Fachhochschule Köln
Cologne University of Applied Sciences

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ
FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA
PROGRAMAS MULTIDISCIPLINARIOS DE POSGRADO EN CIENCIAS AMBIENTALES
AND
COLOGNE UNIVERSITY OF APPLIED SCIENCES
INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

BIOCLIMATIC RESIDENTIAL BUILDING DESIGN UNDER TROPICAL HUMID CONDITIONS: SHORT ON-SITE COMFORT EVALUATIONS AND PHYSICAL INVESTIGATIONS FOR DIFFERENT CASE STUDIES IN QUINTANA ROO, MEXICO

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FOCUS AREA “ENVIRONMENTAL AND RESOURCES MANAGEMENT”
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Cologne, Germany August, 2012

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ABSTRACT

Within the scope of this work, requirements on bioclimatic building design have been investigated for the provision of thermal comfort for residential buildings in the warm-humid climate of Quintana Roo, Mexico. Resulting environmental impacts were estimated with focus on embodied energy and CO_2 emissions of the building materials. Series of temperature and humidity measurements of indoor climate in comparison with exterior have been conducted for several days and for three different bioclimatic building types during the high temperature season. The resulting values confirmed the estimations by supportive decision tools that exclusive natural ventilation does not meet the comfort requirements year-round. By indoor temperature at medium body height 4 Kelvin below the exterior in the afternoon, the test results suggest the suitability of natural pitched roofs. The replacement of natural by more durable materials causes loss of permeability and thus requires elaborate measures for adequate ventilation. In addition, the environmental impact increases many times over, due to high energy input for manufacture and transport. Therefore, locally available materials are preferable. Fundamental guidelines for building planning in Quintana Roo have been elaborated and reassessed with regard to the specific case studies.

Key words: bioclimatic building design, ecological architecture, warm-humid climate, Quintana Roo, natural ventilation, thermal comfort

Resumen (Spanish)

En el marco del presente trabajo, se investigaron los requerimientos al diseño bioclimático para proveer de confort térmico a viviendas en el clima cálido húmedo del estado de Quintana Roo, México. Los impactos ambientales correspondientes se estimaron a través del contenido energético primario y las emisiones de CO_2. Se realizaron mediciones de temperatura y humedad del clima interior en comparación al exterior a lo largo de varios días para tres diferentes tipos de edificios bioclimáticos en la temporada de temperaturas altas. Los valores obtenidos confirmaron las estimaciones por herramientas de cálculos que con exclusiva ventilación natural no cumplirán las exigencias de confort térmico para todo el año. Con temperaturas interiores a un metro del suelo, correspondiente a lugar de mayor estancia larga, que se mantuvieron a 4 Kelvin por debajo de los valores de las temperaturas exteriores en la tarde, los resultados de medición confirmaron la adecuación de techos naturales de dos vertientes (palapas). La sustitución de materiales naturales por otros más resistentes resulta en una pérdida de permeabilidad, requiriendo entonces medidas sutiles para obtener la ventilación adecuada. Adicionalmente, el impacto ambiental aumenta varias veces, debido al gasto energético en la fabricación y el transporte. Por lo tanto se prefieren materiales locales. Por último se planteó una propuesta de directrices fundamentales para la planeación de edificios en Quintana Roo con base en el análisis y la aptitud para los estudios de caso específicos.

Zusammenfassung (German)

Im Rahmen der vorliegenden Arbeit wurden die Anforderungen an bioklimatische Bauweise untersucht, um behagliches Raumklima in Wohnhäusern im feuchtwarmen Klima des Staates Quintana Roo in Mexiko zu schaffen. Resultierende Umweltbelastungen wurden mithilfe von Primärenergieinhalt und CO_2-Ausstoß der Baustoffe abgeschätzt. Während der warmen Jahreszeit wurden für drei bioklimatische Gebäudetypen mehrtägige Temperatur- und Feuchtemessungen des Innenklimas im Vergleich mit außen vorgenommen. Die Messwerte bekräftigten die auf Berechnungstools basierende Abschätzung, dass ausschließliche natürliche Belüftung nicht ganzjährig die Behaglichkeitsanforderungen erfüllt. Mit Innentemperaturen auf mittlerer Körperhöhe 4 Kelvin unter der Außentemperatur am Nachmittag bestätigten die Messergebnisse die Eignung schräger Naturdächer. Der Ersatz von Naturstoffen durch beständigere Baustoffe hat den Verlust der Luftdurchlässigkeit zufolge und erfordert deshalb wohldurchdachte Maßnahmen um ausreichende Durchlüftung sicherzustellen. Zudem steigt die Umweltbelastung um ein Vielfaches, bedingt durch den hohen Energieaufwand für Herstellung und Transport. Daher sind regional verfügbare Baustoffe vorzuziehen. Wesentliche Vorgaben zur Gebäudeplanung wurden für die Region Quintana Roo ausgearbeitet und mit Bezug auf die einzelnen Fallstudien bewertet.

ABBREVIATIONS

AC	Air conditioning
BEEC	Building Energy Efficiency Code
CFE	*Federal Electricity Commission* (Comisión Federal de Electricidad)
CONAVI	*National Housing Agency* (Comisión Nacional de Vivienda)
CO_2	Carbon Dioxide
EnEV	*German energy saving regulation* (Energieeinsparverordnung)
FovISSSTE	*ISSSTE Residential Fund* (Fondo de la Vivienda del ISSSTE)
HVAC	Heating, ventilation and air conditioning
INEGI	*National Institute of Statistic and Geography* (Instituto Nacional de Estadística y Geografía)
INFONAVIT	*National Workers' Housing Fund* (Instituto del Fondo Nacional de la Vivienda para los Trabajadores)
ISSSTE	*Institute for Social Security and Services for State Workers* (Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado)
ISV	*Indicator of Sustainable Homes* (Índice de Sustentabilidad de Vivienda)
K	Kelvin (temperature unit; temperature differences between values in °C are given in K)
LEED	Leadership in Energy and Environmental Design
LPG	Liquefied (petroleum) gas
$MgCl_2$	Magnesium chloride
NaCl	Sodium chloride
NZEB	Net Zero Energy Building
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
WSVO	*German regulation of thermal insulation* (Wärmeschutzverordnung)

DEFINITIONS

Bioclimatic (building) design

In the context of buildings, the expression *bioclimatic* refers to spaces with natural ventilation whose exposition to the climatic environment is tackled by passive design measures. Contrary, tempered buildings attempt to disconnect from their surroundings in order to provide indoor climate at constant levels of air temperature and facilitate heating or cooling without major energy losses (so-called ‘western’ approach). The term *Bioclimatic Design* was introduced in the 1960s by the Olgyay brothers (see Olgyay, 1973, original edition in 1963) who emphasized the complex interrelations of life and climate (natural factors) with building design and presented a methodology by which architecture can be developed adequately along with specific climatic conditions. Over the years, more works have been published and further expressions like environmental design, natural design, eco-design, bio-design, green or sustainable building/architecture etc. came in use, but they agree on the importance of design in the relation between human being and nature.

In Mexico, a discipline called *Bioclimatic Architecture* (Spanish: *arquitectura bioclimática*) arose in the middle of the 1970s from the combined knowledge of the heritage of native population, who has ever known how to adapt to the climate of their region, and of scientific investigations. Bioclimatic architecture according to the Mexican definition introduces important elements. However, in the scope of this works, the term bioclimatic design is used as the general definition of an interior climate that makes use of natural ventilation and further natural means for provision of thermal comfort. (Parsons, 2002; Olgyay, 1973; Fuentes Freixanet, 2002)

Building design, Construction method

Within the context of the present research, two fundamental strategies of building construction can be distinguished. From natural and ancient forms of construction as mankind has used to live since centuries and even millenniums, originated the bioclimatic design, as it is named in this context (see also previous subsection).

The modern age alternative is the technological or industrialized approach which comes along with industrialization. Therefore, it has been developed by industrial countries and is adjusted to the prevailing climatic conditions in those regions. Thermal insulation and thermal mass are key elements of energy-efficient design using this construction method, with the intent to disconnect the indoor climate from the exterior climatic conditions. Low energy building, passive house and (net) zero energy building are some of the standards which have been introduced within the context of improvements of this strategy; however, these standards vary from region to region in their exact definition and can be similarly applied to bioclimatic building design.

The two different approaches of construction in consideration of tropical climates are introduced in chapter 4.

Energy efficiency

An energy efficiency measure brings a reduction of energy used for a given service, such as lighting, cooling, heating or water warming. Usually, an increase of efficiency is the result from technological improvements; however, it can also be achieved by means of better organization and management. By lowering the demand side, energy efficiency is a highly effective measure to reduce energy consumption.

The following factors have a great significance in regard to energy efficiency of buildings:

- Integration of efficient methods and systems;
- Adaption to the user’s needs;
- Consideration of ambient and climatic conditions.

(World Energy Council, 2011)

(Net) Zero Energy Buildings

The energy balance of a *Net Zero Energy Building* (NZEB) is neutral. In Europe, the following NZEB definition was introduced: “As a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources on site” (ECEEE, 2009). As pointed out by Laustsen (2008), a NZEB achieves being neutral over one year by feeding in at least as much energy to the supply grid as it uses from the grid on a yearly base. The allowance of zero energy to be balanced over one year, which highly facilitates the possibility to implement such a building, is due to the inclusion “Net” in the expression Net Zero Energy Building. This very loose definition is congruent with the general American definition and it does not necessarily require energy efficiency measures, as any energy consumptions can be balanced out by correspondingly large on-site energy generation. At a closer look only at the net zero energy definitions, several criteria have to be considered; the U.S. American organization ASHRAE found the following differentiation of NZEB:

- Net zero **site** energy use building;
- Net zero **source** energy use building;
- Net zero energy **emissions** building;
- Net zero energy **cost** building.

Following the ASHRAE definition, "a net zero **site** energy building produces as much energy as it uses when measured at the site" (Jarnagin, 2008). The use of this definition is simple as it can be verified by on-site metering; however, contrary to the further definitions neither the impacts of different fuel types nor inefficiencies in the use of the grid are considered. Also the cost-related definition is controversial as this consideration depends on the local grid regulations in terms of feed-in tariffs and electricity prices. (Jarnagin, 2008; Torcellini, 2006)

On the example of an U.S. American initiative, Figure 1 demonstrates the stepwise advance from a conventional home to a NZEB (see ZEH-0) whose remaining energy demand, already being largely reduced by means of energy efficiency measures, is completely covered by solar supply. The in-between level of ZEH-50 allows 50 % of the energy consumption prescribed in the American building regulations and is classified as a low energy building. (Laustsen, 2008)

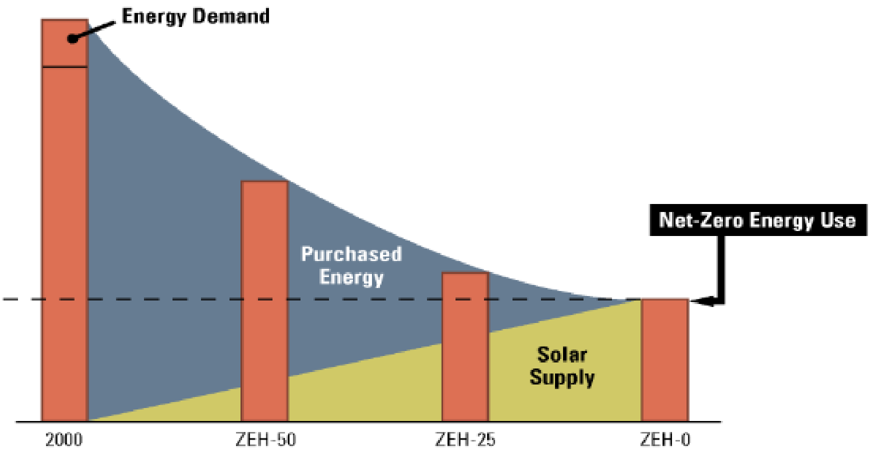

Figure 1: The way to net zero energy buildings in the U.S. Source: Laustsen, 2008

Temperature: distinction of different physical quantities of temperature

Dry bulb, wet bulb and dew point temperature are important to determine the state of humid air, whereat two of these values must be known to determine the state.

The dry bulb temperature (in general linguistic usage known as air temperature) refers basically to the ambient air temperature. It is called "Dry Bulb" because the air temperature is indicated by a thermometer which is not affected by the moisture of the air.

The wet bulb temperature is the temperature of adiabatic saturation. This temperature can be measured by using a thermometer with the bulb wrapped in wet muslin. In practice, this temperature measure is put into relation with dry bulb temperature and humidity. The wet bulb temperature is lower than the dry bulb temperature, unless at the dew point; at this state (saturated state at 100% relative humidity), water vapor starts to condense out of the air and the wet bulb temperature is equal the dry bulb temperature. Above this temperature the moisture will stay in the air, forming fog. (Engineering Toolbox, 2012)

The mean radiant temperature is the mean temperature of all objects which surround a person. In practice, the temperature values of all surrounding areas of a room are averaged to determine the mean radiant temperature. It will be positive when the surrounding objects are warmer than the average skin temperature and negative when they are colder.

Operative temperature is a function of mean radiant temperature and dry bulb temperature.

The effective temperature (in Madsen (1984) named equivalent temperature) is a blend of dry bulb temperature with wet bulb temperature and air velocity. This temperature expresses the actual temperature that a person senses in the given environment.
(Madsen, 1984; ISO 7730, 2005)

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1 Introduction

In order to meet targets on the mitigation of CO_2 emissions and fossil fuels consumption, energy efficiency is a highly effective measure. The implementation of energy efficiency measures lowers the energy demand what results in energy savings. The building sector accounts for about a third of the total energy consumption on a worldwide scale. Due to the rapid growth of countries in development, construction booms. In addition, activities in this branch have a long-term effect because of the lifespan of buildings. Therefore, buildings offer a large potential for improving energy use and tackling climate change. While every single user is called to make responsible use of energy, the main responsibility is left to politics to make the way for adequate comprehensive measures.

The trends of population growth and urbanization in developing countries, together with increase of wealth, are expected to boost the energy demands of buildings in the particular regions – in contrast to industrialized countries that are characterized by already high standards of living and much slower growth. This perspective manifests the prior urgency to tackle developing countries, and therein mainly regions where active space heating or cooling is required, as tempering is a built-in energy load tied to the design and construction of buildings, thus it should be addressed from the beginning of the planning process.

Mexico’s most south-eastern state Quintana Roo has undergone rapid change in the last decades, mainly due to expanded tourism activities. Within this context, the state has developed some economic wealth, but also large contrasts have evolved. The gap between rich and poor is increasing, as not everybody has been able to make profit from the new opportunities. Same as native ecosystems like coral reefs, many treasures of the Mayan heritage are sensitive and in danger of extinction. Appropriate development of homes in this region should take those issues into consideration.

In order to implement sustainable building design, it is necessary to adapt to the complexity of the locally predominant conditions before serious decisions are taken. For instance, loading a building with a lot of material and advanced technology does not necessarily bring the desired effect; if it does not, it leads to sunk costs for a high investment. Furthermore, as the performance is not as expected, the sacrifice will always be higher energy expenses in order to obtain the same originally desired results. These additional efforts affect both the budget of the building users and the environment, because higher energy consumption also causes increased contamination. For those reasons, a construction project always requires diligent planning and the consideration not only of immediate impacts but also of the consequences on the long run.

2 Mexico's energy characteristics and the building sector

2.1 General introduction of Mexico

Mexico, officially United Mexican States, shares 3,152 km borderline with the United States of America in the north, furthermore 956 km with Guatemala and 278 km (thereof 85 km waterline in the Lagoon of Chetumal) with Belize in the southeast. With a population of 112 million inhabitants and 1.96 million km^2 continental area, Mexico is the second-most populated Latin American country behind Brazil and the third-largest behind Brazil and Argentina.

Due to high variety of climatic conditions in Mexico, the country is characterized by an exceptional diversity of species. The abundance of resources is comparable; the country contains large reserves of oil and natural gas as well as high potential of geothermal, wind and solar energy. From the blend of Aztecan and Mayan prehistory with Spanish colonization, the Mexican population and culture is also diversified today. The oil industry and income from Mexicans who live in the United States are the most important revenues. Also in form of imports, Mexico traditionally depends highly on the U.S. market. However, the wealth is poorly distributed; poverty and drug traffic are countrywide concerns. (INEGI, 2011-A; IMF, 2010)

2.2 Mexico's energy sector

2.2.1 Energy supply mix

Owing to the large share of the transportation sector (45% in 2008), where oil is unrivaled, oil predominates the primary energy supply of Mexico. In 2008 it added up to more than half of the total energy supply, as visualized by Figure 2-1. Gas was the second most important resource with 27%; combustible renewables and coal, followed by the exclusive electricity fuels were all below 5%. If hydropower is included in this aspect, a combined share of 10% of total energy was provided by renewable sources in 2008, while combustible renewables accounted for the largest share within this group. Geothermal, solar and wind together only contributed 3.4% in 2008, in spite of a much greater potential. (IEA, 2008)

2.2.2 Electricity generation in Mexico

Figure 2-2 illustrates the electricity generation of Mexico in its chronological sequence from the year 1972 until 2008. It stands out that the use of oil for power generation was somewhat reduced recently, while gas power was largely extended since the turn of the millennium. In addition, coal has become an increasingly important resource since the mid-90s. One single nuclear plant was installed in the state Veracruz in 1990, but with its 1.4 GW capacity it still has a significant share in the total power production today. The contribution of biomass and waste, in contrast, is irrelevantly small. Hydropower has always been an important resource for electricity production; however, its contribution only grew slightly since the 70s.

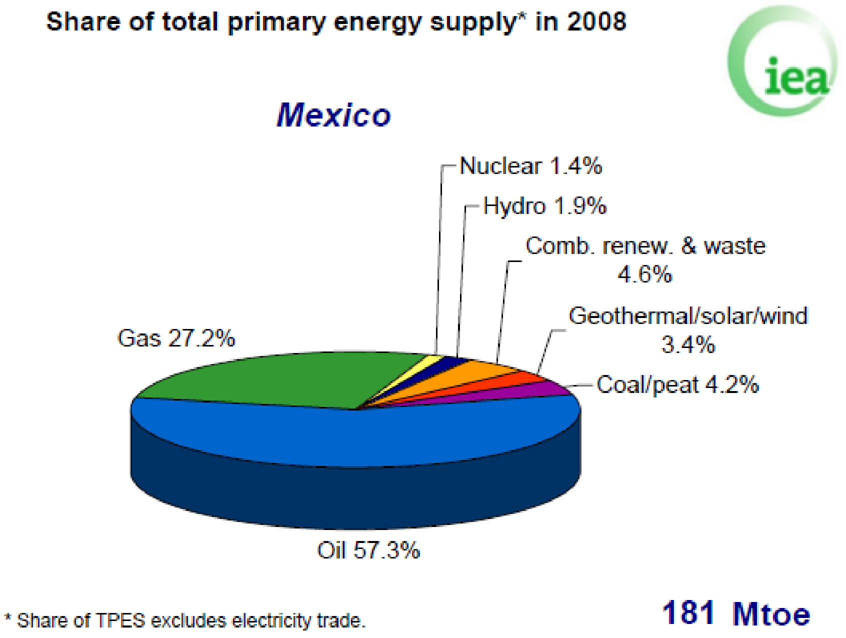

Figure 2-1: Mexico's total primary energy supply by fuel. Source: IEA, 2008

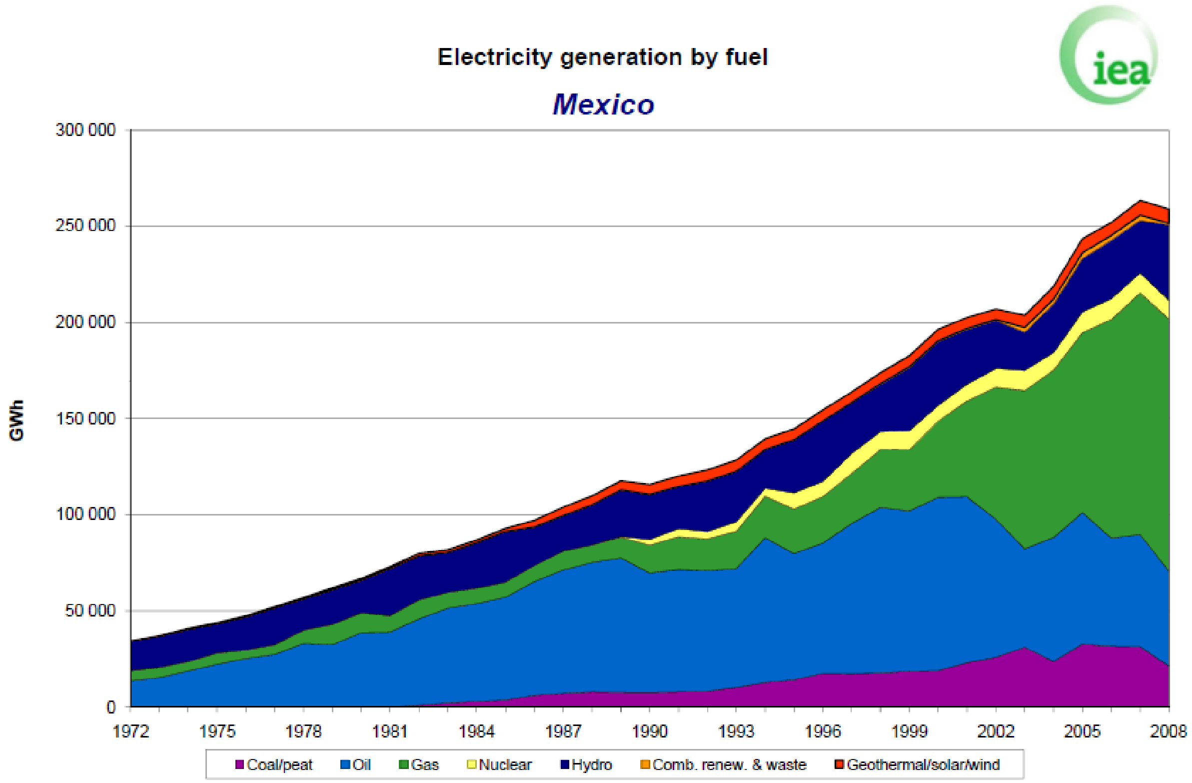

Figure 2-2: Development of Mexico’s electricity generation by fuel. Source: IEA, 2008

Geothermal energy has been exploited since the 1970s, mainly in the federal state Baja California, furthermore in Michoacán, Puebla and Baja California Sur, with a total installed capacity of 965 MW; wind power merely has been utilized in Oaxaca with a capacity of 85 MW and another 1 MW in Baja California Sur until today.

