Energy Performance of Public Housing Buildings in Sao Paulo, Brazil

An Evaluation of the Current Design Process

By

Alexandra Maria Aguiar Leister

Student ID# 80045

Dissertation submitted in partial fulfillment of

Master of Science in Sustainable Design of the Built Environment

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Abstract

With global warming and its impact on the environment becoming more evident, sustainability has become a major factor to lessen the damage being produced by men. Numerous are the reasons why sustainability is hard to achieve and various are the culprits for environmental damage. Among all, buildings have been identified as one of the biggest causes to environmental damage. On one hand, attention has been drawn to astounding designs that trespass human imagination. On the other hand, the worldwide population increase forced the implementation of mass production constructions to solve housing deficits. Frequently, buildings for the underprivileged lack design, compromising the environment and the achievement of sustainability. This is especially true in developing societies.

This research examines how public housing design has been produced to attend low income populations in Sao Paulo, Brazil and how much changes in the existing design affects the quality of the dwellings and energy consumption. The hypothesis of this research is that energy efficient architecture concepts applied to the current design of public housing in Sao Paulo are able to reduce energy consumption in the buildings. In this study, computer simulations are used to evaluate current energy performance of public housing buildings as well as to simulate the incorporation of new materials into the design and assess their performance.

The findings showed that there are many opportunities for architects to influence the quality of the design being produced for less fortunate populations in public housing buildings in Sao Paulo, which positively impact comfort conditions of the buildings and most important, reduce energy consumption by up to 50 percent.

Acknowledgments

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Chapter 1 – Introduction

1.1 Introduction

Efficient energy use has become a hot topic in the past years all around the world. It is known that the world temperature has increased over the past decades and one of the main causes has been the large amounts of carbon emissions being released in the atmosphere. Global surface temperature has increased in the past century around 0.05°C/decade (0.09°F/decade); however in the last thirty years scientists have observed an increase of approximately 0.16°C/decade or 0.29°F/decade (NOAA 2008.)

The climate change challenge is a succession of reckless events that have happened due to industrial revolution and capitalism. Such activities require extensive amounts of energy to be created and to be maintained. “Electricity, mostly generated from fossil fuels, is at the core of this challenge, accounting for more than 40 % of global energy-related CO_2 emissions” (IEA 2009.) Buildings for example account for a great part of this issue. The man-made structures have been responsible for several types of pollution such as carbon emissions, waste and degradation of natural resources.

The Energy Information Agency has accredited thermal control as one of the main issues associated with buildings’ high energy consumption (EIA, 2010.)
Despite all of the new technology, in order to sustain and protect the environment, it is very important that buildings’ design become more efficient. Since the cost of efficient and sustainable design is still very high, designers must developed creative strategies to increase buildings’ performance. This subject becomes even more sensitive once applied to places with economic challenges. Developing countries face numerous challenges and housing is one of the major. In addition, the population rate at developing countries has grown

exponentially, and so has the number of the low income families that lack resources for basic living such as housing.

Economical factors have great impact on design dynamics. It has been said that that good design is expensive and thus only a small parcel of the population is able to afford it. Therefore, public housing becomes synonym of mass production, lacking design quality and comfort. Design quality as well as energy consumption has not been a priority on public housing design, and this is reasonable at some level. Governmental initiatives in regards to public housing don't involve a complex design process. Since economic factors are a problem in most of the countries faced with the burden of a large low income population, the target becomes solving the problem at low cost and thus some steps are neglected.

This scenario is especially true in big metropolitan areas in developing countries. Such reality is even more complicated when referred to one of the largest metropolitan areas in the world. In Brazil, the Sao Paulo city has observed a problem in the public housing scenario and the issues are stressed by the large number of low income families. When public housing starts to be a matter of quantity instead of quality, the outcomes are dwellings that lack in comfort, aesthetic and value. The social value and preconception behind public housing is also an indicator of the low level of interest from the government and designers in this category of development. There is a misconception about public housing architecture, "…some might even claim that such works are not really architecture" (Davis 1995.) If there was a chance of improving places people live while contributing environmental protection, this opportunity should not be missed. Architects have the influence to make public housing better perceived and accepted by society. They can also design buildings to become more energy efficient as well as more comfortable for dwellers. Therefore, this research examines how public housing design has been produced in Sao Paulo and how much changing the existing design directly affects energy consumption and improves comfort levels within the buildings.

1.2 Energy Consumption in Brazil

A large source of environmental and social issues in Brazil is electricity generation and consumption. The country is among the three biggest energy consumers in the western hemisphere and the 10th in the world (EIA 2005). Most of Brazil's electricity generation capacity comes from a renewable energy resource – hydropower. Nevertheless, Brazil reflects global statistics on energy consumption as mentioned above, which shows that the majority of the electricity consumption comes from building construction and maintenance.

Hydropower serves around 50 million consumers, which is equivalent to 95 percent of the households. According to Krishnaswamy et al (2007) the "demand for electric power has increased in the past 20 years from 70 to 300 TWh" (fig 1.1) and the country is mostly dependent on hydroelectric power generation. The dependency on hydroelectric power should not represent a setback if compared to other sources of electricity generation, since it is a clean source of energy as well as cheap when compared to oil. Nevertheless, there are disadvantages on relying on this particular resource for power generation.

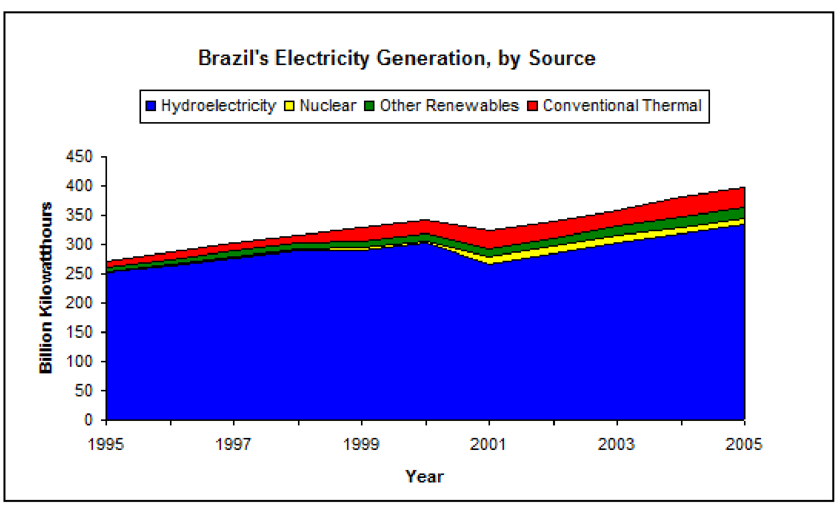

Figure 1.1 Brazil's electricity generation by source. Image source: EIA International Energy Annual.

Hydroelectric plants are known to cause massive environmental impacts on the local ecosystems, especially on the fish population, as well as harming the riparian habitat, negatively impact water quality and water flow, and last but not least, the system is very sensitive to droughts (EERE 2005.)

The demand on hydroelectric power keeps growing each year and it represents a problem for the federal government and a concern for consumers. In the years of 1991/ 2001/2002, with the later year being the most dramatic situation ever experience by the nation, the country experienced a severe energy crisis due to extensive droughts, that led to economical measures to downsize energy use by implementing new taxes and increasing energy cost even more (Krishnaswamy et al 2007 a.) Even though, some agree that there is a problem of generation capacity in the country, officials reinforce that there is not an investment issue.

The latest episode observed regarding energy consumption in Brazil was the blackout in November 2009, which left tens of thousands of people without power created a chaos throughout the country. Although the government has invested in expanding and increasing the quality of the generation capacity, energy is still a problem in Brazil. The possibility on expanding the capacity has a massive impact on the ecosystem and all natural and untouched areas in the country. Most of all, electricity is a very pricey commodity controlled by the government. Even though hydroelectric power usually implies low cost, this is not applicable in Brazil, where the monopoly of the resource creates high prices and offers no alternatives for the population. Hence, energy saving strategies should be taken into consideration during the design process of any building and especially in public housing, which is a growing market that represents a great parcel of electricity consumers in the country and has not been given enough attention.

1.3 Sao Paulo: Is Architecture A Privilege for the Wealthy?

Sao Paulo is the strongest city in Brazil, which is a developing country in South America, with an area of 8.541.876 KM2 and a population of over 193 million

(UNSTATS 2009), of which 84, 2 percent are urban area residents. According to World Health Statistics (2008), until 2006, 16 percent of the total urban population of Brazil did not have access to improved sanitation and almost 10 percent did not have access to potable water and a great parcel of the population live in urbanized areas. Politics in Brazil is a sensitive subject that amid other problems, it seriously affects the construction sector and therefore public housing.

Due to the intense industrialization of certain areas in the country, such as Sao Paulo, the immigration rate skyrocketed and serious environmental and social problems arose. The rapid growth became a burden on the land, and also on public health and sanitation. Currently Brazil's total housing deficit is around 6.272.645 houses, and half of the housing deficit number in the country is connected to major population agglomerations in the country. Therefore, due to the outstanding population size, Sao Paulo state stands out in this matter among the other Brazilian states.

Sao Paulo state belongs to the southeast region of the country, with a population count of 39.827.570 (IBGE 2007) in a total area of 248.209,426 Km2 and 645 municipalities, of which its homonymous capital – Sao Paulo city- is the biggest metropolitan area of the country. Due to the intense conurbation process, the Sao Paulo city area and its surrounds cities are now part of a large industrial area called the "Metropolitan Region of Sao Paulo." Sao Paulo city accounts for almost one third of Brazil's GDP and it is alone the biggest metropolitan area of South America. According to PricewaterhouseCoopers (2007) in a report ranking the cities by their GDP, as of March 2005, Sao Paulo is the 19^{th} richest and most populated city in the south hemisphere (WIKIPEDIA 2009.)

In spite of the fact that the development that has happened in Sao Paulo city over the years brought economical and industrial growth, it also contributed to environmental issues, such as water and air pollution and ecosystem damage.

The later is also due to the great amount of resources used to maintain the large population. The elevated number of people that are attracted to the city's potential keeps growing each year, and that reflects not only a stress on the environment, but also low quality architecture that has been built to accommodate this immigrants that face poverty and very harsh living conditions on trying to pursuit their dreams of a better life. This research intends to address the issue of public housing in large metropolitan areas and their contribution to a sustainable society.

Chapter 2 – Literature Review

2.1 Public Housing around the World

Public housing also called “affordable housing is the latest in a long list of synonyms to denote housing for those who cannot afford the free-market price” (Davis 1995 a.) The concept embraces a wide range of variants and a “combination of services: space, environmental (water supply, waste disposal, energy use), and location (access to jobs and social infrastructure such as education and health)” (Lakshmanan et al 1977.) The only basic concept of public housing that can be applied to all societies is that it is a governmental initiative to battle poverty. The quality of spaces and type of construction vary widely among countries, cities and even locations within the same city.

The literature reviewed in this thesis observed a variety of public housing initiatives in developing countries; however, the majority of literature available in this topic, relates to public housing in developed countries. The literature showed that developed countries are more advanced in the quality and construction standards of public housing buildings. The buildings, either houses or apartments usually follow sustainable guidelines for construction and offer good educational opportunities for the population. The design quality of the developments allows integration of public housing into, avoiding segregation, as usually happens in developing countries. Such examples of good practice are examples to be followed as design guidelines and governmental practices.

2.1.1 Public Housing in Australia

Australia showed a competent public housing program that revealed a variety of design patterns that serve different levels of low income population. The latest projects offer design quality and are good examples on how architecture can be applied to lower classes.

The "K2 apartments" (State Government of Victoria 2009) finished in 1997, have won awards for being a new concept of public housing. It encompasses the social as well as economic aspects of sustainability as important as the natural environmental aspects from its surroundings. Among its goals, the government has focused on sustainable initiatives for public housing projects. Some of the design considerations are the use of energy efficient lighting, the inclusion of environmentally sustainable construction techniques that improve the quality of the buildings as well as protect the environment such as insulation, weather seals, and water saving devices.

Figure 2.1 Australia's K2 apartments. Image source- http://www.vic.gov.au/

2.1.2 Public Housing in Hong Kong

Amid the countries that provide public housing taking into consideration environmental practices is Hong Kong. The Hong Kong Housing Society is a not-for-profit organization in partnership with the government that provides housing opportunities for the population. In order to incorporate more sustainable practices into the design, the organization adopted environmental policies which are certified to ISO 14001. Several guidelines are used to ensure the protection and enhancement of the living environment.

The Flat-for-Sale-Scheme was a program developed in Hong Kong in the 80's that targeted the development of housing units at concessionary price. The tenants should fit the eligibility criteria under the Home Ownership Scheme in order to apply for a house. The development was completed in 1989 and received a certificate of Merit by the Hong Kong Architecture Society. The apartments have between 233.9 - 469.10 sq. ft. for rental purpose and 420 - 646 sq. ft. for buying.

Hong Kong has successfully attended the low income population by providing good quality buildings that reflect the concern to solve the house deficit at the same time it engages sustainable practices to respect the environment.

Figure 2.2 Hong Kong high rise public housing. Image source- http://www.housingauthority.gov.hk/en

Figure 2.3 Hong Kong public housing site plan. Image source- http://www.housingauthority.gov.hk/e

2.1.3 Public Housing in Singapore

Housing and Development Board - HDB - is a public housing organization created by the government of Singapore to provide housing opportunities for the population. Their mission is to provide affordable housing that ensures quality living spaces. With the objective to end poor and unhealthy living conditions in the country, in 1960 the government developed a strong organization targeted to build affordable housing and good living conditions to a large parcel of the population living under unhealthy and hazardous conditions.

Figure 2.4 (From left) Singapore flats aerial view; Singapore flats' plan view.
Image source- http://www.hdb.gov.sg/

Furthermore, Singapore housing program has greatly incorporated energy saving strategies in residential buildings design. The adoption of the program "Energy Save" provides sustainable solution for buildings such as passive design and active design solutions to reduce energy use after construction (Housing and Development Board, 2008.)

2.1.4 Public Housing in the United Kingdom

National Housing Federation is a not-for-profit organization of independent housing associations in the United Kingdom that envisions the promotion of affordable housing and the work of housing association at the same time it reinforces sustainable development. The housing associations are composed of social businesses that focus on the provision of social housing in the country. Amid the organization's environmental goals is the POWER HOUSE EUROPE (CECODHAS 2009), a project that targets the residential sector's energy savings. Through educating home owners, the project teaches refurbishment and constructions techniques to optimize energy consumption.

Carbon emissions caused by buildings in the United Kingdom have been a constant concern not only to the housing organization, but to the government as well. Among the information regarding greener construction is the importance of utilizing efficient insulation on walls and roofs, which are the areas of a building which most heat escapes. "More than half the heat lost in a typical home escapes through the walls or the roof. Installing loft and cavity wall insulation will reduce the heat escaping. Combined with a degree of draught exclusion, it could also cut your fuel bills by up to £180 every year" (DirectGov 2009.) Other design considerations that affect the building's energy performance such as the use of double glazed windows as well as hot water tank insulation, have been United Kingdom's target regarding not only the construction market as a whole, but public housing market.

Figure 2.5 (Left) United Kingdom public housing. A tower block in Seacroft, Leeds. Seacroft. Image source- http://www.communities.gov.uk/housing/

Figure 2.6 (Right) Public housing apartments United States. Brooklyn condos- twenty story Hylan Houses Bushwick. Image source: www.wikipedia.com

2.1.5 Public Housing in the United States

Through the U.S. Department of Housing and Urban Development, the United States has tried to serve the low income population in regards to affordable housing. The department houses several offices that serve different aspects of community needs. The Office of Housing "…oversees the Federal Housing Administration (FHA), the largest mortgage insurer in the world, as well as regulates housing industry business" (HUD 2009.)

The housing programs main focus is to create safe communities and provide house ownership; however, there is also the concern about the environment when constructing affordable communities and homes. One of the challenges faced by U.S. Department of Housing and Urban Development is to reduce energy consumption in residential buildings, which can cause serious environmental issues as well as direct effect on home owners and utility bills. According to the department, "…Utility bills burden the poor and can cause homelessness. The burden on the poor is more than four times the average 4% others pay. 26% of evictions were due to utility cut-offs in St. Paul, MN" (HUD 2009a.)

Energy efficiency strategies have the support of the federal government which emphasizes the important of preservation and using fewer resources from the environment. Programs such as the ENERGY STAR FOR GRANTEES (HUD 2009b) provides homeowners with guidelines for a more efficient buildings, where owners can access information on water efficiency, renewable energy, recycling, waste and all the products available in the market. Insulation, window types, mechanical ventilation, air sealing and water heating are main topics related to energy saving. These are important design elements that must be taken into consideration during the design and construction process of public housing as well.

2.1.6 Lessons Learned from Other Countries

Various lessons were learned by studying design for public housing in other countries. Even though the common goal was alike in all countries, which is to reduce housing deficit and social issues, the design strategies were different. The governmental approach as well as the organizational profile of each of the countries studied was varied; however environmental issues appeared as major aspirations of all of the countries.

Most of the countries have different climate profiles than Brazil, and the design techniques are usually distinct depending on the climate; however, the studies revealed that even countries with similar climate as Brazil do use energy savings strategies and sustainability values. Australia uses energy efficient lighting, environmentally sustainable construction techniques, insulation, weather seals, and water saving devices in public housing buildings.

The major lessons taken from other countries are the concern with the environment when designing public housing buildings, the use of building materials that improve energy consumption and the use of energy strategies incorporated into the building that saves energy after construction. Comfort within the buildings is also a concern and a focus of design on several countries and it improves the quality of the construction and the quality of life of people living in them.

2.2 Public Housing in Brazil

In a document concerning the *Origins of social housing in Brazil* (1994), Bonduki mentioned that the first social housing complex constructed in Brazil dated from 1906 in Rio de Janeiro and 1926 in Recife, northeast region of the country. It was only in 1946 that a social housing program was effectively created, known as

“Fundacao Casa Popular” – National House Foundation, and which was very ambitious but not successful (Politica Nacional de Habitacoes 2006.)

Throughout the years, several programs and autarchies were developed in the federal and state level, and among all, the Sao Paulo public housing history stood out due to the size of the program and number of delivered houses. Even though social housing presents an issue to the country, it was not only after the dictatorship, 1930-1989, that small initiatives started to appear as a solution to solve the deficit at the time. The housing deficit in Sao Paulo is the largest from all regions in the country. While Brazil’s total housing deficit is around 6.272.645 houses, the Sao Paulo state accounts for 1,234 million, of which half of this number is the deficit in the Sao Paulo Metropolitan Region alone (FJP 2008.)

The current deficit is a consequence of decades of social, economic and political interests that are related to large metropolitan areas. In the case of Sao Paulo, housing is a long lasting issue and it was only in the 19th century that governmental initiatives of public housing started, even though they were mainly privatized programs, motivated by the government aggressive capitalist thinking, which targeted the labor population that come to the city to work on the developing industrial sector, envisioning profit by construction and renting investments (Bonduki 1994 a.)

During the economic growth period of the coffee plantations’ boom, Sao Paulo city received a large amount of labor immigrants, which increased the price of housing in the city, and directly affected the new immigrant’s life by forcing them to leave in shanty towns (Bonduki 1994 b.) The industrial villas were housing units built by private corporations to house their workers, who would pay a small rent or in some cases they were free. Even though these communities were the first initiatives of social housing in Sao Paulo, they were not successful in the following years, mainly because of economical reasons; and reminiscent of this type of urban areas are rarely seen in Sao Paulo nowadays (Bonduki 1994c.)

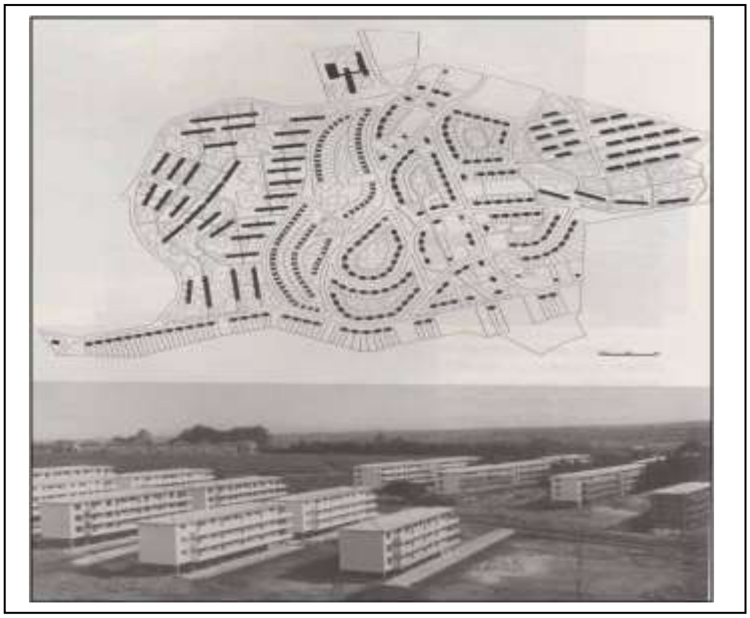

Figure 2.7 Public housing 1940's- Residential buildings Vila Guiomar, Santo André County, SP.

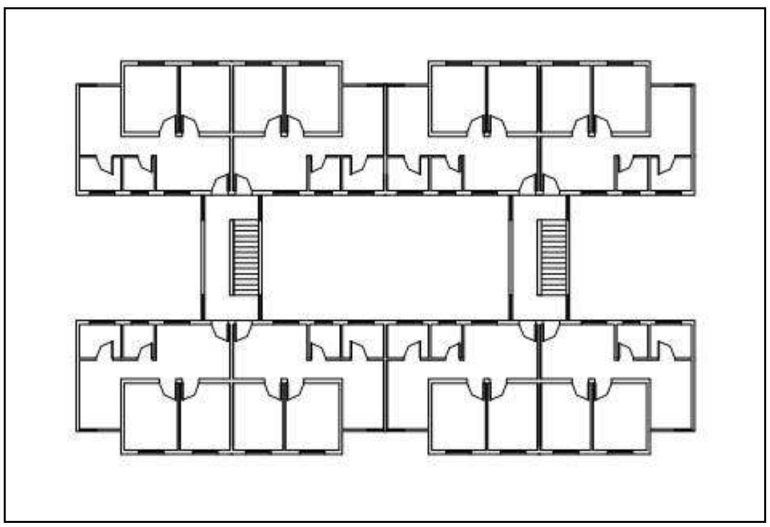

Figure 2.8 Public housing 1940's- Residential buildings Vila Guiomar. Santo André County, SP. Plan view. Images source- Origens da habitação social no Brasil. São Paulo: Ed. Estação Liberdade: FAPESP, 1998.

Regarding the architecture, most of the public housing movement in Sao Paulo was significantly influenced by European housing production and modernist architecture, with mass housing complexes developed in urban areas with community elements incorporated into them (Bonduki 1994d.) They were good examples of mass architecture, were dwellers would receive the necessary urban structure and sense community at the same time they would be living in a comfortable and well design building. Experienced architects greatly contributed to the development of those modernist communities and incorporated new architectural elements in the buildings that trace as of it can still be seen in the housing communities.

The construction of multi storey buildings was one of the modernist influences that really changed the face of public housing, since until then most communities were houses instead of apartment buildings. As the demand increased, the government came across economical and political issues that directly affected the quality of the housing programs and the standard of what was first established as social housing communities.

Figure 2.9 (Left) Public housing complex.
Image source- http://www.citiesalliance.org/ca/

Figure 2.10 (Right) Vila dos Idosos, Sao Paulo, SP. (Elderly Villas) Image source- http://www.capital.sp.gov.br/portalpmsp/homec.jsp

It was only in the 1960's that the Sao Paulo state implemented the first social housing initiative, with the creation of the State Company of Social Housing - CECAP - which had several changes in its structural organization and adopted different names throughout the years, of which now is known as CDHU- Housing and Urban Development Company of the State of Sao Paulo (SEHAB 2009.)

2.2 Housing and Urban Development Company of the State of Sao Paulo

The CDHU - Housing And Urban Development Company of the State of Sao Paulo- is a state organization under the Brazilian Housing Secretary department responsible for the housing policy, urbanization and land issues that are relevant to public housing matters. The company's main goal is to lower the state housing deficit number by developing large scale building complexes to house thousands of families that can acquire a property through a low percentage of their monthly income.

CDHU is the major public housing and urban development company in the country. It is a public company with the major holder being the Sao Paulo government and it is composed of a presidency and five directorship acting in different areas (fig 2.11.) Each directorship has its own specific network of management and bureaus. The regional management agencies and the housing service centre are placed in specific cities to serve the population and house owners about any issue related to the public housing programs and financial matters as well as manage all phases of project implementations. Its liquid assets as of December 2008 was 10.000.000, 00 (SEHAB 2008 a)[1]and the company moves around 350 million dollars a year and already built 440.000 public housing units, that served around 2 million people (SEHAB 2009 b.)

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[1] The *Directorship Report 2008* available from CDHU website:

http://www.habitacao.sp.gov.br/download/balanco/patrimonial2008.pdf

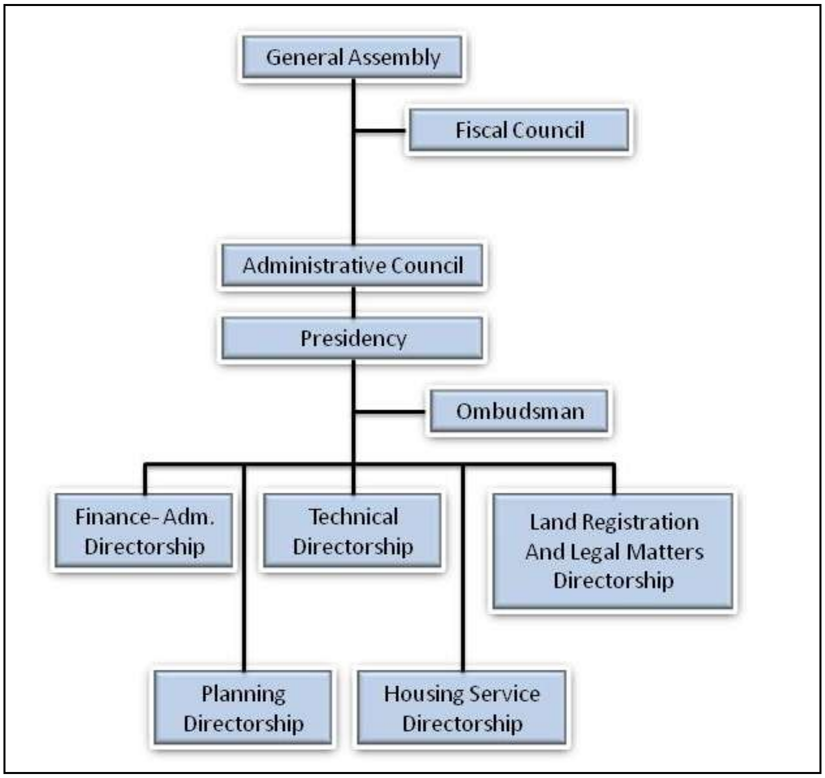


Figure 2.11 CDHU organization profile. Image source-
http://www.habitacao.sp.gov.br/

The financial resources of the company were initially obtained from the Housing Financial System, a public body from the National Financing System that was specialized on public housing in Brazil. The system was responsible for gathering funds for public housing, lend funds for housing purchases, as well as subsidize low income families to buy their properties. The subsidy amount varies according to the families' income (BCB 2009) and the installments amount is a percentage of the total income[2] (Table 2.1.) This amount led to the creation of a federal law to decrease the number of breaches in contract and lack of payment from owners. Later, a percentage of federal taxes was also directed to fund public housing which made possible lessen interest rates, and providing more affordable prices, thus beneficiating a larger number of families.

