference during the design process.

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Appendix

Table 31 UDI values in Classroom type B

Classroom type B

Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
BASE CASE	0.0%	61.0%	38.0%	0.0%
DS40	10.0%	90.0%	0.0%	0.0%
DS80	14.0%	85.0%	0.0%	0.0%
DS120	18.0%	81.0%	0.0%	0.0%
DS40L	40.0%	60.0%	0.0%	0.0%
DS80L	62.0%	37.0%	0.0%	0.0%
DS120L	66.0%	33.0%	0.0%	0.0%

Table 32 UDI values in Classroom type D

Classroom type D

Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
BASE CASE	0.0%	14.0%	85.0%	0.0%
DS40	0.0%	100.0%	0.0%	0.0%
DS80	0.0%	100.0%	0.0%	0.0%
DS120	0.0%	100.0%	0.0%	0.0%
DS40L	2.0%	97.0%	0.0%	0.0%
DS80L	40.0%	60.0%	0.0%	0.0%
DS120L	51.0%	48.0%	0.0%	0.0%

Table 33 UDI values in Classroom type F

Classroom type F

Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
BASE CASE	0.0%	0.0%	100.0%	0.0%
DS40	0.0%	40.0%	60.0%	0.0%
DS80	0.0%	44.0%	56.0%	0.0%
DS120	0.0%	56.0%	44.0%	0.0%
DS40L	0.0%	56.0%	44.0%	0.0%
DS80L	0.0%	52.0%	48.0%	0.0%
DS120L	0.0%	52.0%	48.0%	0.0%

Table 34 UDI values in the workshop

Workshop

Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
BASE CASE	0.0%	0.0%	100.0%	0.0%
DS40	0.0%	100.0%	0.0%	0.0%
DS80	0.0%	100.0%	0.0%	0.0%
DS120	0.0%	100.0%	0.0%	0.0%
DS40L	0.0%	100.0%	0.0%	0.0%
DS80L	0.0%	100.0%	0.0%	0.0%
DS120L	0.0%	100.0%	0.0%	0.0%

Table 35 UDI values in the library

Library				
Type	0-100 lux	100-500 lux	500-3000 lux	>3000 lux
BASE CASE	0.0%	0.0%	94.0%	5.0%
DS40	0.0%	68.0%	31.0%	0.0%
DS80	0.0%	51.0%	48.0%	0.0%
DS120	0.0%	73.0%	26.0%	0.0%
DS40L	0.0%	100.0%	0.0%	0.0%
DS80L	2.0%	97.0%	0.0%	0.0%
DS120L	2.0%	97.0%	0.0%	0.0%