The energy mix that provided Mexico's electricity for the year 2008 is displayed in Figure 2-3. Coal and oil contributed with shares of 8% and 19% respectively, while 51% out of the 259 TWh total power generation was provided by gas turbines. Nuclear power contributed 4%, while hydropower holds the largest share of renewables with 15%. Geothermal holds a share of 3%, wind and biomass contributed fractions from 0.1 to 0.3%. A microscopic contribution of 0.003% was generated by photovoltaic panels. (IEA, 2008; CFE, 2011)

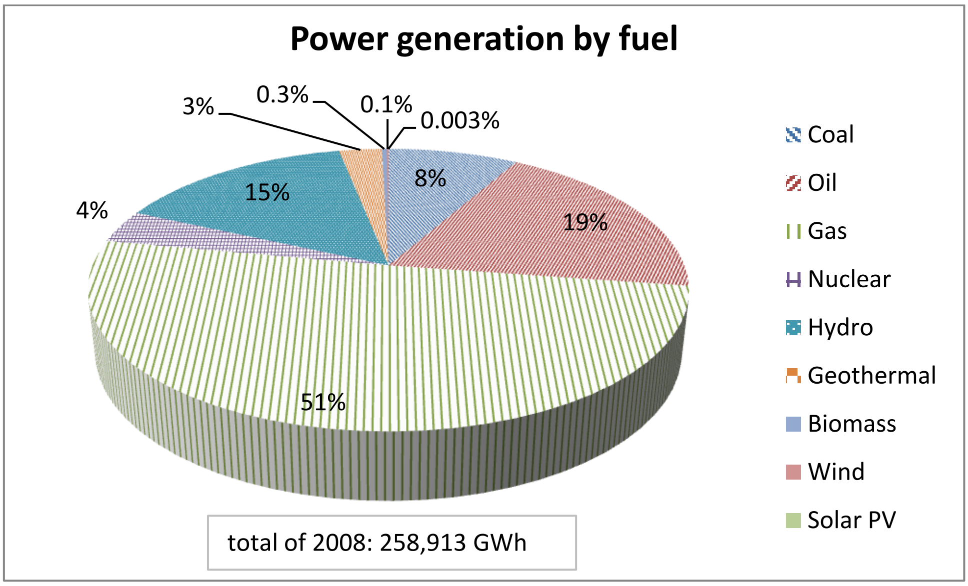

Figure 2-3: Mexico's energy mix of 2008: Power generation by fuel. Data: IEA, 2008

2.2.3 Installed power capacity in Quintana Roo

As one of the smaller federal states, Quintana Roo only makes a small contribution to the nationwide power generation. In the context of nationwide electrification, the first gas power plant was installed in 1968. Figure 2-4 illustrates the development with further installations from that moment until today.

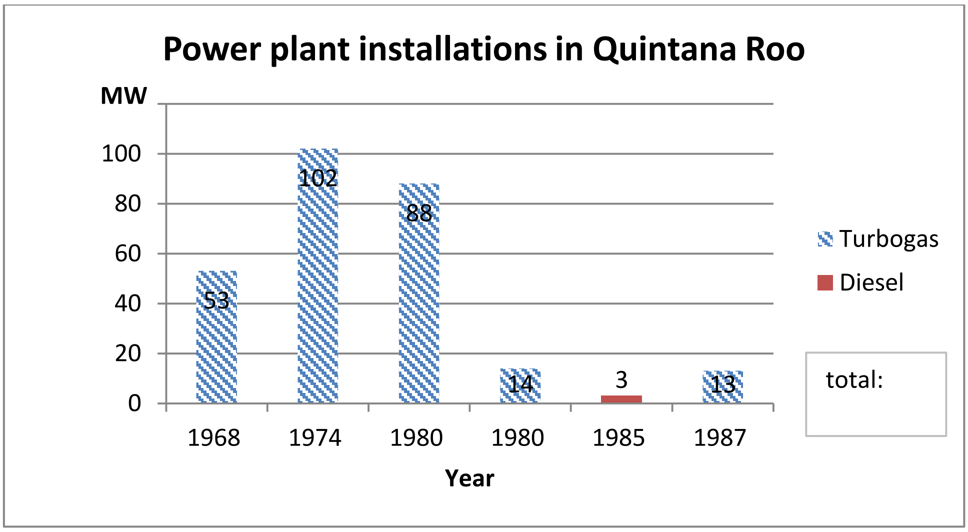

Figure 2-4: Power plants in Quintana Roo by installed capacity and year. Data: CFE, 2011

2.3 Characteristics of energy consumption in Mexico

2.3.1 Characterization of energy consumption by sector

Figure 2-5 gives an insight into how Mexico's energy is distributed within different consumer groups. Mexico has a high oil share, mainly due to the high demand of transportation, and because abundant domestic reserves make its use convenient. The comparably abundant energy source natural gas is used even more than oil for industrial processes, besides it is an important resource for water heating and cooking. Combustible renewable energy such as biomass plays an important role for the residential sector, due to persistently extensive use in rural regions.

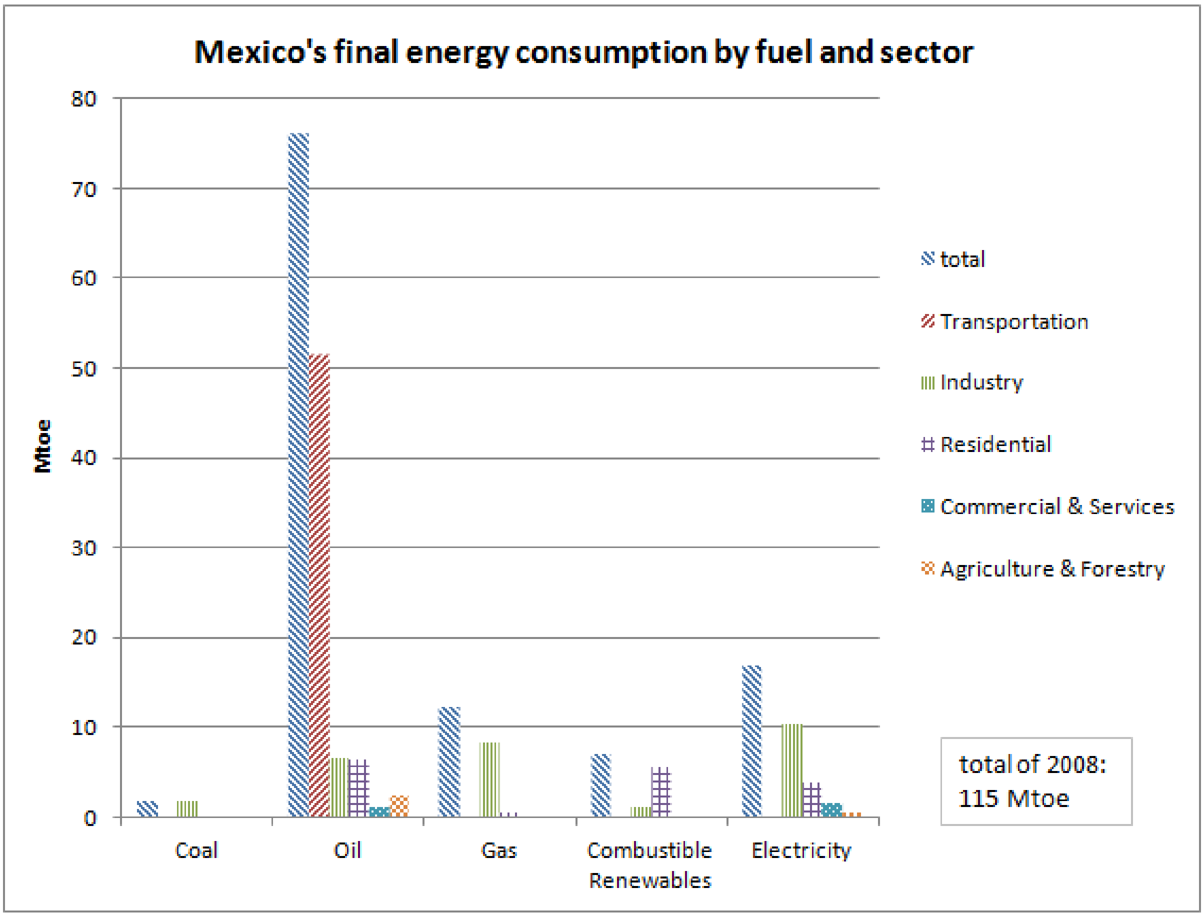

Figure 2-5: Mexico's final energy consumption[1] by fuel and sector. Data: IEA, 2008)

Electricity is the main resource both for the sectors industrial and commercial/services. Concerning domestic use, electricity plays the major role for well-developed regions of Mexico with a good infrastructure. The sectors 'residential' and 'commercial/services' together consumed 18% of Mexico's final energy in 2008; residential buildings alone were responsible for 15%. Therefore, Mexican buildings have lower final energy consumption than the world average. However, the relatively high shares of air

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[1] Mtoe: Megatons of oil equivalent, equal thousand ktoe

conditioning, while heating whose energy conversion is much better is not common, translate into increased primary energy demand and weaken the lower share of building use on final energy in this way. (IEA, 2008)

2.3.2 The residential building sector

The share of fuels to provide the required energy for residential buildings is presented in Figure 2-6. Liquefied gas (LPG) as the common resource for water warming and cooking has the highest share, followed by biomass as the primal resource in rural areas and electricity in third place with 23%. An important consideration is the future development; due to the high migration into cities, the current share is undergoing a fast change with an increasing share of electricity as part of the trend. In contrast to most regions of industrialized countries and due to the warmer climate, heating is not common in Mexico. Instead, as another important factor, air conditioning (AC) is becoming increasingly widespread in the warmer climate zones of Mexico. According to Johnson (2010), the market saturation of domestic air conditioning systems was about 20% in 2005, in contrast to 95% in U.S. regions with comparable cooling demands. Because of rapidly growing sales rates, the electricity use by AC systems is forecasted to increase up to 10-fold in Mexico until 2030. (Wehner, 2010; Johnson, 2010; IEA, 2008)

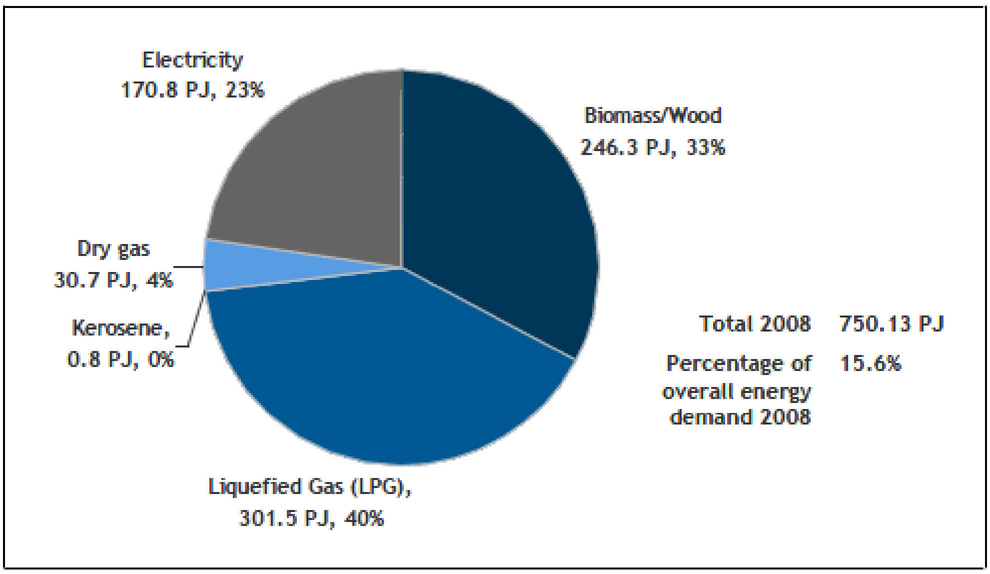


Figure 2-6: Energy consumption in residential buildings by fuel. Source: Wehner, 2008

2.4 Basic characteristics of the building sector

2.4.1 General future projections

As mentioned in the introduction, there are various motivations for improvement of the energy performance of buildings. Forecasts assume more than a duplication of the urban building stock of countries in development by 2030, what originates from strong economic and population growth. This trend, together with urbanization and enhancement of living standards, is expected to boost the worldwide energy demand of buildings. The left chart of Figure 2-7 contrasts the building energy use of 2003 including a projection for 2030 of three key countries in rapid development with three major industrialized centers. The total consumption is subdivided into the residential and the commercial sector. India and Brazil are expected to double, China to multiply by more than 2.5. In contrast, industrialized countries are characterized by much slower growth, due to saturated population growth and advanced urbanization. This perspective manifests the prior urgency to tackle the building sector in developing countries. The right chart in Figure 2-7 shows the recent development of the Mexican housing stock, including a forecast until the year 2030 according to Wehner (2010). Despite lower increase compared to the recent progress (44% increase from 1990 to 2010), still a significant growth is predicted for the future development of Mexico's residential building stock (25% increase from 2010 to 2030). (Claussen, 2008; Liu, 2010; Wehner, 2010)

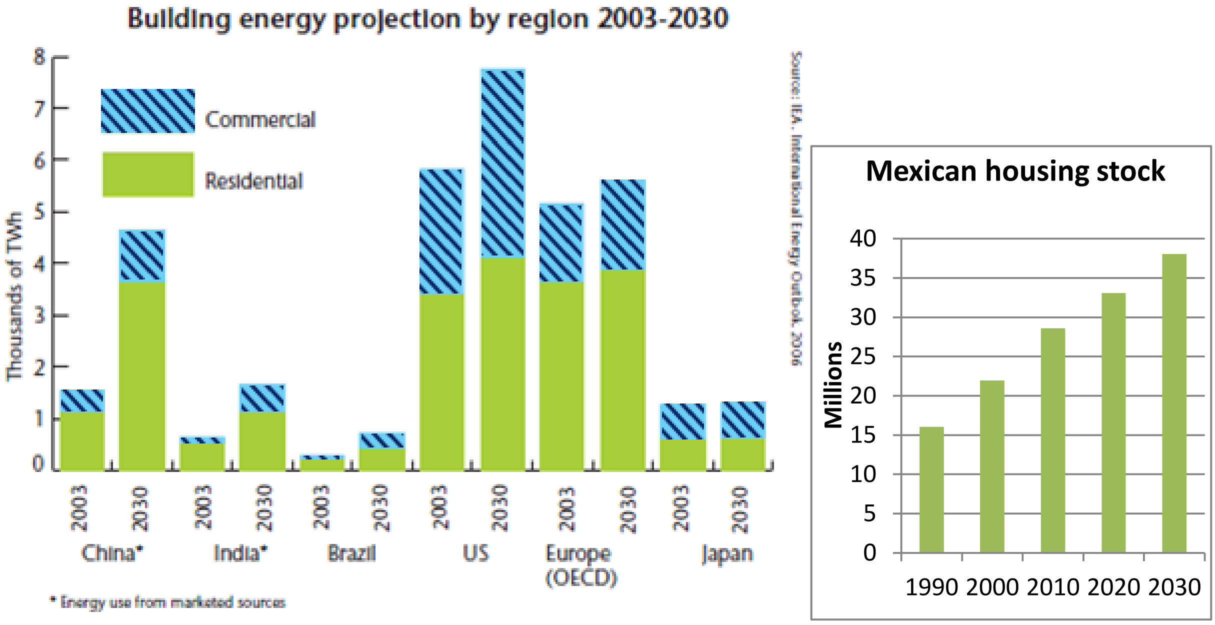


Figure 2-7: Left: Forecasts of building energy use for 2030 by sector[2] and region; right: Development of Mexican housing stock in total numbers. Source: Claussen, 2008; INEGI, 2011-A and Wehner, 2010

2.4.2 Building Energy Efficiency Codes

In order to achieve energy efficiency in the building sector, the legislative body is asked to take action. The common measure is the implementation of *Building Energy Efficiency Codes* (BEECs) which are legal requirements that regulate the energy performance of building designs and control their compliance during construction. BEECs were enforced in most of the industrialized countries in the late 1970s and are broadly accepted today. They have proved to be an effective tool for lowering the energy demand during the life cycle of new buildings.

Several developing countries began to adopt BEECs in the 90s. However, poor institutional and economic conditions and underdeveloped technical capacity prevented successful implementation in most cases, especially in the residential sector. The market availability of necessary, technically advanced components is a major requirement to enforce regulations in the construction sector. Figure 2-8 illustrates the development of German BEECs based on the WSVO and EnEV standards over the past decades and contrasts it with the maximum achievements of its day. The German BEEC, which is part of the German building law, was introduced as one of the first of its kind and has served as a model for many other countries. The upper line shows the increasingly strict minimum requirements until 2004, reduced from 220 to 80 kWh/m^{2}a over the observed period. Due to a rather small proportion of new building stock in comparison from the moment that the first regulations came into effect and since restrictions on existing buildings are somewhat relaxed, today's stock still uses more than the minimum requirement in average. The achievements show that zero energy was already accomplished before the turn of the millennium. (Liu, 2010; Claussen, 2008; Laustsen, 2008)

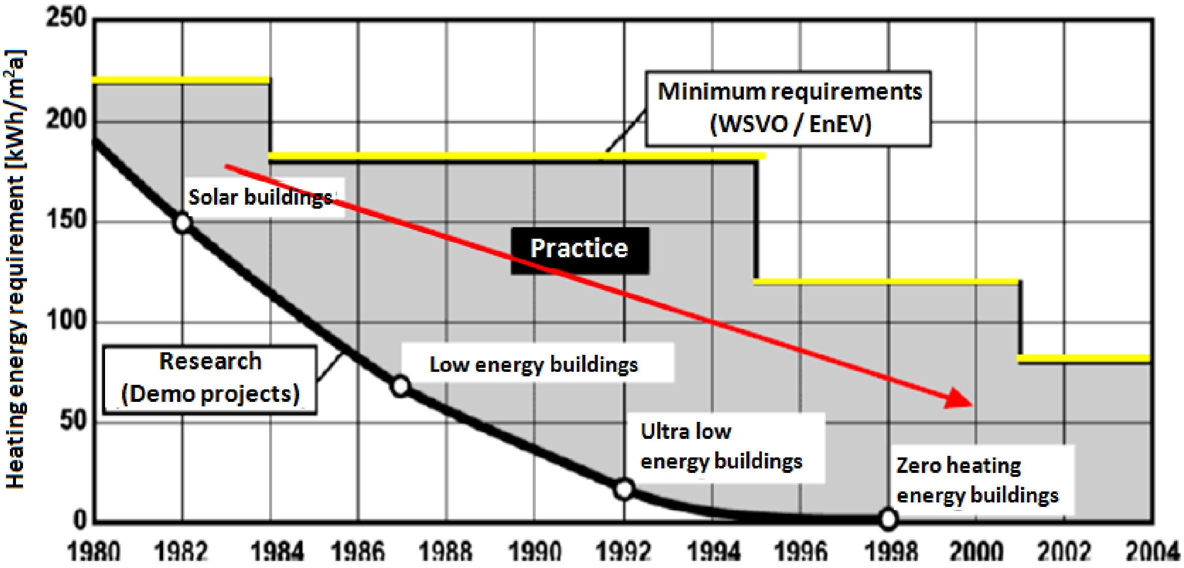


Figure 2-8: Development of German energy codes for heating energy requirement in comparison to parallel achievements. Source: Laustsen, 2008

2.4.3 Basic aspects about the Mexican building sector

Concerning building efficiency in Mexico, some positive results have been achieved in the public building sector to date. Guaranteed by government subsidies, incentives have been set up to encourage private house owners to implement energy efficiency measures. However, initiatives run by the *National Housing Agency* (CONAVI) and the *National Workers' Housing Fund* (INFONAVIT) are voluntary housing regulations. Federal states and municipalities have not integrated any requirement of energy efficiency into their building regulations. A significant obstacle in this matter is the high autonomy of Mexican municipalities which makes it difficult to adopt countrywide regulations.