[2] Brazilian minimum wage average value in US dollars as of July 2009 is U$S 262, 50.

Table 2.1 CDHU family income

Maximum limit of income commitment	
Minimum Wage	% on family income
1,00 to 3,00	15%
3,01 to 5,00	15 a 20%
5,01 a 8,5	20 a 25%
8,5 a 10	25 a 30%

Data source- http://www.habitacao.sp.gov.br/

Table 2.2 Number of municipalities

Number of atended municipalities	1986	1999	2004	2008
Sao Paulo Metropolitan Region	4	20	35	35
Outskirts of Sao Paulo	15	495	566	582
Total	19	515	601	617

Data source- http://www.habitacao.sp.gov.br/

2.2.1 CDHU's Housing Program Overview

The CDHU housing program serves low income population through different types of programs. The different types of programs benefit a variety of social classes and needs. Today, under the current governance, the initiatives[3] being offered by CDHU are (CDHU 2008):

1- Housing Provision
2-Housing Requalification
3- Slum Urbanization and Precarious Settlements
4- Environmental Sanitation in Regional Water springs

[3] See appendix A for more information on the CDHU - Housing And Urban Development Company of the State of Sao Paulo programs.

The Housing Provision Program focuses on producing buildings to attend low income families in partnership with small and medium size municipalities in the state of Sao Paulo and was chosen as the study area of this dissertation since it deals primarily with architecture issues. The monetary resources for this program are directed to the municipality that will implement the project by the federal government.

The housing units are executed in urban areas provided with enough structure such as water, sanitation and community services necessary to ensure a good quality of life for new low income dwellers. Through this program, the state decentralizes the actions, and the municipalities are responsible for all the steps of the project. They target population with incomes raging between 1 to 10 minimum wages, although preference is given to those with an income up to 5 minimum wages. These programs also focus on the elderly population, police officers and special needs citizens. In order to become legible as a buyer, the prospective owner has to (CDHU a):

-Earn from 1 to 10 minimum wage salaries (US$ 262, 50 to US$ 2625, 00.)
-Have lived for at least 3 years in the municipality of the future housing community.
-Do not have any real state property in the country or any property in its own name in the country.
-Being new in the public housing program, never being attended and having not owned a property or transferred a property in the program before.

Through time, the CDHU developed standard buildings typologies as a way of making the construction of housing communities more affordable, thus being able to serve a larger section of the population. Today the majority of CDHU projects are based on standard typologies available in booklets and they attend the most needed part of the population.

2.3 Energy Consumption and Comfort Level

Energy conservation has been a constant issue around the world. Energy consumed by buildings has become a problem, since the amount of energy buildings require before and after construction is alarming. Moreover, the demand for buildings has increased due to the population increase.

Even thought, strategies for energy conservation in buildings have increased, there are still gaps in this matter. A lot has been done regarding energy efficient design of buildings, but it must be said that there has still been an association between efficiency in design and high costs. Moreover, environmentally friendly design is usually linked to state of the art buildings that are performed to and by higher social classes' designers and clients. In order to understand the dynamics of a building and how to achieve thermal comfort through design, one has to understand principles of environmental thermal conditions.

"One primary function of a building is to modify or filter the outside climate to produce pleasant indoor conditions" (Holm 1983.) Thus, buildings are human shelters that should consequently provide comfort for its dwellers. Comfort is a subjective concept. It depends not only on temperature, humidity and wind, but more important on people's comfort levels, which may vary depending on region and even culture. Comfort is not only related to the human body's ability to dissipate heat, but it is also related the environmental conditions and the natural conditions that allow that action to occur. According to Lechner (2001), there are four conditions that simultaneously contribute to human comfort: "air temperature, humidity, air velocity and mean radiant temperature."Thus thermal comfort must be a target concept to designers when designing buildings. "…Temperatures in the winter should range from 68-74° F and 73-79° F in the summer" (ASHRAE 2009.)

Site specific characteristics as well as building materials and design elements are crucial techniques to achieve good indoor conditions. Moreover, indoor comfort levels depend on human reaction to temperature in a certain site and consequently affect energy consumption in a building. Hence, designers must incorporate design strategies in buildings that are able to provide good indoor conditions, but still saving energy.

2.4 Thermal Comfort in the Building Envelope

There are two different approaches to achieve thermal comfort within a building envelope. The first is by using passive design techniques into the design process. The second is by using artificial systems such as heat and air conditioning and improve the other elements such as windows, insulation, roof and walls to work together to provide comfort and save energy.

Passive design is an active part of the design process. It is not an add-on or something that can be adapted after construction. Strategies include orientation, form, window and glass type, material selection, shade elements, location and finishing materials. Passive design is more than just an energy saving mechanisms, it is a way of designing buildings, and it provides quality spaces and great architecture.

There are some constraints about utilizing passive design strategies in multi-family buildings. Due to the reduced surface area exposed to environmental conditions such as sun and wind, apartment buildings present one disadvantage when compared to single family homes. Moreover, the different tenants might use each unit differently, interfering with natural ventilation, daylight incidence, lighting, and air conditioning. According to Rouse (1983) in a study for passive solar program for multi-family buildings in Massachusetts, "…inappropriate multi-family passive solar solutions may replace heating bills with bills for cooling and lighting, saving little energy, or worse, increasing total energy costs."

On the other hand, providing thermal comfort by relying on artificial system may increase energy consumption. "The more insulation, the better" (Lechner 2001a) refers to the improvements insulation materials can provide and comfort levels that can be achieved once insulation is incorporated into the building.

Table 2.3 Insulation material

Material	Thermal Resistance	Physical Format	Comments on Applications
Fiberglass	3.2	Rolls, batts, and blankets	Good fire resistance Moisture degrades R-value
Rock wool	2.2	Loose fill Rigid board	Fairy inexpensive
Perlite	2.7	Loose fill	Very good fire resistance
Cellulose	3.2 3.5	Loose fill Sprayed in place	Required treatment for resistance to fire and rot
Polystyrene (expanded)	4	Rigid board (bead board)	Fairly low cost per R-value Combustible Must be protected against fire and sunlight
Polystyrene (extruded)	5	Rigid board	Very high moisture resistance Can be used below grade Combustible Must be protected against fire and sunlight Good compressive strength Higher cost and R-value than expanded polystyrene
Urethane/ isocyanurate	7.2	Rigid board	Very high R-value per inch Combustible and creates toxic fumes Must be protected against fire and moisture
	6.2	Foamed in place	For irregular or rough surfaces
Reflective foil	Varies widely	Thin sheets separated by air spaces	Effective in reducing summer heat gain through roof Foil must face air spaces Foil should be face down to prevent dust from covering the foil

*The thermal resistance are given in R-values per inch thickness. The actual resistance varies with density, type, temperature, and moisture content.
*The thermal resistance depends on the orientation of the foil-faced space and the direction of the heat flow (Table 15.68.)

Lechner, N. 2001 a. *Heating, Cooling, Lighting. Design Methods for Architects*. Second Edition. John Wiley and Sons, INC. New York.p443

Some improvements are money saving, increased thermal comfort, relatively inexpensive, very durable, functions in summer and winter and easy to install during construction. Over insulated building envelopes are become more and more common. By using insulating improvements such as decreased heat loss, moisture and fire resistance can be expected, adding value to the building envelope. Examples of insulation categories are: blankets, loose fill, foamed-in-place, boards, and radiant barriers (Lechner 2001b.)

Another important element of design is the roof. Roof insulation, type and material also play an important role in the building envelope, since it is the major area of heat transmission. Strategies for building include light-colored roofs, which despite having high albedo, reduce thermal load on the building envelope by reflecting the heat. Roofs temperatures can get as high as 150^{o}F in summer time, which affect internal temperatures of the building as well as building performance.

Furthermore, window selection is a major component of building design. They allow light and heat into the building, as well as provide air inside the building in the case of operable windows. Conduction of energy through the windows and it affects the building performance. Window performance is measure though: Solar Heat gain Coefficient – SHGC, Visible Transmission- VT, and Thermal Resistance- U-value. Windows' categories vary from single glaze, double-glaze and triple-glaze.

In conclusion, it does not matter the approach chosen to achieve thermal comfort within a building envelope, passive design or active design. Most and foremost, it is essential to design buildings that provide shelter for humans, are safe and comfortable and most important, are sustainable constructions that do not negatively impact the environment.

2.5 Aim and Objectives

2.5.1 Specific Objectives of this Research

The main objective of this research is to investigate the design of public housing in Sao Paulo, and to analyze and evaluate its construction techniques effectiveness in reducing energy consumption buildings and becoming more sustainable. The motivation for this research is the aspiration to find a solution to improve thermal comfort for social housing dwellers and to provide insightful information on strategies to improve the current design in regarding energy consumption.

From the literature review it was clearly revealed the existence of different public housing initiatives across countries. There has been a connection between affordable housing design and sustainability in most of the cases. Developed countries revealed a great concern for environmentally friendly design in the construction and maintenance of this type of design. This review revealed a limited study on developing countries design strategies for public housing and research on this topic is also limited.

Most of the studies on energy efficient design strategies available relate to cold climate zones and a few relate to subtropical zones such as encountered in the south hemisphere. The references to energy saving strategies on tropical climate often relate to passive design concepts. Literature reviewed several design techniques available for efficient building design. These techniques represent a significant opportunity to promote more knowledge and connection among designers on how affordable housing in Sao Paulo has the potential to incorporate sustainable design techniques in the design process.

2.5.2 The Aim of the Research

- Identify public housing strategies on design around the world as a base for this study.
- Identify current energy performance of public housing buildings in Sao Paulo in terms of energy performance and thermal comfort.
- Analyze effectiveness of major building envelope components in reducing building's energy consumption.
- Create a final building composition with the best results from the analysis above in order to examine the effectiveness of the materials' performance collectively.

2.6 Outline of Thesis

Chapter 1 – Introduction – The importance of sustainable design and energy saving through design strategies in public housing is debated, along with the establishment of the research topic and research objectives.

Chapter 2 – Literature Review – Findings on literature review on public housing around the world, public housing history and organization in Sao Paulo, energy consumption in Brazil and Sao Paulo. Review of thermal comfort concepts as well as building materials and energy performance.

Chapter 3 – Methodology – Methodologies used in the past studies on thermal performance of buildings are discussed and their relevance to the research is explored and discussed. Furthermore, the methodology for the research is defined and described. The hypothesis is established followed by the methodological framework. Then, description of the research boundaries is explained as well as the selection process for the potential case studies. The chapter ends with an evaluation of the external parameters affecting the model.

Chapter 4 – Results and Analysis – Analysis and development of the research. The case studies research is presented along with results. The variables used in the simulation process are described and analyzed. All results and graphics from each case study are shown and discussed based on the hypothesis and research objectives.

Chapter 5 –Conclusion and Recommendations – Final conclusions from findings are drawn followed by recommendations and a summary of the steps involved in the research.

Chapter 3 – Methodology

3.1 Energy Consumption and Thermal Comfort Analysis Design Tools

The study of the energy consumption on low income housing involves the analysis of thermal comfort and energy consumption in multi-family buildings. The building envelope is assessed in terms of energy use while creating comfortable temperatures for the dwellers. Comfort level in public housing dwellings is a subjective concept which varies according to environmental conditions and cultural values. Inhabitants of northern areas might be more prone to colder conditions indoors and outdoors than southern populations. A number of studies have been done to assess energy consumption and thermal conditions of buildings in tropical climates.

A greater number of passive design studies for public housing have focused on thermal comfort. On the other hand, most of the studies related to energy consumption relate to enclosed buildings envelopes, which is most common in colder climates. Studies such as the one done in the French tropical islands, involved experimental research as well as a sociological survey to analyze the passive design techniques incorporated into two buildings that were especially done for the research (Garde et al 2004.)

Studies developed to assess residential design energy performance are available and help the study of public housing energy performance. The tools used for the analysis must involve as many parameters that affect the buildings as possible, in order to produce realistic results. Among the options, softwares specifically developed to simulate natural condition are great tools to provide accurate results in a short period of time. More research methods are discussed in the next chapter.

3.2 Monitoring

Monitoring is largely implemented in research of energy performance of buildings. The process involves measurement of different variables that are transcribed to a database, which is analyzed after the end of the measurement period.

Studies such as the one done by Filippın and Beascochea (2005) in Argentina are good examples of field monitoring research. In this study, energy-efficient housing for low-income students was analyzed using two different types of measurements taken for a period of approximately one month: hygrothermal and energetic performance were measured, as well as thermal comfort conditions.
Solar irradiation was measured with a pyranometer Kipp & Zonen, which was located on the roof top. After the end of the data collection, the results were plotted for analysis.

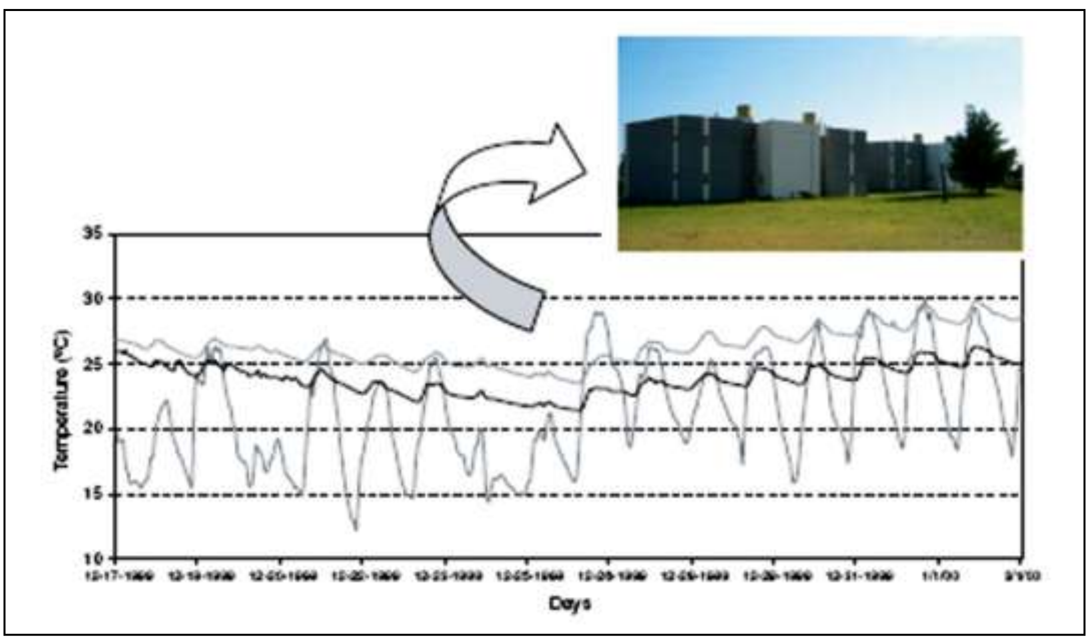


Figure 3.1 Thermal behavior between apartments in the ground floor and upper floor and a South view. Image source-Filippın;Beascochea, A. 2005. Energy-efficient housing for low-income students in a highly variable environment of central Argentina. Santa Rosa, La Pampa, Argentina Universidad Nacional de La Pampa, Argentina. Renewable Energy 32 (2007) p13.

Field monitoring approach is one the most precise approach to measure building performance if given enough time for collection of results. This method has the advantage to have accurate results, because it is executed in the exact same place of study. It requires numerous equipments and it can only be done after the project/building is finished. Although methods such as monitoring offer realistic insights in building performance assessment, the equipments necessary to do the research represent a downfall. The process tends to be expensive due to the requirement for specialized measurement tools, an existing building and constant monitoring. In addition, accurate results in this method include a long period of monitoring time.

3.3 Computer Simulation Model

Computer simulation method is a widely used tool of architecture research. The method consists of an abstract model that is built using specific computer software, that is then simulated under defined. Computer simulations software have become very popular as pre-design tools for designers. One of them is ECOTECT 5.5, which is a building design and environmental analysis software developed by Autodesk. The software allows users to model 3D buildings and simulate thermal analysis, solar analysis, shading design, ventilation and air flow, acoustic analysis, lighting design as well as building regulations. By using EPW weather file, the simulations become more realistic, since the weather data can be specified for different locations.

Other software for building simulation include HEED, developed by University of California and that simulates energy savings of designs. The 3D modeling tool is user friendly and also works with EPW weather files that allow more accurate results. Among its features, the software offers a material library as well as gas, utilities, oil, propane rates to simulate energy costs and savings. It is also possible to include simulate energy saving by quickly choosing he options on operable shading, attic radiant barriers, roof color and window type.

Even though HEED is straightforward in terms of interface, some downfalls may apply. One is that the software is mainly used for the northern hemisphere, which makes it harder to use with southern areas of the globe. Also, utility rates are set for the California region; therefore, the results of money savings become less accurate to other regions.

TRANSSOLAR is another thermal simulation tool for buildings used by designers. The software allows the validation of energy simulations such as building equipments, occupant behavior and energy system. Some of the features include a component library, add-ons as well as interactivity with other programs during the simulations.

The use of computer simulations for building analysis has become an indispensable tool for architects and engineers in the conceptual part of the design process. Best decisions can be made based on simulations results and analysis of building components and performance. One issue of this method is the accuracy of which the parameters are introduced and established in the model. One has to make sure that all the variables necessary for the simulation of a certain model have been included in the model. The oblivion of one parameter can mislead the results.

3.4 Selected Research Methods

The objective of this research is to investigate the design of public housing in Sao Paulo and identify design strategies that could help reduce energy consumption and make the dwellings more comfortable to inhabit.   The building envelope is the target of the evaluation, so there is no assessment related to a single apartment unit. In this study, computer simulation method was the best fit to assess the research objectives.

3.4.1 Computer Simulation Models

The software chosen to perform the simulations was ECOTECT 5.5. Due to its wide acceptance by architects and researchers and also due to the available features, the software proves to be a accurate analysis tool in the field. Even though the literature hasn't shown traces of the use of this software in the design of public housing in Sao Paulo, the applications on residential design or commercial design has proven to be very effective. Moreover, ECOTECT 5.5 has been used at thesis and assignments at The British University in Dubai.

The current public housing building design in Sao Paulo does not employ mechanical ventilation systems as a mean to control thermal comfort within the apartments. Even though the city belongs to a subtropical climate region, summers and winters make temperature levels within the building envelope quite uncomfortable. Moreover, since to simulate energy performance in ECOTECT 5.5 the building envelope has to be enclosed, the buildings chosen to be studied were assigned with heating, ventilation and air conditioning system – HVAC as well as occupancy levels based on the profile of each building.

The simulation parameters provided by the software include direct solar gain, relative humidity, and other parameters related to passive design strategies that even though are part of the energy performance result, they cannot be simulated at the same as energy consumption by the software. Moreover, the focus on this particular study is energy consumption and the building components that can affect the consumption. Thus, efforts are focused on building elements and their contribution to energy consumption.

3.5 Building a Hypothesis

The purpose of this research is to investigate the design of public housing in Sao Paulo and identify design strategies that could help reduce energy consumption in public housing and make the dwellings more comfortable to inhabit. Typically in Sao Paulo, low income buildings were built of mud bricks and plaster. The walls were standard thickness and openings were enough to allow natural light and air into each of the rooms. No concern was given to thermal comfort besides providing shading elements to protect from very hot sun and rain.

The concept that is being explored has been influenced by the possibility of design strategies to reduce energy consumption as well as provide comfortable temperatures throughout the year. From assessing other public housing design around the world, the main idea is to incorporate sustainable design strategies such as insulation, efficient window types and wall materials to create a better design to public housing design. First, since there are a large number of public housing buildings in Sao Paulo, the energy being consumed by these buildings is also very high. Thus, finding a design that decreases energy consumption from this large parcel of the population affects the country's energy generation and the population as well.

Even though for the purpose of this research, the buildings are assumed to be enclosed envelopes with mechanical heating, air conditioning and ventilation systems, there is a possibility of lesser consumption than the current existing design. During winter time energy consumption is extremely high because of the increased use of space heaters. In summer, refrigerators, fans and portable air conditioning systems also cause an increase in energy consumption. Therefore, the hypothesis is that by incorporating energy efficient building elements in the current design, public housing buildings are able to consume less energy.

Despite the fact that public buildings in Sao Paulo could incorporate mechanical ventilation systems, for such a hypothesis to work, the same building model has to be used. No changes in the shape of the building should be in order to evaluate the current situation. However, orientation, window type, insulation and shade elements must be incorporated in order to identify their efficiency in the current design. It is clear that the current building standard for public housing in Sao Paulo is very simple and low cost. But if small and inexpensive changes were made, would that be enough to increase the comfort and decrease energy consumption within the buildings? This study looks for a new design strategy to improve housing standards that are extremely low not because of lack of funds, but because of lack of interest by designers and government to produce sustainable buildings with comfortable spaces.

3.6 Methodological Framework

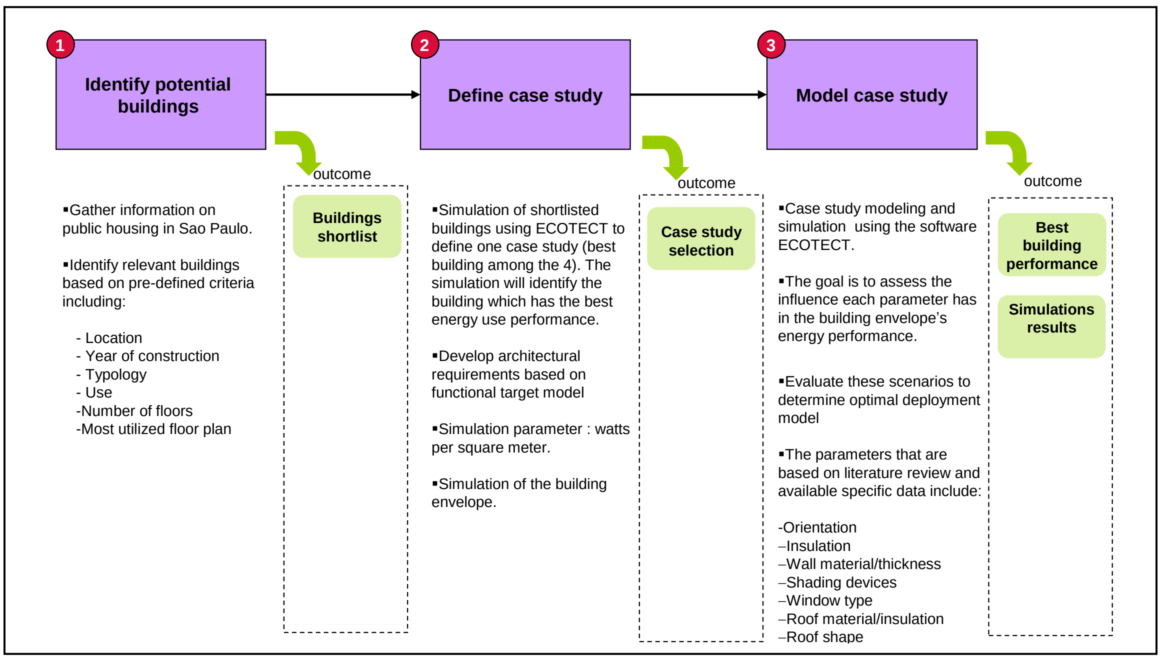


Figure 3.2 Methodological framework.

The methodological framework demonstrates a three-step approach strategy for the research development. The graphic represents the overall structure of which the research was conducted. The first step described the identification steps to find the four buildings for the first pass on the simulations that would led to the second step, definition of the case studies. The third step was a consequence of the second, which provided two buildings for further investigation. That step was targeting the analysis of each specific components of the building envelope, in order to understand the current design practice in low income housing in Sao Paulo and also to potentially provide recommendations for future designs based on the simulations results. All of the three steps illustrated in the methodological framework will be further described in full detail in the next chapters.

3.6.1 Defining the Research Boundaries - Identify Potential Buildings

Several buildings were considered to define the research boundaries. A set of decision were used to arrive at the optimal choice for the first step of the process. During the selection process it was evident that due to the relatively long history of public housing in Sao Paulo, it was important to understand whether there was an architectural design evolution of the public housing in Sao Paulo and an improvement on the quality of the design been offered throughout the years. The decision parameters were:

Location –The buildings should belong to the same location. In this case, the buildings should belong to the city of Sao Paulo.

Year of construction – The buildings should have been built in different years, so as to evaluate if there was an improvement in design as well as to understand the quality and standard of public housing architecture in Sao Paulo.

Typology – Sao Paulo as well as any other large metropolitan region faces land scarcity problems, therefore, to accommodate a larger number of people, buildings are usually more constructed than houses. Therefore, the criterion for selection was that buildings must have at least three floors.

Building area- According to the Housing Secretary data, a greater part of public housing buildings comprises 2 bedrooms and roughly similar square area, which can vary from 45 to 60 square meters. For that reason, it was clear that this was the type of apartment to be assessed. Thus, the buildings must have two bedrooms and square area between 45 to 60 m2.

Use- The selected buildings to be evaluated must be residential, since the goal is to evaluate public housing and quality of construction for families in Sao Paulo.

Floor height – Since the majority of public housings buildings are four or more storey high to accommodate a larger number of people, buildings between four and six floors were the last selection criterion.

With all the criteria established, the search for potential buildings was narrowed. Throughout the selection process, it was noticed that there was not a complete database on public housing in Sao Paulo. The information available covered basic records such as name of the housing complex, year of construction and location. There was not an architectural database such as floor plans, sections and other architectural drawings. The accessible information on housing programs and buildings were scattered in dissertations and publications; nevertheless it was not a complete set of information.

The most complete and reliable data of all was a booklet from the Housing and Urban Development Company of the State of Sao Paulo. The booklet, which was composed in 1995 (CDHU 2009) contains different typologies for low income residential building and was an initiative of the government to create standardization in buildings. The Paraisopolis building, does not belong to the booklet since it was a recent design, constructed in 2005, but still follows the same pattern presented in past design. This building was selected because it was one of a few available from a recent period that had enough data available.

The building's designs selected were standard for the region of Sao Paulo. All potential buildings had the same construction materials and finishing. They also presented alike floor plan which is a rectangular shape with a central staircase, small openings and no exterior rooms, such as balconies. The typology also was a reflection of a design that does not require skilled and specialized work; some of these buildings were constructed in a volunteering system, where ordinary citizens interested in the programs participate in the construction of their own buildings. Having that information as a starting point, other complementary data was then gathered to then close the selection process. Following the buildings selected for the study are presented.

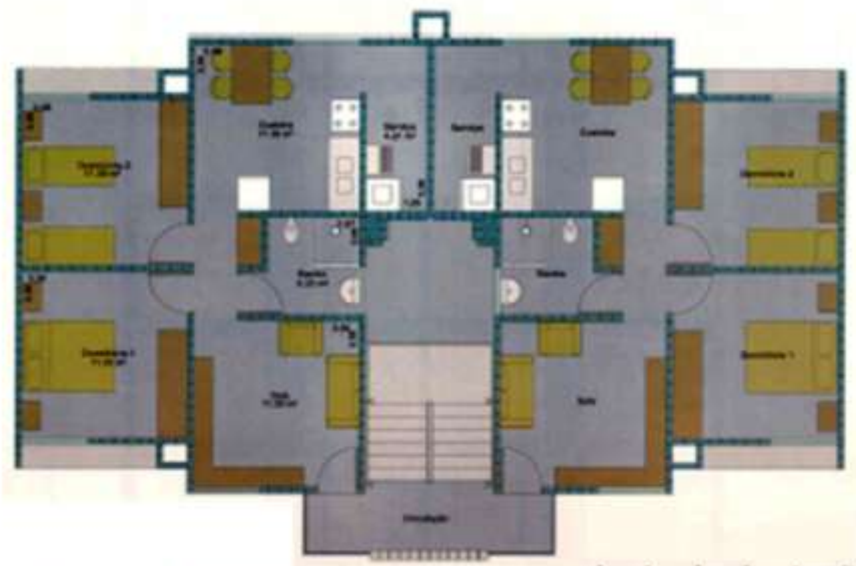
Building 1 – Juta Housing Complex A, Sao Paulo, SP.