L1

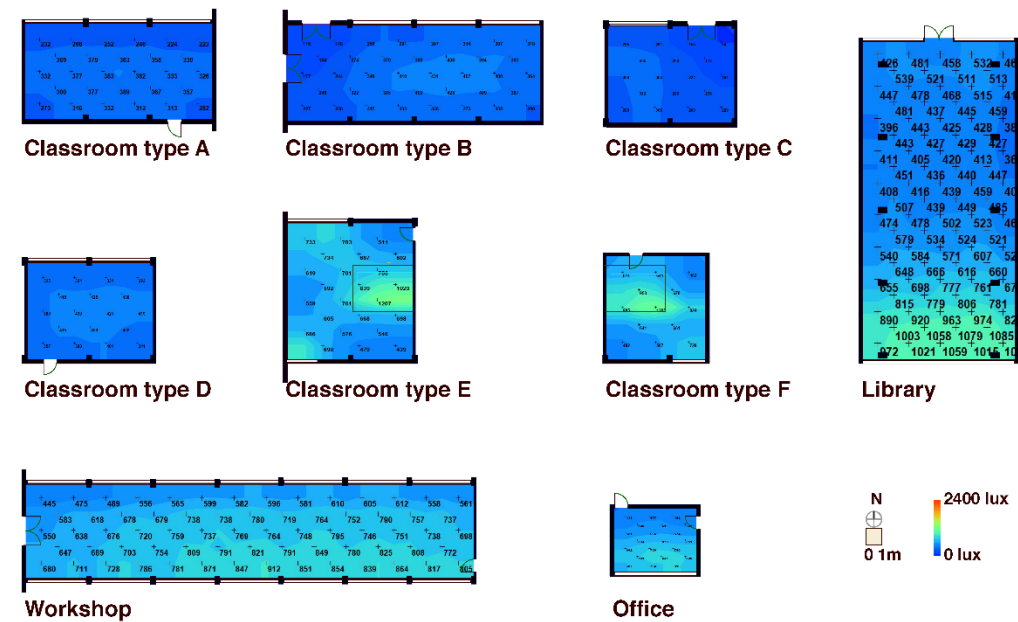


Figure 48 UDI Values Louvre strategy L1

L2

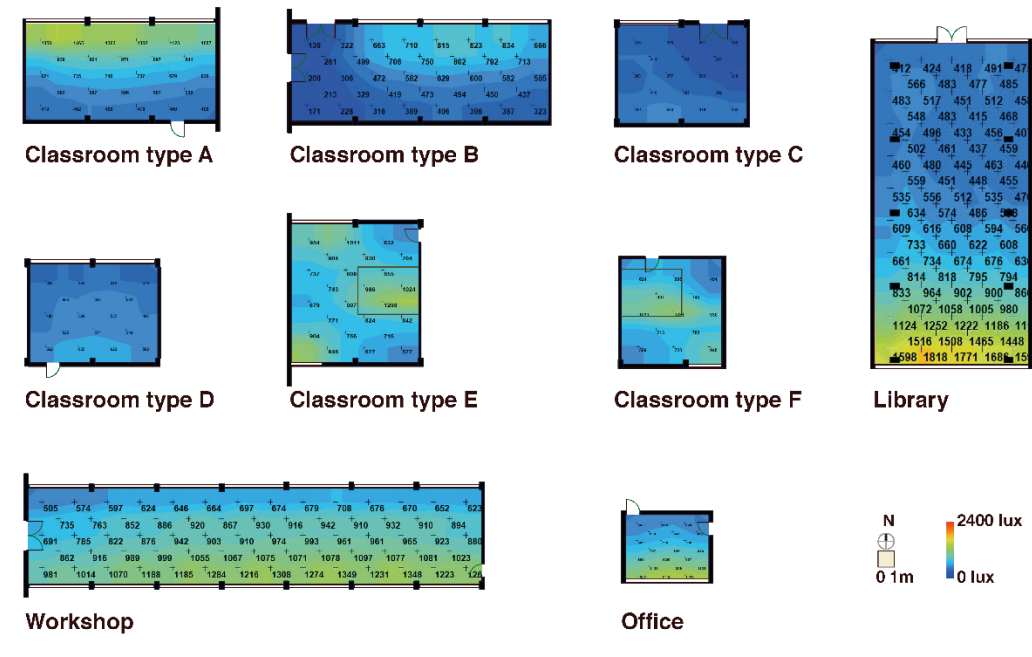