Therefore, private participation has been low and a continuous improvement process of energy efficiency did not penetrate at all levels to date.

Liu (2010) determined the following conditions as the primal barriers to successful BEEC adoption in Mexico:

- Building regulations are under local autonomy, while local authorities do not know about the importance of building energy use and lack knowledge of BEECs at the appropriate political level.
- Building inspections are usually discrete; therefore there are doubts on the effectiveness of compliance enforcement regarding energy efficiency requirements.
- Considerations related to the cost of compliance like new investment (equipment and training in the new processes etc.), limited abilities of low-income households and sunk investment in very specific technologies rise developer resistance.
- High levels of subsidy in electricity rates diminish the interest of both the financing agencies and the end user in acquiring higher first-cost technologies.

Owing to increasing urbanization, concrete blocks have become the most important material for masonry. Adobe, wood, straw and other natural materials still play an important role in rural areas and. Concrete is additionally common for foundations and of great importance as reinforcement for medium and high buildings. (Wehner, 2010; Van Wie McGrory, 2002; Liu, 2010)

3 Antecedents and climatic conditions of Quintana Roo

3.1 Location

The Mexican federal state Quintana Roo is located in the very southeast of the country with Caribbean coastline in the east and north, bordering Belize in the south and the federal states Yucatán and Campeche in the west. The position of Quintana Roo in Mexico is shown in the map on the left of Figure 3-1.

Table 3-1 presents Quintana Roo’s predominant vegetation and other land use. Its soil is of karstic character, evergreen tropical forest is abundant. Owing to the warm-humid climate, 9.1% percent of Mexico’s jungle is found on Quintana Roo’s territory. The extraordinarily high share of secondary vegetation indicates the high susceptibility to forest fires and hurricanes. Even though Quintana Roo shelters slightly more than 1% of Mexican population to date, it only contributes 0.3% to the total of agriculture. 2.4% of

Quintana Roo's area is cultivated in contrast to 16% of Mexico's area in average. The fraction of urban areas is slightly below the national average.

Figure 3-1: Location of Quintana Roo in Mexico (left); map of Quintana Roo with its major settlements. Source: Map 1, map 2

Table 3-1: Per area vegetation and land use of Quintana Roo in comparison with the national level. Source: INEGI, 2011 (data from 2005)

Earth Surface	Quintana Roo			Mexico	
	Area (km^2)	Percentage on Quintana Roo's area	Percentage on Mexico's area	Area (km^2)	Percentage
Continental area	42,361	**100%**	2.2%	1959248	**100%**
Surface of water bodies	444	1.0%	1.7%	25770	1.3%
Agriculture	1,037	2.4%	0.3%	310179	16%
Grassland	1,309	3.1%	0.5%	274269	14%
Forest	4	0.0%	0.0%	222245	11%
Jungle	11,106	26%	9.1%	122245	6.2%
Xeric bush	0	0.0%	0.0%	528776	27%
Other types of vegetation	3,955	9.3%	13.1%	30231	1.5%
Secondary vegetation	24,208	57%	5.7%	423543	22%
No vegetation	80	0.2%	0.9%	9307	0.5%
Urban surface areas	217	0.5%	1.7%	12634	0.6%

The map on the right of Figure 3-1 shows the Mexican federal state Quintana Roo with its major settlements; beyond the state capital Chetumal in the south, the biggest towns are settled on the Riviera Maya (coastline from Cancun to Tulum) in the touristic northern half of the Caribbean coast with the most populated city Cancun in the northeast end of the state. From almost 2000 settlements registered in 2010, 15 had more than 5000 inhabitants and four of them more than 50,000 inhabitants. Table 3-2 lists the nine municipalities with their corresponding numbers of inhabitants and homes. A map which allocates the municipalities to the territory of Quintana Roo is presented in Figure A-1 in the annex. In total, Quintana Roo had a population of 1.3 million inhabitants in 2010, only 0.3% of whom lived in collective homes with other persons or families, but the vast majority in particular homes. (INEGI, 2011-C)

Table 3-2: Quintana Roo's municipalities – Population, number of homes; Source: INEGI, 2011-C

Municipality	Main town	Population	Homes	Inhabitants/home
Benito Juárez	Cancún	661,137	188,555	3.5
Cozumel	Cozumel	79,535	22,201	3.6
Felipe Carrillo Puerto	Felipe Carrillo Puerto	75,026	17,148	4.4
Isla Mujeres	Isla Mujeres	16,203	4,520	3.6
José María Morelos	José María Morelos	36,179	8,295	4.4
Lázaro Cárdenas	Kantunilkín	25,333	6,163	4.1
Othón P, Blanco	Chetumal	244,534	65,893	3.7
Solidaridad	Playa del Carmen	159,309	48,922	3.3
Tulum	Tulum	28,263	7,629	3.7
Total		**1,325,519**	**369,326**	**3.6**

The geographic coordinates of Quintana Roo range from 18 to 22° North (Latitude) and from 86 to 89° West (Longitude). The region is furthermore characterized by flatness. Quintana Roo borders Belize in the south, the state Campeche in the southwest and the state Yucatan in the northwest. Quintana Roo together with the mentioned neighboring states forms the peninsula Yucatan which makes up 7.5% of Mexican territory. (Lutz, 2000)

3.2 Climatic conditions

The climate map in Figure 3-2 shows the prevailing climes in Mexico. As most of Mexico's offshore regions, Quintana Roo is dominated by warm-humid climate which is characterized by monsoon and humid savanna. The very south of the state is merging into rain forest regions. The central Mexican highlands are allocated as upland zones, large parts of the lower north far from the Gulf of Mexico as hot-arid zones.

Quintana Roo is dominated by tropical climate, with monthly mean temperatures between 24 and 28°C, average relative humidity of 85% in the morning and 73% in the afternoon. The wind speed ranges from 15 to 17 km/h in monthly average. The larger area of the municipality Benito Juárez, from the center to the northeast where the city Cancun and most of the further settlements are located, is classified as warm, sub-humid climate with abundant summer rainfall. The remaining area oriented to the inland is more humid (see annex Figure A-2). Additionally, the climate map for the municipality Othón P. Blanco which includes the capital Chetumal is shown (see annex Figure A-3).

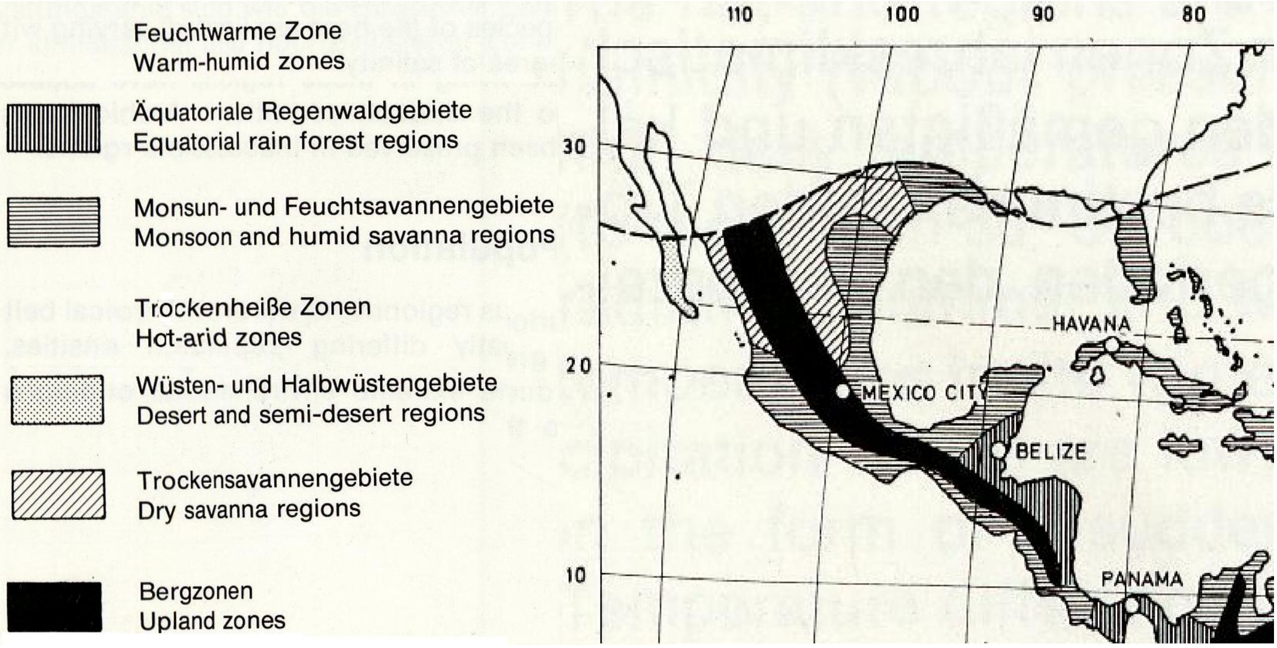


Figure 3-2: Distribution of climate zones in Mexico and the greater area. Source: Lippsmeier, 1980

With approximately 5 kWh/m^2, the solar radiation in Quintana Roo is rather low in national level (see annex Figure A-4). For the outlined characteristics, climatic conditions in Quintana Roo differ largely from those present in the regions which standards of building energy efficiency such as the NZEB concept have been developed for. Therefore, the climate of Cancun was compared to a reference case; due to great advances in building energy efficiency, Freiburg in Southwest Germany was chosen. The temperature profiles of Cancun and Freiburg are presented in Figure 3-3.

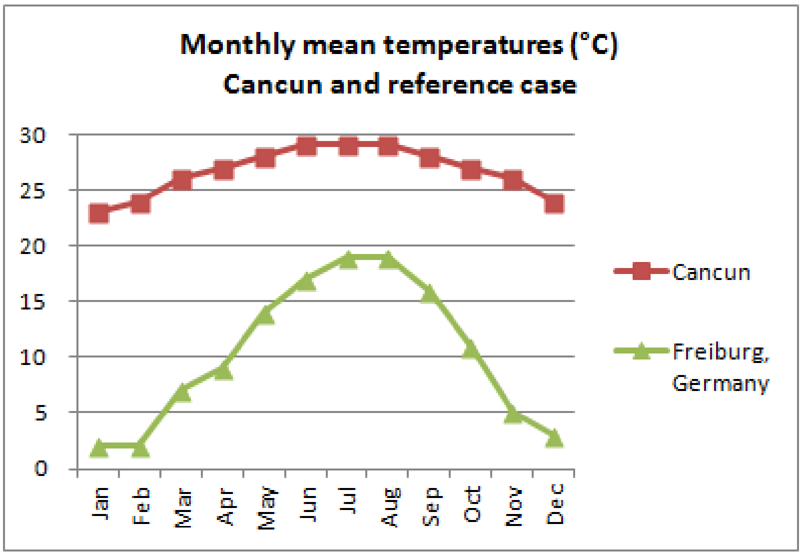


Figure 3-3: Monthly mean temperature curves, Cancun and Freiburg. Climate data: My Forecast, 2011

Figure 3-4 contrasts the humidity of Cancun with that of the reference case; for this purpose, the extreme values from morning and afternoon are depicted. Contrary to Central European climate, which is shaped by the four seasons, Cancun's climate stands out for continuously high temperatures and somewhat high humidity throughout the year. (My Forecast, 2011; INEGI, 2009)

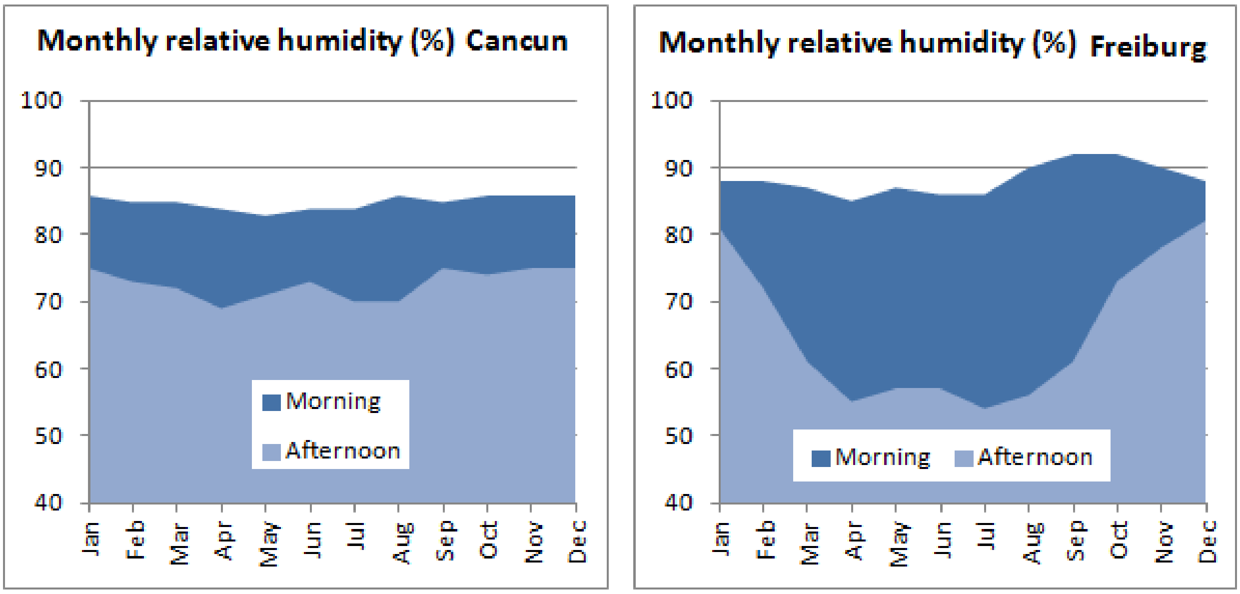


Figure 3-4: Monthly relative humidity values of morning and afternoon, Cancun and reference case. Climate data: My Forecast, 2011

3.3 Historic background

When the Spanish entered the peninsula in the early 16th century, the conquerors found land cultivated by disperse Mayan population. The Spanish conquerors and their Creole descendants took over the political and economic control, the population recovered slowly after the decimation of Mayan indigenous by the confrontation. However, population then grew much faster in the northwest, where today's state Yucatan is located, and also on the coast of today's Campeche; in those areas, people lived from different agricultural activities and the exploitation of resources. At the beginning of the 19th century, the establishment of sugar plantations in the province of the state Yucatan brought large-scale monoculture to the region, as a strong contrast and in competition to traditional Mayan land cultivation. Maya who did not capitulate were expelled from their lands into the forests in the south and east, where today's Quintana Roo is located. From that area, the indigenous outcasts gathered force and counterattacked in the Caste War of Yucatan in which the town Felipe Carrillo Puerto, formerly Chan Santa Cruz, played an important role. As consequence of the rebellion, half of the peninsula's population died; but some indigenous population resettled over the peninsula. Quintana Roo became an undesirable region, when President Porfirio Diaz used it as a labor camp for political prisoners in the late 19th and early 20th century. The population did not increase significantly until the 1970s. (Lutz, 2000; Anderson, 2011)

3.4 Recent development

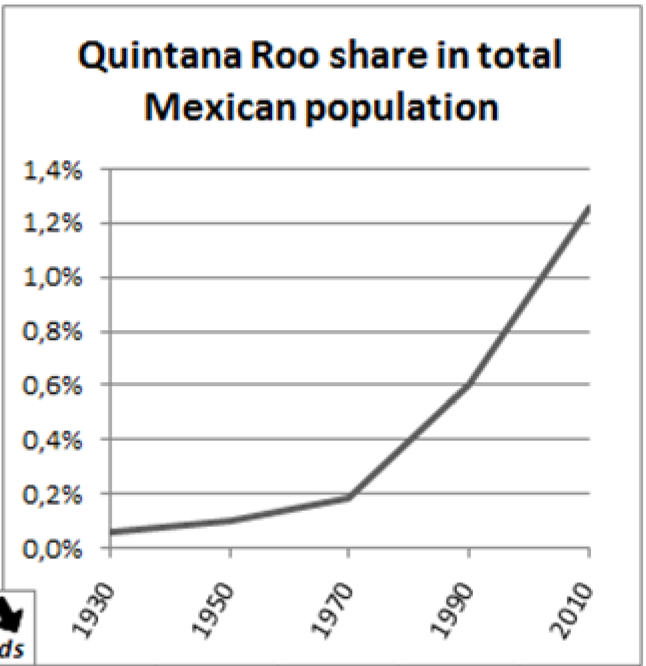
The landscape of Quintana Roo is characterized by diverse attractions. In addition to the Caribbean coast line which offers long sand beaches and a great riff for snorkeling and diving, Quintana Roo is famous for Mayan ruins like Tulúm and Cobá. Chitzen Itza as the largest and most visited archeological site on the peninsula is located in the state Yucatan, but not too far from Cancun. Apart from the long sand beaches, natural attractions like lagoons, cenotes (deep natural pits or sinkholes which are connected to a large underground water system on the peninsula) and the jungle are further popular tourism destinies. While only some moderate touristic activities have been conducted on the island Cozumel before, tourism at large scale was introduced in the former fishing village Cancun in the 1970s as part of a well-planned national policy. This gigantic development attracted not only domestic but also foreign investors who have seized their chance to get involved ever since. In this way, large parts of the development potential have been divested and foreign interests as in the form of import products have played an essential role in the planning and construction process of new built-up areas – hotel zones, holiday resorts, new city centers, residential areas and related infrastructure. Those extensive tourism activities have caused harm on the fragile eco-systems of the region and led to scarcity of resources. On the other hand, because of the abundance of new employment opportunities, Quintana Roo soon attracted migrants from the neighbor states and elsewhere in the country, and Cancun with its international airport became the main starting point of tourism activities and is well-known far beyond the Mexican boundaries today. Cancun also displaced Chetumal as the main economic center of the state Quintana Roo. Furthermore, the new boom accelerated the touristic development of Cozumel; in later years, the development expanded into the surrounding regions and new sites became touristic destinations, especially Playa del Carmen and Tulum in the south and the island Isla de Mujeres north of Cancun. (Lutz, 2000; De Anahí Ay Robertos, 2012)

In 2009, with 4.0 million out of 8.2 million in total, almost half of the foreign tourists who came to Mexico chose Quintana Roo as their destination. Most of the tourism is distributed between the municipalities Benito Juárez (Cancun) and Solaridad (Playa del Carmen), followed by Isla Mujeres and Tulum already far behind. (INEGI, 2011-B; INEGI, 2011-C)

3.5 Population growth

The state Yucatan is the smallest (29% territory share) but most populated state on the peninsula. In 1995, it sheltered 54% of inhabitants of the peninsula with an average density of 36 persons/km^2. Campeche, despite of having the largest territory share (39%), only contributed 22% of inhabitants to the total of the peninsula in 1995, with 11 persons/km^2 average density. Quintana Roo, which has a territory share of 34% on the peninsula, is characterized by an immense growth rate; from 1970 to 1995, the average density increased from 2 to 14 persons/km^2. (Lutz, 2000)

The population explosion of the Mexican state Quintana Roo in the 1970s – within a still strong overall Mexican growth – clearly sticks out by the sharp bend in Figure 3-5, underlining the great significance of the tourism sector for the metropolitan area of Cancun.