JUTA A HOUSING COMPLEX

Year of completion: 1993

4 storey
4 apartment units per floor

Apartment area: 56,13 m2
kitchen
living room
1 bathroom
2 bedrooms
laundry room



Floor plan - 4 apartments per floor

Figure 3.3 Juta A building. Image source- Typology booklet Sao Paulo

Building 2 - Juta Housing Complex C, Sao Paulo, SP.

Figure 3.4 Juta C building. Image source- Typology booklet Sao Paulo Municipality

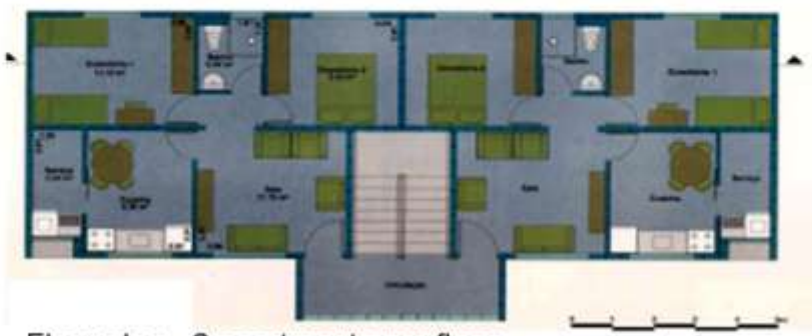
Building 3 – Jaragua Voith Housing Complex, Sao Paulo, SP.

JARAGUA- VOITH HOUSING COMPLEX

Year of completion: 2001

4 storey
2 apartment units per floor

Apartment area: 46,96 m2
kitchen
living room
1 bathroom
2 bedrooms
laundry room



Floor plan - 2 apartments per floor

Elevation

Figure 3.5 Jaragua Voith building. Image source- Typology booklet Sao Paulo Municipality

Building 4 – Paraisopolis Housing Complex, Sao Paulo, SP.

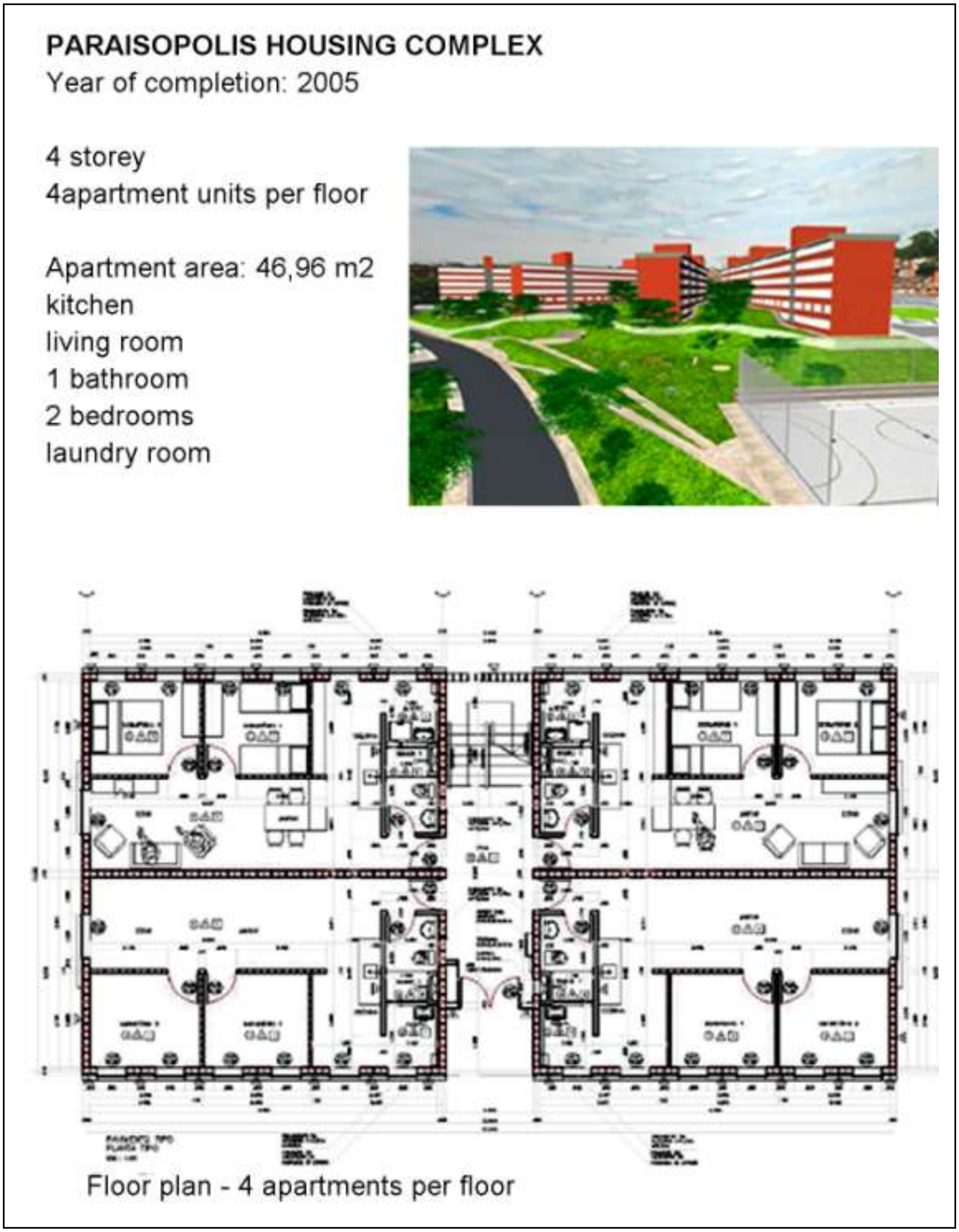


Figure 3.6 Paraisopolis building. Image source- Cities Alliance. Sharing the Urbanization Experience of Paraisopolis, p57.

3.6.2 Defining the Case Studies

After the identification and selection of the four buildings based on the parameters previously discussed, the next step consisted of the modeling of all the selected buildings in the ECOTECT 5.5 software and simulation to analyze their comfort levels and energy performance. For this assessment, the inside partitions and openings were not detailed and considered for the simulations. The goal was to assess the overall building performance, not the individual zones within the envelope.

First, in order to assess the comfort level within the envelope and compare the building's performance, the buildings were simulated in their original state, which is natural ventilation. In the ECOTECT 5.5 software, buildings without heating or cooling are studied based on passive measures such as temperature, indoor comfort and losses and gains. Thus, the thermal comfort was assessed for each building and compared to understand how much time temperatures were in the comfort range under natural ventilation.

The second step was to assess energy use of each building. Therefore, to measure the amount of energy consumed for each building, air conditioning was incorporated into the models. In ECOTECT 5.5, air conditioned spaces measure the amount of energy needed to maintain indoor temperatures. The temperatures provided are not the real air temperatures. They actually represent environment temperatures created from a component of mean radiant temperature (basically area weighted surface temperatures) and air temperature. This makes them a superior indicator of comfort than simple air temperatures. Thus, this tool sums the number of degree hours below and above the comfort level for each hour of each month of the year.   The results were given in number of hours and degrees

– discomfort degree hours[4] as well as hours- the buildings were outside the comfort zone.[5]

3.7 External Parameters Affecting the Model

Some parameters play an important role in the development and outcomes of the research. The weather information available for Sao Paulo has an important role in the development and outcomes of this research. The weather file used for the climate data in ECOTECT 5.5 was the EPW file available from the Energy Plus Energy Simulation software. The file is an ext-based format and derived from the Typical Meteorological Year 2 (TMY2) weather format (Refer to Appendix A.)

Some climate consideration about Sao Paulo is that it belongs to a southern hemisphere with a subtropical climate. It is important to highlight that the climate in the south hemisphere is milder that in the north hemisphere, nevertheless extreme temperature in winter and summer may occur. The sun position in relation to the building is one important factor that needs to be taken into consideration, since it is one of the major causes of heat gain and performance.

At last, the number of cases selected for study were based on the buildings typologies available in Sao Paulo and identified in the literature review. Moreover, the decision of developing three case studies was a mean of validating research methods and better tests the hypothesis.

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[4] Terminology used by ECOTECT 5.5.

[5] Comfort zone for Sao Paulo city was established 20C to 26C.

Chapter 4 – Results and Analysis

4.1 Introduction

The results from the simulations of the four buildings revealed differences in energy consumption among them. Based on the results from the thermal comfort and energy consumption, two buildings were chosen to be further studied.

From the thermal comfort analysis, it could be seen that on all of the four cases the amount of hours they were outside the comfort zone was significant. Hence, in order to maintain the internal comfort conditions and to assess energy performance, the buildings were equipped with air conditioning system. In an air-conditioned zone, the internal comfort will always be maintained and it is just a matter of the amount of energy required to keep the comfort level inside depending on external conditions.

Therefore, the simulations were done in degree hours and hours. The first is the sum of degrees above or below the comfort band that the internal zone temperature is for each hour of each month. The later is the proportion of time each month that the temperatures were outside the comfort band. The results were compared and the most efficient and less efficient buildings were chosen as the case studies, resulting in two buildings, which were analyzed in more depth in subsequent simulations. The objective was to observe the energy consumption performance of the building envelope with different types of materials within the same temperature range and under air conditioned system.

The comfort temperatures obtained from the simulations of the four initial buildings showed a significant difference, even though they have very similar design patterns, plan form, area and materials. The results showed that the building with the least amount of hours out of the comfort zone was also the one that had the least energy consumption to maintain the comfort level throughout the year. And also, the building with the higher number of hours outside the comfort zone was the one with highest energy consumption. Following are the results for the initial simulations.

4.2 Thermal and Energy Simulation of Four Cases

Case 1 – Juta A Building, Sao Paulo, SP

In order to identify the comfort levels during different periods of the year and especially peak hot and cold days, the building was simulated in its current state. The goal was to understand comfort levels of the building when natural ventilation is used. The results from Juta A simulation indicated that the building is too hot 1842 hours of the year and too cool during 630 hours. The building is 2472 hours outside comfort band during the year.

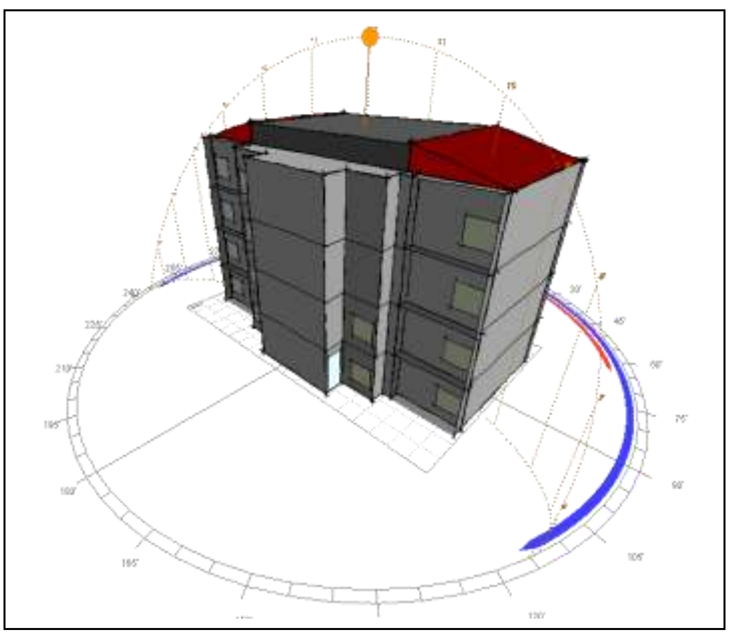

Figure 4.1 Juta A building. South- east view.
Image source: ECOTECT 5.5 model

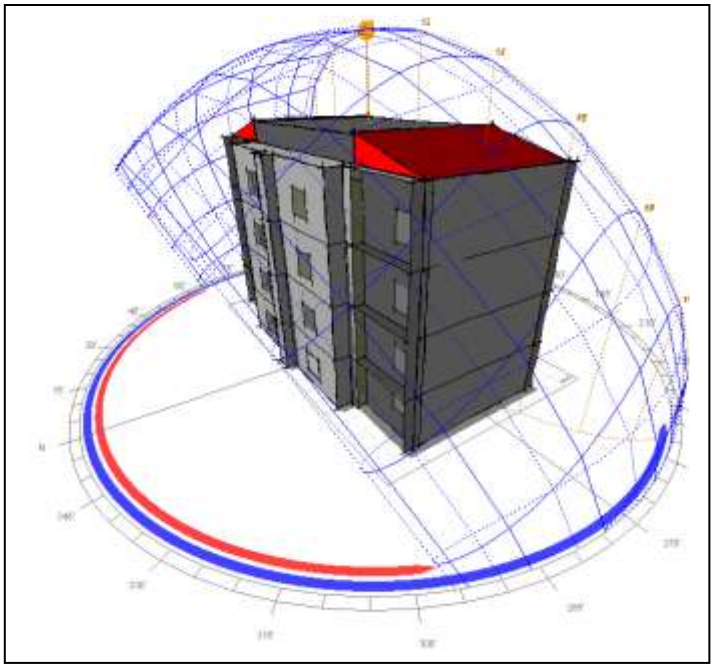

Figure 4.2 Juta A building. North-west view. Image source: ECOTECT 5.5 model

Table 4.1 Thermal Comfort in Degree Hours- Juta A

NATURAL VENTILATION

JUTA A
DISCOMFORT DEGREE HOURS

All Visible Thermal Zones
Comfort: Zonal Bands

	TOO HOT	TOO COOL	TOTAL
MONTH	(DegHrs)	(DegHrs)	(DegHrs)
Jan	1045	3	1048
Feb	823	0	823
Mar	871	0	871
Apr	386	1	387
May	121	96	217
Jun	36	346	382
Jul	20	289	310
Aug	200	279	480
Sep	147	116	264
Oct	149	25	174
Nov	266	1	267
Dec	710	0	711
TOTAL	4774.5	1158.2	**5933**

Table 4.2 Thermal Comfort in Hours- Juta A building

NATURAL VENTILATION

JUTA A

DISCOMFORT PERIOD

DISCOMFORT HOURS

All Visible Thermal Zones
Comfort: Zonal Bands

	TOO HOT	**TOO COOL**	**TOTAL**
MONTH	(Hrs)	(Hrs)	(Hrs)
------	--------	---------	-------
Jan	293	4	297
Feb	293.5	0	293.5
Mar	295.5	0	295.5
Apr	179	3	182
May	74	66	140
Jun	34.5	152	186.5
Jul	24	149	173
Aug	92.5	128	220.5
Sep	66	88	154
Oct	88	33.5	121.5
Nov	152	4.5	156.5
Dec	250	2	252
------	--------	---------	-------
TOTAL	1842	630	**2472**

After analyzing the thermal performance of the Juta A building, artificial heating and air conditioning system was incorporated into the model. The model was simulated for energy consumption. The results showed that cooling loads were high above the heating loads, which indicates that the building is overheating almost every month. During cold months, the building needed more heating than cooling; however the cooling was still needed. During summer months, no heating was necessary, but in January. This reflects the climate in Sao Paulo and an unbalanced building's envelope. Even though temperatures are very high during the summer, the summer storms that occur every afternoon bring temperatures down. The combination of the cooling down after the rains and cold fronts have the potential to change temperatures significantly, cooling the temperatures inside the building envelope and making the heating necessary to keep comfort levels.

Table 4.3 Monthly Heating and Cooling Loads – Juta A

HVAC SYSTEM - FULL AIR CONDITIONED

JUTA A

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 29577 W at 03:00 on 17th August
Max Cooling: 56862 W at 16:00 on 20th January

	HEATING	**COOLING**	**TOTAL**	**KWh/M2**
MONTH	(Wh)	(Wh)	(Wh)	
Jan	56357	13494355	13550712	
Feb	0	12699520	12699520	
Mar	0	13232230	13232230	
Apr	186528	8719320	8905848	
May	655637	4465564	5121202	
Jun	2232537	1852023	4084560	
Jul	2167376	1427417	3594794	
Aug	1955387	4829346	6784734	
Sep	1067548	3724001	4791549	
Oct	356716	5266740	5623456	
Nov	14954	7772248	7787202	
Dec	0	11998096	11998096	
TOTAL	8693041	89480864	98173904	
PER M²	13834	142404	156238	**156.24**
Floor Area:	628.360 m2			

Case 2 – Juta C Building, Sao Paulo, SP

In the thermal comfort analysis of the Juta C building to understand comfort levels of the building when natural ventilation is used, the results showed that the building stayed a total of 3131 hours outside comfort level in one year. The temperatures were mainly hot, 2999.5 hours above thermal comfort, and only 131 hours the temperatures were below comfort level.

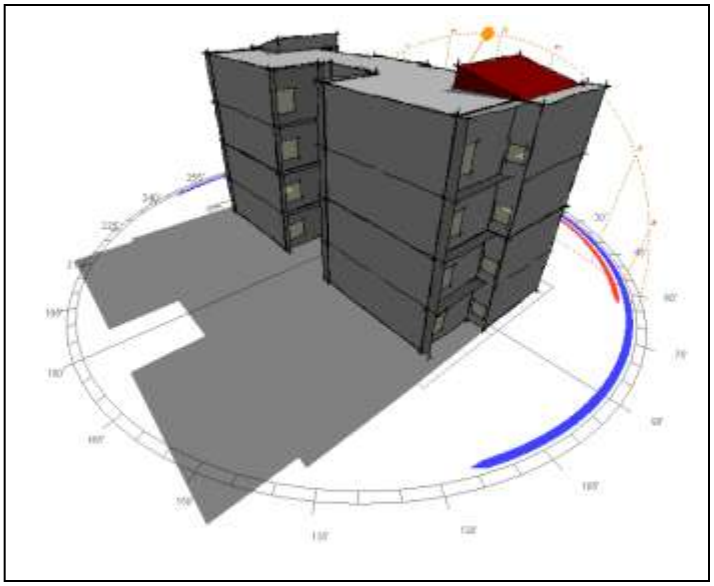

Figure 4.3 Juta C building. South- east view.
Image source: ECOTECT 5.5 model

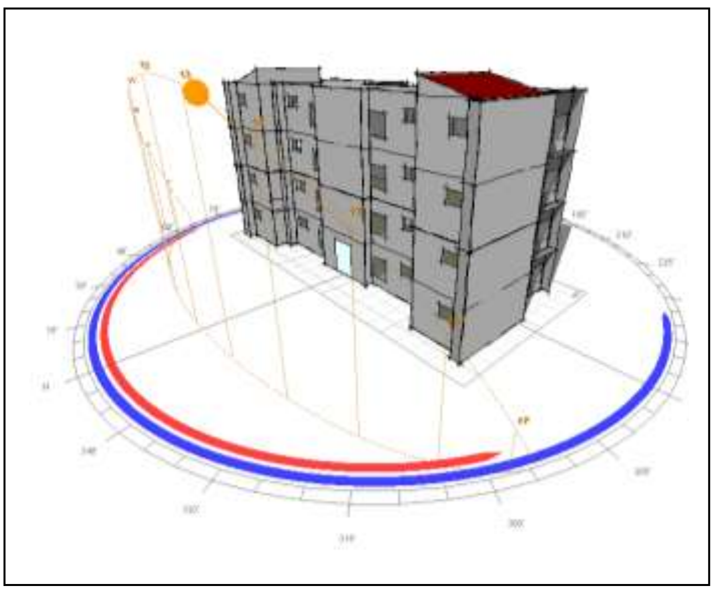

Figure 4.4 Juta C building. North- west view.
Image source: ECOTECT 5.5 model

Table 4.4 Thermal Comfort in Degree Hours – Juta C

NATURAL VENTILATION

JUTA C

DISCOMFORT DEGREE HOURS

All Visible Thermal Zones
Comfort: Zonal Bands

	TOO HOT	TOO COOL	TOTAL
MONTH	(DegHrs)	(DegHrs)	(DegHrs)
Jan	1886	0	1886
Feb	1649	0	1649
Mar	1768	0	1768
Apr	1031	0	1031
May	468	3	471
Jun	219	57	277
Jul	154	26	180
Aug	542	36	578
Sep	425	3	429
Oct	520	0	520
Nov	843	0	843
Dec	1493	0	1493
TOTAL	10998.6	126.5	**11125**

Table 4.5Thermal Comfort in Hours – Juta C

NATURAL VENTILATION

JUTA C

DISCOMFORT PERIOD

DISCOMFORT HOURS

All Visible Thermal Zones
Comfort: Zonal Bands

	TOO HOT	TOO COOL	TOTAL
MONTH	(Hrs)	(Hrs)	(Hrs)
------	--------	---------	-------
Jan	349	0	349
Feb	333.5	0	333.5
Mar	363.5	0	363.5
Apr	303	0	303
May	202.5	5.5	208
Jun	122	49	171
Jul	101	35	136
Aug	178.5	36.5	215
Sep	165	5	170
Oct	232.5	0	232.5
Nov	297.5	0	297.5
Dec	351.5	0	351.5
------	--------	---------	-------
TOTAL	2999.5	131	**3131**

After the results from the thermal performance were obtained, the artificial heating and air conditioning system was incorporated into the model in order to assess energy consumption. The simulations showed that cooling loads were high above the heating loads, which identifies that heat is being lost in the building, either by conduction through walls, floors and roof or by infiltration.

Table 4.6 Monthly Heating and Cooling Loads – Juta C

JUTA C

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 15463 W at 03:00 on 17th August
Max Cooling: 56689 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
Jan	0	18685018	18685018	
Feb	0	17167864	17167864	
Mar	0	18704716	18704716	
Apr	8538	15489920	15498458	
May	17608	10833930	10851538	
Jun	390222	6624741	7014963	
Jul	233599	6249636	6483236	
Aug	274315	9357392	9631707	
Sep	45475	9221299	9266774	
Oct	0	13305778	13305778	
Nov	0	15395224	15395224	
Dec	0	18102158	18102158	
TOTAL	969756	159137680	160107440	
PER M²	1534	251661	253194	**253.19**
Floor Area:	632.350 m2			

Case 3 – Jaragua Voith Building, Sao Paulo, SP

The Jaragua Voith building thermal comfort simulation showed that the building stayed out of the comfort zone for about 2491hours per year. Contrary to the other previous cases, most of the time temperatures are out of comfort zone in this case, it is due to cold air in winter months – May to July.

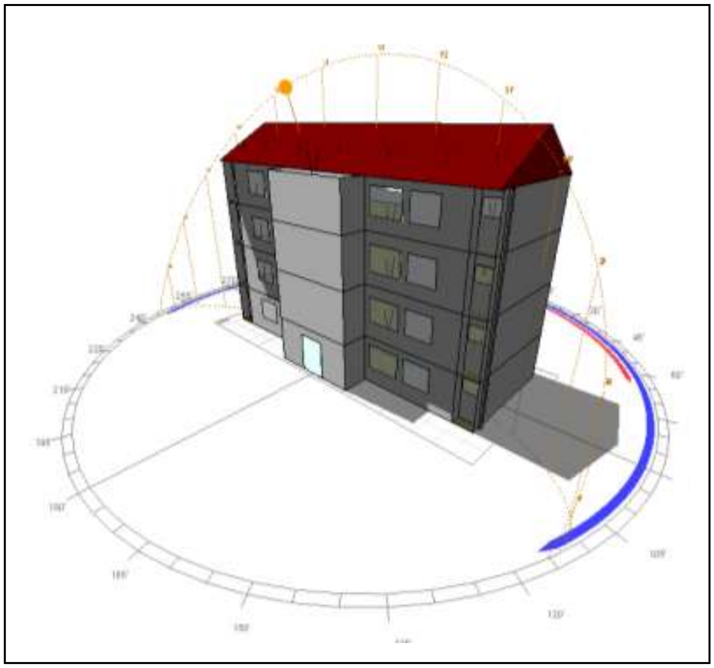

Figure 4.5 Jaragua Voith building. South- east view. Image source: ECOTECT 5.5 model

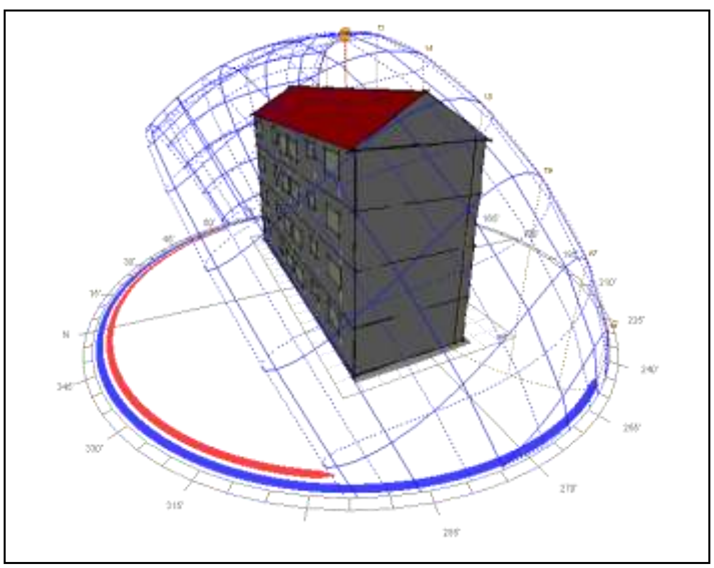

Figure 4.6 Jaragua Voith building. North- west view. Image source: ECOTECT 5.5 model

Table 4.7 Thermal Comfort in Degree Hours – Voith

NATURAL VENTILATION

VOITH

DISCOMFORT DEGREE HOURS

All Visible Thermal Zones
Comfort: Zonal Bands

	TOO HOT	TOO COOL	TOTAL
MONTH	(DegHrs)	(DegHrs)	(DegHrs)
------	---------	---------	---------
Jan	242	90	332
Feb	111	24	135
Mar	127	39	166
Apr	35	183	219
May	1	697	699
Jun	0	1253	1253
Jul	0	1281	1281
Aug	9	1027	1037
Sep	20	805	825
Oct	11	509	521
Nov	17	232	249
Dec	113	98	210
------	---------	---------	---------
TOTAL	686.3	6239.6	**6926**

Table 4.8 Thermal Comfort in Hours – Voith

NATURAL VENTILATION

VOITH

DISCOMFORT PERIOD

DISCOMFORT HOURS

All Visible Thermal Zones
Comfort: Zonal Bands

	TOO HOT	TOO COOL	TOTAL
MONTH	(Hrs)	(Hrs)	(Hrs)
------	--------	---------	-------
Jan	127	53.5	180.5
Feb	83	17	100
Mar	94	32.5	126.5
Apr	31.5	112.5	144
May	3	244	247
Jun	0	297	297
Jul	0	319.5	319.5
Aug	17	248	265
Sep	13	262	275
Oct	9	224.5	233.5
Nov	17.5	140.5	158
Dec	72.5	72.5	145
------	--------	---------	**--------**
TOTAL	**467.5**	**2023.5**	**2491**

After the heating and air conditioning system were incorporated into the model, the energy consumption was 78.12 KWh per square meter. The results indicated that cooling is more necessary than heating through almost the entire year, with the exception of June and July. During the peak months of winter s, cooling is not necessary, but during the beginning and end months of winter-May and August-there was need for cooling.