Figure 49 UDI Values Louvre strategy L2

L3

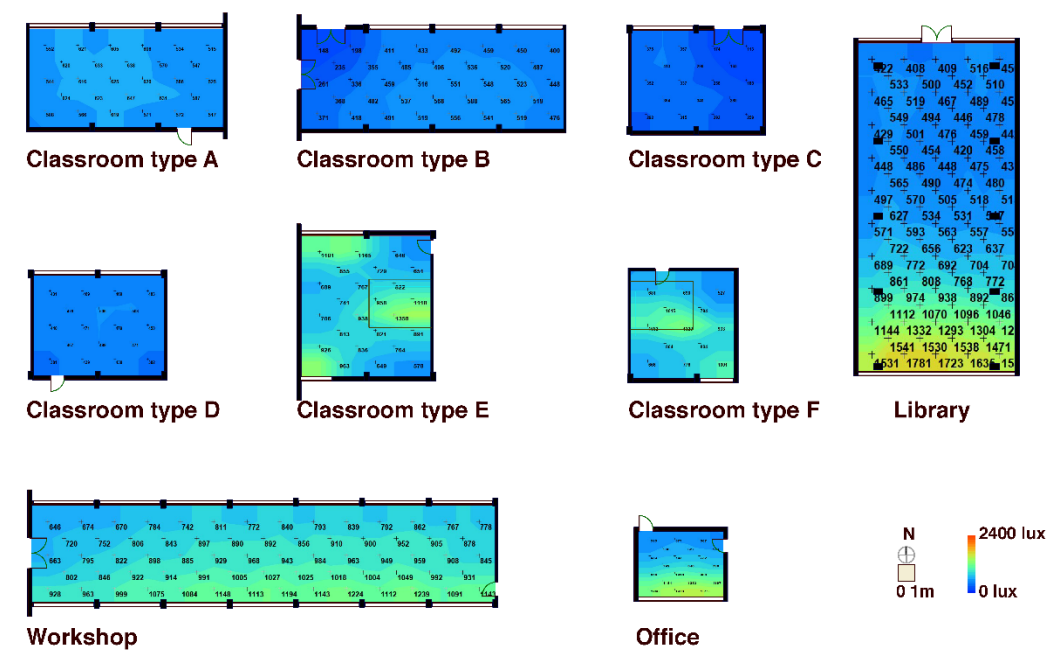
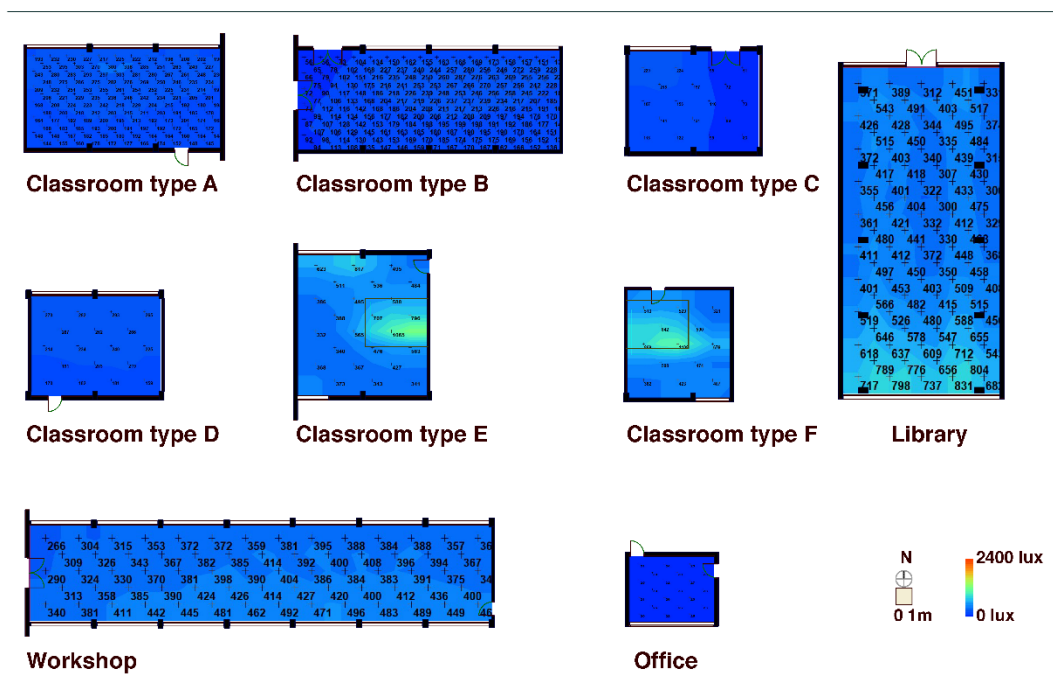