Habitants in Thousands

Year	1930	1950	1970	1990	2010
Mexico	16,600	25,800	48,200	81,200	108,400
Quintana Roo	10.6	27.0	88.2	493	1360

Figure 3-5: Proportional population growth of Mexico and Quintana Roo, total numbers of inhabitants (see table). Data: INEGI, 2011-A; CONAPO, 2005

From that time on, the development is characterized by much faster growth which slightly regressed over the years, but until today keeps growing steadily and substantially stronger than the overall Mexican development. The line graph shows the proportionate growth of the province in reference to overall Mexico from 1930 to 2010, with the total numbers of inhabitants listed in the table. Within the observed period, the percentage increased from 0.06% in 1930 to 1.25% in 2010. (INEGI, 2011-A; CONAPO, 2005)

3.6 Electricity consumption in Quintana Roo

As a consequence of the excessive tourism activities in Quintana Roo, the electricity demand still keeps growing extraordinarily fast. This trend in comparison with the overall Mexican development is illustrated by Figure 3-6, including the particular developments of the residential sector for both cases. Within the observed period of 20 years, the electricity consumption of Quintana Roo – both residential and in total – multiplied by more than six, while Mexico's consumption tripled respectively almost quadrupled. Furthermore, it stands out that Quintana Roo kept growing steadily during overall Mexico's temporary slump around the year 2006. (CFE, 2009)

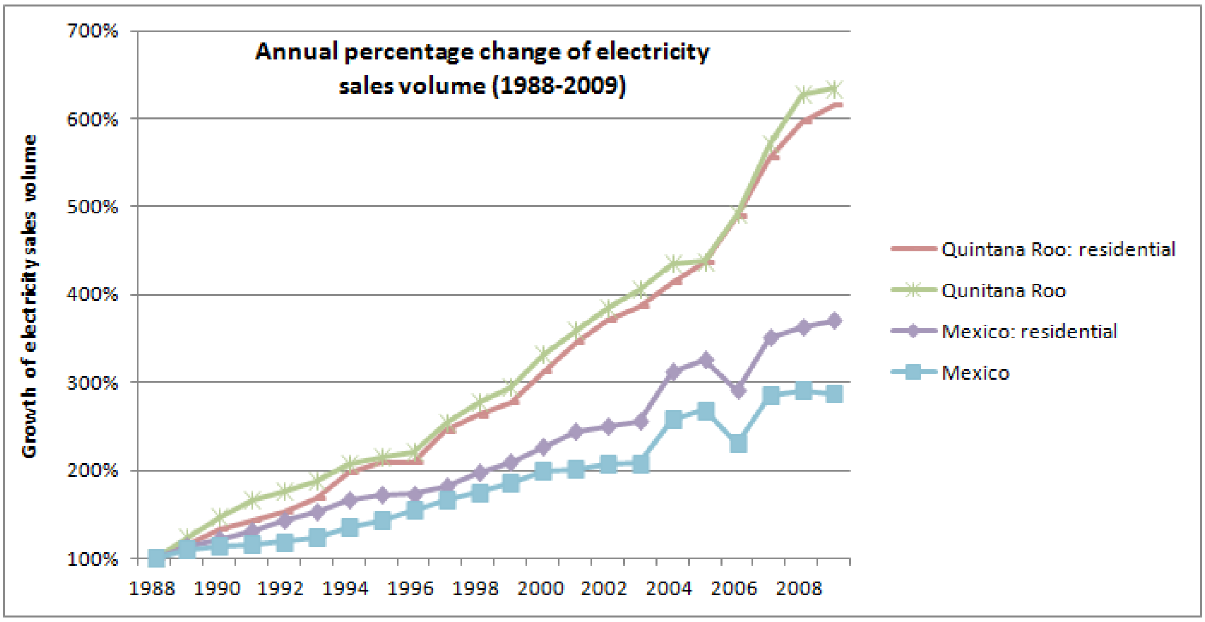


Figure 3-6: Electricity consumption trends of Mexico and Quintana Roo. Data: CFE, 2009

Quintana Roo's exceptional growth is not only due to the enormous population growth but also accelerated by the growing and very consumptive tourism sector which generally stands out for high energy consumption; evidently, this group is not registered as population and might be the reason for higher overall growth than in the residential sector. Figure 3-7 subdivides the total electricity consumption of Quintana Roo and Mexico into the responsible sectors.

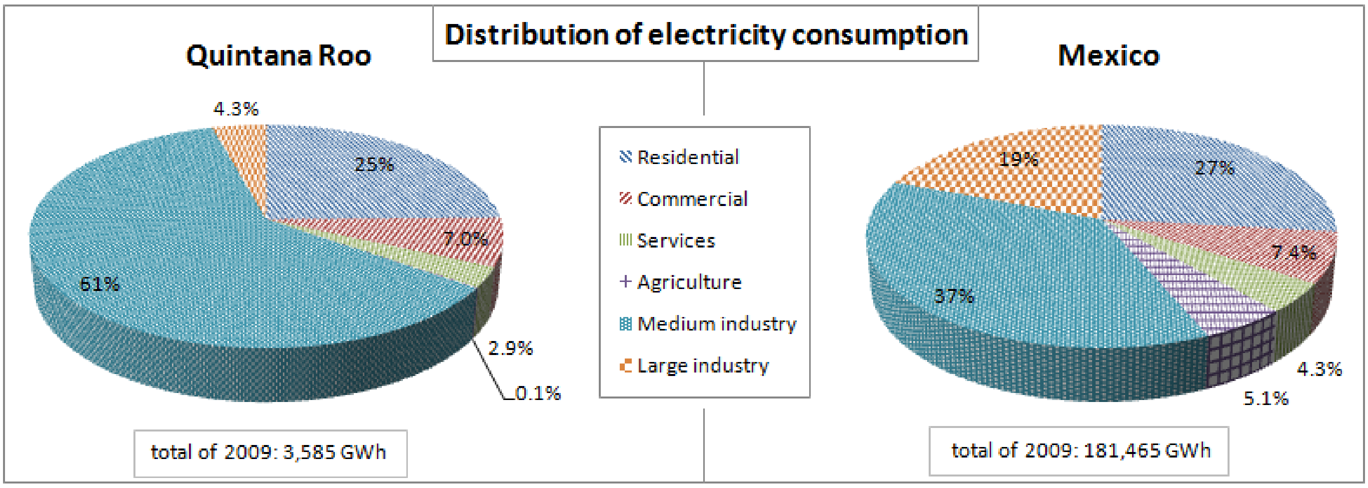
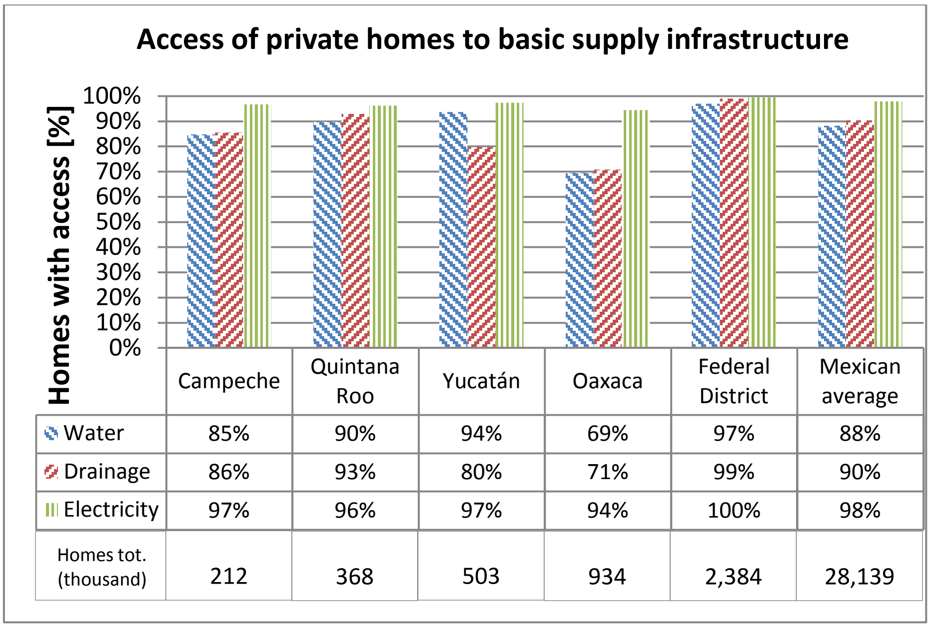


Figure 3-7: Electricity consumption of Mexico and Quintana Roo by sector. Data: CFE, 2009

It stands out that, in contrast to the national level, Quintana Roo's agriculture contribution is negligible small (0.1%); all of the further categories residential, commercial and services have a somewhat smaller share in Quintana Roo, which is due to the strong industry sector with almost $^{2}/_{3}$ (including the share of large industry). Altogether, Quintana Roo contributes 2% to the total electricity consumption of Mexico, but only shelters 1.2% of Mexican population, which means that Quintana Roo's electricity consumption is almost the double of Mexican average. (CFE, 2009; CONAPO, 2005)

On the other hand, as pointed out by Figure 3-8, despite of the high electricity consumptions Quintana Roo still lacks 4% to accomplish statewide electrification – even the national average is 2% higher. The federal district as the best-performing state has complete coverage, the worst-performing state Oaxaca is only 2% below Quintana Roo. This condition marks the uneven distribution of wealth within the territory of the state – augmenting the gap between the rich and the poor respectively between the industrialized urban areas and rural, isolated regions in the back country of the state. Quintana Roo's achievements about water supply and drainage are lower with 90 and 93% respectively, but still above the national average. (INEGI, 2011-B)



	Campeche	Quintana Roo	Yucatán	Oaxaca	Federal District	Mexican average
▨ Water	85%	90%	94%	69%	97%	88%
▨ Drainage	86%	93%	80%	71%	99%	90%
▥ Electricity	97%	96%	97%	94%	100%	98%
Homes tot. (thousand)	212	368	503	934	2,384	28,139

Figure 3-8: Quintana Roo's access to water, drainage and the electricity grid in comparison to other Mexican states; water access refers to the connection to the water piping system. Data: INEGI, 2011-B

3.7 Building materials for residential buildings

By means of the charts of Figure 3-9 for wall and roof materials, the trend can clearly be read that advanced industrialization has promoted the use of cement products while natural materials have become less important. Both for walls and for roofs/ceilings the construction methods using cement exceed 80% of the total of materials in use.

The minor fractions of further wall materials are mainly natural, while metal lamination is found amongst further roof materials; certainly its thermal characteristics are little advantageous for tropical heat. An alarming remark is the fact that even small amounts of asbestos are still in use for both wall and roof, although it has been proved to cause cancer. Bahareque is a construction technique made of wood. This and other typical construction methods and components for the region are introduced in section 4.5.

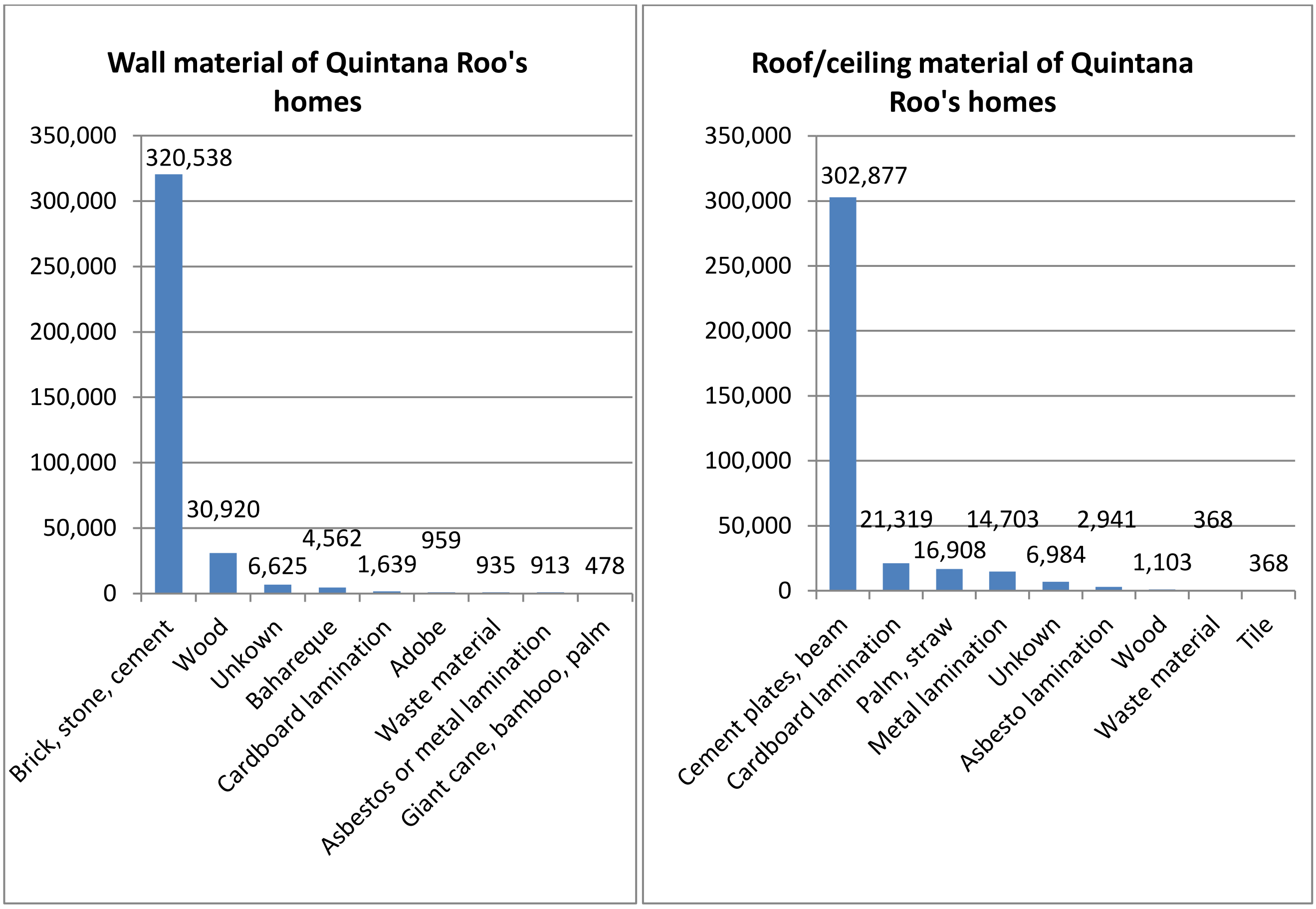


Figure 3-9: Wall (left) and roof material used for residential buildings[2] in Quintana Roo in 2010. Data: INEGI, 2011-C

3.8 Conclusions and further considerations

The strong growth rates manifest the essential contrast that has emerged between the booming urban, industrially developed areas under strong touristic influence on the one hand and rural areas on the other hand. This contrast has large impacts on the social and economic structure of the region. Due to the increased living expenses, many workers and employees in the services sector started to live above their financial possibilities. In addition, underdeveloped urban areas evolved, mainly in peripheral regions. Amongst others, the situation is worsened by today's understanding of air conditioning units as a standard installation in private and public spaces; their necessity is not questioned in many cases, instead their use has become a popular practice. Comparably, the number of indigenous who adapt to industrialized forms of living is increasing, while the contrary movement back to nature is seen as rather odd and often lacks willingness and

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[2] The total number of homes investigated for this survey in 2010 amounts to 367.569.

acceptance of involved persons to be put into action. The strong contrasts are also reflected by substantially different methods of construction which will be outlined in the following.

4 Building in the tropics and building technologies

4.1 Bioclimatic building design

Different to the situation in temperate climate zones where the demand for heating dominates throughout the year, architecture in warm climate, if diligently elaborated, can possibly provide comfortable indoor climate without uncoupling from the exterior.

Bioclimatic architecture can make significant contributions to health and well-being, to effectiveness, and to healthy economy and ecology. However, successful implementation requires a conceptual change of the mentioned relation, away from conventional and towards integral ways of thinking, in order to consider all factors of which one interacts with each other. To overcome common grievances and to be able to adapt built-up spaces to the natural environment, the following building design objectives should be contemplated as guiding principles over the complete planning process and construction of the building:

1. Create livable spaces that fulfill their functional and expressive purpose and are physically and psychologically healthy and comfortable in order to promote the optimum development of human beings and of their activities.
2. Make effective use of energy and resources and tend to self-sufficiency of the buildings.
3. Preserve and improve the environment by integrating the human into a balanced ecosystem.

In this manner, architectural spaces with ecological understanding are created. For that, the building envelope should be designed as a dynamic agent that interacts favorably between exterior and interior, which is to say like a selective bio-thermal, luminous and acoustic filter able to modify the natural elements in a favorable way, by transmitting, rejecting or transforming them. According to Olgyay (1973), the procedure of building a climatically balanced house is divided into four steps with the architectural design as the ultimate. The process involves the investigation of climatic conditions, the biology by means of exploring human sensations and needs, technological solutions and finally the accomplishment of the previous findings in the architectural implementation. Essential elements of bioclimatic architecture and corresponding measures are introduced in the following sections. (Olgyay, 1973; Fuentes Freixanet, 2002)

4.2 Classification of tropical climes

Lippsmeier (1980) summarized essential characteristics and architectural issues in dependence on the present tropic climate zone. These are listed in Table 4-1 for the warm-humid climate as present in Quintana Roo in comparison with the two other prevailing climates of Mexico.

Table 4-1: Primal characteristics and architectural problems of climes in Mexico; Source: Lippsmeier, 1980

Clime	Main climatic characteristics	General and architectural problems	General guidelines for building design
Warm-humid	High precipitation and humidity at constantly high temperature; little wind; medium to strong solar radiation	Sultry heat; little evaporation due to little air movement; protection from sun, rain, insects; wind protection at offshore locations	Open arrangement of buildings to enhance air circulation; north-south orientation to reduce sun exposure[3]; low building depth to enhance cross ventilation; shade exterior rooms without hindering air circulation; sufficient rain water drainage/storage; lightweight building with low heat retention
Hot-arid	Strong direct solar radiation incl. high reflection by earth's surface; low precipitation and humidity; high temperature day and night differences	Protection from direct solar radiation and reflected radiation from surface and surrounded buildings; protection from insects, sand, dust; alleviation of dryness in the air	Closed arrangement of buildings for mutual shading and minimized sun exposure; compact building design with small openings, but orientation to shaded inner courtyards; deep rooms; protected open-air areas with plants and water pools for cooling; heavy thermal mass for good heat retention properties
Upland zones	More temperate climate than surrounding lowlands, but stronger solar radiation; cold winter nights and large temperature fluctuations	Protection of openings and exterior spaces from strong solar radiation and cold winds; possibly heating required in cold winter nights (high heat dissipation); possible formation of dew	Relatively compact building arrangement; aligned in east-west direction with main openings to north or south – openings in the west are exposed to the largest incidence of solar radiation with the highest air temperature; open areas protected from the summer solar radiation, but open to winter solar radiation

4.3 Thermal comfort

Adequate building planning aims to create a comfortable indoor climate in all inhabited spaces of the building in order to facilitate maximum well-being for the user. Beyond the depicted macroscopic circumstances which are owing to the climatic conditions and define the boundary conditions of indoor climate for the specific region, the complexity

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[3] Orientation of the longer facades towards south and north minimizes solar gains; due to solar altitudes close to zenith in the tropic latitudes, the south facade (for the northern hemisphere) is barely exposed to the sun, but east and west facade are exposed significantly; this equally applies to the north facade in the southern hemisphere. Therefore, east and west facade should be small-dimensioned in both hemispheres.

of many factors gives the indoor climate the decisive shape. Those criteria are partly conditioned by the specific individual and partly by the immediate surroundings; the last point is where building design plays a decisive role.

4.3.1 Internal and external factors

The metabolism is one of the essential factors for the human perception of comfort. Therefore, the level of human activity has decisive impact on thermal comfort. Table 4-2 shows different human activities and the corresponding metabolic rates in W/m^2.

Table 4-2: Examples of human activities and related metabolic rates, clothing unknown. Source: ISO 7730

Activity	Metabolic rate	
	W/m^2	met
Reclining	46	0,8
Seated, relaxed	58	1,0
Sedentary activity (office, dwelling, school, laboratory)	70	1,2
Standing, light activity (shopping, laboratory, light industry)	93	1,6
Standing, medium activity (shop assistant, domestic work, machine work)	116	2,0
Walking on level ground:		
2 km/h	110	1,9
3 km/h	140	2,4
4 km/h	165	2,8
5 km/h	200	3,4

The right column presents values in the metabolic unit *met*[4]. According to Recknagel (1999), 1.0 met corresponds to 100 W of heat dissipation. The addressed publication determined 125 W of heat emission for sedentary activity and 80 W for reclining. Human activity also has an effect on the moisture content of a room; Table 4-3 shows the exhaust of water vapor by humans at sedentary state as a function of air temperature.