Table 4.9 Monthly Heating and Cooling Loads – Voith

HVAC SYSTEM - FULL AIR CONDITIONED

VOITH

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 27256 W at 03:00 on 17th August
Max Cooling: 52128 W at 14:00 on 20th January

	HEATING	**COOLING**	**TOTAL**	**KWh/M2**
MONTH	(Wh)	(Wh)	(Wh)	
Jan	70778	7483131	7553909	
Feb	17928	4904446	4922374	
Mar	39109	5436474	5475583	
Apr	287599	1863701	2151300	
May	827111	151269	978380	
Jun	2260107	0	2260107	
Jul	2347051	0	2347051	
Aug	1997545	870893	2868438	
Sep	1262980	886943	2149923	
Oct	612825	577981	1190806	
Nov	254222	1047342	1301565	
Dec	102365	4393698	4496063	
TOTAL	10079620	27615880	37695500	
PER M²	20890	57234	78124	
Floor Area:	482.510 m2			**78.12**

Case 4 – Paraisopolis Building, Sao Paulo, SP

The results from the thermal comfort simulation revealed that indoor temperatures were too high most of the time and especially during hotter months. The temperatures inside the building were outside the comfort level during 3118 hours in the year. This building showed to be the one the one that needed cooling the most. It was only during winter months that some heating was necessary. In the month of July, which is usually the coolest month of the year in Sao Paulo, the heating was needed during 47.5 hours of the month, which represents approximately 7 percent of the entire month hours. It is clear in this case that the building was overheating most of the time and a lot of energy was necessary to cool it down.

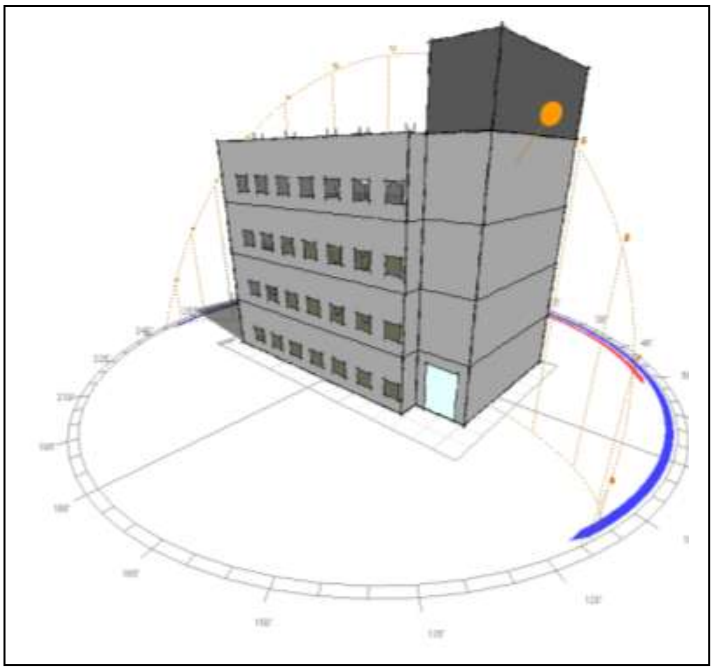

Figure 4.7 Paraisopolis building. South- east view.
Image source: ECOTECT 5.5 model

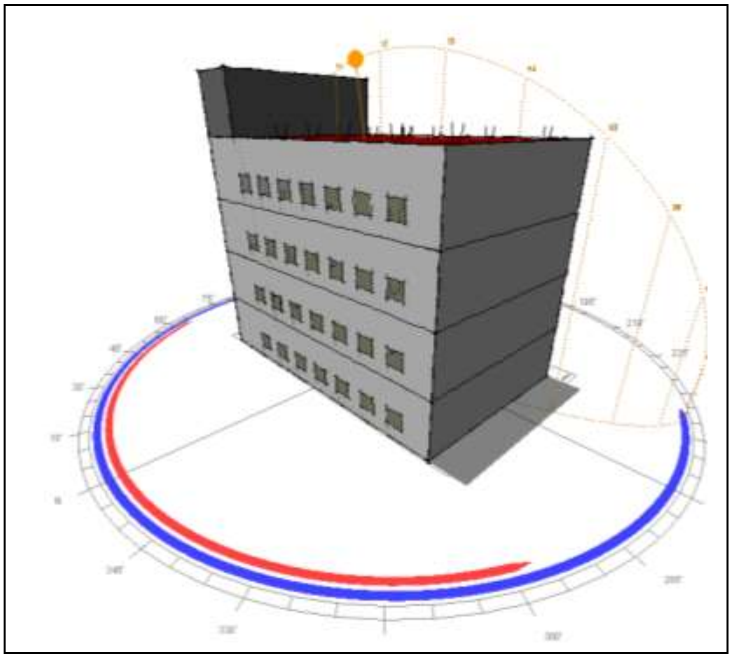

Figure 4.8 Paraisopolis building. North- west view.
Image source: ECOTECT 5.5 model

Table 4.10 Thermal Comfort in Degree Hours – Paraisopolis

NATURAL VENTILATION

PARAISOPOLIS
DISCOMFORT DEGREE HOURS

All Visible Thermal Zones
Comfort: Zonal Bands

	TOO HOT	TOO COOL	TOTAL
MONTH	(DegHrs)	(DegHrs)	(DegHrs)
Jan	2037	0	2037
Feb	1784	0	1784
Mar	1897	0	1897
Apr	1129	0	1129
May	531	3	534
Jun	258	59	317
Jul	195	27	222
Aug	603	36	639
Sep	503	3	506
Oct	653	0	653
Nov	985	0	985
Dec	1657	0	1657
TOTAL	12232.8	128.4	**12361**

Table 4.11 Thermal Comfort in Degree Hours – Paraisopolis

NATURAL VENTILATION
PARAISOPOLIS
DISCOMFORT PERIOD
DISCOMFORT HOURS

All Visible Thermal Zones
Comfort: Zonal Bands

	TOO HOT	**TOO COOL**	**TOTAL**
MONTH	(Hrs)	(Hrs)	(Hrs)
------	--------	---------	-------
Jan	346	0	346
Feb	331	0	331
Mar	362	0	362
Apr	296	0	296
May	193	9	202
Jun	116.5	61	177.5
Jul	95	47.5	142.5
Aug	175	42.5	217.5
Sep	165.5	8.5	174
Oct	229	0	229
Nov	291	0	291
Dec	349.5	0	349.5
------	--------	---------	-------
TOTAL	2949.5	168.5	**3118**

The energy simulation results showed that the Paraisopolis building consumed 271, 87 KWh per square meter. The cooling loads were higher than the heating loads to maintain comfort levels in the building envelope. Cooling was needed the entire year, whereas heating was not necessary during the warmer months in January through April and October through December. The results of the energy simulation confirmed the thermal analysis results. It was clear in this case that the building overheated during the entire year and it was observed that this building had the least shading elements of all of the four cases. The building shape did not provide any kind of shade during the day and the flat roof did not add any protection from the sun as well. Thus, the occurrence of such elevated need for cooling throughout the year.

Table 4.12 Monthly loads simulation - Paraisopolis

HVAC SYSTEM - FULL AIR CONDITIONED

PARAISOPOLIS

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46539 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
Jan	0	15863482	15863482	
Feb	0	14496138	14496138	
Mar	0	15620130	15620130	
Apr	0	12712697	12712697	
May	12769	8582824	8595593	
Jun	290688	5259620	5550308	
Jul	185708	4811768	4997476	
Aug	215952	7705612	7921564	
Sep	24835	7634718	7659554	
Oct	0	10784028	10784028	
Nov	0	12765098	12765098	
Dec	0	15356087	15356087	
TOTAL	729952	131592208	132322160	
PER M²	1500	270365	271865	
Floor Area:	486.720 m2			**271.87**

4.3 Thermal and Energy Simulation Summary

After the analysis and comparison of the results from the four cases, the consumption of the Paraisopolis building, built in 2005, revealed to be the highest and the Voith building's consumption was the lowest amongst all. In order to understand such a great difference in numbers between building built in the same standards, the design were studied as well with the energy simulations results and the summary was discussed in this chapter.

For the Paraisopolis building keep up with indoor thermal comfort, it consumes 271.87 KWh. Some factors showed to be the basis for such a high energy consumption.

At first, even though the Paraisopolis building was the newest construction, it was also clear that it was the building with the simplest design regarding shape, sun protection and openings. The building shape was a basic rectangle without any shading devices; the cutouts on the other buildings casted shade on the building in different places during the day, which helped reduce heating loads. Second, the windows were positioned on the north and south façade. No openings were placed on the east and west facades, where the predominant winds blow. Thus, by enclosing the building envelope due to the addition of the air conditioning system, the building did not function well and overheated, increasing energy consumption. Third, the other three buildings had shading devices that protected them from the high heat of summer at some point during the day.

The Voith building was the most efficient of all four cases. It was understood, by analyzing energy consumption, thermal comfort and building shape, that even though this building was built before the Paraisopolis building, the design was more complex regarding shading elements, openings placement and size. The pitched roof and the windows' position in the building acted as cooling elements, since they provided shade and protection from the direct sun light.

In summary, it was clear that not only the energy results alone were the important factor to analyze the energy performance of the four cases. The comparison between the four buildings was the first step to isolate the best cases to a more in depth analysis.

In summary, a holistic approach in this study was essential to a better evaluation of the results and of the design of public housing buildings in Sao Paulo. It was showed in the simulations that the current business – as - usual model of designing public housing in Sao Paulo has not focused on construction and design matters, but on solving housing and social problems. The designs have not showed a significant progress throughout the years, they are just basic designs that have been applied as a standard for low income population's buildings. Therefore, in order to assess potential improvements in public housing design in Sao Paulo, the Paraisopolis and Voith building were selected to a more in depth analysis.

4.3 Selected Buildings

The Paraisopolis and Voith building were the designs selected to be further studied since they represented the most efficient and the least efficient of the four buildings. This step evaluated whether differences in orientation, materials and shading would benefit the designs or not. Therefore, both case studies were simulated for each predefined parameter and the results interpreted and compared. The idea of remodeling the buildings was an attempt to find the best energy performance building model for low income public housing design.

Once all the parameters were analyzed in isolation, the best result of each category was put together in a final simulation. It was important to identify the best parameters from each category and then to have them mutually set in the building to understand whether there was a significant improvement in the design by grouping all the different strategies into one model.

Another important consideration was the comfort level throughout the year inside the buildings. In low income building design in Brazil cooling or heating systems are never considered as a design elements, first because of the climate characteristic and second because of the high costs. Nevertheless, the comfort levels were evaluated as a mean to improve not only energy consumption rates but also life quality standards. The buildings when analyzed in their current status showed a great need for air conditioning system during several months of the year to maintain comfortable temperatures indoors, especially in the hotter months.

4.4 Computer Simulation Variables

After the four buildings were evaluated and the results from thermal performance and energy performance were analyzed, two buildings were chosen to be further simulated in order to analyze building materials strategies to decrease energy consumption. The Voith building and the Paraisopolis buildings were preferred for the simulations since they represent the more effective and less effective cases among the four cases studied. Six variables that demonstrated potential in transform the buildings' energy performance were chosen based on the current design of the buildings and the literature reviewed.

First, orientation was the first variable explored in the simulations as a factor to investigate differences in energy consumption. A building that is in harmony with its location has a greater chance of being more energy efficient. In the case of the southern hemisphere, north facing buildings receive more heat than those facing the south.

Second, due to the climate and economical factors, construction techniques used in low income buildings in Sao Paulo are usually minimalist. Insulation which is such an important technique do reduce energy consumption and increase comfort levels, is not often incorporated into these buildings. Since the goal of this study is to improve the current design, insulation was used as another variable added to the design.

Third, the wall material was one more variable assessed. The material often used for this type of buildings is one layer of brick and plaster on the inside walls. The external walls don't have any kind of protection against the weather and harsh environmental conditions.

Forth, shading devices were also assessed regarding their contribution to the energy performance. Therefore, shading elements were incorporated onto the buildings in order to analyze their efficiency throughout the year and their influence in energy consumption.

Fifth, windows are an important element in the overall building design since they influence temperature variations through radiation and conduction. The window type current being used was aluminum with single glass pane for both buildings. Therefore, other window types were used to assess the buildings' energy performance.

Finally, roofs were the last variable evaluated. Traditional roofs in Sao Paulo are constructed of red tiles or concrete and insulation is usually used only in the case of the later. In order to study how the roof could affect the building's energy performance, different types of materials and shapes were used in the buildings according to their current form. The findings and analysis of the simulations are explained in the following section.

4.5 Simulation of Selected Case Studies

Case 1- Voith Building

The building was simulated under the different variables in order to evaluate energy consumption. For each variable the results were recorded and transferred to a database.

For the orientation, the model was simulated for different orientations: north, south, east, west, southwest, southeast, northwest and northeast. Orientation towards the north, which was the original building orientation, was the best option in terms of energy consumption. If compared to the worst result, the orientation to the north was 6 percent more efficient.

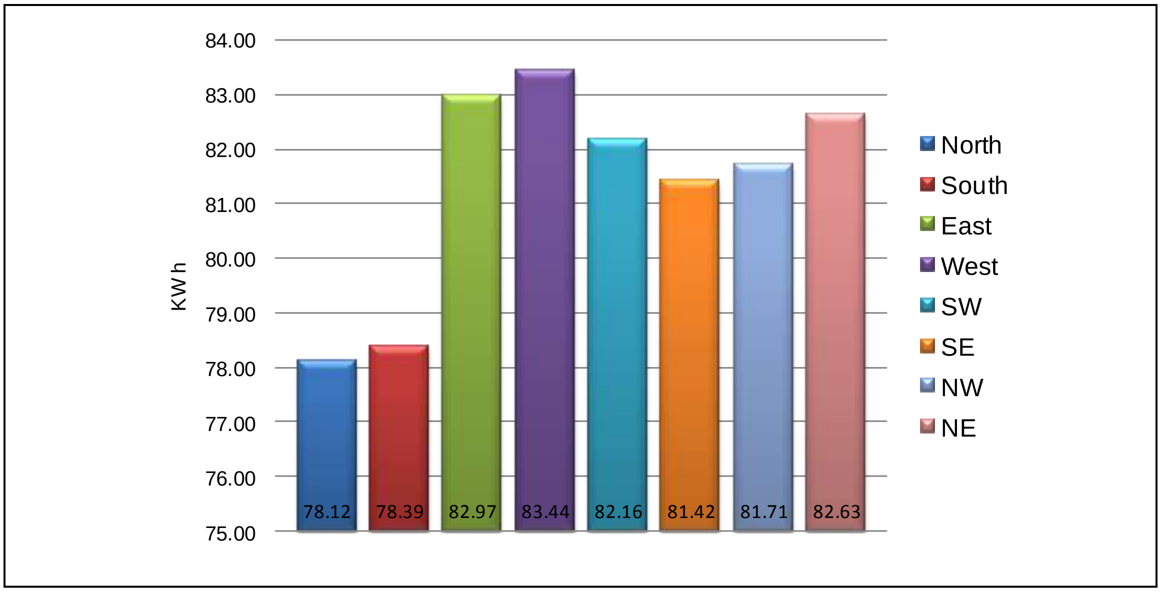

Figure 4.9 Voith orientation study result

The insulations simulated were: brick timber frame with air gap insulation, brick plaster with polystyrene 50 mm and reverse brick veneer- R20 assemble, which was brick on the inside of the building and the timber frame on the outside; in this case, the reverse brick allows the brick to stay within the insulation and use the high thermal mass of the brick.

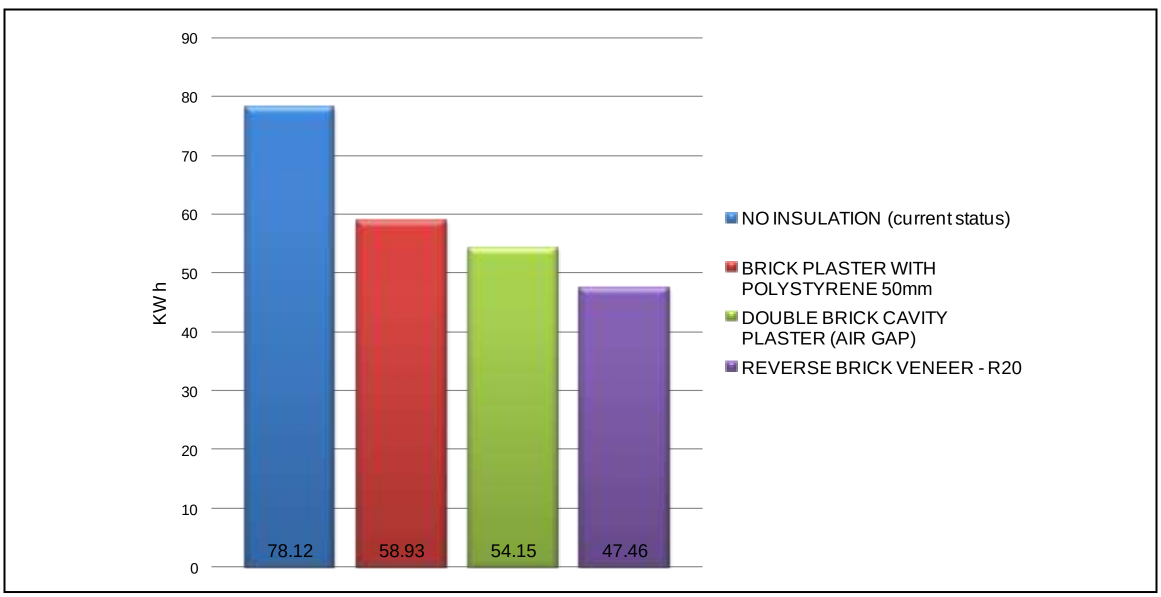

Figure 4.10 Voith insulation study result

The results showed that the reverse brick had the best performance with 47.46 KWh per square meter compared to 78.12 KWh per square meter of the original design; representing an improvement of 39.24 percent.

The standard wall material of the buildings was concrete block and plaster. The variables for the simulation were: concrete blocks plastered, concrete blocks render, double brick wall with solid plaster and brick-concrete-block wall with plaster. Even though the brick-concrete-block wall with plaster had a good performance, the double brick wall with solid plaster decreased energy consumption in 30 percent.

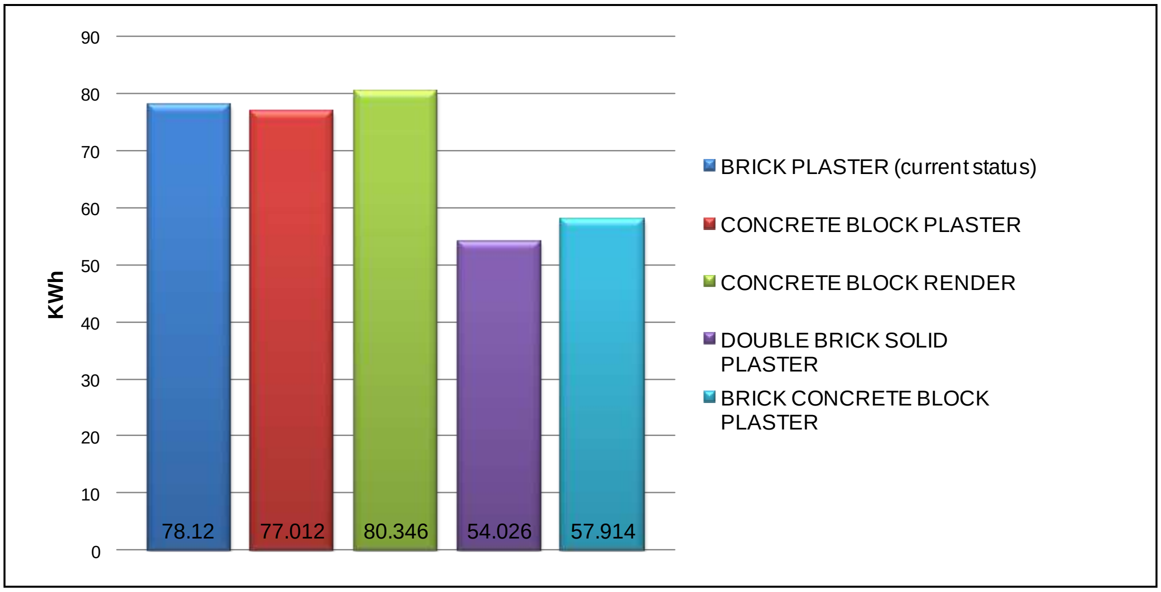

Figure 4.11 Voith wall material study result

The shading device variable evaluated energy performance by incorporating changes in the existing roof. Since a tiled roof was already part of the initial design, the decision was to modify the existing roof and evaluate changes in energy consumption. Following are the roof changes incorporated for the energy performance analysis.

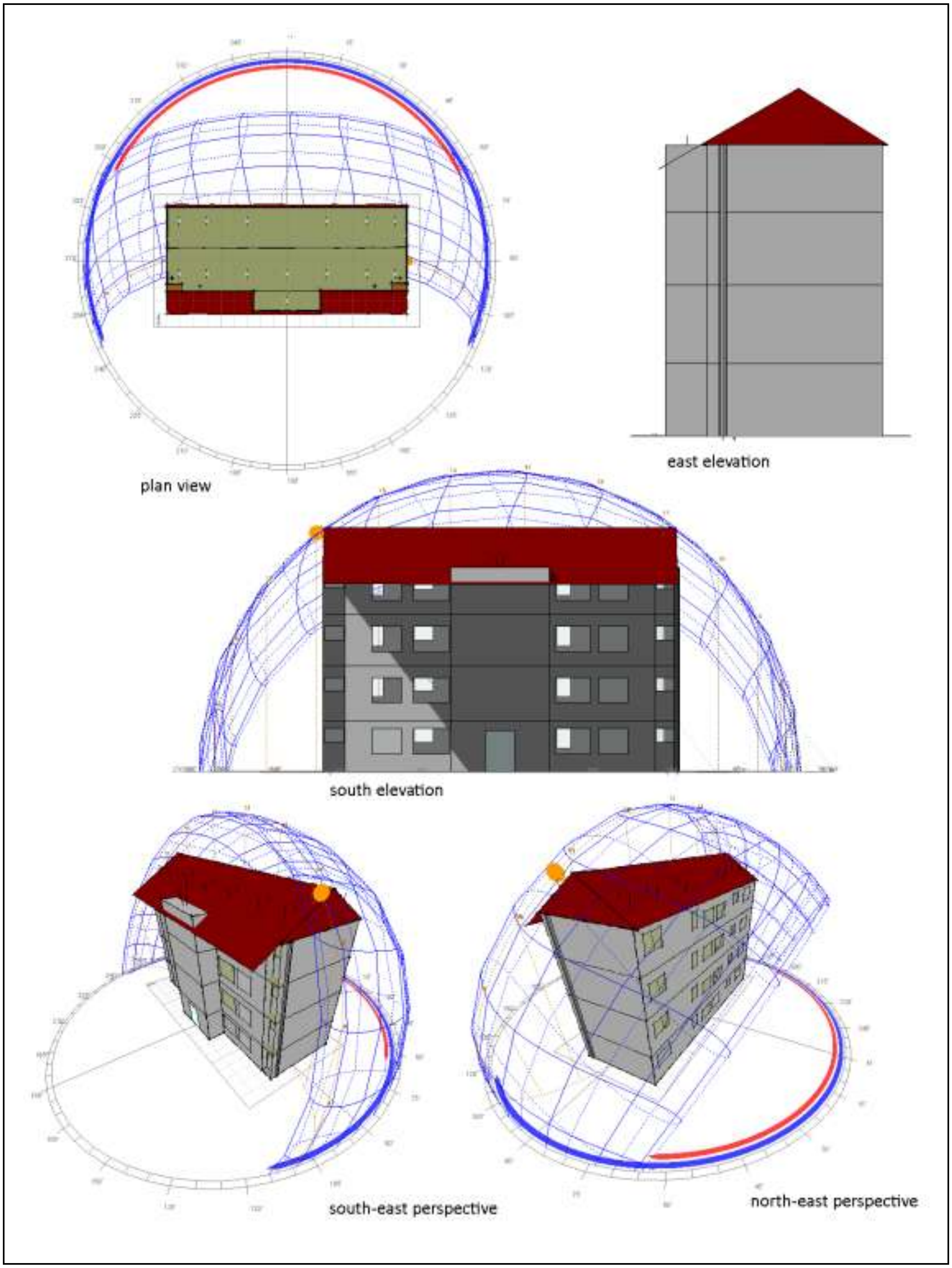

Figure 4.12 Voith shading devices study. Extension of south side of the roof. Image source: Ecotect 5.5.

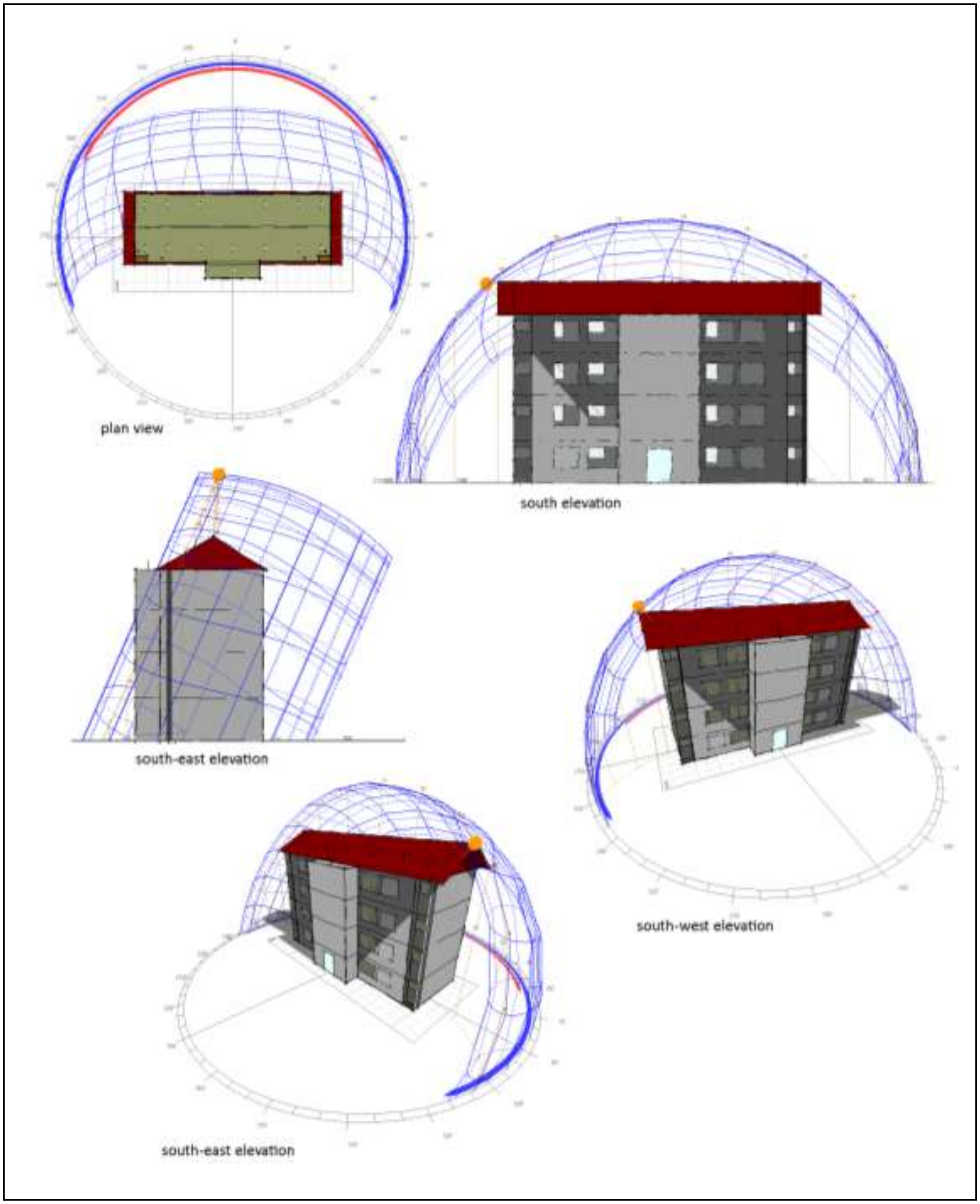

Figure 4.13 Voith building – extension of east and west sides of the roof. Image source: Ecotect 5.5.