Figure 50 UDI Values Louvre strategy L3

Figure 10 displays the illuminance distribution in various rooms, categorized by room type. The rooms shown are Classroom type A, Classroom type B, Classroom type C, Classroom type D, Classroom type E, Classroom type F, and the Library. Each room is represented by a color-coded map showing the distribution of light intensity (lux) across the space. The maps are color-coded according to the legend, which ranges from 0 lux (blue) to 2400 lux (red). The Library map shows the highest illuminance values, reaching up to 2400 lux. The Classroom type A map shows the lowest illuminance values, ranging from 0 to 100 lux. The Classroom type B map shows illuminance values ranging from 0 to 100 lux. The Classroom type C map shows illuminance values ranging from 0 to 100 lux. The Classroom type D map shows illuminance values ranging from 0 to 100 lux. The Classroom type E map shows illuminance values ranging from 0 to 100 lux. The Classroom type F map shows illuminance values ranging from 0 to 100 lux. The Library map shows illuminance values ranging from 0 to 2400 lux. A scale bar indicates 0.1m, and a North arrow is provided.

Figure 51 UDI Values Louvre strategy L4

DS40



DS40L

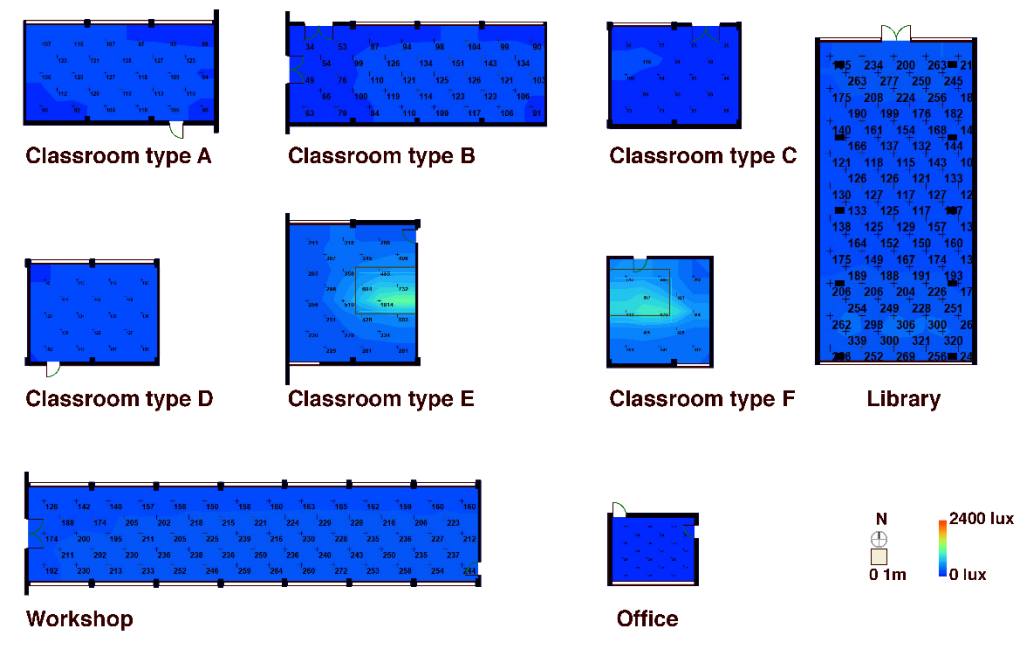


Figure 53 UDI Values double skin strategy DS40L

DS80

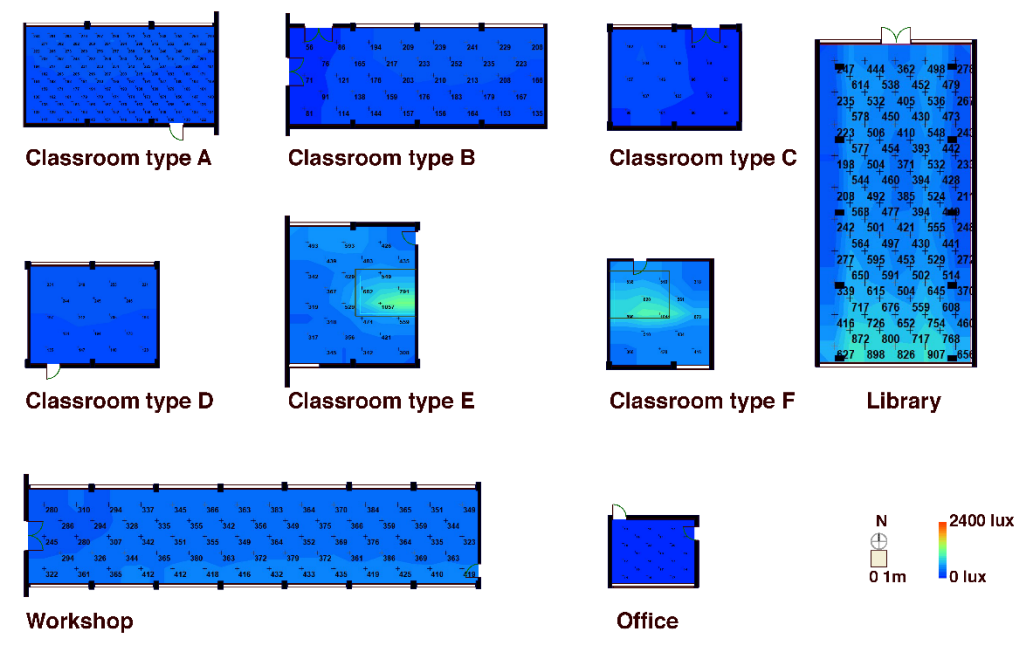


Figure 54 UDI Values double skin strategy DS80

DS80L

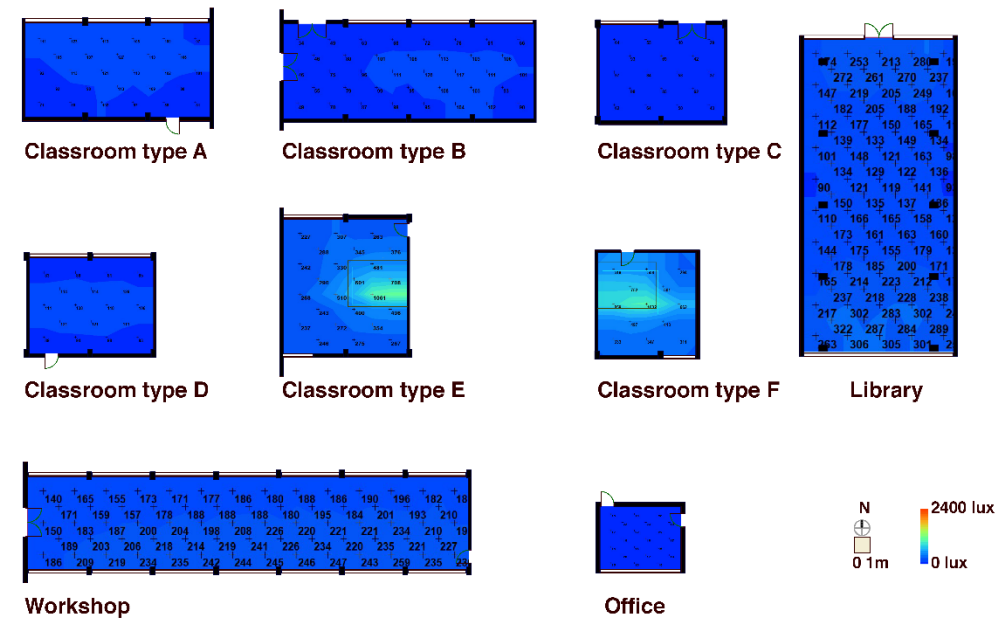


Figure 55 UDI Values double skin strategy DS80L

DS120

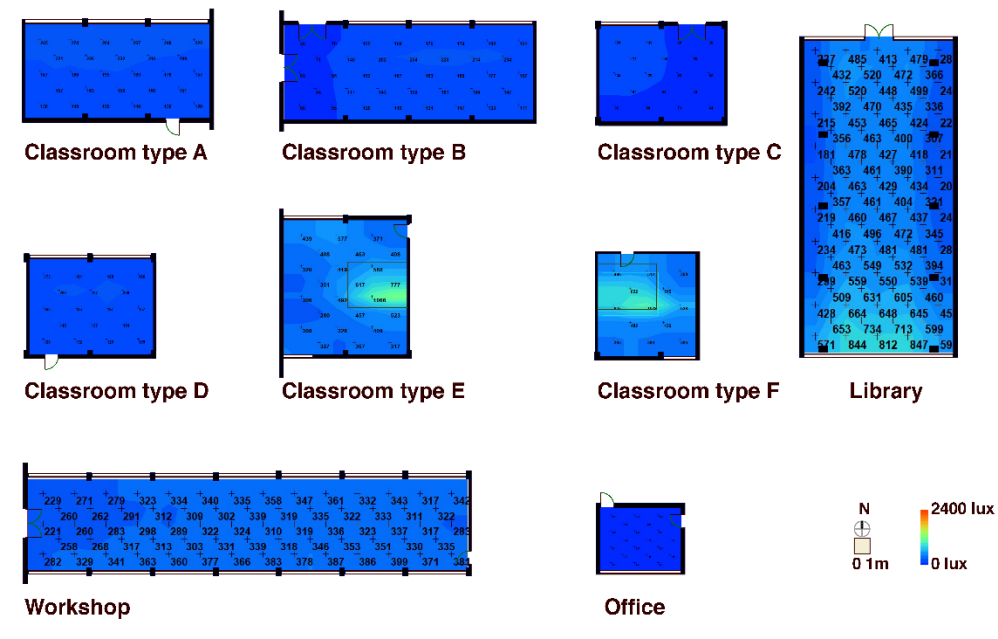


Figure 56 UDI Values double skin strategy DS120

DS120L

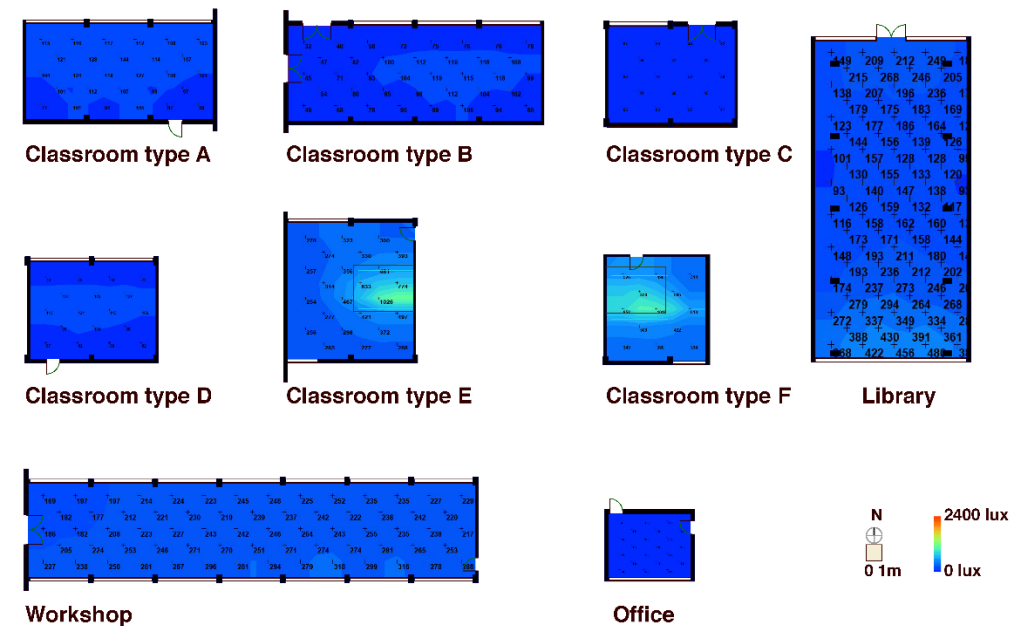


Figure 57 UDI Values double skin strategy DS120L