Table 4-3: Water vapor exhalation by sedentary man at still air humidity between 30 and 70%, normal clothing and light activity. Source: Recknagel, 1999

Air temp. (°C)	Vapor exhaust (g/h)
20	38
22	47
24	58
26	70
28	85
30	98
32	116

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[4] The metabolic unit is defined as: 1 met = 1 kcal/(kg·h) = 4.184 kJ/(kg·h) and is equal 58.2 W/m^2.

Some related internal factors that have direct influence on the metabolism are age, gender, body form and surface, accumulation of fat, condition of health and the types of nutrients. The following are the fundamental external factors:

- Level of clothing;
- Air temperature;
- Radiant temperature (thermal radiation);
- Air humidity;
- Air movement;
- Noise;
- Luminous comfort.

The heat transfer between the body and its environment varies depending on the **level of clothing** because of the higher respectively lower amount of thermal heat that the body can dissipate. The difference between **air temperature** and the constant human body temperature[5] defines the heat flow; however, due to the complexity of the human body, the optimum air temperature for thermal comfort depends on various factors – besides the already mentioned aspects, the acclimatization of the individual plays an important role: a person who is used to a specific climate has a higher tolerance than a visitor who comes from a different climate. Besides the air temperature, also the **radiant temperature** has a strong effect on the individual thermal sensation; this becomes evident by experiencing the sensation of comfort perceived by heat radiation from a bonfire or solar radiation in cold air.

Air humidity has minor effect on the sensation of thermal comfort itself, but great significance in the heat exchange of the human body with its environment, both by skin (perspiration) and by pulmonary organs (evapotranspiration). For that, the moisture content of the air is an important indicator for the human compatibility with the corresponding climate. The higher the moisture content, the less tolerable becomes the climate; this condition is worsened if both temperature and humidity are high. Humans usually feel uncomfortable at vapor pressure above 2 kPa. The cooling effect of evaporation from the skin is prevented above this level and the air itself cannot absorb enough moisture.

Although it does not cause temperature change in a direct way, **air movement** also affects the individual thermal sensation; the movement of air increases heat dissipation (through the skin), both by incrementing the convective heat loss and by accelerating evaporation. However, air movement also has mechanical impact on human comfort. The role of air movement for bioclimatic building design is treated in section 4.4.2.

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[5] Under healthy conditions, the human body temperature ranges between 36.5 and 37.5 °C.

Especially when the movement of air is required for accomplishing thermal comfort, **noise** is a considerable factor. In this sense, controlled ventilation as with air-conditioning or simple ventilators has the advantage that sound absorbers can reduce noise emissions. Natural ventilation implies large open areas to the exterior and thus the exposure to the outside noise from the street or other sound sources which could only be avoided by temporally closing the openings and accepting limitations in ventilation.

Luminous comfort refers to the perception through the visual senses; these react on the degree of brightness and the distribution of light within the field of vision. Significant deviation from the pleasant range leads to overstrained eyes and thus to uncomfortableness, for example because of glare or dimmed light. In the tropics, slightly under-lit spaces would be preferable to over-lighting because of psychological effects and the sensation of overheating. Implications for building design and urban planning are considered in the following. Models and standards of thermal comfort are introduced in chapter 5. (Koenigsberger, 1978; Lippsmeier, 1980; Fuentes Freixanet, 2002)

4.4 Important influencing factors and approaches

The previously presented internal and external factors translate into the following requirements and considerations about building planning that will be treated in this subchapter.

Meanwhile, it is important that the users of a building act responsibly. Contributions like dressing appropriately depending on the weather of the day, season and year, opening and closing sun protection devices and windows in dependence on the outside conditions and stopping increased physical activities during extraordinarily hot and sultry hours are basic rules that are not in the responsibility of the architect or building planner.

4.4.1 Reflection and absorption of solar radiation

Typically, intense sunlight and strong reflection of sunlight prevail in tropical climates. The strong radiation and resulting contrasts in brightness cause glaring effects and feel uncomfortable. However, there is a fundamental difference between the glare in hot-arid and in warm-humid climes. The dry air of hot-arid climes results in strong glaring effects due to reflection from ground surfaces and surrounding buildings; generally, the reflecting effect is amplified by plain surfaces because of spare and low vegetation. The illustrations in Figure 4-1 give a good example of possible impacts; the sterile urban design with exclusively plain, rectangular surfaces on the left side results in a maximum yield of reflection and absorption. In contrast, the loosening elements consisting of balconies, vegetation and inclined roof on the right side provide for better distribution of the impacting irradiation.

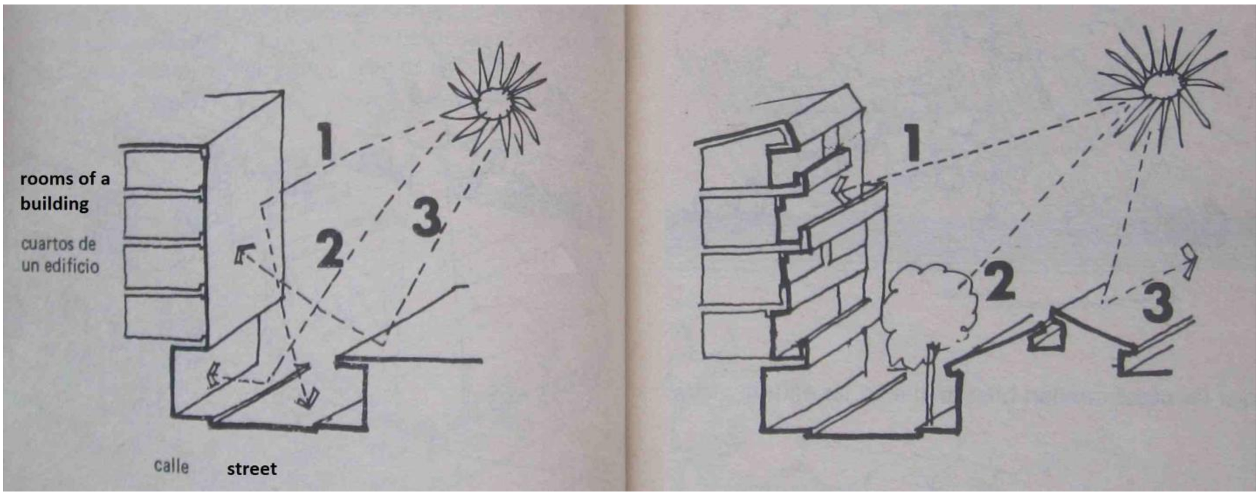


Figure 4-1: Impact of design of urban surfaces on reflection and absorption. Source: Van Lengen, 2007

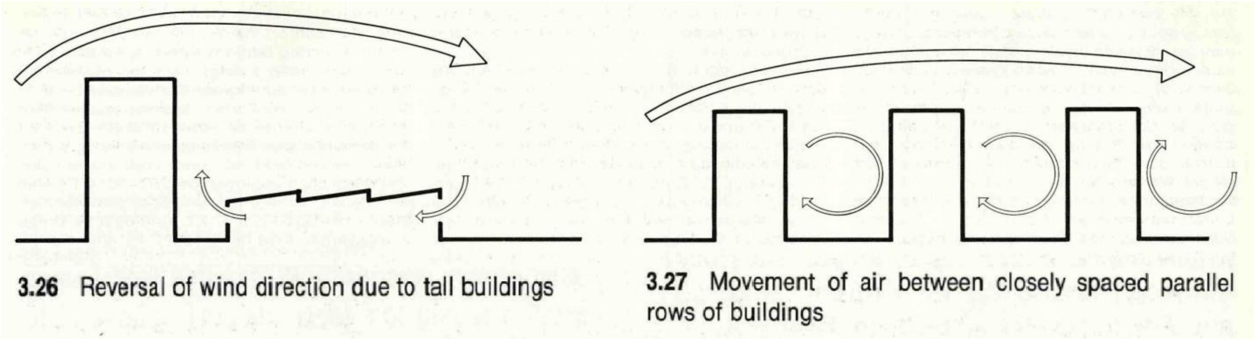
In contrast to hot-arid climate, the diffuse solar radiation due to high cloudiness of humid tropical regions causes a glaring effect from the sky. In both cases, the absorption of solar radiation by the earth's surface contributes largely to heating during the day. The difference between the effect of highly absorptive dark colors and that of less absorptive but highly reflective light colors should be considered accordingly, both for the building facades and for the surrounding areas. In the usual case for tropical climes, solar control is necessary and all glazed areas should be protected from direct sunlight; only in regions of high elevations direct sunlight might be partially desirable (see also Table 4-1).

Because of the different angles at which the building facades are exposed to the sun and considering the different daytimes at which irradiation occurs at each, the depth of rooms, spacing and screening elements should be designed individually in order to achieve the desired effect of solar control. This can be achieved by vegetation, opaque horizontal and vertical building elements and solar control glass. A further evident solution is a close arrangement of buildings for mutual shading; this method has great tradition in hot-arid regions, but for warm-humid climes it is not appropriate because it would hinder natural ventilation. (Lippsmeier, 1980; Van Lengen, 2007)

4.4.2 Air movement

Due to its cooling effect and the mentioned impact of high humidity, the movement of air has essential influence on human comfortableness and is thus especially important in warm-humid regions. Contrary, in warm-arid regions the circulation of the strongly heated outdoor air is not desired during the day, while the usually much cooler air at night brings a good cooling effect. Light ground winds of cooler air are desired for tropical humid zones in order to improve the micro climate, but protection against the threats of strong winds and hurricanes is necessary.

Accordingly, exposition to wind and protection from it need to be balanced carefully. In the end, the susceptibility to wanted or unwanted air movement highly depends on the present type of vegetation (jungle, savanna, etc.). In agreement with Lippsmeier (1980), dense forest extracts about 30% of the wind's original force after 30 m, 50% after 60 m and 93% after 120 m. Loose cover of vegetation makes the wind lose a bit in force, but keep its direction. Contrary, clearings in thick forests or even less homogenous earth's surfaces such as urban areas considerably disturb the air-currents. Nevertheless, continuous arrangements of buildings can bring certain regime into the air currents. As visualized by Figure 4-2, tall buildings provoke counter-rotating air currents that are sufficient for the ventilation of lower buildings situated in the downwind side of the tall elevations (see left side of the figure).


3.26 Reversal of wind direction due to tall buildings

3.27 Movement of air between closely spaced parallel rows of buildings

Figure 4-2: Wind effects in interaction between different buildings. Source: Lippsmeier, 1980

Ground wind can be influenced by the orientation, spatial sectioning and facade structure of the building and by its surroundings of vegetation and neighboring buildings (see right side of Figure 4-2). The effectiveness of ventilation depends on the pressure difference between the windward and downwind side of the building. In addition, air movement can be generated by the contrast of irradiated and shady facade areas, where the ventilation effectiveness depends on the temperature difference between both sides. In any case, an elaborate design for continuous natural ventilation, called cross ventilation, can spare the need for an electric air conditioning system. Therefore, openings are required on the opposing sides of a building.

In Figure 4-3, some examples for the influence of shading elements and vegetation on the ventilation are illustrated. On the left side, from top to bottom, the air circulation without shading device, with installed shading device but without air passage and with shading device including a small gap are shown. The inclusion of the gap enables well-distributed air circulation comparable to the situation without shading device, while the lack of air passage though the shading element makes the air drift straight towards the ceiling.

As depicted in the figures to the right, bundling the ground winds by a bush and afterwards a thick tree can create good air movement into the room, while in the figure at the bottom, the bush next to the room makes the wind pass by above. This accentuates the importance of precision and exact planning in order to achieve adequate arrangements that have the desired impacts on the direction and intensity of ground winds. Accordingly, very dense and poorly directed vegetation arrangements in regard of the wind direction can result unfavorable in warm-humid climes as air movement will be diminished to a minimum; in addition, dense vegetation tends to attract insects. On the other hand, dense vegetation offers better protection from undesired, excessive air movement. Besides the aspect of wind, vegetation can provide shading and protects both from glare and from radiant heat in this way. Furthermore, it can absorb dust and prevent from erosion. (Lippsmeier, 1980)

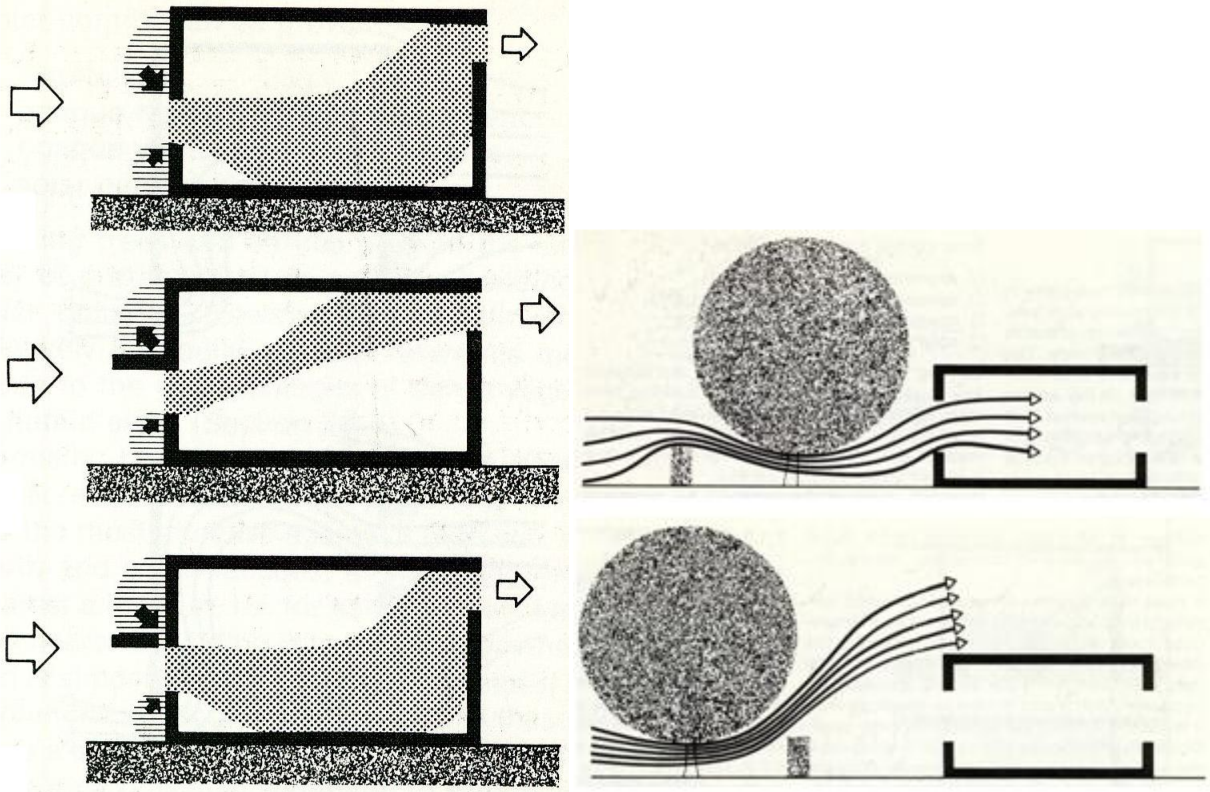


Figure 4-3: Influence on ventilation: shading elements (left side), vegetation (right). Source: Lippsmeier, 1980

4.5 Building materials and local construction techniques

Comparable to the decision between highly technological and more natural approaches for the building design, also the selection of building materials distinguishes between two approaches. Since the beginning of human building activity, people have been creative in using available materials at their direct surroundings and constructed their shelter by their own hands. Natural, local building materials made from stone, wood, soil, bamboo, leaves, grass etc. are easy to produce. In contrast, industrialized building materials generally require high energy inputs for the exploitation of raw materials, their processing and the transport of materials but stand for high resistance and durability.

4.5.1 Industrialized materials

The advanced industrialization of building materials also results in increased production of waste whose disposal is difficult and costly in many cases. Indeed, over time the value of many materials has been discovered for reuse; however, reprocessing of the materials again requires high energy inputs. According to Claussen (2008), more than 10% of the total energy consumption of a building is typically embodied in its building materials, adding up to 15% together with maintenance and renovation.

Beside the basic conditions of climate and surroundings and the specified influences that the building design can exert, the operational energy consumption – the energy consumption during the use of the building – also depends on the occupants of the building. This parameter can be influenced accordingly throughout the life of a building and accumulates over that time. In contrast, the energy spent on the building materials is embodied energy thus independent of the users, but it greatly depends on the choices of materials and construction methods. except maintenance and renovation, embodied energy occurs all at once. For those reasons and also due to varying but usually enormous energy inputs required from the discovery of the raw material to the final product used as building material, embodied energy content varies largely and is important to consider.

Increased embodied energy content is often justified by its contribution to reduce operating energy. Typically in temperate climates, large thermal masses, which are rich in embodied energy, reduce heating demand of well-designed buildings significantly and facilitate their energy-efficient operation. As energy-efficient building operation has attained more awareness and higher levels of implementation, embodied energy has become increasingly important, but has often remained out of consideration. In most cases, simpler and more natural materials with comparable insulation or heat-detention quality to highly-processed energy-intensive building materials can be found; Kennedy (2004) presented some examples of successful implementations. (Reardon, 2008; Kennedy, 2004; Lippsmeier, 1980; Claussen, 2008)

The industrial fabrication of cement provides employment; this criterion, corresponding to both economic and social interests, could have high priority in the evaluation of the governmental body rather than environmental concerns. Furthermore, in spite of the disadvantages that it might have for warm-humid climates, cement is very robust; this quality gives much confidence for the confrontation with hurricanes, (forest) fires, insects and other threads, even thieves.

4.5.2 Natural materials

Locally available materials for the construction of walls are wood and stone. Especially wood historically has played an important role on the Yucatan peninsula. Traditional

Mayan houses consist of walls made of wood sticks which are permeable to air and arranged in oval form. In combination with a palapa[6] roof with an elevated crest and comparably permeable to air, a refreshed interior is provided. This effect is intensified by two doors on opposite sides, which provoke cross ventilation. On the left, Figure 4-4 presents a photograph from a model for a typical Maya house, taken at the Museum of Mayan Culture in Chetumal.

The leaf of fan palm (Spanish: *huano*, species: *Sabal yapa*, *Sabal mexicana*), especially the female one, is most suitable for roofs as more area can be covered by one single leaf, and it is easier to accommodate. Figure 4-4 (right side) shows the fan palm in its natural appearance and in treated form as palapa roof. However, fan palm leafs are difficult to purchase as there are restrictions on sales, since the species has been overexploited. Huano leafs have incorporated excessively for roofs in the tourism sector in Quintana Roo. They are a protected species today and their cultivation is plodding because it takes about eight years to get full-grown fan palms of huano.

Figure 4-4: Model of a traditional Maya house (left); roof of fan palm (huano) next to growing fan palm. Pictures taken by Moie, 2012

A more accessible alternative is zacate¸ a species of long grass. However, zacate with a lifetime of just about 10 years has to compete with huano that lasts at least 15 years. (Brunner Morales, 2012; Canul González, 2012)

4.5.3 Traditional building techniques

The pillar construction technique <u>Bahareque</u> is of pre-Columbian origin and made of local woods. It was widespread in Latin America before the introduction of industrial

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[6] Roofs that are made of palm leafs or straw are called “palapa” in Mexico.

construction methods. Also the structure of a Maya house follows the principles of the bahareque technique. The assembly of different columns, beams and bearings to a complete bahareque skeleton can be observed in Figure 4-5. As variation, a bahareque construction can also be covered with clay or mud after filling the interspaces of the skeleton with wooden piles.