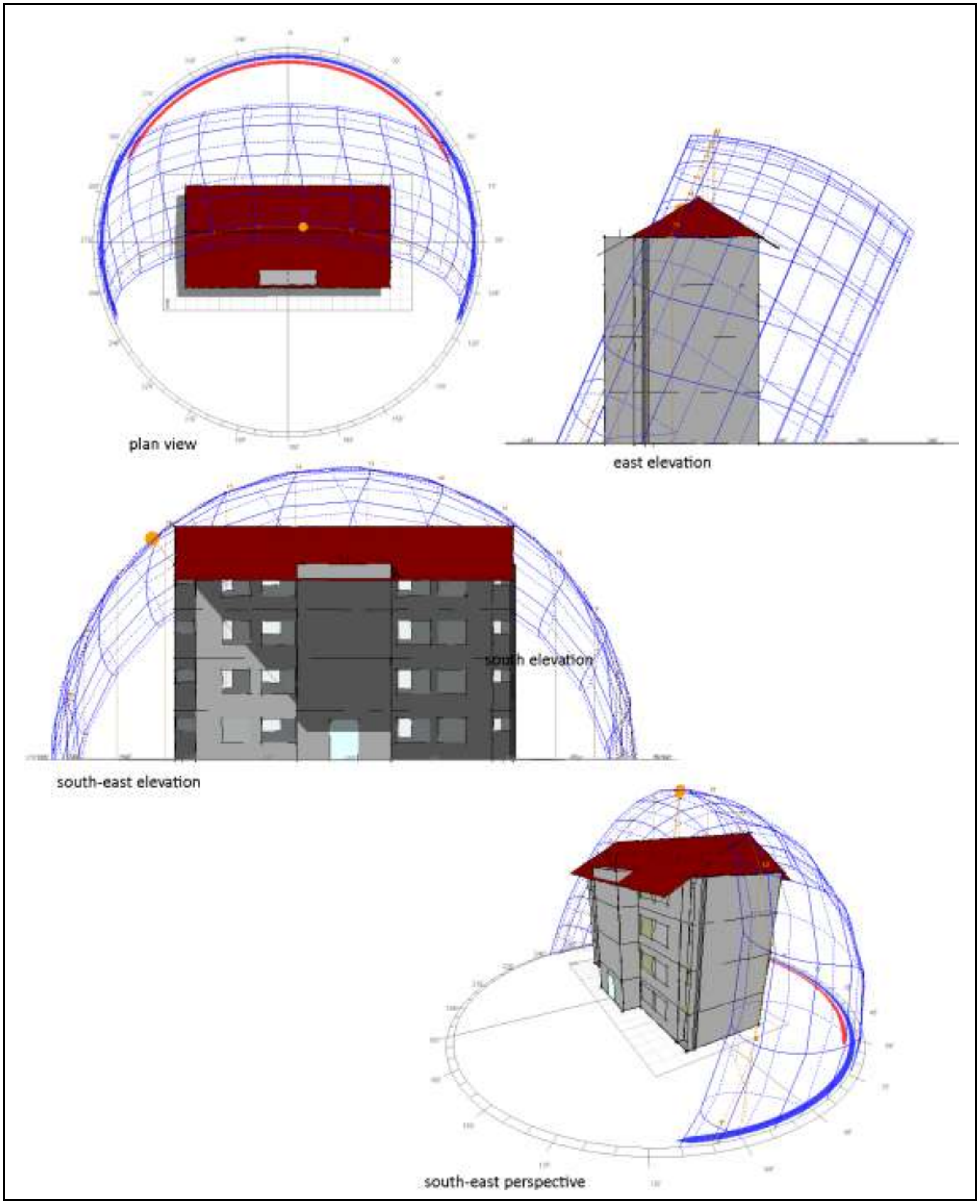

Figure 4.14 Voith building – extension south and north side of roof. Image source: Ecotect 5.5.

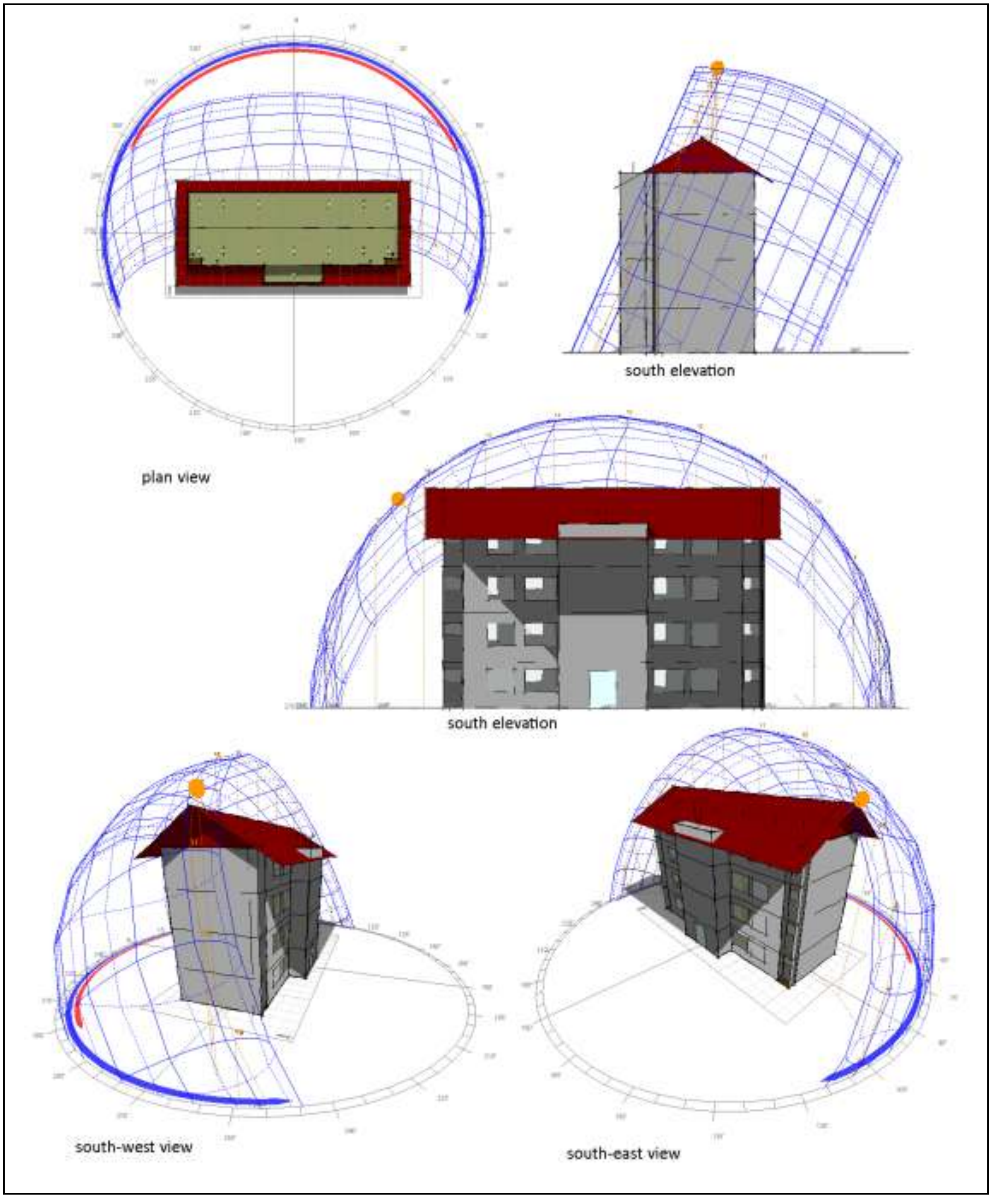

Figure 4.15 Voith building – extension all sides of roof. Image source: Ecotect 5.5.

The results showed that the expansion of all the sides of the roof reduced energy consumption in almost 2 percent. The result also indicated that more shaded areas were a good alternative to reduce energy consumption in this specific case.

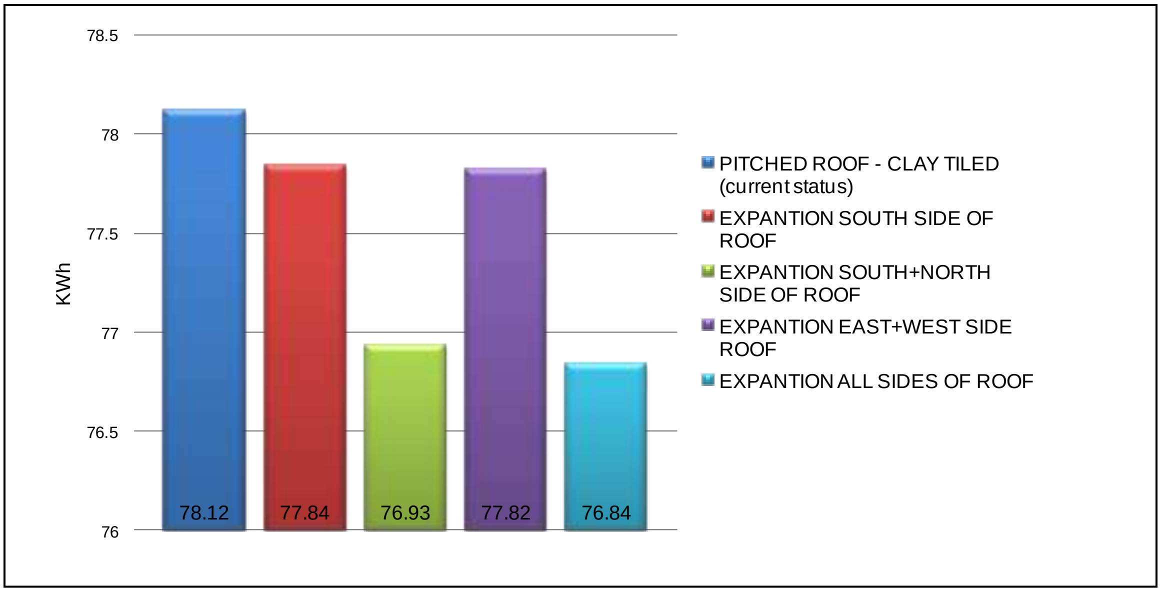

Figure 4.16 Voith shading devices study.

Furthermore, windows were another variable in this study. The current design standards were single glazed window with aluminum frame.

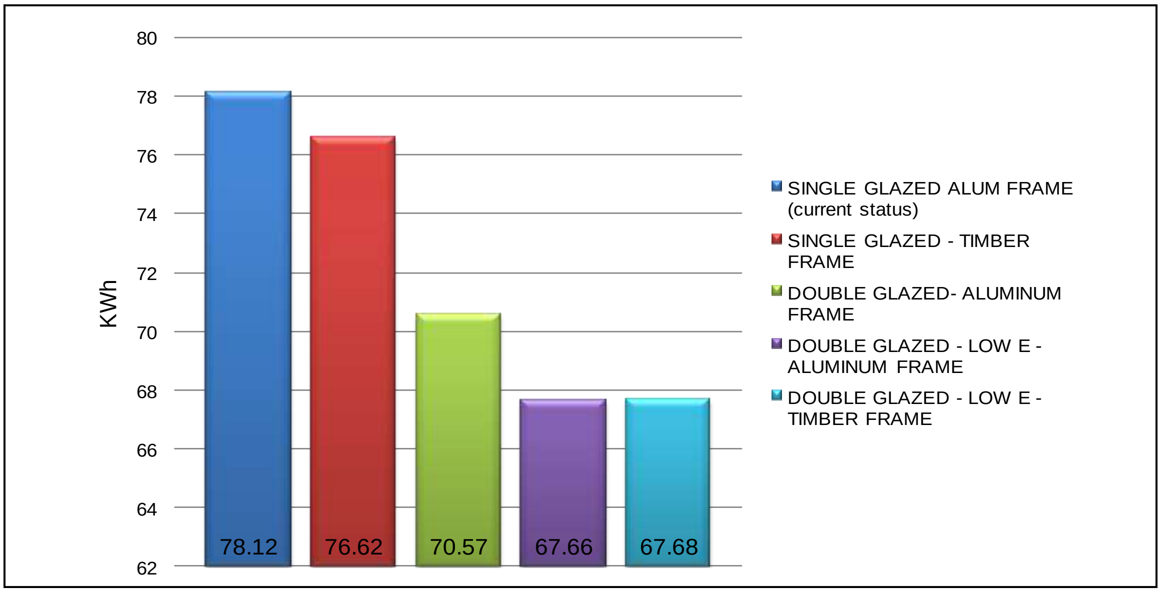

Figure 4.17 Voith window study.

The double glazed lo-e aluminum frame window had the best performance. It was 13.36 percent better than the original single glazed windows.

Lastly, the roof material was investigated. Among the different options were: concrete rooftop with asphalt surface; clay tiled roof with foil and Gyproc[6] – a thermal insulating plaster board that provides additional performance for thermal control; plaster foil with heat retention and ceramic; and corrugated flat metal roof, which is sometimes in public housing in Sao Paulo to decrease construction costs. Among all, the concrete roof with asphalt had the best performance. The roof consisted of 150mm concrete lightweight, 6mm of asphalt cover and 10mm of plaster cover molded dry. This option was 6 percent better than the original clay tiled pitched roof.

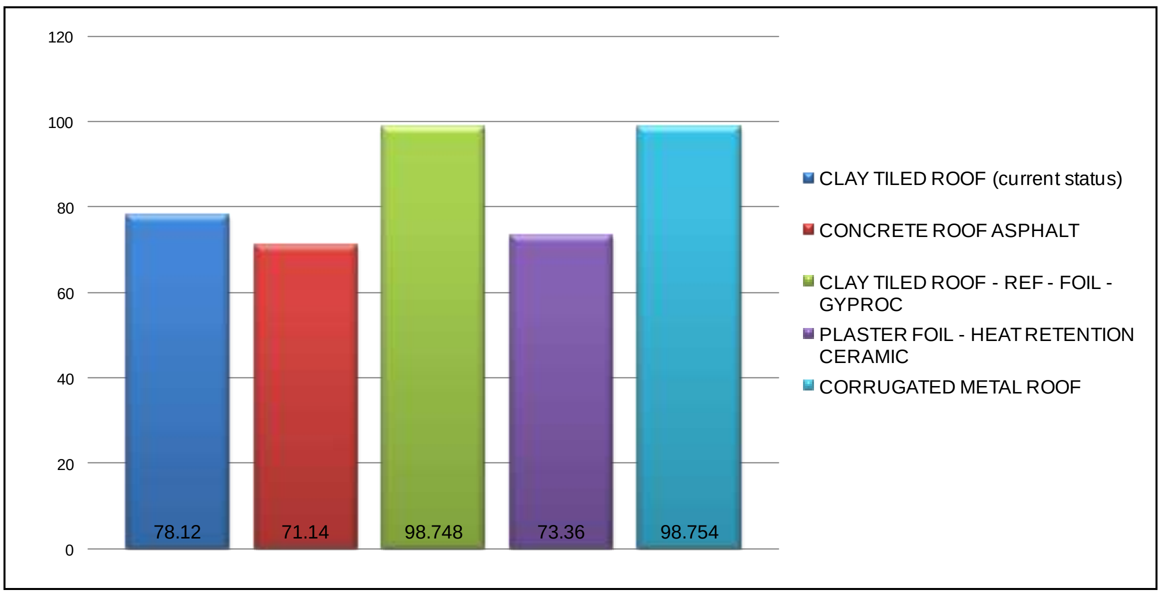

Figure 4.18 Voith roof study.

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[6] Gyproc product information is available at: www. http://www.british-gypsum.com/Default.aspx

Case 2- Paraisopolis Building

In this case the building was simulated under the same variables as the case above. The goal is to evaluate energy consumption of different building materials. For each variable the results were recorder and transferred to a database.

For the orientation simulation - north, south, east, west, southwest, southeast, northwest and northeast- the results indicated that the best orientation was the original orientation. By being oriented to the north, the building has its longest sides facing north-south and thus the hot afternoon sun does not penetrate the building's openings, which are on the north and south facades. The south side is completely protected from the sun path throughout the year. This contributes to elevated heating loads during cold months and cooling loads in the apartments facing north.

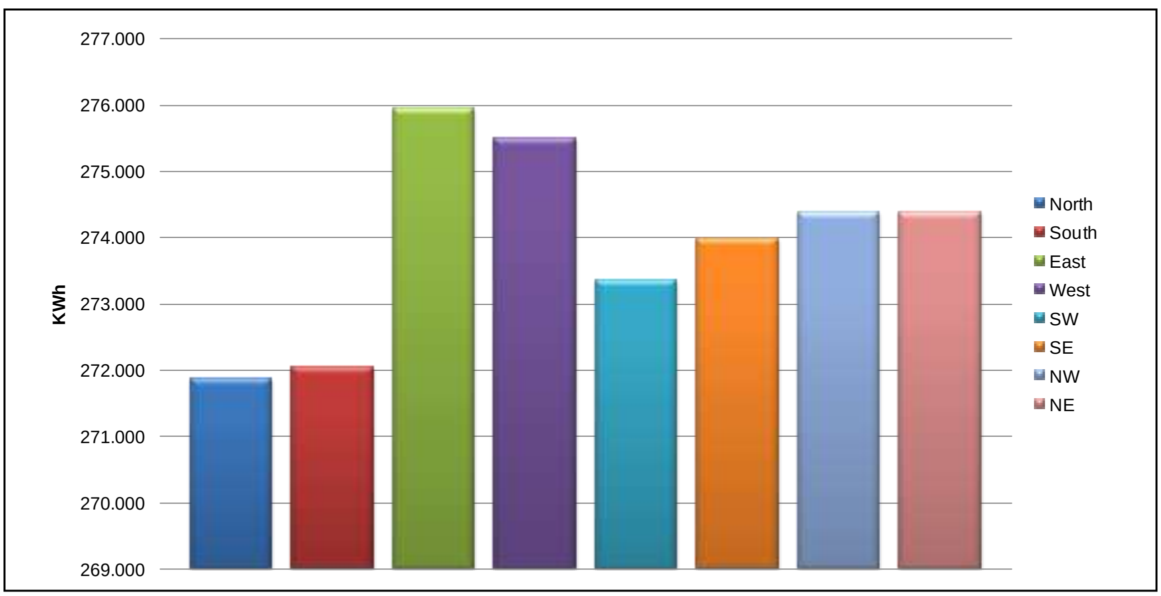

Figure 4.19 Paraisopolis orientation study.

The insulation simulations in the Paraisopolis building showed that the actual composition uses less energy to keep comfort levels within the envelope. Some alternatives such as the reverse brick veneer, increased energy consumption in 10 percent. The shape of the building and openings distribution might contribute to higher energy consumption when insulation is added in this case.

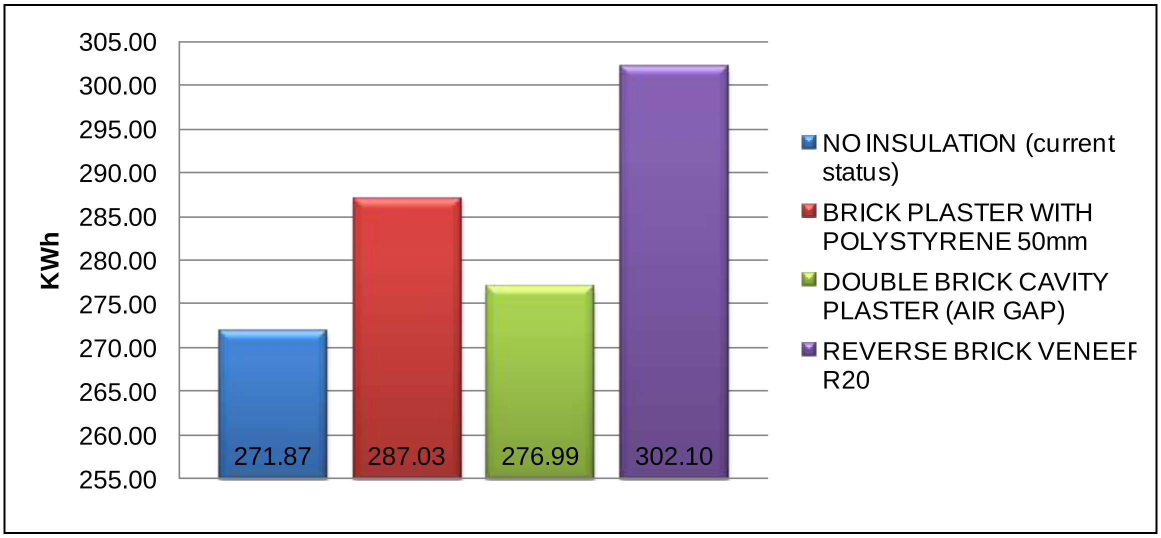

Figure 4.20 Paraisopolis insulation study.

The variables for the energy simulation regarding wall materials were concrete blocks rendered, double brick wall with solid plaster and brick-concrete-block wall with plaster. The brick plaster wall, which is the current material being used in this building had the best performance among all.

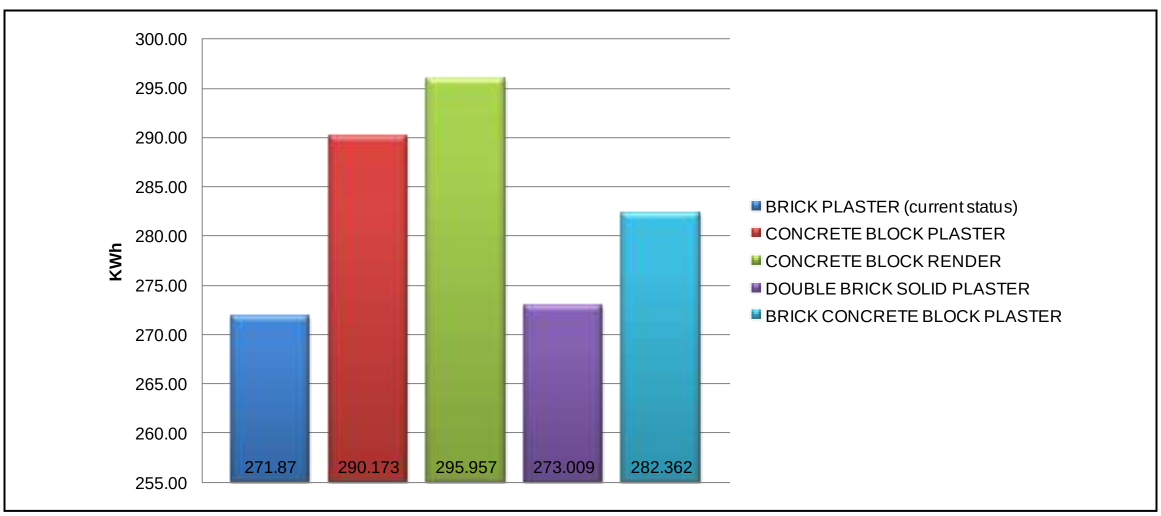

Figure 4.21 Paraisopolis wall material study.

A flat roof is the current situation on this building and there are no shading elements at all. Since there was no roof, the decision was to first add a pitched roof and analyze the energy performance. Second, incorporate shading elements on the exterior walls, such as breeze-soleil to study any changes in energy consumption. The outcome was that by using horizontal and vertical concrete plaster shading devices there was a reduction in almost 2 percent in energy consumption.

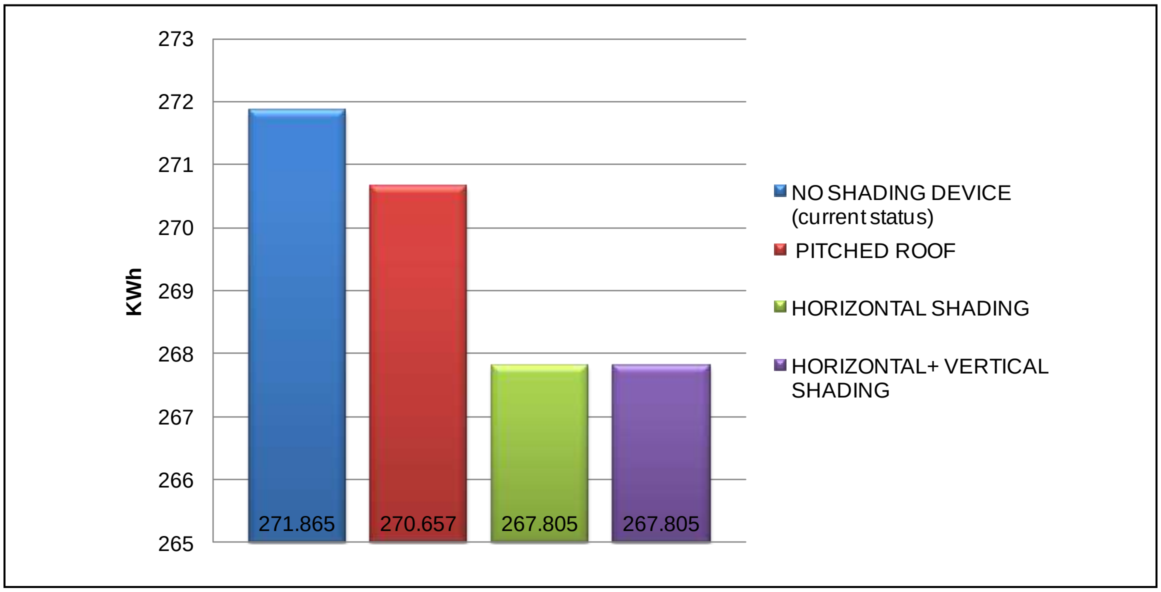

Figure 4.22 Paraisopolis shading devices study.