Figure 4-5: Structure of a bahareque construction. Picture taken by Moie, 2012

The roof covering can be made by use of palm leafs or grass, as mentioned in the previous section. Figure 4-6 shows, how the roof is bound with palm leafs. The leafs have to be folded from the branch over the belt to one side; with two more belts at each side, the leafs are fixed to the belts with a twine. The very endings of the final beam can be omitted from roof covering in order to leave openings for ventilation. (Van Lengen, 2007)

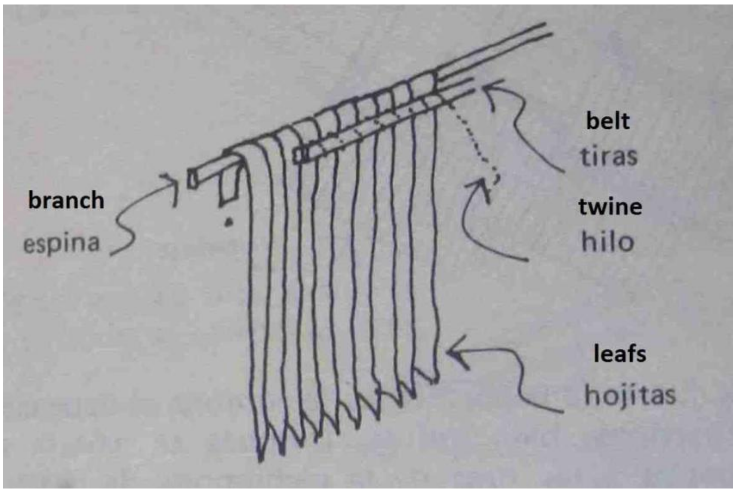

Figure 4-6: Braiding of roofing with palm leafs. Source: Van Lengen, 2007

4.5.4 Tie-beam and vent block system

A popular construction method for ceilings and roofs in Mexico is the tie-beam and vent block system (Spanish: *vigueta y bovedilla*). With the function to sustain the weight exerted on the floor and transmit the stress to the surrounding walls, the tie-beam (*vigueta*) is the structural element of the combined system which is filled with cement after assembly. In turn, the vent block (*bovedilla*) which is a ribbed hollow body alleviates the structure as contrast to massive construction; this method lowers the demand for cement and reduces the heat retention of the building component. The combination of both components to the tie-beam and vent block system is shown in Figure 4-7. Apart from the mentioned filling of the tie-beam with cement, the total structure is usually covered by a concrete layer after completion.

Figure 4-7: Tie-beam and vent block system. Source: Grupo Joben, 2011

Owing to the hollow space in the tie-beam and vent block structure, the lower level is thermally decoupled from the upper plane with affected exterior influences and infrared radiation. Furthermore, the space can be used for air exhaust.

Similarly, bricks for wall mounting, which are manufactured as hollow blocks, are only filled at corners, end sections or other areas where high mechanical stress needs to be sustained, while the remaining parts are left empty. (Bojórquez, 2012; Díaz, 2012)

4.6 Building design technologies and on-site energy generation

Representing the so-called ‘western approach’, energy-efficient homes in industrialized countries, in most cases in temperate climates, stand out for the application of elaborate building design principles, which are rather complex and usually rich in technology components in comparison to more traditional construction principles as those introduced in the previous sections. The principal aspects which have been originally developed for temperate climate will be introduced in the following.

4.6.1 Structural elements

The selection and design of building components such as walls, windows and ceilings has a high impact on its thermal performance. When making use of passive solar energy, the

typical case for temperate climate, the building envelope[7] serves as absorber and the building structure as heat detention. Thermal energy can be stored and released to the rooms by means of the available thermal mass of a building. The thermal mass is provided by heavy-weight elements, mainly walls and ceilings, whose storage capacity depends on the density of the used materials. Concrete has a much higher heat storage capacity than wooden materials, for example. The stored energy is released to the surrounding ambient, when the thermal mass is warmer than the ambient temperature.
Inversely, for cooling, the penetrating heat is decelerated, while the effects of chill ground earth and night-time cooling-down produce further relief. The result of efficient heat detention is a more inert indoor climate[8] which can help to reduce heating or cooling demands significantly. However, the method is more common and more functional in tempered climate. In those latitudes, thermal insulation serves to reduce heat losses to the surroundings and thus requires a good balance in the combination of different materials and thicknesses, including the selection of windows with good thermal insulation characteristics. But sealing measures are rather contrary to the concept of bioclimatic design and are only applied for roofing. Instead, the deflection of wind is an essential measure for massive constructions in the tropics in order to enhance the entering air movement. (Laustsen, 2008; Kaltschmitt, 2007)

4.6.2 Active use of energy sources on site

Roofs are an attractive spot for the capture of solar energy, in this way no additional space is needed. The direct current generated by photovoltaic panels is converted into alternate current by means of an inverter to make conventional electric devices usable. Off-grid systems require a back-up system to store the generated energy. A sufficient battery capacity keeps up self-sufficient electricity supply round the clock.

The inclination of the panels is geared to the geographic latitude, but should have higher inclination for exclusive use in winter by about 10° or opposite for summer.

Applications of solar energy
Meeting the usual needs in the tropics, solar energy can also be utilized for absorption or adsorption processes in order to provide cooling or dehumidification. Absorption refrigerators require a heat source which can be provided by solar energy in order to extract the thermal energy from the treated object in an elaborate thermodynamic process of combined cycles which basically works like an inverted heat pump. Adsorption chiller is the counterpart to absorption that uses solids instead of liquid

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[7] In technical terminology, all components of a building that serve to shield heated and/or cooled living space from their surroundings are subsumed under the term thermal envelope; this includes wall and roof assemblies, insulation, air/vapor retarders, windows and caulking. In the following, the term building envelope is also used for bioclimatic envelopes without sealing function.

[8] An inert indoor climate has a low adaptation to the outside temperature change between day and night.

solutions for the process. Dehumidification can be accomplished by drying agents such as silica gel for the extraction of moisture. Solar energy can be used to reactivate the drying agents in order to guarantee a continuous process. Those are alternatives with exclusive use of renewable energy sources in contrast to the highly energy-consuming air-conditioning systems. However, due to the complicated processes and materials involved, partly also toxic, high investment costs are required. For the low and constant temperatures levels that are available in the upper layers of earth, shallow geothermal energy is a reliable resource and especially suitable for space heating and cooling. The resource has increasingly been utilized for heating by using heat pumps to elevate the temperature of the exploited energy to a useful level.

In general, also simple heat exchange by leading water tubes through the ground at depths of few meters can have a great effect for heating or cooling purposes. The water is pre-heated or pre-cooled before entering the corresponding room or adjacent surface and the indoor climate can be provided in an energy-saving manner without high technological effort. However, this method is problematic and barely functional in combination with humid climate. (Laustsen, 2008; Kaltschmitt, 2007; Hussain, 2003)

4.6.3 Further aspects

As already mentioned, the described methods and technologies have been developed for industrialized countries. Accordingly, the different climatic and environmental conditions as well as economic and cultural factors that dominate the region of investigation are important to consider. Furthermore, to facilitate low-energy buildings, it is important to use effective electrical devices that save energy from the demand side, instead of loading the elaborate overall system with evitable electricity demand. Those devices, as well as various components of the complex building structure and the on-site technology have high investment costs. Therefore, establishing future-ready technology in new markets is a long process, although diligently planned systems often pay off within a few years due to the high energy savings. Due to the socio-economic background, the situation is difficult in countries in development like Mexico.

4.7 Conclusion

From the first conceptual ideas until the realization of the building, the environmental situation and especially climatic conditions have to be taken into account. The orientation of the building and its envelope, which is to say materials, form, color, spaces and openings, need to be developed in dependence on these conditions. In terms of orientation, the consideration of the sun should be prioritized; only after that, the wind direction for good ventilation is regarded, because in comparison to the sun, wind effects can be deflected. Always in consideration of comfortable indoor climate, the dependence on mechanic systems that serve as supportive systems should be reduced as far as possible, in order to keep the energy consumption during operation low. If all mentioned aspects are regarded adequately, the created building is developed with good understanding of the environment and is consistent with its surrounding, in conformity with bioclimatic architecture. (Lippsmeier, 1980; Olgyay, 1937)

5 Fundamentals of the investigation

5.1 Basic principles of the assessment

5.1.1 Hypothesis

The hypothesis that motivated the conduction of this investigation is the proposition that in the warm-humid climate of Quintana Roo thermal comfort can be provided by simple means with focus on natural principles, without any use of air conditioning systems.

5.1.2 Methodology

Six different residential buildings within the state Quintana Roo have been chosen based on the consideration of the following criteria:

- Involvement of energy efficiency principles;
- Consideration of different types of architecture;
- Consideration of different regions within the state;
- Use of natural materials (only applies partially).

Time constraints and limitations in the carried measurement equipment allowed for conducting measurement series for three of the selected buildings over a period of a minimum of seven days each. Those were realized in April and May 2012; corresponding to the specific climate data (defined in section 5.3.1), temperatures amongst the highest of the year may be expected. Therefore, the obtained statements by the measurements of the selected buildings are assumed to be representative for the maximum cooling loads.

The map in Figure 5-1 shows the locations of the different study cases within the state of Quintana Roo. All of the selected buildings are inhabited and represent real conditions in this way. They differ in many aspects, amongst others the following:

- Design concepts;
- Form;
- Materials;
- Number of inhabitants;
- Lifestyle of inhabitants;

- Roles of building planners and inhabitants (planners and inhabitants are the same persons or different persons and known/unknown);
- Surrounding area: city, village or tropical forest.

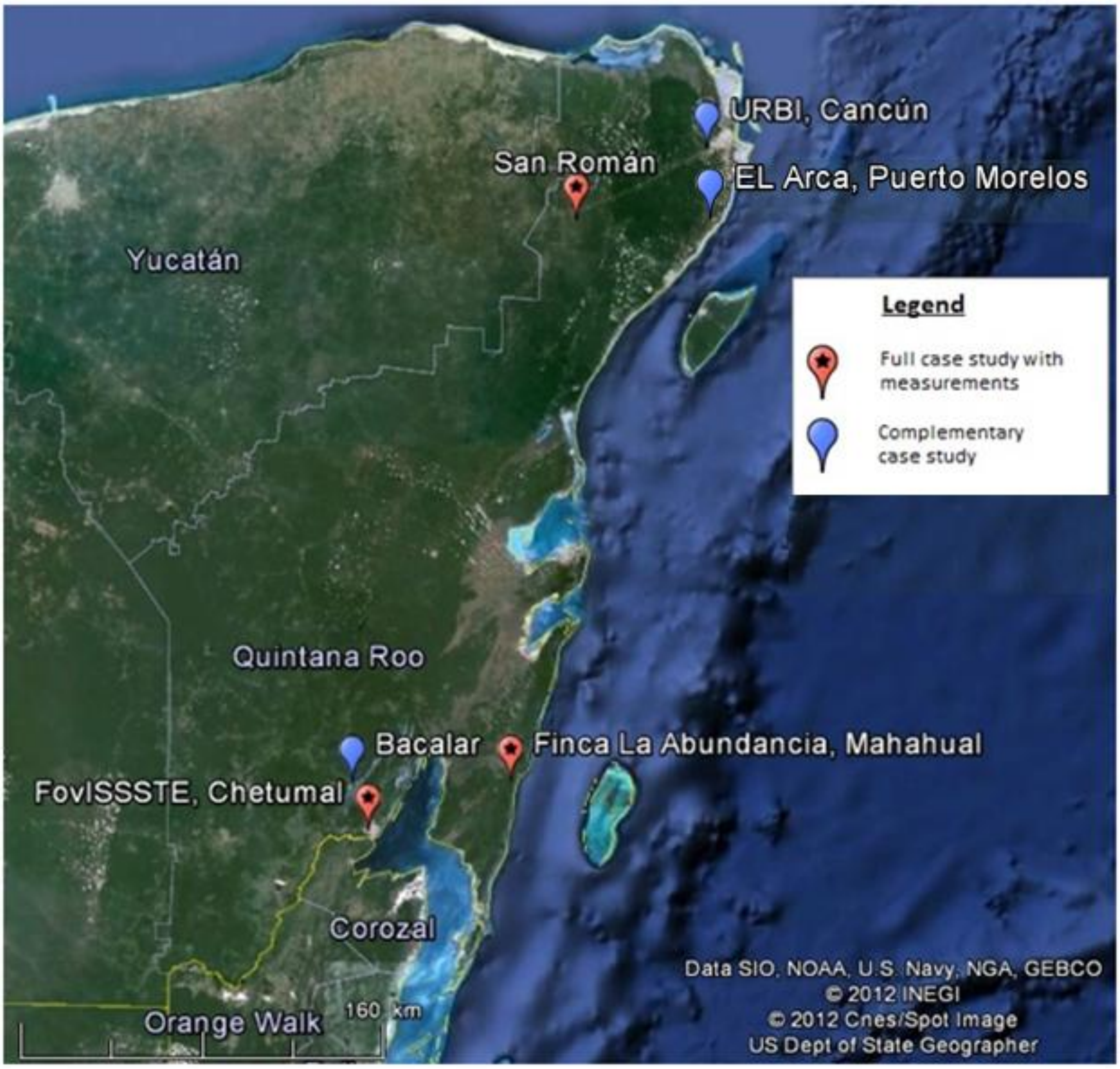

Figure 5-1: Map of Quintana Roo locating the different case studies. Source: Google Earth, 2012

Not only for the planning process – when the role differs from case to case – but above all during the operation of the building, the users have decisive influence; their perception of thermal comfort dominates the use of ventilators, opening and closing of windows and doors, for instance.

5.1.3 Procedure of the assessment

The three main case studies have been evaluated based on the following aspects:

1. Thermal performance and compliance with a tolerable indoor climate;
2. Environmental impact of the building for construction: embodied energy and CO_2 emissions.

Temperature and humidity measurements for interior in comparison to exterior allowed for conclusions on performance of the examined buildings in terms of thermal comfort. Therefore, the limits of thermal comfort had to be defined and operands basing on the measured values were derived; those further steps and specifications about the measurements are outlined in the subchapters 5.5 and 5.2 respectively.

The environmental impact of building construction refers to embodied energy, the energy intent of the used building materials for their fabrication, and the related CO_2 emissions.

5.1.4 Assessment of environmental impact

A healthy balance of operational energy and embodied energy content of buildings needs to be found; for that, the overall environmental impact and use of resources must be assessed. This issue was introduced in section 4.5 of the previous chapter; considering that the investigated buildings provide thermal comfort at low contribution of auxiliary technical means, the consumption during the operation of a bioclimatic building is supposed to be significantly lower than that of buildings which manage heating and cooling loads with heating and air-conditioning systems. At the most, ventilators are used in order to improve the indoor climate. Corresponding to the operational energy demand which is supposed to be rather low in comparison, the embodied energy has an increased share on the total energy consumption of the building and therefore requires to be inspected diligently.

The amounts of different construction materials were gathered by adding up the particular volumes of the building elements (in the case of Casa Macías Villalobos the masses have been available directly from the list of construction materials); subsequently, the mass was extracted by means of the specific bulk density. By multiplication of the derived masses with the environmental factors (embodied energy in MJ/kg, CO_2 emissions in kg CO_2/kg) the specific consumed energy and released carbon emissions for each building material were revealed. In addition to the derived total numbers of embodied energy and CO_2 emissions, total building mass per living space and per inhabitant were used as further indicators; the total numbers also were broken down into the single materials. The calculation tables elaborated for the estimations of materials and impacts are shown in annex B on p. 165 ff.

However, the used parameters in this evaluation can fluctuate largely from region to region. Embodied energy has a wide range since manufacturing processes and also transport distances can differ essentially. Those variables comparably affect the consumption of the various fuels that are involved in the different processes and are responsible for the emissions of CO_2. The parameters therefore all highly depend on the used energy sources for the different manufacturing steps, from the extraction of raw materials until the transportation of the final product, furthermore construction and installation themselves. Therein, the efficiencies in the conversion from the used fuel to the required energy form, the efficiency of the fabrication processes themselves as well as the means and distances of all required transport distances are some of the major factors included in the parameters for embodied energy and CO_2 emissions. Figure 5-2 delivers insight into the different steps of a product's lifecycle, subdivided into three main phases. It becomes clear that also the possibilities of reuse and recycling play an important role in the assessment of the overall environmental impact of a material. In order to obtain as representative parameters as possible for the estimation, several references were included in order to take the average values from the available individual numbers.

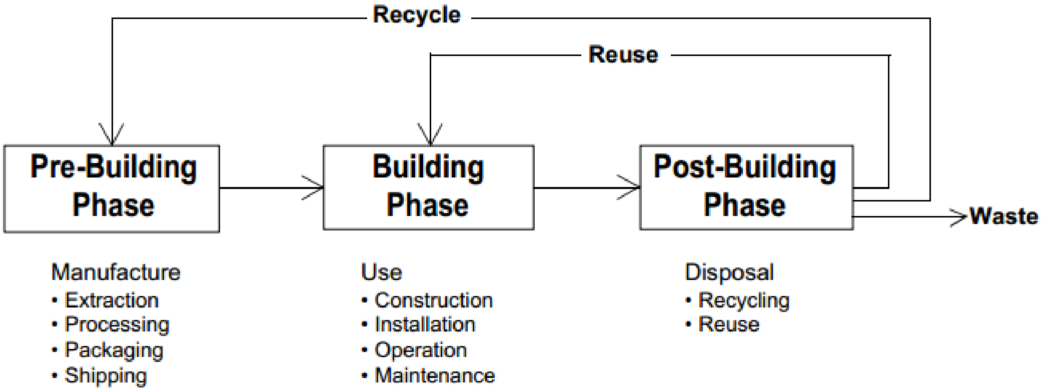

Figure 5-2: Three phases of the building material life cycle. Source: Kim (1998)

Another important consideration is the lifetime of a material; natural materials have significantly shorter lifetimes than industrially fabricated products which are designed for high strain and thus are characterized by high durability. This factor is not included in the estimations of environmental impact for the different case studies. On the other hand, artificial materials usually contain residues which are complicated to treat and thus cause another environmental impact, in contrast to unproblematic biological degradation of natural materials; in this sense, the neglect of lifetime is supposed to be balanced a bit. (Milne, 2008; Kim, 1998)

5.2 Fundamentals for the measurements of thermal comfort

5.2.1 Measurement equipment

The used measurement equipment contains three resistance temperature detectors (RTDs) of the type PT 100, one of them put into a black globe for analysis of thermal radiation, one comfort sensor and for exterior measurements one combined temperature (PT 100) and humidity sensor. The comfort sensor measures the effective temperature which is a function of dry bulb temperature, wet bulb temperature and air velocity. The relevant differences between dry and wet bulb temperature were introduced in the "Temperature" section of "Definitions", before the introduction. The PT 100 sensors are PTC resistors which means that they have a positive temperature coefficient; PT 100 resistors measure the temperature by correlating it with the conductor resistance of a built-in platinum element. Corresponding to common accuracy values and standardization by IEC 60751 (2008), a limiting deviation of ± 0.3 K is assumed. The black globe in combination with an inserted temperature sensor measures radiant temperature at a limiting deviation of ± 0.3 K (Campbell Scientific, 2012). In agreement with the findings from recalibration (see annex section 5.2.1), the effect by radiation was neglected and the measured temperature was approximated as dry bulb temperature. The used temperature sensors are characterized by minor limiting deviations and thus are interchangeable without recalibration.

The humidity sensor (hygrometer) correlates electric capacity generated on two thin conductive plates between a dielectric with relative temperature at approximately linear dependency. For two-point calibration, a limiting deviation of ± 2 % relative humidity can be assumed. (Bull, 2006) After completion of the measurements, the hygrometer was recalibrated in order to correct the measured values; therefore, two measuring points obtained by aqueous salt solutions at oversaturated state in a sealed container were used (see also section 5.2.2 of the annex).

The wires of each sensor for current or voltage and the signal were connected to the terminal block of a data logger of the type MODAS 1632, distributed by NES Measuring Systems (Viel, 2004). The wiring scheme is presented in annex B p. 138.

5.2.2 Conduction of measurements and collecting of values for thermal evaluation

Some complications occurred during the preparation and installation of the measurement equipment; these can be read in section 5.1.1 of the annex. The conduction of measurements and subsequent post-processing are described in section 5.1.2, 5.1.3 and 5.2 of the annex, by dealing with the following items:

- Installation of measurement equipment (overview table of wiring, mounting of sensors and observations; a scheme plan of wiring is attached in annex B on p. 138);
- Recalibration of black globe and humidity sensor.

Further post-processing of data such as the determination of indoor humidity and of air movement is related to the thermal comfort assessment and is outlined in subchapter 5.5.

The final values based on the results from the measurements themselves and the documentation about the mentioned subsequent works are attached in annex B (see p. 141 ff. and p. 139 f. respectively). Due to the immense accumulation of data by a mean time of two minutes for the registration of measured data in the data logger, the documentation is reduced to hourly values. These were retrieved by calculating the average values for each hour, for example for 9 a.m. the values from 8:30 to 9:28 were taken into account.

5.3 Thermal comfort

For each of the three measurement series, one typical day was chosen for comprehensive assessment. The values pertinent to the selected days are highlighted by gray background in the summaries by hour in annex B (see p. 141 ff.).

From there, the comparison between inside and outside measured values and especially the present deviation for each hour from the thermal comfort zone are explored and evaluated for each case study. Under reference to the comfort diagram by Szokolay, the corresponding demand of air movement in order to comply with the comfort requirements is estimated for every hour of the selected days.