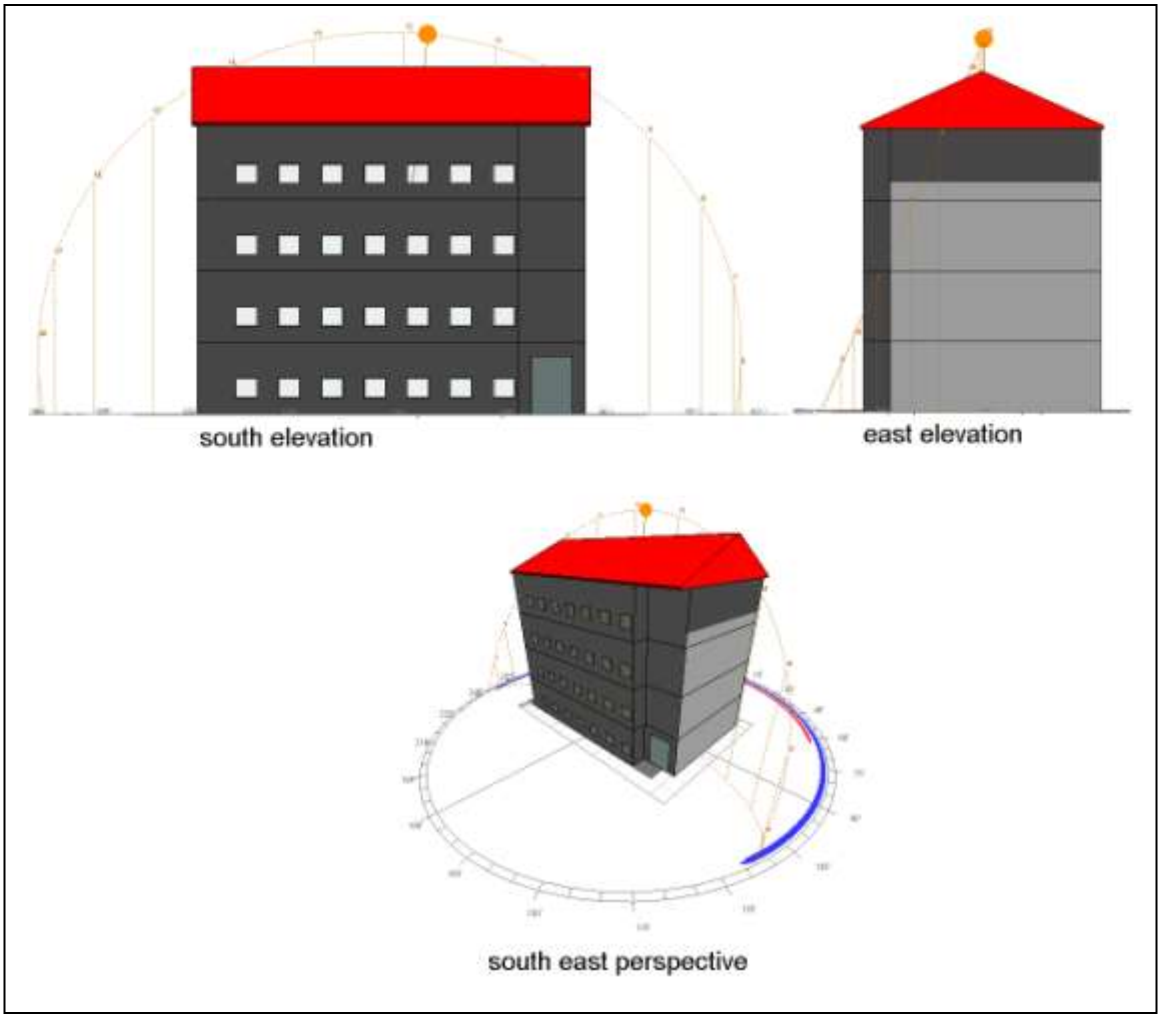

Figure 4.23 Paraisopolis building – pitched roof. Image source: Ecotect 5.5.

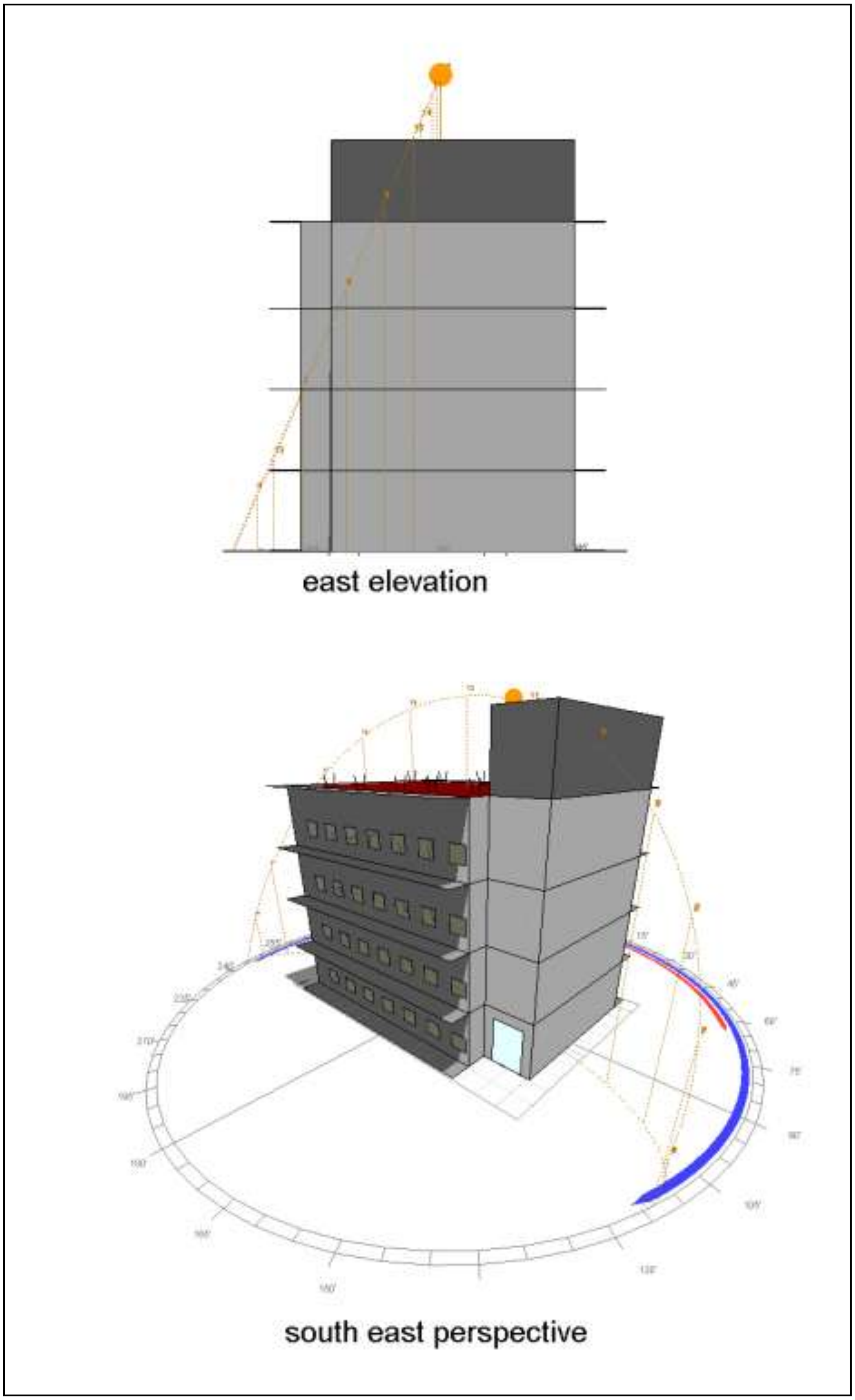

Figure 4.24 Paraisopolis building – horizontal shading device.
Image source: Ecotect 5.5.

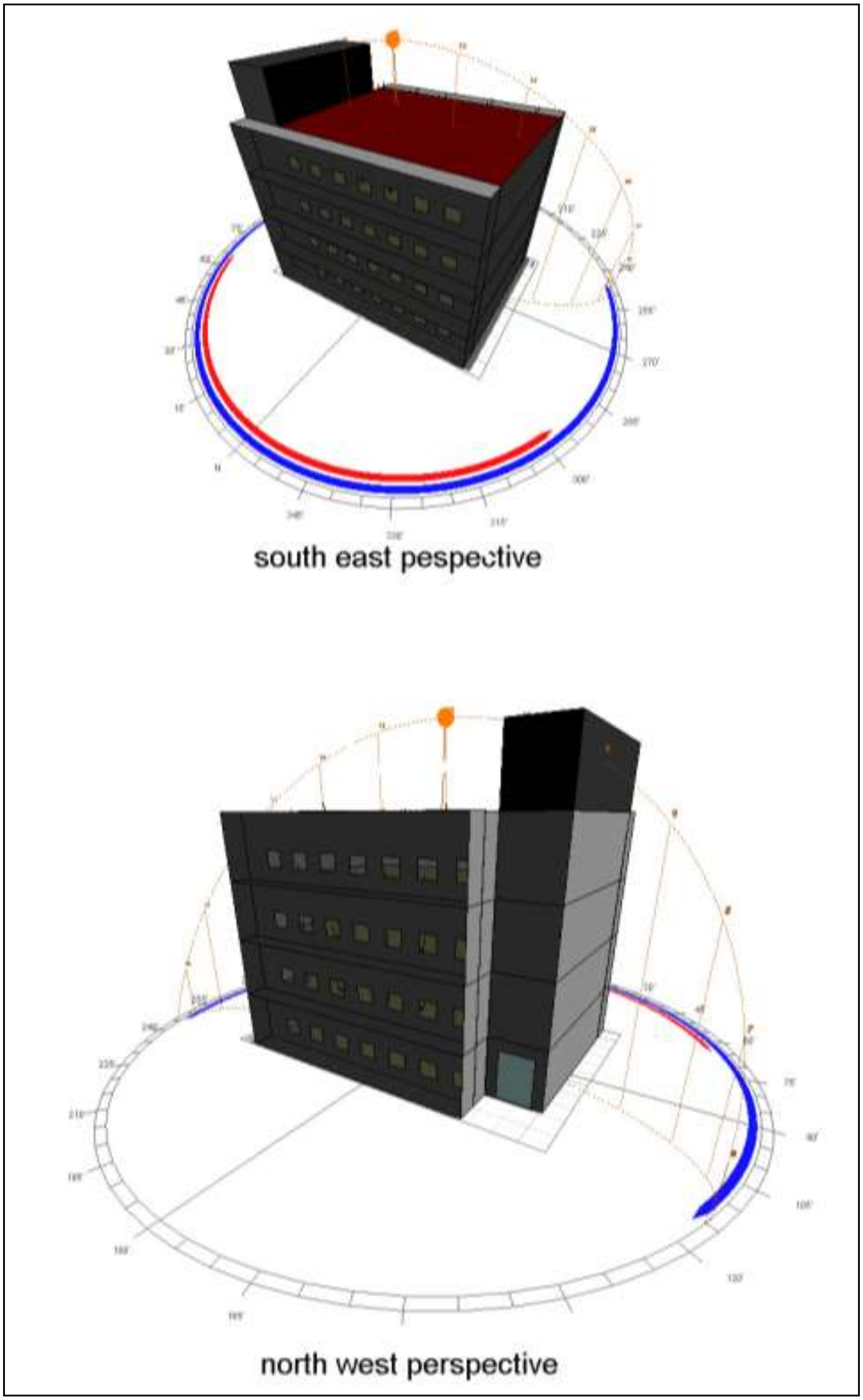

Figure 4.25 Paraisopolis building – horizontal and vertical shading device. Image source: Ecotect 5.5.

The windows simulations showed that double glazed low-e aluminum frame was the best alternative among the others; however the decrease in energy consumption was only one percent compared to the original windows. Since the current design standards provide simple glazed window with aluminum frame, and no shading elements and limited openings are also part of the design, the double glaze window proved to be very efficient in adapting the existing situation and decreasing energy consumption.

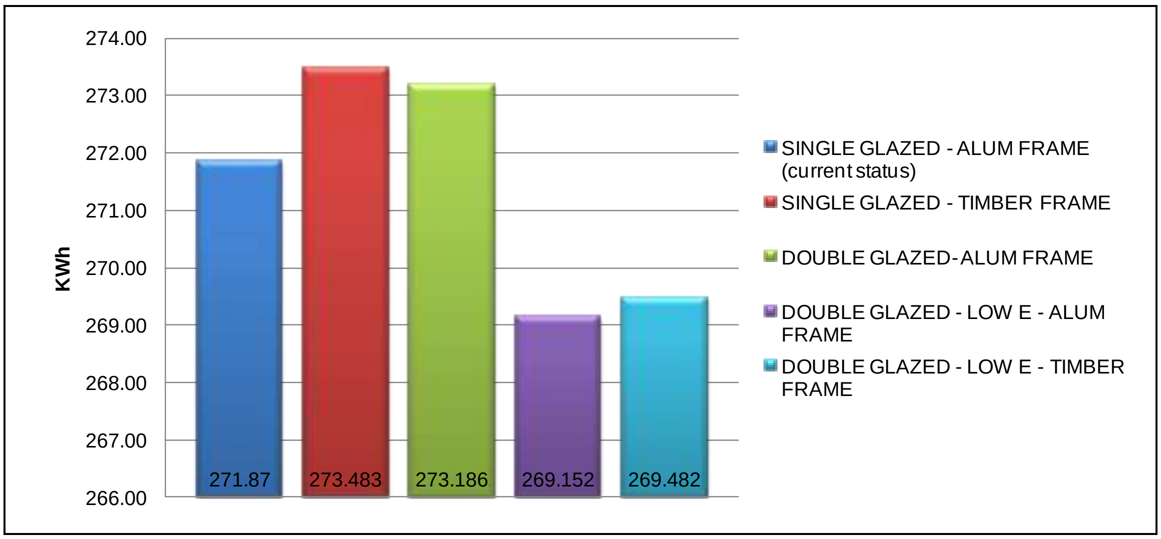

Figure 4.26 Paraisopolis window study result.

At last, the roof simulation for this case study showed that the existing flat roof is not efficient. The best result came from the addition of a pitched roof; however the decrease in energy consumption was very modest. In fact, when other roof systems were incorporated, the results remained almost the same. Even though the pitched roof slightly decreased the energy use and it was not a significant reduction compared to the other variables, it must be considered for future design strategies once it can be designed as part of a holistic design approach to lower energy consumption.

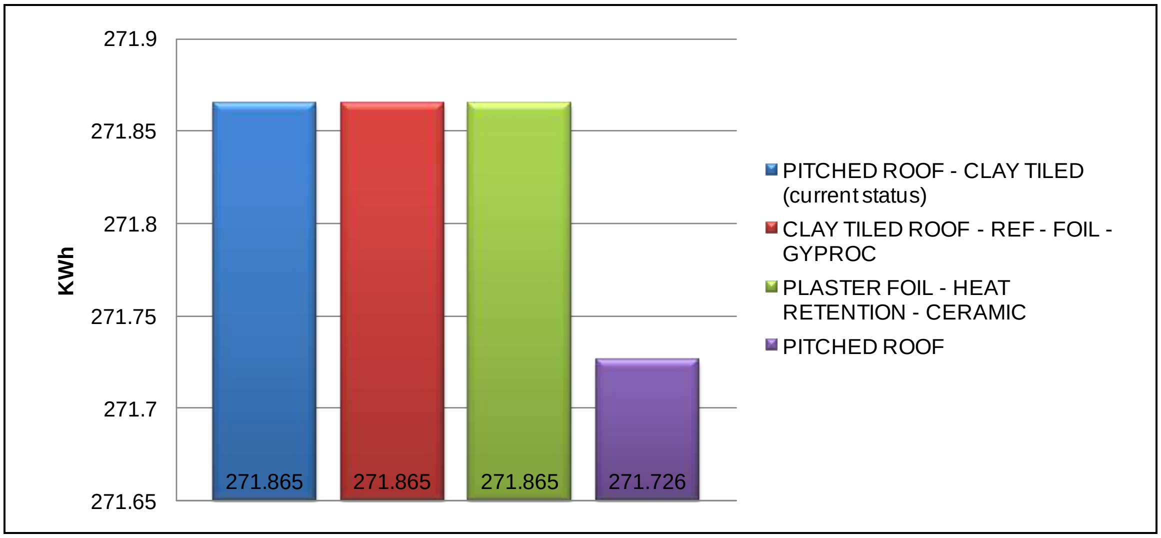

Figure 4.27 Paraisopolis roof study result.

4.5 Simulation of Best Results

The two case studies simulated – Voith and Paraisopolis - were an exploration on design and materials that were believed to have an impact on energy consumption in public housing buildings in Sao Paulo besides improving comfort levels in the dwellings. The top results of each variable obtained for each building were combined in one model. One model had the top results for Voith building and the other model had the best results for the Paraisopolis building. The goal was to understand how the final model would respond when simulated with all of the best results from each category which were: orientation, insulation, wall material, shading devices, window type and roof type and material.

4.5.1 Case Voith

The top results orientation, insulation, wall material, shading devices, window type and roof type and material were incorporated into one single model and then simulated. It was observed that both cooling and heating loads numbers improved. From the initial 78.13 Kilowatt hour per square meter of energy consumption, the final optimum building result reached 36.73 Kilowatt hour per square meter. The final model had north orientation; reverse brick veneer R-20; double glazed - low E – aluminum frame windows; and the current pitched tiled roof expanded on all sides and with concrete asphalt base. The results showed there was an improvement in energy consumption of 52 percent.

Table 4.13 Voith monthly loads simulation

COMBINED VARIABLE RESULTS
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 47696 W at 15:00 on 24th March
Max Cooling: 0.0 C - No Cooling.

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	--------	---------	
Jan	738320	0	738320	
Feb	251997	0	251997	
Mar	962046	0	962046	
Apr	1536472	0	1536472	
May	1731229	0	1731229	
Jun	2069829	0	2069829	
Jul	1988139	0	1988139	
Aug	2637800	0	2637800	
Sep	1569310	0	1569310	
Oct	1337063	0	1337063	
Nov	1373116	0	1373116	
Dec	1524680	0	1524680	
------------	---------	--------	---------	
TOTAL	17719998	0	17719998	
------------	---------	--------	---------	
PER M²	36725	0	36725	**36.73**
Floor Area:	482.510 m2			

This building already presented the best results among the four initial cases and it was apparent that it could be improved even more. When more than one building material, that had the potential to reduce energy consumption, was used in conjunction with others the result improved exponentially. It appeared that the current building shape in this case was successful and once combined with material to improve its performance, the results were better yet. Among the variables simulated in isolation, the insulation was the one that decrease energy consumption the most. This variable combined with the building shape and shading elements was assumed to have contributed to the great diminish in energy consumption. Hence, this was a successful case of the potential that public housing building has and have not been explored.

4.5.2 Case Paraisopolis

The top results for the Paraisopolis were: north orientation; no insulation on the walls; brick with plaster walls; horizontal and vertical shading elements on all sides of the building façade; double glazed - low E - aluminum frame windows; and pitched roof. The energy consumption decreased from 271, 86 Kilowatt hour per square meter from the original design to 265, 39, Kilowatt hour per square meter, which represents an improvement of 2.3 percent in consumption. In this case, the improvements were smaller if compared to the previous case.

Even though the results were small, there was an improvement in energy consumption. This case was the worst case among the four initial cases. It was believed that the shape of the building and reduced shading elements were responsible for such a high energy consumption, especially if compared to the best case of all, the Voith building. None of the variables alone were enough to decrease energy consumption significantly. This case study showed that there is room for improvement in this type of buildings in Sao Paulo; however, a holistic design is more efficient and provides more improvements. This building was already a difficult case and when changes were done, the results were worst than the original sometimes. It proved that not only one material alone is enough to improve a building’s performance, either been thermal or energy performance. From the variables that had better result alone, the results combined were yet able to reduce the energy consumption.

Table 4.14 Paraisopolis monthly loads

COMBINED VARIABLE RESULTS
PARAISOPOLIS
MONTHLY HEATING/ COLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 10037 W at 03:00 on 17th August
Max Cooling: 44278 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15218118	15218118	
Feb	0	13900088	13900088	
Mar	0	15042998	15042998	
Apr	0	12401938	12401938	
May	5851	8695955	8701806	
Jun	206618	5387641	5594259	
Jul	118921	5010734	5129655	
Aug	156473	7501512	7657985	
Sep	16210	7582298	7598509	
Oct	0	10792451	10792451	
Nov	0	12413411	12413411	
Dec	0	14721287	14721287	
------------	--------	----------	----------	
TOTAL	504074	128668432	129172504	
------------	--------	----------	----------	
PER M²	1036	264358	265394	**265.39**
Floor Area:	486.720 m2			

4.6 Summary

The simulation of a final model for each of the cases provided insights about the buildings. It showed that building elements alone are at times not enough to improve a building's performance and that a holistic design from the beginning of the project is essential.

The simulations also showed that the existing design of public housing in Sao Paulo has the potential to be improved in several different levels. The evaluations also showed that it is possible to improve the comfort levels within the building envelope at the same time energy is saved. One important message is that new buildings must be studied more carefully in order to incorporate sustainable concepts in order to contribute to energy savings; however, the existing buildings can also become more sustainable with the incorporation of few design solutions that contribute to energy savings.

These results also provided ground for future simulations, since more variables could be incorporated into the buildings to be analyzed. New strategies applied to building materials and shape could also be studied to improve design of public housing buildings in Sao Paulo. Generally, comfort levels are not taken into consideration during the design process; however, by carefully analyzing materials, orientation and shading elements better building could be designed.

This chapter presented the analysis process and results of the building selection, the simulation of selected case studies and the simulation of the final models with best results incorporated together, followed by the discussion of the results.

CHAPTER 5 - Conclusion and Recommendations

5.1 Conclusions

After the assessment of the buildings it was concluded that the incorporation of building materials, that have the potential to improve energy performance, help reduce energy consumption in the cases studied. By adding insulation, double glazed windows, improved wall assembles and shading elements, the energy performance of the buildings assessed improved considerably.

Furthermore, by assessing environmental characteristics of the site, understanding the best sun path to take advantage of the natural elements to maximize comfort levels, there is a possibility of improving the design of public housing in Sao Paulo. All of the variables were important in the final simulation. It was clear that windows can improve energy consumption levels significantly; insulation materials have also shown to contribute to the indoor environmental conditions, and lower energy consumption. Since insulation is not usually part of the construction process in Brazil, this research showed how significantly this component is among all of the materials investigated. In addition, shading devices should always be thought out throughout the design process, since in this investigation they significantly reduced energy consumption when assessed separately.

The most valuable message is the importance of a holistic approach to the design process and the influence it has on energy efficiency and building performance. Most of the parameters assessed in this dissertation had a positive impact on the energy consumption.

5.2 Recommendations

It was observed here the benefits of improving building specifications and designs to reach better energy performances. Even though some of the strategies used to lower energy consumption in this study might represent extra costs for housing, the fact that the amount of public housing being produced has increased exponentially and so has the amount of energy consumed is already an advantage. On the other hand, if energy consumption numbers are overlooked, another advantage is the possibility of providing better dwellings for the population.

Suggestions for future research that came up from undertaking this research were: cost-benefit of implementing these improvements in public housing buildings; assessment of building form and site implementation; ventilation patterns in the building complex that can affect energy performance; embodied energy and carbon footprint; maintenance cost of improved buildings design; and finally, a qualitative analysis of the impacts of such improvements in the low income population and its advantages for the government and for the population.

5.3 Summary

This dissertation assessed the current energy performance of low income public housing in Sao Paulo. It provided an overview of the current situation of the issue. The literature review showed that affordable housing has been built all around the world and great attention has been given to sustainable practices in this field. Later, the methodology was presented followed by the analysis and results. The simulations carried out herein reflected the reality of current public housing situation in Sao Paulo. This research clearly showed that there are areas for improvements in this field. Through the results it was understood that even small changes carefully applied to the current design process significantly increased the building's energy performance. By incorporating better practices into the design process in the public housing field in Sao Paulo, the government has the potential to improve quality, which would directly affect the low income population and all levels of society.

While there are still many solutions to be reached in low income buildings in Sao Paulo, there is also promising horizons. This research demonstrated that there is ground for improvements regarding energy performance and thermal comfort in low income buildings in Sao Paulo. Moving towards deep thinking on high performance public housing in Sao Paulo is an essential step to achieve better designs and better living places for the less fortunate part of the population. If changes are implemented into the design process of public housing in Sao Paulo, then, not only citizens will be given a better quality of life, but our city will be a source of proud and enjoyment to millions of people.

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Web Resources

Database

Elsevier provided by Cardiff Electronic Resources
Ingenta Connect
Science Direct

Search Engines

Google Images
Google Scholar

E-Journals

Building and Environment, Elsevier (www.elsevier.com)
Energy and Buildings, Elsevier (www.elsevier.com)
Renewable Energy (www.elsevier.com)

Softwares

Climate Consultant 4.0 – Available from UCLA at http://www.energy-design-tools.aud.ucla.edu/

ECOTECT Autodesk 2009

Appendix A

WHEATER CHARTS FOR SAO PAULO FROM CLIMATE CONSULTANT 4.0

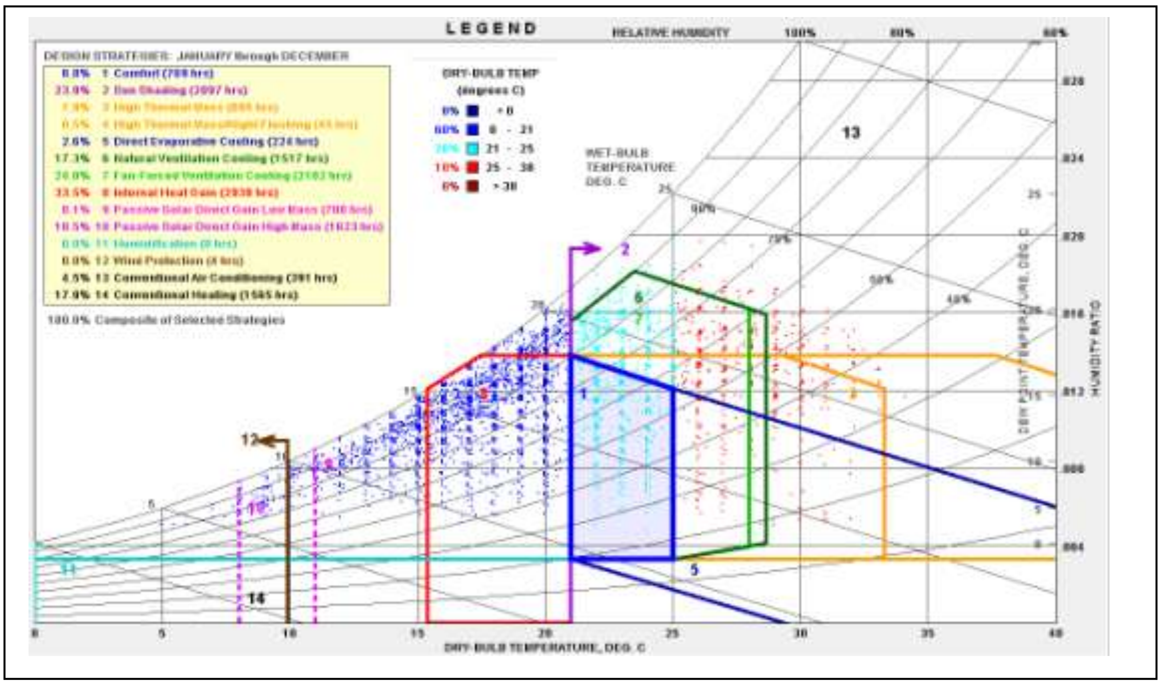
Location:

Sao Paulo/Congonhas, Brazil

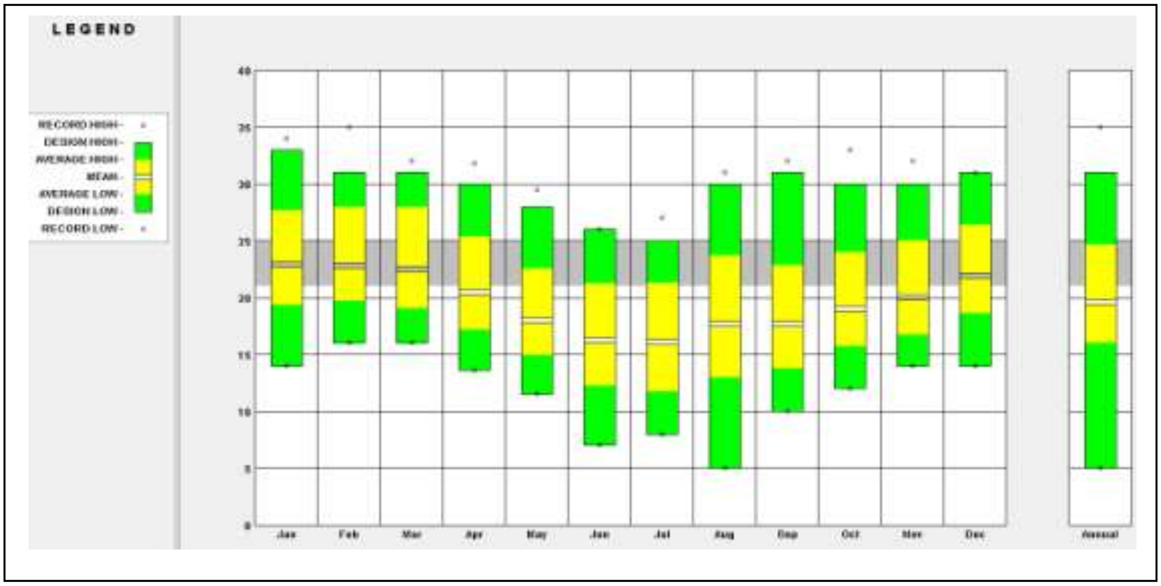
23.62^{o} South

46.65^{o} West

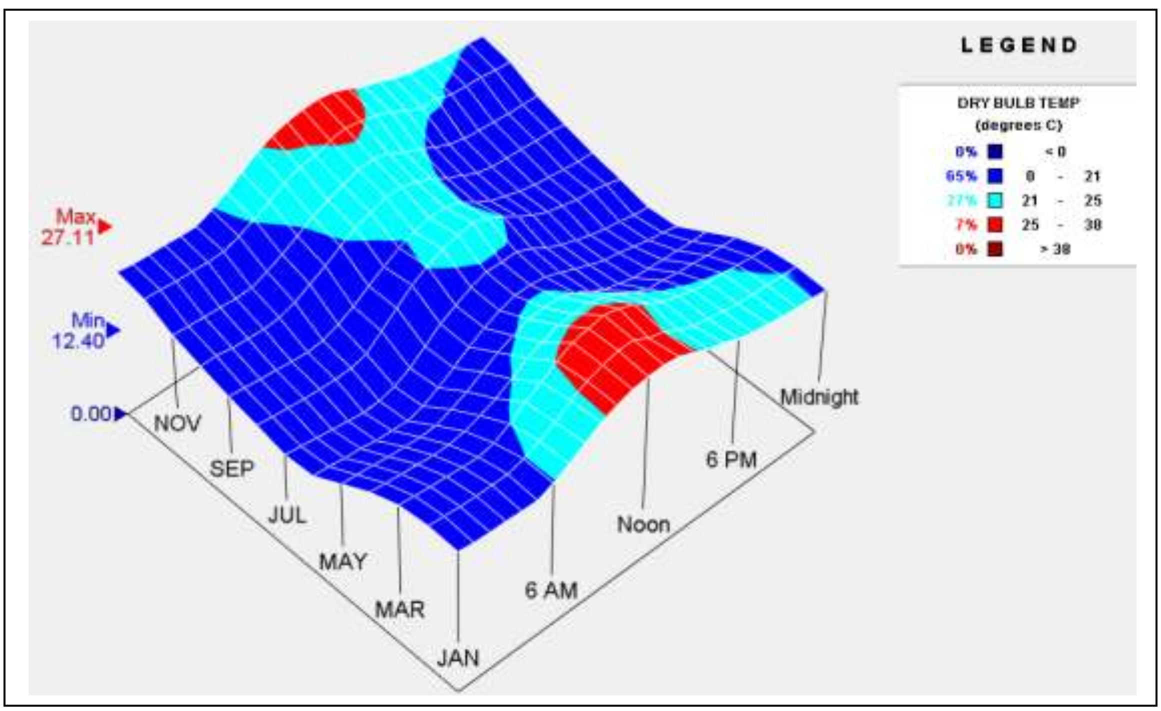
Psychrometric Chart



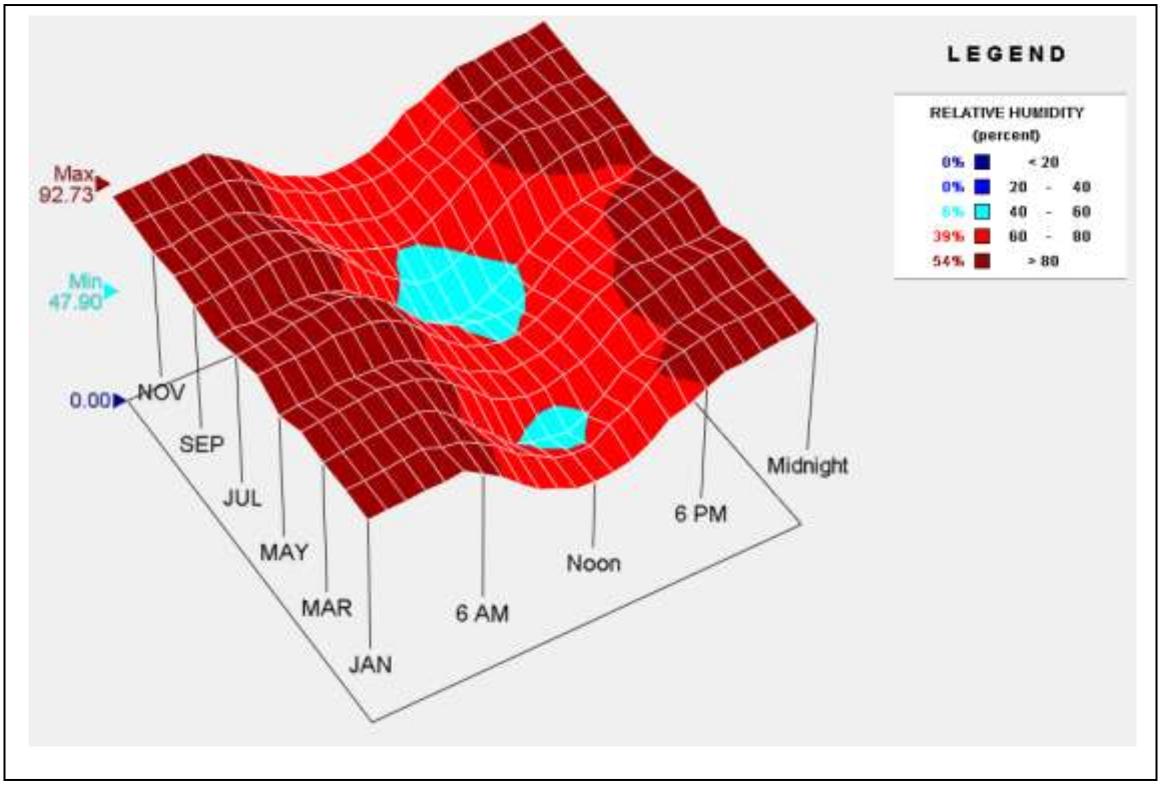
Temperature Range



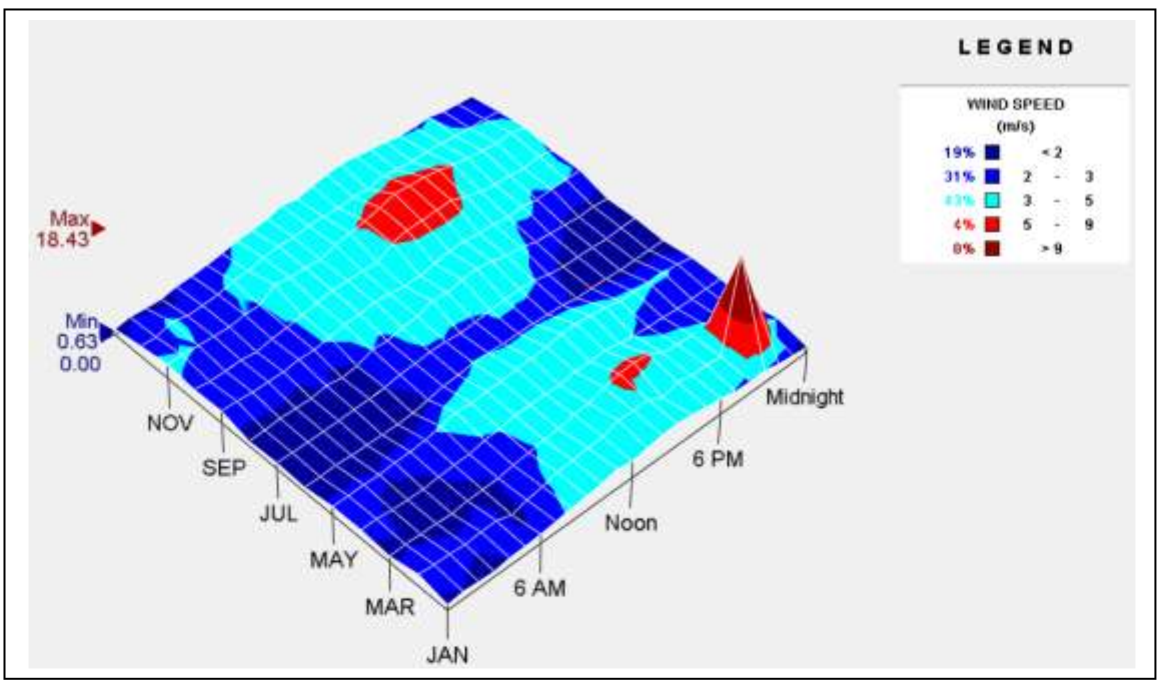
Dry Bulb Temperature



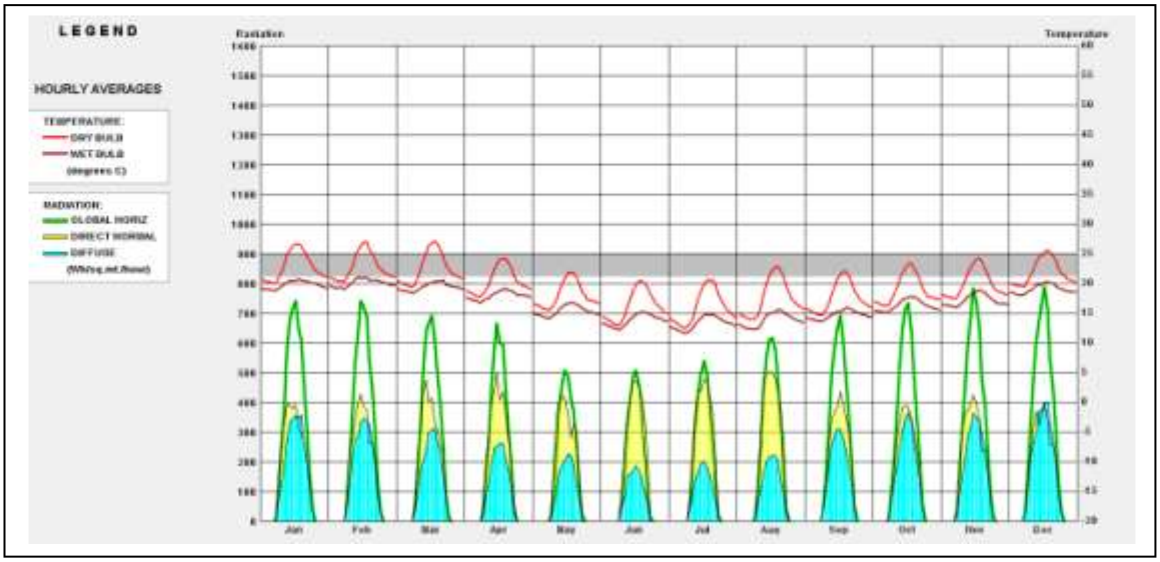
Relative Humidity



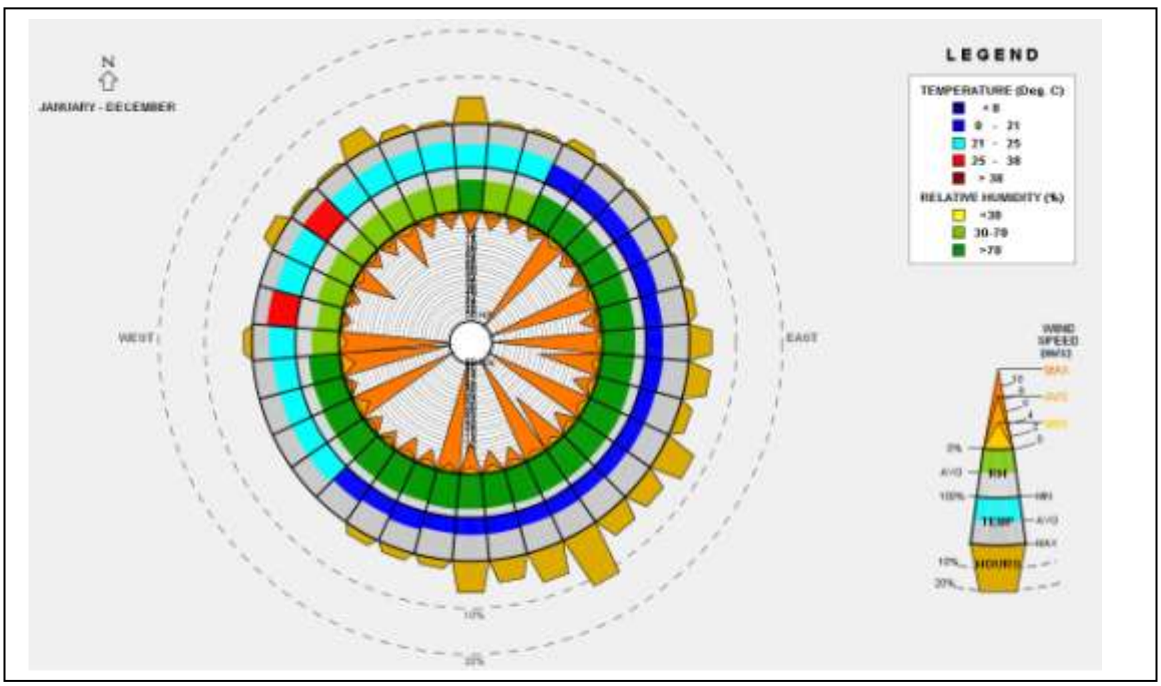
Wind Speed



Monthly Diurnal Averages



Wind Wheel



Appendix B

MODEL SIMULATION RESULTS FROM ECOTECT

Case Voith – Orientation

NORTH
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 27256 W at 03:00 on 17th August
Max Cooling: 52128 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
Jan	70778	7483131	7553909	
Feb	17928	4904446	4922374	
Mar	39109	5436474	5475583	
Apr	287599	1863701	2151300	
May	827111	151269	978380	
Jun	2260107	0	2260107	
Jul	2347051	0	2347051	
Aug	1997545	870893	2868438	
Sep	1262980	886943	2149923	
Oct	612825	577981	1190806	
Nov	254222	1047342	1301565	
Dec	102365	4393698	4496063	
TOTAL	10079620	27615880	37695500	
PER M²	20890	57234	78124	**78.12**
Floor Area:	482.510 m2			

SOUTH
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 26987 W at 03:00 on 17th August
Max Cooling: 52589 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	71327	7442260	7513586	
Feb	17852	4998898	5016749	
Mar	38282	5482952	5521234	
Apr	279058	1901191	2180248	
May	809041	153126	962167	
Jun	2222190	0	2222190	
Jul	2304624	0	2304624	
Aug	1967111	944870	2911982	
Sep	1248855	859746	2108601	
Oct	609187	580355	1189542	
Nov	256681	1050269	1306950	
Dec	103159	4484135	4587294	
------------	--------	---------	---------	
TOTAL	9927365	27897800	37825164	
------------	--------	---------	---------	
PER M²	20574	57818	78392	**78.39**
Floor Area:	482.510 m2			

EAST

VOITH

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 26988 W at 03:00 on 17th August

Max Cooling: 55025 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	70371	8071256	8141626	
Feb	17755	5603392	5621148	
Mar	38091	6131882	6169974	
Apr	261791	1812090	2073881	
May	800277	53659	853937	
Jun	2190622	0	2190622	
Jul	2257068	0	2257068	
Aug	1935353	733464	2668818	
Sep	1227479	836195	2063674	
Oct	604495	676090	1280585	
Nov	250217	1257764	1507981	
Dec	101984	5101265	5203249	
------------	--------	---------	---------	
TOTAL	9755503	30277056	40032560	
------------	--------	---------	---------	
PER M²	20218	62749	82967	**82.97**
Floor Area:	482.510 m2			

WEST

VOITH

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 27182 W at 03:00 on 17th August

Max Cooling: 55372 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	---------	---------	
Jan	71582	8095284	8166866	
Feb	18034	5598431	5616465	
Mar	39069	6155400	6194469	
Apr	272520	1836611	2109131	
May	825136	83405	908541	
Jun	2259326	0	2259326	
Jul	2346052	0	2346052	
Aug	1964248	765473	2729722	
Sep	1242271	804616	2046887	
Oct	615075	674196	1289271	
Nov	259855	1226246	1486101	
Dec	103378	5003458	5106836	
------------	---------	---------	---------	
TOTAL	10016547	30243118	40259664	
------------	---------	---------	---------	
PER M²	20759	62679	83438	**83.44**
Floor Area:	482.510 m2			

SW

VOITH

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 27072 W at 03:00 on 17th August

Max Cooling: 54429 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	---------	---------	
Jan	71462	7792087	7863549	
Feb	17958	5325117	5343076	
Mar	38651	5801568	5840219	
Apr	282982	1878048	2161030	
May	827044	173690	1000734	
Jun	2313529	0	2313529	
Jul	2412260	0	2412260	
Aug	1999544	889805	2889349	
Sep	1247221	925326	2172547	
Oct	612302	635543	1247844	
Nov	259341	1159505	1418846	
Dec	103362	4877685	4981047	
------------	---------	---------	---------	
TOTAL	10185655	29458376	39644032	
------------	---------	---------	---------	
PER M²	21110	61052	82162	**82.16**
Floor Area:	482.510 m2			

SE

VOITH

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 26932 W at 03:00 on 17th August

Max Cooling: 54080 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	70864	7789824	7860688	
Feb	17778	5446792	5464570	
Mar	38000	6036496	6074496	
Apr	262498	1923907	2186406	
May	794523	56279	850802	
Jun	2163863	0	2163863	
Jul	2235446	0	2235446	
Aug	1929815	739145	2668960	
Sep	1228324	859359	2087684	
Oct	605642	663394	1269036	
Nov	253528	1167565	1421093	
Dec	102677	4901172	5003849	
------------	--------	---------	---------	
TOTAL	9702959	29583936	39286896	
------------	--------	---------	---------	
PER M²	20109	61313	81422	**81.42**
Floor Area:	482.510 m2			

NW

VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 27269 W at 03:00 on 17th August
Max Cooling: 54296 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	71324	7802279	7873602	
Feb	18007	5427609	5445616	
Mar	39278	6043048	6082325	
Apr	274618	1967624	2242242	
May	818313	55502	873815	
Jun	2208151	0	2208151	
Jul	2286271	0	2286271	
Aug	1969223	769132	2738355	
Sep	1246216	857845	2104060	
Oct	615199	661706	1276904	
Nov	257466	1164639	1422105	
Dec	103062	4770660	4873721	
------------	--------	---------	---------	
TOTAL	9907129	29520044	39427172	
------------	--------	---------	---------	
PER M²	20532	61180	81713	**81.71**
Floor Area:	482.510 m2			

NE

VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 27136 W at 03:00 on 17th August
Max Cooling: 54102 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	---------	---------	
Jan	70238	7946914	8017153	
Feb	17816	5358970	5376786	
Mar	38607	5931540	5970147	
Apr	278891	1822987	2101878	
May	825737	171201	996938	
Jun	2322337	0	2322337	
Jul	2396025	0	2396025	
Aug	1989798	851099	2840897	
Sep	1245353	921859	2167212	
Oct	607446	634642	1242088	
Nov	250317	1143808	1394125	
Dec	101793	4943613	5045406	
------------	---------	---------	---------	
TOTAL	10144358	29726636	39870992	
------------	---------	---------	---------	
PER M²	21024	61608	82632	**82.63**
Floor Area:	482.510 m2			

Case Voith – Insulation

BRICK PLASTER WITH POLYSTYRENE 50mm
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 16290 W at 03:00 on 17th August
Max Cooling: 42214 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	22621	6604376	6626996	
Feb	1277	4730079	4731356	
Mar	4071	4884790	4888861	
Apr	115351	1550779	1666130	
May	293047	45712	338759	
Jun	862702	0	862702	
Jul	886387	0	886387	
Aug	762584	703826	1466410	
Sep	473652	710956	1184608	
Oct	205112	453840	658952	
Nov	65436	945009	1010445	
Dec	23463	4089540	4113003	
------------	--------	---------	---------	
TOTAL	3715703	24718906	28434608	
------------	--------	---------	---------	
PER M²	7701	51230	58931	**58.93**
Floor Area:	482.510 m2			

DOUBLE BRICK CAVITY PLASTER (AIR GAP)
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 19605 W at 03:00 on 17th August
Max Cooling: 44870 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	31916	6751910	6783826	
Feb	4513	4024231	4028744	
Mar	9094	4181903	4190998	
Apr	137627	1286672	1424299	
May	403828	0	403828	
Jun	1137776	0	1137776	
Jul	1167916	0	1167916	
Aug	1015921	130978	1146899	
Sep	632142	550026	1182167	
Oct	282038	280251	562289	
Nov	101625	696552	798177	
Dec	37283	3264751	3302034	
------------	--------	---------	---------	
TOTAL	4961679	21167272	26128952	
------------	--------	---------	---------	
PER M²	10283	43869	54152	**54.15**
Floor Area:	482.510 m			

REVERSE BRICK VENEER - R20
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 16408 W at 03:00 on 17th August
Max Cooling: 42394 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	22928	6343521	6366449	
Feb	1388	3538461	3539849	
Mar	4287	3855437	3859724	
Apr	115532	1117411	1232943	
May	296613	0	296613	
Jun	869505	0	869505	
Jul	892304	0	892304	
Aug	768906	55931	824837	
Sep	477374	537295	1014669	
Oct	207347	186487	393834	
Nov	66507	548661	615168	
Dec	23789	2969640	2993428	
------------	--------	---------	---------	
TOTAL	3746480	19152844	22899324	
------------	--------	---------	---------	
PER M²	7765	39694	47459	**47.46**
Floor Area:	482.510 m2			

Case Voith – Wall Material

CONCRETE BLOCK PLASTER
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 24454 W at 03:00 on 17th August
Max Cooling: 50343 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	50743	7642150	7692894	
Feb	12388	5451639	5464028	
Mar	24755	5691775	5716530	
Apr	213976	2071242	2285218	
May	639770	222411	862181	
Jun	1743856	0	1743856	
Jul	1786183	0	1786183	
Aug	1560811	799080	2359891	
Sep	979466	880284	1859749	
Oct	465659	615399	1081058	
Nov	187677	1112073	1299750	
Dec	72387	4935301	5007688	
------------	--------	---------	---------	
TOTAL	7737670	29421352	37159024	
------------	--------	---------	---------	
PER M²	16036	60976	77012	**77.01**
Floor Area:	482.510 m2			

CONCRETE BLOCK RENDER

VOITH

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 24774 W at 03:00 on 17th August

Max Cooling: 51409 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	52443	7889494	7941936	
Feb	13018	5756298	5769317	
Mar	25667	5903801	5929468	
Apr	218027	2110340	2328367	
May	655445	260390	915835	
Jun	1781559	0	1781559	
Jul	1825211	0	1825211	
Aug	1590721	944731	2535452	
Sep	1001538	938882	1940419	
Oct	478442	633434	1111876	
Nov	193125	1195684	1388810	
Dec	74861	5224786	5299646	
------------	--------	---------	---------	
TOTAL	7910056	30857840	38767896	
------------	--------	---------	---------	
PER M²	16394	63953	80346	**80.35**
Floor Area:	482.510 m2			

DOUBLE BRICK SOLID PLASTER

VOITH

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 20185 W at 03:00 on 17th August

Max Cooling: 45062 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	33723	6682502	6716226	
Feb	5091	4015361	4020452	
Mar	10233	4135370	4145603	
Apr	143756	1230005	1373762	
May	425853	0	425853	
Jun	1197289	0	1197289	
Jul	1224500	0	1224500	
Aug	1068904	132196	1201100	
Sep	665273	524108	1189381	
Oct	299049	282227	581276	
Nov	109177	677221	786398	
Dec	40230	3166210	3206440	
------------	--------	---------	---------	
TOTAL	5223080	20845200	26068280	
------------	--------	---------	---------	
PER M²	10825	43202	54026	**54.03**
Floor Area:	482.510 m2			

BRICK CONCRETE BLOCK PLASTER
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 20565 W at 03:00 on 17th August
Max Cooling: 46316 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	34187	6982096	7016282	
Feb	5475	4373921	4379396	
Mar	10538	4486856	4497394	
Apr	145047	1406230	1551277	
May	435544	0	435544	
Jun	1226338	0	1226338	
Jul	1254226	0	1254226	
Aug	1092145	254074	1346219	
Sep	680554	541664	1222218	
Oct	307382	320323	627705	
Nov	111342	767806	879147	
Dec	41439	3467118	3508557	
------------	--------	---------	---------	
TOTAL	5344216	22600088	27944304	
------------	--------	---------	---------	
PER M²	11076	46839	57914	**57.91**
Floor Area:	482.510 m2			

Case Voith – Shading Devices

EXPANTION SOUTH SIDE OF ROOF
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 27293 W at 03:00 on 17th August
Max Cooling: 51925 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	---------	---------	
Jan	70849	7446663	7517512	
Feb	17945	4876814	4894760	
Mar	39237	5382291	5421528	
Apr	288433	1857030	2145464	
May	829856	151308	981164	
Jun	2270814	0	2270814	
Jul	2357493	0	2357493	
Aug	2004616	867987	2872603	
Sep	1266926	886209	2153134	
Oct	612526	578043	1190569	
Nov	253329	1041397	1294726	
Dec	102359	4356856	4459214	
------------	---------	---------	---------	
TOTAL	10114382	27444596	37558976	
------------	---------	---------	---------	
PER M²	20962	56879	77841	**77.84**
Floor Area:	482.510 m2			

EXPANTION SOUTH+NORTH SIDE OF ROOF

VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 27349 W at 03:00 on 17th August
Max Cooling: 51464 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	---------	---------	
Jan	71900	7295332	7367232	
Feb	18247	4759568	4777816	
Mar	39813	5287366	5327178	
Apr	291572	1838837	2130408	
May	834948	119840	954788	
Jun	2285511	0	2285511	
Jul	2371726	0	2371726	
Aug	2017630	883634	2901264	
Sep	1276600	879863	2156463	
Oct	617945	600420	1218365	
Nov	257083	1027526	1284610	
Dec	103791	4241904	4345694	
------------	---------	---------	---------	
TOTAL	10186766	26934288	37121056	
------------	---------	---------	---------	
PER M²	21112	55821	76933	**76.93**
Floor Area:	482.510 m2			

EXPANTION EAST+WEST SIDE ROOF

VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 27310 W at 03:00 on 17th August
Max Cooling: 51938 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	---------	---------	
Jan	71168	7419396	7490565	
Feb	18052	4853880	4871931	
Mar	39421	5411974	5451396	
Apr	288974	1857222	2146196	
May	829896	151110	981005	
Jun	2267994	0	2267994	
Jul	2355167	0	2355167	
Aug	2004483	867780	2872262	
Sep	1267184	885168	2152352	
Oct	614857	576690	1191546	
Nov	255422	1041810	1297232	
Dec	102898	4369665	4472563	
------------	---------	---------	---------	
TOTAL	10115515	27434696	37550212	
------------	---------	---------	---------	
PER M²	20964	56858	77823	**77.82**
Floor Area:	482.510 m2			

EXPANTION ALL SIDES OF ROOF
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 27385 W at 03:00 on 17th August
Max Cooling: 51443 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	---------	---------	
Jan	72185	7282860	7355044	
Feb	18345	4729912	4748256	
Mar	40043	5278345	5318388	
Apr	292414	1836516	2128930	
May	836726	119847	956572	
Jun	2289835	0	2289835	
Jul	2376310	0	2376310	
Aug	2021580	882581	2904160	
Sep	1279336	879325	2158661	
Oct	619436	600075	1219511	
Nov	258020	1025393	1283413	
Dec	104182	4233148	4337330	
------------	---------	---------	---------	
TOTAL	10208411	26868000	37076412	
------------	---------	---------	---------	
PER M²	21157	55684	76841	**76.84**
Floor Area:	482.510 m2			