5.3.1 Agreement on the use of climate data

Although the region where the investigation was carried out extends over some hundred kilometers, this research aims to evaluate buildings on the adequacy of their designs, rather than drawing comparisons between different climate data. Therefore, one location was chosen as the common reference. The selection of Chetumal as the standard for climate data allows for an approximate evaluation of the different case studies.

In order to be able to evaluate buildings on thermal comfort, the limits of the comfort zone need to be set. Options and selection criteria will be discussed in the following paragraphs.

5.3.2 Thermal comfort model of Olgyay

One of the pioneers in the area of bioclimatic design was Victor Olgyay; the limits of thermal comfort elaborated by Olgyay (1973) are directed to tropical climate zones. Most general, the human comfort is influenced by temperature and humidity. The comfort zone presented by the area filled in dark gray in Figure 5-3 is spanned by dry bulb temperature and relative humidity and represents the limits under the condition of still air without movement. Under this condition, comfortable indoor climate ranges from 23 to 29.5°C dry bulb temperature at a relative humidity between 18 and 50%, higher humidity up to 78% is tolerable only at lower temperature, decreasing to a maximum of 23°C for the highest tolerable humidity.

However, by bringing in air movement, the comfort zone can be extended upwards to higher temperatures, and downwards by adding heat; this is indicated by the lines starting at the second scale from the right. Contrary, for buildings where space heating applies, the permitted air movement according to effective standards is highly restricted, often to 1 m/s. The influencing factors of indoor climate have been described more in depth in the previous chapter (see section 4.3 and 4.4). (Lippsmeier, 1980)

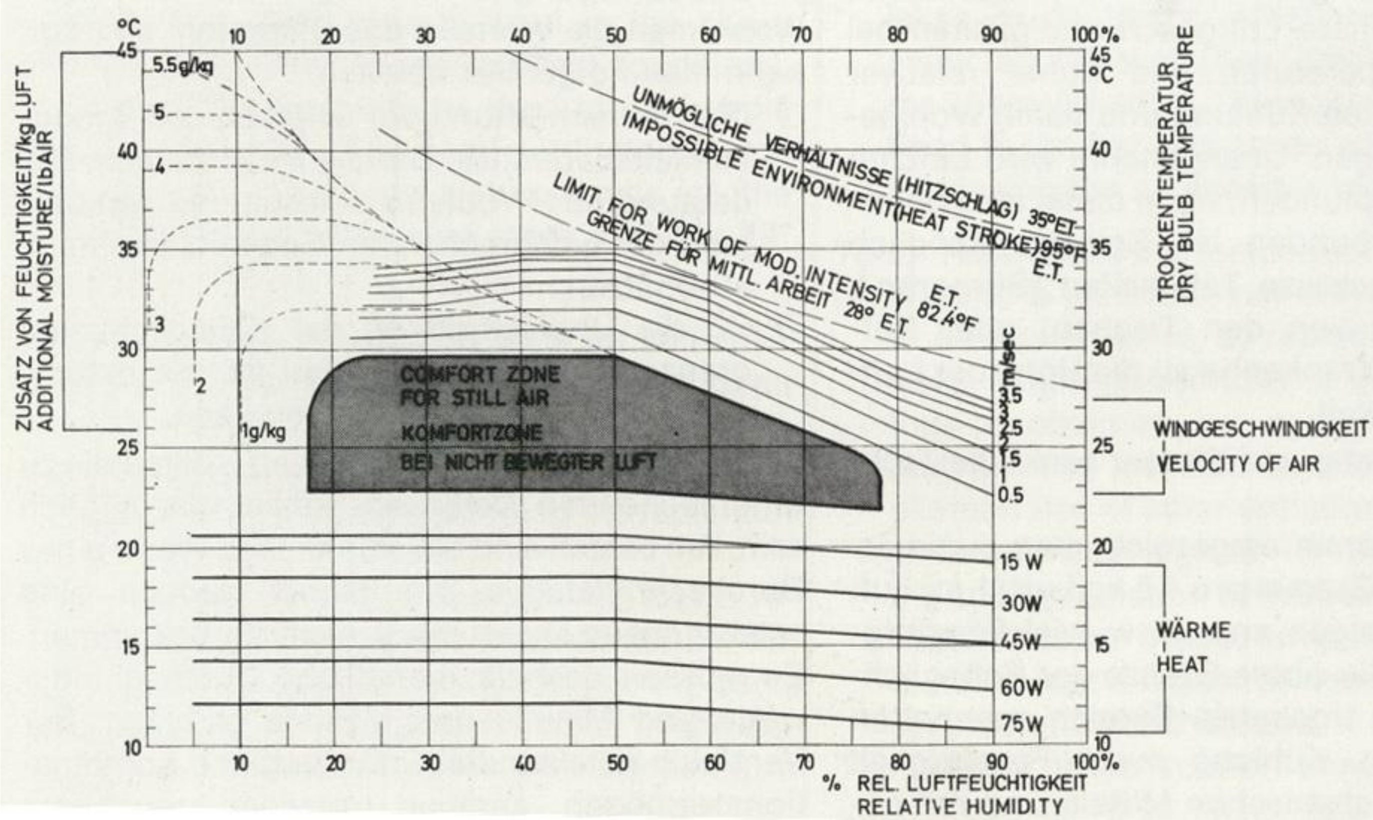

Figure 5-3: Bioclimatic diagram by Victor Olgyay. Source: Lippsmeier, 1980

5.3.3 Comfort model of Szokolay

Beginning with the optimum temperature, commonly called neutral temperature, various authors and institutions have defined different temperature ranges as thermal comfort zones which represent the tolerable range for thermal comfortableness of individuals.

The comfort diagram based on the achievements by Olgyay (1973) was extended by Szokolay[9] by adapting the comfort zone to the local climatic conditions and corresponding human acclimatization. Therefore, the neutral temperature (optimum temperature) was integrated in the following way:

First, the annual mean temperature $T_{m,\ annual}$ is defined by taking the median of the monthly average temperatures; then, the neutral temperature T_n is calculated as follows:

$$T_n = 17.6\ °C + 0.31 \cdot T_{m,\ annual} \quad (1)$$

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[9] Skokolay, S. (1984), “Passive and low energy design for thermal and visual comfort“, Passive and low Energy Ecotecniques Applied to Housing (PLEA’84), Pergamon Press, New York, England

The Range of Thermal Comfort RC is defined by a span of 2.5 K around the neutral temperature:

$$RC = T_n \pm 2.5\ K \quad (2)$$

As shown in Figure 5-4, the central point of orientation at 50% relative humidity spans the comfort zone with the 2.5 K range towards both extremes, with the horizontal arrow pointing onto that point of the dry bulb temperature scale which represents the neutral temperature.

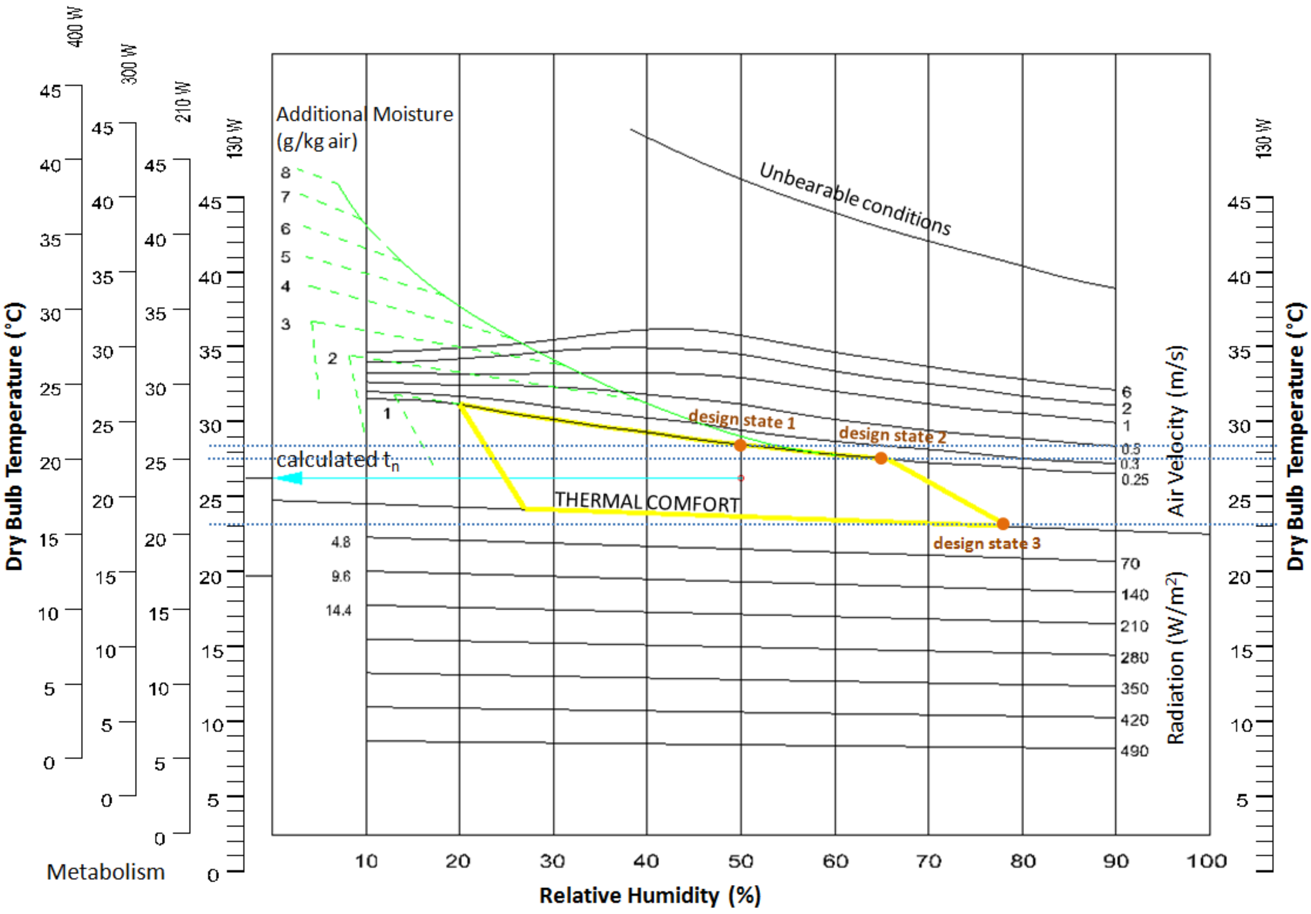

Figure 5-4: Thermal comfort zone according to Szokolay with adjustments corresponding to the climatic conditions of Chetumal; design states elaborated for metabolism of 130 W. Source: Bojórquez, 2012

Based on the psychrometric chart (see annex Figure A-6) which by default relates air temperature to humidity (one perpendicular to each other for humidity as moisture content), the graph includes radiation by the parallel, almost horizontal lines below the framed comfort zone, furthermore air movement by the curved lines above the comfort zone and metabolism by the dry-bulb temperature scale in four different adjustments on the left side of the chart. Additional moisture content (g/kg air) is plotted on the upper left. The curved line on the upper right symbolizes completely incompatible climatic conditions which hold the risk of suffering a heat stroke. (Olgyay, 1973; Bojórquez, 2012)

5.3.4 Limits of thermal comfort

Due to the applicability and the evident use in the investigated region, the limits defined in the adjusted model of Szokolay seem appropriate and will be used within the scope of this investigation.

5.4 General guidelines based upon the specific climatic conditions

5.4.1 Prognostications by use of comfort diagram

By use of the historical weather data of Chetumal, the challenges coming along with the present climatic conditions can be prognosticated. The requirement of a comprehensive data set which includes high mean and low mean values in monthly average for air temperature and relative humidity was fulfilled by MyForecast (2012). The mentioned temperature and humidity values according to the specific climate data were drawn into the previously presented comfort diagram after Szokolay for each month; this is visualized by the excerpt shown in Figure 5-5 whereat Latin letters indicate the particular months and two different cycles are distinguished.

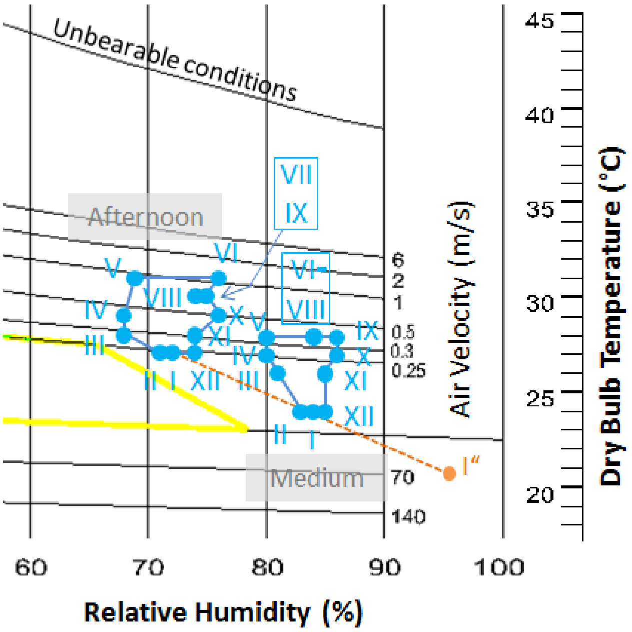

Figure 5-5: Excerpt of comfort diagram after Szokolay with Chetumal's monthly average temperature and relative humidity values; upper left cycle: high mean temperature and average afternoon relative humidity; lower right cycle: mean temperature and relative humidity averaged between morning and afternoon. Diagram based on Bojórquez, 2012; climate data: My Forecast, 2012

The cycle to the upper left shows the course over the year for high mean temperature and the corresponding relative humidity in the afternoon. The cycle to the lower right shows the mean temperature (daily medium) and the particular relative humidity which was therefore averaged between morning and afternoon; this state approximately corresponds to the conditions at noon. As visible by the diagram, the exterior climatic conditions are outside of the thermal comfort zone for the entire year under the simplified consideration of average values; this is mainly due to the strong penetration of sultry heat.

It also turns out that climatic conditions all over the year are relatively constant, in contrast to certain fluctuation throughout the day. As a consequence, the conditions at the two distinct daytimes, which have been specified by the two cycles, are strictly separated and thus face different challenges; the afternoon conditions at the temperature peak generally maintain within a still tolerable humidity range, while the mean values hint at problems related to the high relative humidity. Moreover, the mean values which refer to noon naturally represent moderate conditions. The morning conditions could be projected in the diagram of Figure 5-5 by point reflection of the afternoon state on the mean value; this is indicated exemplarily for state I, resulting in the point shown as ‘I’’ for January in the morning. As a first conclusion, the conditions exceed thermal comfort all over the year for both considered daytimes, and peak in the beginning of the second half of the year. However, from the contemplation in the diagram, even the highest loads seem manageable by somewhat accelerated air movement. Input of air movement, be it by natural means or by forced ventilation, is definitely required for large times of the year in order to provide tolerable indoor climate. This measure produces relief both for sultry heat and for temperature levels above thermal comfort at less humid conditions. Apart from the first rough overview by manual integration of month-based climate data into the comfort diagram, the following software tools have been used to give a more comprehensive insight and estimate the requirements on the building design.

5.4.2 Mahoney table

(Grimme, 2006; climate data based on My Forecast, 2012)

The Mahoney table offers decision support by analyzing the specific climatic conditions; the climatic characteristics are linked to the general scope for design by using a selection filter. By controlling which of the different options meet the requirements, the adequate approaches are selected and shape the list of recommendations.

By entering the climatic conditions of Chetumal according to My Forecast (2012), the following guidelines were obtained from the decision tool, ordered by the category of design element (see also Excel™ calculation sheet attached in annex B p. 156):

- Layout: North-south orientation which means the long axis reaches from east to west;
- Spacing: Open spacing for ventilation, but protection from hot and cold wind;
- Air movement: Single-row rooms, continuous measures for air movement;
- Openings:
    - Large openings, 40 - 80 % of the facade;

  - North-south windows in wind direction at body height;
  - Windows: avoid direct irradiation;
- Walls: Light-weight, with short phase shifting;
- Roofs: Light-weight, but well-insulated (<u>only for roofs made of solid materials</u>).

The final point about well-insulated roofs is controversial. A light-weight roof can be made of natural materials like straw of palm leafs as typical pitched roofs in the region are; consequently, in this case the building concept should benefit from the good permeability which offers strong heat dissipation of indoor air upwards and toward the roof. However, thermal insulation makes sense for roofs that are built with solid materials like concrete; in this case, heat penetration from exterior toward the roof can be reduced without impairing the air exhaust of heated air.

5.4.3 Climate consultant

(Climate Consultant, 2011; climate data based on Energy Plus, 2010)

By means of the software Climate Consultant 5.2®, complementary, more detailed statements were made about the challenges and possibilities that building design will have to face within its objective to provide comfortable indoor climate. The statements are based on the climate data for Chetumal in the required file format as provided by Energy Plus® (2010), available in Table A-3 of the annex.

In agreement with the common consensus, the software establishes a relationship of thermal comfort with dry bulb temperature, clothing level, metabolic activity (in met), air velocity, humidity and mean radiant temperature.

Therein, the climate tool distinguishes several comfort models, two of which are considered for assessment in the scope of the present climatic conditions:

- <u>Adaptive Comfort Model in ASHRAE Standard 55-2004:</u> This model exclusively considers natural means for ventilation; it takes thermal response into account, which means better adaption of the users to the outdoor climate in comparison to those who live with centralized HVAC[10] systems, what results in a wider comfort range. Beyond the necessity to open and close windows adequately, it is important in this strategy to adapt clothing to thermal conditions (clothing varies from 0.5 to 1 clo). Furthermore, the model assumes that the users are sedentary (1.0 to 1.3 met, equal to 100 to 130 W of heat dissipation).
- <u>ASHRAE Standard 55-2004 using PMV Model:</u> Technical means are included as far as necessary, its assumptions for thermal comfort base on the PMV model (Predicted Mean Vote, see section 5.5.5). The model equally assumes that occupants adapt

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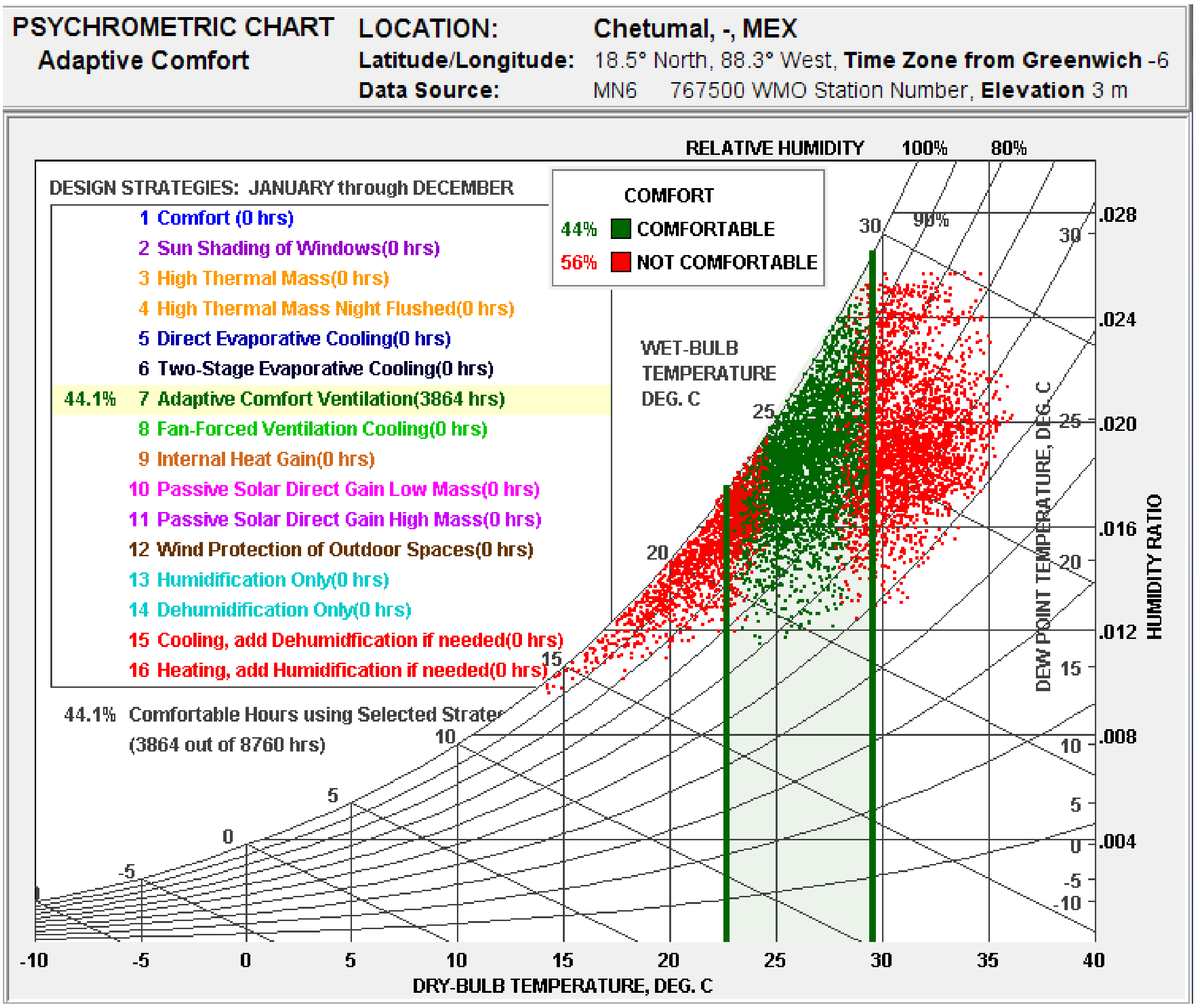
[10] HVAC: heating, ventilation and air conditioning

their clothing to the season, but they accept higher air velocities, thereby allowing for a wider range of comfort than in buildings with centralized HVAC systems. The set parameters can be reviewed in the annex in Table A-4.