Case Voith – Window Type

SINGLE GLAZED - TIMBER FRAME
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 26496 W at 03:00 on 17th August
Max Cooling: 51606 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	65955	7379218	7445173	
Feb	16538	4876560	4893098	
Mar	36425	5399090	5435515	
Apr	273080	1852819	2125899	
May	782835	119721	902556	
Jun	2151122	0	2151122	
Jul	2237323	0	2237323	
Aug	1907322	835628	2742950	
Sep	1203379	908241	2111620	
Oct	579096	601274	1180370	
Nov	238056	1042366	1280421	
Dec	96459	4369556	4466015	
------------	--------	---------	---------	
TOTAL	9587590	27384474	36972064	
------------	--------	---------	---------	
PER M²	19870	56754	76624	**76.62**
Floor Area:	482.510 m2			

DOUBLE GLAZED- ALUMINUM FRAME

VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 24468 W at 03:00 on 17th August
Max Cooling: 49365 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	54431	7005680	7060112	
Feb	12832	4532476	4545308	
Mar	29301	5092603	5121904	
Apr	239456	1705853	1945309	
May	679991	81997	761988	
Jun	1913812	0	1913812	
Jul	1995230	0	1995230	
Aug	1692423	718712	2411134	
Sep	1058237	813702	1871940	
Oct	494361	553137	1047499	
Nov	199436	1000856	1200292	
Dec	81204	4094854	4176058	
------------	--------	---------	---------	
TOTAL	8450715	25599870	34050584	
------------	--------	---------	---------	
PER M²	17514	53056	70570	**70.57**
Floor Area:	482.510 m			

DOUBLE GLAZED - LOW E - ALUMINUM FRAME

VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 24223 W at 03:00 on 17th August
Max Cooling: 48579 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	53608	6644396	6698005	
Feb	12384	4267986	4280370	
Mar	28471	4758352	4786824	
Apr	240220	1606783	1847003	
May	678104	78508	756613	
Jun	1943782	0	1943782	
Jul	2025040	0	2025040	
Aug	1699666	652466	2352132	
Sep	1055120	793175	1848295	
Oct	485758	542833	1028591	
Nov	195079	901736	1096815	
Dec	79863	3902413	3982276	
------------	--------	---------	---------	
TOTAL	8497097	24148646	32645744	
------------	--------	---------	---------	
PER M²	17610	50048	67658	**67.66**
Floor Area:	482.510 m2			

DOUBLE GLAZED - LOW E - TIMBER FRAME
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 24097 W at 03:00 on 17th August
Max Cooling: 48525 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	52985	6646232	6699217	
Feb	12160	4270442	4282603	
Mar	28043	4761208	4789250	
Apr	237482	1608075	1845557	
May	670991	78648	749638	
Jun	1922986	0	1922986	
Jul	2003866	0	2003866	
Aug	1683306	687092	2370398	
Sep	1044782	793252	1838034	
Oct	480566	542639	1023205	
Nov	192860	923373	1116233	
Dec	78889	3934693	4013582	
------------	--------	---------	---------	
TOTAL	8408915	24245656	32654572	
------------	--------	---------	---------	
PER M²	17427	50249	67676	**67.68**
Floor Area:	482.510 m2			

Case Voith – Roof Type

CONCRETE ROOF ASPHALT
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 25578 W at 03:00 on 17th August
Max Cooling: 48012 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	68827	7014004	7082832	
Feb	16502	4370524	4387026	
Mar	33367	4900924	4934290	
Apr	275111	1643750	1918861	
May	786827	82431	869257	
Jun	2140420	0	2140420	
Jul	2194305	0	2194305	
Aug	1897700	551976	2449676	
Sep	1196987	794293	1991280	
Oct	588011	524754	1112765	
Nov	246557	923777	1170334	
Dec	95729	3978976	4074705	
------------	--------	---------	---------	
TOTAL	9540343	24785406	34325748	
------------	--------	---------	---------	
PER M²	19772	51368	71140	**71.14**
Floor Area:	482.510 m2			

CLAY TILED ROOF - REF - FOIL - GYPROC

VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 31884 W at 03:00 on 17th August
Max Cooling: 59211 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	---------	---------	
Jan	117725	8274449	8392174	
Feb	30090	5913630	5943720	
Mar	63990	6313470	6377460	
Apr	410954	2293256	2704210	
May	1161254	398481	1559735	
Jun	2963327	0	2963327	
Jul	3078458	0	3078458	
Aug	2611460	1497859	4109319	
Sep	1712205	1303324	3015528	
Oct	887321	1027753	1915074	
Nov	404844	1495483	1900327	
Dec	163929	5523580	5687509	
------------	---------	---------	---------	
TOTAL	13605556	34041284	47646840	
------------	---------	---------	---------	
PER M²	28197	70550	98748	**98.748**
Floor Area:	482.510 m2			

PLASTER FOIL - HEAT RETENTION - CERAMIC

VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 26068 W at 03:00 on 17th August
Max Cooling: 49698 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	---------	---------	
Jan	66003	7127652	7193656	
Feb	16197	4532214	4548410	
Mar	34098	5109651	5143749	
Apr	272836	1711054	1983890	
May	793626	114496	908122	
Jun	2180965	0	2180965	
Jul	2243553	0	2243553	
Aug	1926189	633365	2559554	
Sep	1207347	820979	2028326	
Oct	583252	575636	1158888	
Nov	238803	950827	1189630	
Dec	94767	4161373	4256140	
------------	--------	---------	---------	
TOTAL	9657636	25737248	35394884	
------------	--------	---------	---------	
PER M²	20015	53340	73356	**73.36**
Floor Area:	482.510 m2			

CORRUGATED METAL ROOF
VOITH
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 31886 W at 03:00 on 17th August
Max Cooling: 59215 W at 14:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	---------	---------	---------	
Jan	117723	8274938	8392661	
Feb	30090	5913999	5944088	
Mar	63990	6313842	6377833	
Apr	410973	2293373	2704346	
May	1161359	398501	1559860	
Jun	2963590	0	2963590	
Jul	3078737	0	3078737	
Aug	2611664	1497938	4109602	
Sep	1712320	1303398	3015718	
Oct	887358	1027828	1915186	
Nov	404846	1495578	1900424	
Dec	163926	5523930	5687856	
------------	---------	---------	---------	
TOTAL	13606576	34043324	47649900	
------------	---------	---------	---------	
PER M²	28200	70555	98754	**98.754**
Floor Area:	482.510 m2			

Case Paraisopolis – Orientation

NORTH - ORIGINAL
PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46539 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15863482	15863482	
Feb	0	14496138	14496138	
Mar	0	15620130	15620130	
Apr	0	12712697	12712697	
May	12769	8582824	8595593	
Jun	290688	5259620	5550308	
Jul	185708	4811768	4997476	
Aug	215952	7705612	7921564	
Sep	24835	7634718	7659554	
Oct	0	10784028	10784028	
Nov	0	12765098	12765098	
Dec	0	15356087	15356087	
------------	--------	----------	----------	
TOTAL	729952	131592208	132322160	
------------	--------	----------	----------	
PER M²	1500	270365	271865	**271.87**
Floor Area:	486.720 m2			

SOUTH

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46534 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15842769	15842769	
Feb	0	14496641	14496641	
Mar	0	15629690	15629690	
Apr	0	12730389	12730389	
May	12769	8598459	8611228	
Jun	290602	5289088	5579690	
Jul	185664	4822610	5008275	
Aug	215740	7757271	7973010	
Sep	24835	7646314	7671148	
Oct	0	10791944	10791944	
Nov	0	12747428	12747428	
Dec	0	15327404	15327404	
------------	--------	----------	----------	
TOTAL	729609	131680000	132409608	
------------	--------	----------	----------	
PER M²	1499	270546	272045	**272.05**
Floor Area:	486.720 m2			

EAST

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 48376 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	16295933	16295933	
Feb	0	14822491	14822491	
Mar	0	15919311	15919311	
Apr	0	12792580	12792580	
May	12769	8565144	8577913	
Jun	289328	5124408	5413736	
Jul	183914	4744500	4928414	
Aug	206803	7686940	7893742	
Sep	24835	7719274	7744109	
Oct	0	11086695	11086695	
Nov	0	13127544	13127544	
Dec	0	15707593	15707593	
------------	--------	----------	----------	
TOTAL	717648	133592400	134310048	
------------	--------	----------	----------	
PER M²	1474	274475	275949	**275.95**
Floor Area:	486.720 m2			

WEST

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 48564 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	16289575	16289575	
Feb	0	14820645	14820645	
Mar	0	15906900	15906900	
Apr	0	12773961	12773961	
May	12769	8449042	8461811	
Jun	292103	5130438	5422542	
Jul	183905	4719406	4903312	
Aug	207159	7656596	7863756	
Sep	24835	7711185	7736020	
Oct	0	11082496	11082496	
Nov	0	13121939	13121939	
Dec	0	15703680	15703680	
------------	--------	----------	----------	
TOTAL	720772	133365864	134086632	
------------	--------	----------	----------	
PER M²	1481	274009	275490	**275.49**
Floor Area:	486.720 m2			

SW

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 47379 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	16117320	16117320	
Feb	0	14690741	14690741	
Mar	0	15725004	15725004	
Apr	0	12626020	12626020	
May	12769	8408096	8420865	
Jun	293634	5191201	5484835	
Jul	185723	4782390	4968114	
Aug	222131	7637274	7859404	
Sep	24835	7684894	7709728	
Oct	0	10939410	10939410	
Nov	0	12974166	12974166	
Dec	0	15529712	15529712	
------------	--------	----------	----------	
TOTAL	739092	132306232	133045328	
------------	--------	----------	----------	
PER M²	1519	271832	273351	**273.35**
Floor Area:	486.720 m2			

SE

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 47985 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	16090092	16090092	
Feb	0	14699359	14699359	
Mar	0	15803924	15803924	
Apr	0	12758541	12758541	
May	12769	8610113	8622882	
Jun	289257	5172796	5462053	
Jul	186236	4733416	4919652	
Aug	207210	7654676	7861887	
Sep	24835	7656488	7681324	
Oct	0	10966896	10966896	
Nov	0	12975142	12975142	
Dec	0	15513091	15513091	
------------	--------	----------	----------	
TOTAL	720307	132634536	133354840	
------------	--------	----------	----------	
PER M²	1480	272507	273987	**273.99**
Floor Area:	486.720 m2			

NW

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 48405 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	16174003	16174003	
Feb	0	14750955	14750955	
Mar	0	15836489	15836489	
Apr	0	12741959	12741959	
May	12769	8571358	8584127	
Jun	289275	5089722	5378996	
Jul	186471	4704846	4891316	
Aug	206976	7616781	7823757	
Sep	24835	7663741	7688576	
Oct	0	11036410	11036410	
Nov	0	13052143	13052143	
Dec	0	15591603	15591603	
------------	--------	----------	----------	
TOTAL	720325	132830016	133550344	
------------	--------	----------	----------	
PER M²	1480	272908	274388	**274.39**
Floor Area:	486.720 m2			

NE

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 47653 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	16234593	16234593	
Feb	0	14755621	14755621	
Mar	0	15796963	15796963	
Apr	0	12665094	12665094	
May	12769	8414799	8427568	
Jun	292828	5162866	5455693	
Jul	186877	4733391	4920268	
Aug	219600	7627862	7847462	
Sep	24835	7699462	7724296	
Oct	0	10983683	10983683	
Nov	0	13093369	13093369	
Dec	0	15646289	15646289	
------------	--------	----------	----------	
TOTAL	736908	132813992	133550904	
------------	--------	----------	----------	
PER M²	1514	272876	274390	**274.39**
Floor Area:	486.720 m2			

Case Paraisopolis – Insulation

ORIGINAL

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46539 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15863482	15863482	
Feb	0	14496138	14496138	
Mar	0	15620130	15620130	
Apr	0	12712697	12712697	
May	12769	8582824	8595593	
Jun	290688	5259620	5550308	
Jul	185708	4811768	4997476	
Aug	215952	7705612	7921564	
Sep	24835	7634718	7659554	
Oct	0	10784028	10784028	
Nov	0	12765098	12765098	
Dec	0	15356087	15356087	
------------	--------	----------	----------	
TOTAL	729952	131592208	132322160	
------------	--------	----------	----------	
PER M²	1500	270365	271865	**271.865**
Floor Area:	486.720 m2			

DOUBLE BRICK CAVITY PLASTER (AIR GAP)

PARAISOPOLIS

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 4400 W at 03:00 on 17th August

Max Cooling: 38831 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15140400	15140400	
Feb	0	13783789	13783789	
Mar	0	14944949	14944949	
Apr	0	12835731	12835731	
May	0	9865987	9865987	
Jun	14577	6213304	6227880	
Jul	5282	5904738	5910020	
Aug	28190	7839752	7867942	
Sep	0	8601029	8601029	
Oct	0	11836314	11836314	
Nov	0	12989112	12989112	
Dec	0	14814778	14814778	
------------	--------	----------	----------	
TOTAL	48049	134769888	134817936	
------------	--------	----------	----------	
PER M²	99	276894	276993	**276.99**
Floor Area:	486.720 m2			

BRICK PLASTER WITH POLYSTYRENE 50mm

PARAISOPOLIS

MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones

Comfort: Zonal Bands

Max Heating: 8834 W at 03:00 on 17th August

Max Cooling: 43260 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	16206836	16206836	
Feb	0	14704030	14704030	
Mar	0	15827866	15827866	
Apr	0	12938897	12938897	
May	27199	9264415	9291614	
Jun	438620	6213119	6651738	
Jul	293979	6079855	6373834	
Aug	301588	8620939	8922528	
Sep	38062	8781632	8819694	
Oct	0	11438973	11438973	
Nov	0	12970572	12970572	
Dec	0	15554836	15554836	
------------	--------	----------	----------	
TOTAL	1099448	138601968	139701424	
------------	--------	----------	----------	
PER M²	2259	284767	287026	**287.03**
Floor Area:	486.720 m2			

REVERSE BRICK VENEER - R20
PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 0.0 C - No Heating.
Max Cooling: 36453 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	14712204	14712204	
Feb	0	13305936	13305936	
Mar	0	14464686	14464686	
Apr	0	12658616	12658616	
May	0	11611920	11611920	
Jun	0	8970751	8970751	
Jul	0	9810647	9810647	
Aug	0	10692758	10692758	
Sep	0	11061458	11061458	
Oct	0	12510759	12510759	
Nov	0	12853933	12853933	
Dec	0	14382815	14382815	
------------	--------	----------	----------	
TOTAL	0	147036480	147036480	
------------	--------	----------	----------	
PER M²	0	302097	302097	**302.10**
Floor Area:	486.720 m2			

Case Paraisopolis – Wall Material

ORIGINAL
PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46539 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15863482	15863482	
Feb	0	14496138	14496138	
Mar	0	15620130	15620130	
Apr	0	12712697	12712697	
May	12769	8582824	8595593	
Jun	290688	5259620	5550308	
Jul	185708	4811768	4997476	
Aug	215952	7705612	7921564	
Sep	24835	7634718	7659554	
Oct	0	10784028	10784028	
Nov	0	12765098	12765098	
Dec	0	15356087	15356087	
------------	--------	----------	----------	
TOTAL	729952	131592208	132322160	
------------	--------	----------	----------	
PER M²	1500	270365	271865	**271.87**
Floor Area:	486.720 m2			

CONCRETE BLOCK PLASTER
PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 9075 W at 03:00 on 17th August
Max Cooling: 44006 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15863602	15863602	
Feb	0	14395516	14395516	
Mar	0	15575124	15575124	
Apr	0	13183112	13183112	
May	0	10210781	10210781	
Jun	123343	6602909	6726252	
Jul	31304	6579657	6610962	
Aug	107877	8530028	8637905	
Sep	0	9267986	9267986	
Oct	0	12118539	12118539	
Nov	0	13235916	13235916	
Dec	0	15407391	15407391	
------------	--------	----------	----------	
TOTAL	262524	140970560	141233088	
------------	--------	----------	----------	
PER M²	539	289634	290173	**290.17**
Floor Area:	486.720 m2			

CONCRETE BLOCK RENDER
PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 9320 W at 03:00 on 17th August
Max Cooling: 44944 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	16121412	16121412	
Feb	0	14619584	14619584	
Mar	0	15811635	15811635	
Apr	0	13409241	13409241	
May	0	10401734	10401734	
Jun	130671	6774574	6905246	
Jul	32847	6833546	6866394	
Aug	112162	8797027	8909189	
Sep	0	9544666	9544666	
Oct	0	12328775	12328775	
Nov	0	13458008	13458008	
Dec	0	15672457	15672457	
------------	--------	----------	----------	
TOTAL	275681	143772656	144048336	
------------	--------	----------	----------	
PER M²	566	295391	295957	**295.96**
Floor Area:	486.720 m2			

DOUBLE BRICK SOLID PLASTER

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 4952 W at 03:00 on 17th August
Max Cooling: 39015 W at 16:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15154244	15154244	
Feb	0	13806710	13806710	
Mar	0	14964660	14964660	
Apr	0	12779833	12779833	
May	0	9555133	9555133	
Jun	29447	5819142	5848588	
Jul	8343	5515889	5524232	
Aug	37179	7666408	7703586	
Sep	0	8240631	8240631	
Oct	0	11610702	11610702	
Nov	0	12868912	12868912	
Dec	0	14821675	14821675	
------------	--------	----------	----------	
TOTAL	74968	132803936	132878904	
------------	--------	----------	----------	
PER M²	154	272855	273009	**273.01**
Floor Area:	486.720 m2			

BRICK CONCRETE BLOCK PLASTER

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 5314 W at 03:00 on 17th August
Max Cooling: 40306 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15464979	15464979	
Feb	0	14078215	14078215	
Mar	0	15249665	15249665	
Apr	0	13062335	13062335	
May	0	9974827	9974827	
Jun	28470	6284682	6313152	
Jul	10146	6061294	6071440	
Aug	37721	8070871	8108592	
Sep	0	8799442	8799442	
Oct	0	11994579	11994579	
Nov	0	13175179	13175179	
Dec	0	15138614	15138614	
------------	--------	----------	----------	
TOTAL	76337	137354672	137431008	
------------	--------	----------	----------	
PER M²	157	282205	282362	**282.36**
Floor Area:	486.720 m2			

Case Paraisopolis – Shading Devices

ORIGINAL

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46539 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15863482	15863482	
Feb	0	14496138	14496138	
Mar	0	15620130	15620130	
Apr	0	12712697	12712697	
May	12769	8582824	8595593	
Jun	290688	5259620	5550308	
Jul	185708	4811768	4997476	
Aug	215952	7705612	7921564	
Sep	24835	7634718	7659554	
Oct	0	10784028	10784028	
Nov	0	12765098	12765098	
Dec	0	15356087	15356087	
------------	--------	----------	----------	
TOTAL	729952	131592208	132322160	
------------	--------	----------	----------	
PER M²	1500	270365	271865	
Floor Area:	486.720 m2			271.865

PITCHED ROOF

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46263 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15786799	15786799	
Feb	0	14444436	14444436	
Mar	0	15573169	15573169	
Apr	0	12668388	12668388	
May	12769	8559743	8572512	
Jun	290688	5232202	5522891	
Jul	186300	4771894	4958193	
Aug	215962	7684482	7900444	
Sep	24835	7602109	7626944	
Oct	0	10695869	10695869	
Nov	0	12701340	12701340	
Dec	0	15283022	15283022	
------------	--------	----------	----------	
TOTAL	730554	131003456	131734008	
------------	--------	----------	----------	
PER M²	1501	269156	270657	**270.66**
Floor Area:	486.720 m2			

HORIZONTAL SHADING

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 45875 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
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Jan	0	15580886	15580886	
Feb	0	14304227	14304227	
Mar	0	15445780	15445780	
Apr	0	12571200	12571200	
May	12769	8468880	8481649	
Jun	291302	5180604	5471906	
Jul	187780	4716412	4904192	
Aug	216570	7568076	7784646	
Sep	24835	7523640	7548474	
Oct	0	10581926	10581926	
Nov	0	12559860	12559860	
Dec	0	15111261	15111261	
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TOTAL	733255	129612752	130346008	
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PER M²	1507	266298	267805	**267.81**
Floor Area:	486.720 m2			

HORIZONTAL+ VERTICAL SHADING

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 45875 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15580886	15580886	
Feb	0	14304227	14304227	
Mar	0	15445780	15445780	
Apr	0	12571200	12571200	
May	12769	8468880	8481649	
Jun	291302	5180604	5471906	
Jul	187780	4716412	4904192	
Aug	216570	7568076	7784646	
Sep	24835	7523640	7548474	
Oct	0	10581926	10581926	
Nov	0	12559860	12559860	
Dec	0	15111261	15111261	
------------	--------	----------	----------	
TOTAL	733255	129612752	130346008	
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PER M²	1507	266298	267805	**267.81**
Floor Area:	486.720 m2			

Case Paraisopolis – Window Type

ORIGINAL
PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46539 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	
MONTH	(Wh)	(Wh)	(Wh)	
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Jan	0	15863482	15863482	
Feb	0	14496138	14496138	
Mar	0	15620130	15620130	
Apr	0	12712697	12712697	
May	12769	8582824	8595593	
Jun	290688	5259620	5550308	
Jul	185708	4811768	4997476	
Aug	215952	7705612	7921564	
Sep	24835	7634718	7659554	
Oct	0	10784028	10784028	
Nov	0	12765098	12765098	
Dec	0	15356087	15356087	
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TOTAL	729952	131592208	132322160	
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PER M²	1500	270365	271865	**271.87**
Floor Area:	486.720 m2			

SINGLE GLAZED - TIMBER FRAME
PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11209 W at 03:00 on 17th August
Max Cooling: 46303 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
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Jan	0	15884884	15884884	
Feb	0	14475958	14475958	
Mar	0	15600279	15600279	
Apr	0	12783715	12783715	
May	11458	8704468	8715926	
Jun	270164	5416653	5686817	
Jul	168190	4936166	5104356	
Aug	202998	7758999	7961997	
Sep	22673	7737069	7759742	
Oct	0	10925265	10925265	
Nov	0	12836398	12836398	
Dec	0	15374174	15374174	
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TOTAL	675482	132434040	133109520	
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PER M²	1388	272095	273483	**273.48**
Floor Area:	486.720 m2			

DOUBLE GLAZED- ALUM FRAME

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 10164 W at 03:00 on 17th August
Max Cooling: 45406 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15687501	15687501	
Feb	0	14260855	14260855	
Mar	0	15402366	15402366	
Apr	0	12713690	12713690	
May	6130	8909532	8915662	
Jun	214010	5572566	5786576	
Jul	125717	5196611	5322328	
Aug	156189	7747925	7904114	
Sep	16907	7894514	7911422	
Oct	0	11114515	11114515	
Nov	0	12785551	12785551	
Dec	0	15160459	15160459	
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TOTAL	518952	132446072	132965024	
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PER M²	1066	272120	273186	**273.19**
Floor Area:	486.720 m2			

DOUBLE GLAZED - LOW E - ALUM FRAME

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 10037 W at 03:00 on 17th August
Max Cooling: 45008 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15459961	15459961	
Feb	0	14060292	14060292	
Mar	0	15188550	15188550	
Apr	0	12537767	12537767	
May	5851	8817448	8823299	
Jun	206436	5447313	5653749	
Jul	113098	5143868	5256966	
Aug	156177	7586659	7742836	
Sep	9591	7739790	7749381	
Oct	0	10996424	10996424	
Nov	0	12591707	12591707	
Dec	0	14940960	14940960	
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TOTAL	491153	130510736	131001888	
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PER M²	1009	268143	269152	**269.15**
Floor Area:	486.720 m2			

DOUBLE GLAZED - LOW E - TIMBER FRAME
PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 9972 W at 03:00 on 17th August
Max Cooling: 44985 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
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Jan	0	15466895	15466895	
Feb	0	14087386	14087386	
Mar	0	15195678	15195678	
Apr	0	12562990	12562990	
May	5707	8827463	8833170	
Jun	203806	5453494	5657300	
Jul	104439	5173887	5278326	
Aug	154560	7593720	7748280	
Sep	9375	7756805	7766180	
Oct	0	11007051	11007051	
Nov	0	12602166	12602166	
Dec	0	14957023	14957023	
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TOTAL	477887	130684568	131162456	
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PER M²	982	268501	269482	**269.48**
Floor Area:	486.720 m2			

Case Paraisopolis – Roof Type

CONCRETE ROOF ASPHALT
PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46539 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15863482	15863482	
Feb	0	14496138	14496138	
Mar	0	15620130	15620130	
Apr	0	12712697	12712697	
May	12769	8582824	8595593	
Jun	290688	5259620	5550308	
Jul	185708	4811768	4997476	
Aug	215952	7705612	7921564	
Sep	24835	7634718	7659554	
Oct	0	10784028	10784028	
Nov	0	12765098	12765098	
Dec	0	15356087	15356087	
------------	--------	----------	----------	
TOTAL	729952	131592208	132322160	
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PER M²	1500	270365	271865	**271.87**
Floor Area:	486.720 m2			

CLAY TILED ROOF - REF - FOIL - GYPROC

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46539 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15863482	15863482	
Feb	0	14496138	14496138	
Mar	0	15620130	15620130	
Apr	0	12712697	12712697	
May	12769	8582824	8595593	
Jun	290688	5259620	5550308	
Jul	185708	4811768	4997476	
Aug	215952	7705612	7921564	
Sep	24835	7634718	7659554	
Oct	0	10784028	10784028	
Nov	0	12765098	12765098	
Dec	0	15356087	15356087	
------------	--------	----------	----------	
TOTAL	729952	131592208	132322160	
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PER M²	1500	270365	271865	**271.87**
Floor Area:	486.720 m2			

PLASTER FOIL - HEAT RETENTION - CERAMIC

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46539 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15863482	15863482	
Feb	0	14496138	14496138	
Mar	0	15620130	15620130	
Apr	0	12712697	12712697	
May	12769	8582824	8595593	
Jun	290688	5259620	5550308	
Jul	185708	4811768	4997476	
Aug	215952	7705612	7921564	
Sep	24835	7634718	7659554	
Oct	0	10784028	10784028	
Nov	0	12765098	12765098	
Dec	0	15356087	15356087	
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TOTAL	729952	131592208	132322160	
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PER M²	1500	270365	271865	**271.87**
Floor Area:	486.720 m2			

PITCHED ROOF

PARAISOPOLIS
MONTHLY HEATING/COOLING LOADS

All Visible Thermal Zones
Comfort: Zonal Bands

Max Heating: 11600 W at 03:00 on 17th August
Max Cooling: 46504 W at 17:00 on 20th January

	HEATING	COOLING	TOTAL	KWh/M2
MONTH	(Wh)	(Wh)	(Wh)	
------------	--------	----------	----------	
Jan	0	15856047	15856047	
Feb	0	14489627	14489627	
Mar	0	15614215	15614215	
Apr	0	12699994	12699994	
May	12769	8579919	8592688	
Jun	290688	5257868	5548556	
Jul	185782	4809740	4995523	
Aug	215953	7702950	7918903	
Sep	24835	7630615	7655450	
Oct	0	10777682	10777682	
Nov	0	12758090	12758090	
Dec	0	15347773	15347773	
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TOTAL	730027	131524520	132254544	
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PER M²	1500	270226	271726	**271.73**
Floor Area:	486.720 m2			