By selection of 90% acceptability limits in the program, the comfort zone for both selected comfort models reaches from 22.7 to 29.5°C; in the graphic illustrations, the comfort zone is enclosed by vertical isothermal lines at both borderlines. Figure 5-6 displays the results in the psychrometric diagram for the Adaptive Comfort Model.



PSYCHROMETRIC CHART
Adaptive Comfort

LOCATION: **Chetumal, -, MEX**
Latitude/Longitude: 18.5° North, 88.3° West, **Time Zone from Greenwich** -6
Data Source: MN6 767500 WMO Station Number, **Elevation** 3 m

DESIGN STRATEGIES: JANUARY through DECEMBER

1 Comfort (0 hrs)
2 Sun Shading of Windows(0 hrs)
3 High Thermal Mass(0 hrs)
4 High Thermal Mass Night Flushed(0 hrs)
5 Direct Evaporative Cooling(0 hrs)
6 Two-Stage Evaporative Cooling(0 hrs)
44.1% 7 Adaptive Comfort Ventilation(3864 hrs)
8 Fan-Forced Ventilation Cooling(0 hrs)
9 Internal Heat Gain(0 hrs)
10 Passive Solar Direct Gain Low Mass(0 hrs)
11 Passive Solar Direct Gain High Mass(0 hrs)
12 Wind Protection of Outdoor Spaces(0 hrs)
13 Humidification Only(0 hrs)
14 Dehumidification Only(0 hrs)
15 Cooling, add Dehumidification if needed(0 hrs)
16 Heating, add Humidification if needed(0 hrs)

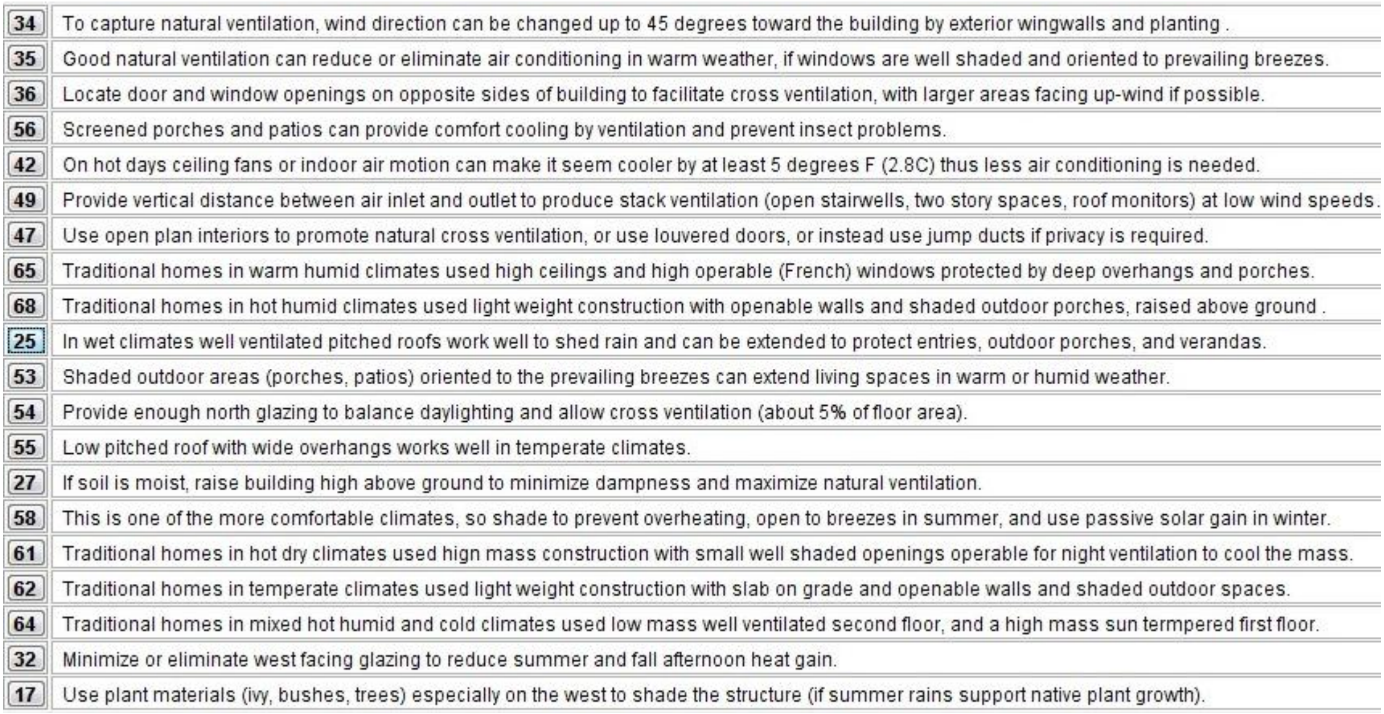
44.1% Comfortable Hours using Selected Strateg
(3864 out of 8760 hrs)

COMFORT
44% 🟩 COMFORTABLE
56% 🟥 NOT COMFORTABLE

Figure 5-6: Psychrometric diagram with all hours of the year for the Adaptive Comfort Model. Elaborated by use of Climate Consultant, 2011.

The states for all hours of the year are presented as green or red dots in the diagram, for comfortable and not comfortable conditions respectively. On the left side, all possible measures on indoor comfort with their corresponding impact (contribution in percentage and hours of the year) are listed. Given the settings for this comfort model in the climate tool, not even other natural means such as sun shading of windows are available to add to the assessment. As a result, the exclusive application of adaptive natural ventilation within the range of available means for room tempering, thermal comfort is only obtained for 44.1% of the year. Adjusted to the particular climatic conditions, Climate Consultant 5.2® presents a list of twenty design guidelines which are ordered by importance, shown in Table 5-1:

Table 5-1: List of design guidelines in the Adaptive Comfort Model for climatic conditions of Chetumal. Source: Climate Consultant, 2011

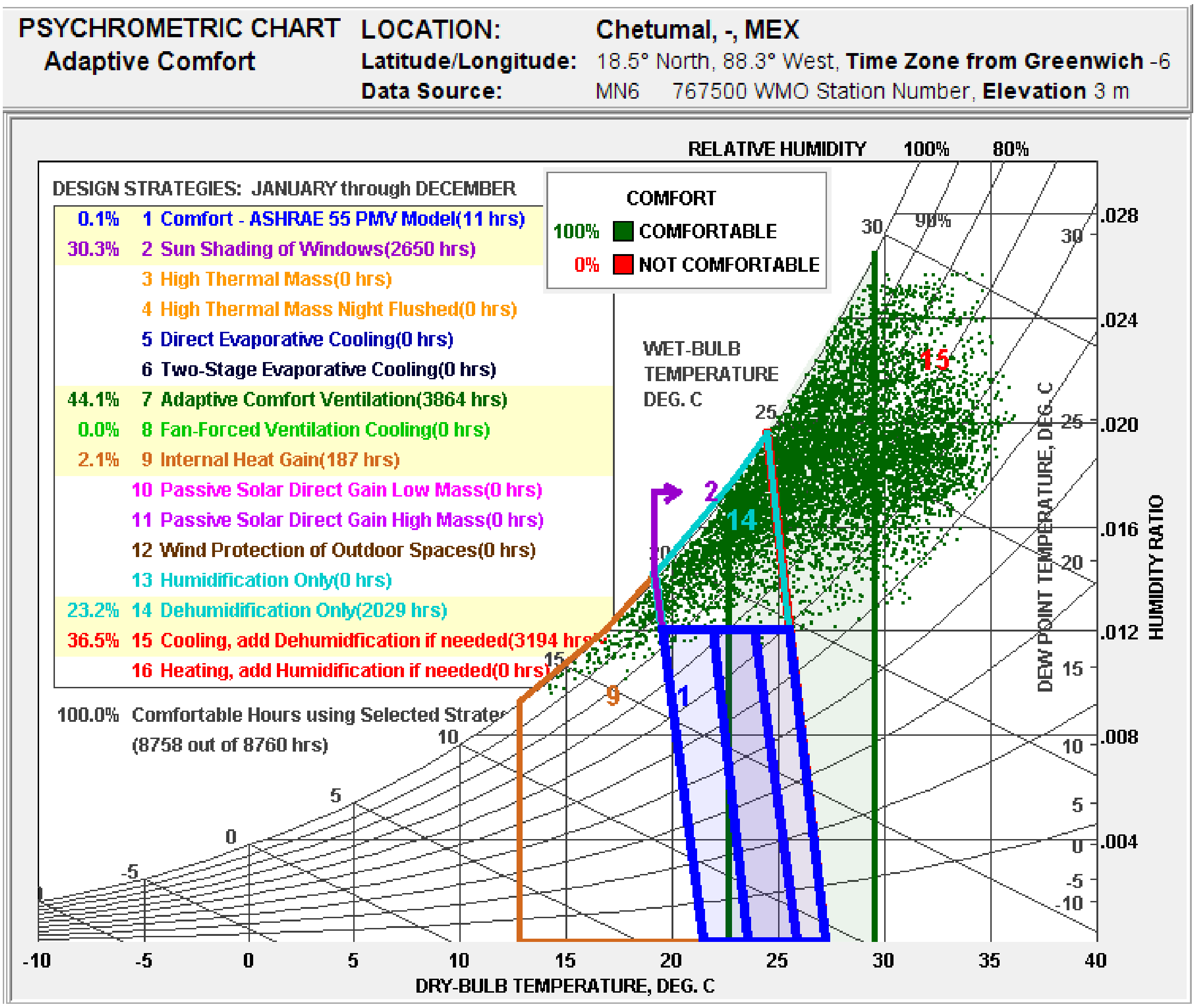


34	To capture natural ventilation, wind direction can be changed up to 45 degrees toward the building by exterior wingwalls and planting .
35	Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes.
36	Locate door and window openings on opposite sides of building to facilitate cross ventilation, with larger areas facing up-wind if possible.
56	Screened porches and patios can provide comfort cooling by ventilation and prevent insect problems.
42	On hot days ceiling fans or indoor air motion can make it seem cooler by at least 5 degrees F (2.8C) thus less air conditioning is needed.
49	Provide vertical distance between air inlet and outlet to produce stack ventilation (open stairwells, two story spaces, roof monitors) at low wind speeds.
47	Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required.
65	Traditional homes in warm humid climates used high ceilings and high operable (French) windows protected by deep overhangs and porches.
68	Traditional homes in hot humid climates used light weight construction with openable walls and shaded outdoor porches, raised above ground .
25	In wet climates well ventilated pitched roofs work well to shed rain and can be extended to protect entries, outdoor porches, and verandas.
53	Shaded outdoor areas (porches, patios) oriented to the prevailing breezes can extend living spaces in warm or humid weather.
54	Provide enough north glazing to balance daylighting and allow cross ventilation (about 5% of floor area).
55	Low pitched roof with wide overhangs works well in temperate climates.
27	If soil is moist, raise building high above ground to minimize dampness and maximize natural ventilation.
58	This is one of the more comfortable climates, so shade to prevent overheating, open to breezes in summer, and use passive solar gain in winter.
61	Traditional homes in hot dry climates used hign mass construction with small well shaded openings operable for night ventilation to cool the mass.
62	Traditional homes in temperate climates used light weight construction with slab on grade and openable walls and shaded outdoor spaces.
64	Traditional homes in mixed hot humid and cold climates used low mass well ventilated second floor, and a high mass sun termpered first floor.
32	Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain.
17	Use plant materials (ivy, bushes, trees) especially on the west to shade the structure (if summer rains support native plant growth).

Evidently, measures for direct enhancements of natural ventilation and also of shading are prioritized, such as proper orientation of openings and deflection of wind. Furthermore, adequate shading of openings and porches are regarded as good measures for improvement of shading. Also a relationship with traditional design elements is established in several recommendations.

Basing on the results for the Adaptive Comfort Model, Figure 5-7 shows all additional measures within the scope of the ASHRAE 55 PMV Model required to achieve 100% of thermal comfort. Same as in the prior diagram, thermal comfort is enclosed by the vertical isotherms. The comfort zone after ASHRAE 55 PMV, displayed for comparison, is encircled by the blue lines, ranging from 19 to 28°C dry bulb temperature and from 0 to 0.012 humidity ratio; this highlights the extraordinary load by high humidity and high temperature levels over large periods of the year. But at least the climatic conditions above, within the borders of the Adaptive Comfort Model (vertical isothermal lines), are covered by natural ventilation; in this way, the high air humidity is tackled by increased air movement and for 44.1% of the year no additional means are required.

The climatic states perceived as uncomfortable in the pure Adaptive Comfort Model (see Figure 5-6) are covered by technical means in form of cooling for 36.5% of all hours of the year (right to the comfort zone) and of dehumidification for 23.2% of the year (left to the comfort zone).



PSYCHROMETRIC CHART **LOCATION:** **Chetumal, -, MEX**
Adaptive Comfort
Latitude/Longitude: 18.5° North, 88.3° West, **Time Zone from Greenwich** -6
Data Source: MN6 767500 WMO Station Number, **Elevation** 3 m

DESIGN STRATEGIES: JANUARY through DECEMBER
0.1% 1 Comfort - ASHRAE 55 PMV Model(11 hrs)
30.3% 2 Sun Shading of Windows(2650 hrs)
3 High Thermal Mass(0 hrs)
4 High Thermal Mass Night Flushed(0 hrs)
5 Direct Evaporative Cooling(0 hrs)
6 Two-Stage Evaporative Cooling(0 hrs)
44.1% 7 Adaptive Comfort Ventilation(3864 hrs)
0.0% 8 Fan-Forced Ventilation Cooling(0 hrs)
2.1% 9 Internal Heat Gain(187 hrs)
10 Passive Solar Direct Gain Low Mass(0 hrs)
11 Passive Solar Direct Gain High Mass(0 hrs)
12 Wind Protection of Outdoor Spaces(0 hrs)
13 Humidification Only(0 hrs)
23.2% 14 Dehumidification Only(2029 hrs)
36.5% 15 Cooling, add Dehumidification if needed(3194 hrs)
16 Heating, add Humidification if needed(0 hrs)

100.0% Comfortable Hours using Selected Strategies
(8758 out of 8760 hrs)

COMFORT
100% 🟩 COMFORTABLE
0% 🟥 NOT COMFORTABLE

Figure 5-7: Psychrometric diagram with all hours of the year, combined Adaptive/55 PMV Comfort Model. Elaborated by use of Climate Consultant, 2011.

The selection of cooling by fan-forced ventilation in the tool stayed without impact (0%), possibly the software assumes that the cooling potential by ventilation is already used up by adaptive comfort ventilation – natural ventilation and adequate clothing. Internal heat gains bring additional relief for a few cold hours in 2.1% of the year, shading of windows brings an additional 30.5%. However the total percentage numbers add up to more than 100% because individual measures can interfere so that various measures can apply at one single state. Especially shading of windows accounts as an additional measure, applied during hours of cooling. The demand of technical means, which the climate tools estimates to apply to 56% of the year, is divided into the mentioned 36.5% of cooling, corresponding to 3194 hours, and 23.2% or 2029 hours of dehumidification, adding up to 5223 hours demand of technical means for both. Corresponding to bioclimatic building design, cooling would require the use of ventilators for 3194 hours of the year. But the impact by high humidity is often overestimated; relief could be produced by further use of ventilators, or possibly high humidity at acceptable temperature levels could even be tolerated without additional means. Without consideration of humidity limits for thermal comfort, approximately 67% of the year would be tolerable without additional means.

The emitted guidelines by the climate tool corresponding to the design with inclusion of technical means coincide with the previous list of guidelines to a large part but in different order; amongst the few different guidelines some refer to design optimizations related to the operation of the air-conditioning system. Additional points that are also worth the consideration for naturally ventilated spaces are the use of light-colored building materials including roofs with high emissivity (item 43), the orientation of most of the glass to the north, shaded by vertical fins (item 57) and window overhangs designed for the particular latitude or operable sunshades (extend in summer, retract in winter, item 37). Considering overhangs, it must be assured that overhangs do not inhibit the air flow; this topic has been discussed in section 4.2.2 of the prior chapter. The whole list of guidelines for the combined Adaptive/55 PMV Comfort Model is available in Table A-5 of the annex.

5.4.4 Compilation of recommendable design guidelines

As conclusion from the guidelines obtained by means of the Mahoney calculation table after Grimme (2006), Climate Consultant 5.2® (Climate Consultant, 2010) and the general statements for warm-humid climate according to Lippsmeier (1980), the following criteria were compiled as the essential principles for building design in Quintana Roo and will be used as assessment matrix of the case studies.

<u>Arrangement and air movement:</u>

1. North-south orientation of the building (long axis reaches from east to west);
2. Open arrangement and low building depth (enhance natural ventilation), but protection from hot and cold wind;
3. High ceilings and high outlets, preferably operable openings protected by overhangs;
4. Openings at body height orientated to prevailing breezes; in addition, planting and wind deflectors facilitate natural ventilation (wind direction can be changed up to 45° toward the building);
5. Large openings (40 - 80 % of the facade), located on opposite sides of the building to enhance cross ventilation (larger areas windward if possible);
6. Most of the openings orientated to the north to balance daylighting and enhance cross ventilation (for the southern hemisphere, the preferred orientation is south);
7. Shading of exterior rooms, especially on the west facade, and avoidance of direct irradiation through openings without hindering air circulation (window overhangs or operable sunshades: extend in summer, retract in winter);

Walls and roof:

8. Light-weight building with low heat retention;
9. Well-insulated roof, if built with industrialized materials;
10. Light-colored building materials, also roofs with high emissivity.

Obviously, contradictions can occur in some cases, above all between orientation to the sun and to the main wind direction. In general, the criteria about sun should be regarded as preferable to wind because wind directions can be modified thus the handling with wind is more flexible. But finally, every case has to be observed individually.

5.5 Preparation of assessment

5.5.1 Dry bulb temperature and relative humidity

In the selected comfort diagram by Szokolay (see Figure 5-4), the dots on the border of the comfort zone represent three design states of dry bulb air temperature (which equals the measured room temperature values) and relative humidity which are set as initial points, taking into consideration that the occurring relative humidity in the three measurement series varies between 40 and 100%. The related approximation of metabolism relies on the assumption of 130 W as human activity level which corresponds to light sedentary work (see also Table 4-2).

By linear interpolation between those states, operands for further calculations within the scope of this research are obtained.

5.5.2 Effective temperature

The nomogram by Koenigsberger (1978) displayed in Figure 5-8 establishes the relationship of thermal comfort with air velocity which is derived with the aid of the effective temperature. The selected graph bases on normal clothing (1 clo) corresponding to the observations made by the investigations in the context of the measurement series. At first, the limits of effective temperature are defined by means of the wet bulb temperature t_{wb}; wet bulb temperature comprises the moisture content and can be determined by the use of the psychrometric diagram (see annex Figure A-6) which establishes the relationship of t_{wb} to the given measured values dry bulb temperature t_{db} and relative humidity (R.H.); for convenience, the climate calculator by ASER (1992) was used.

The drawn-in continuous lines in Figure 5-8 show how the limits of thermal comfort were translated into the effective temperature; the effective temperature is taken from the crossing point at the lower border of the diagram in order to capture the condition for calm air (0.1 m/s). The derivation of design state 1 is not shown in order to maintain a clear visibility.

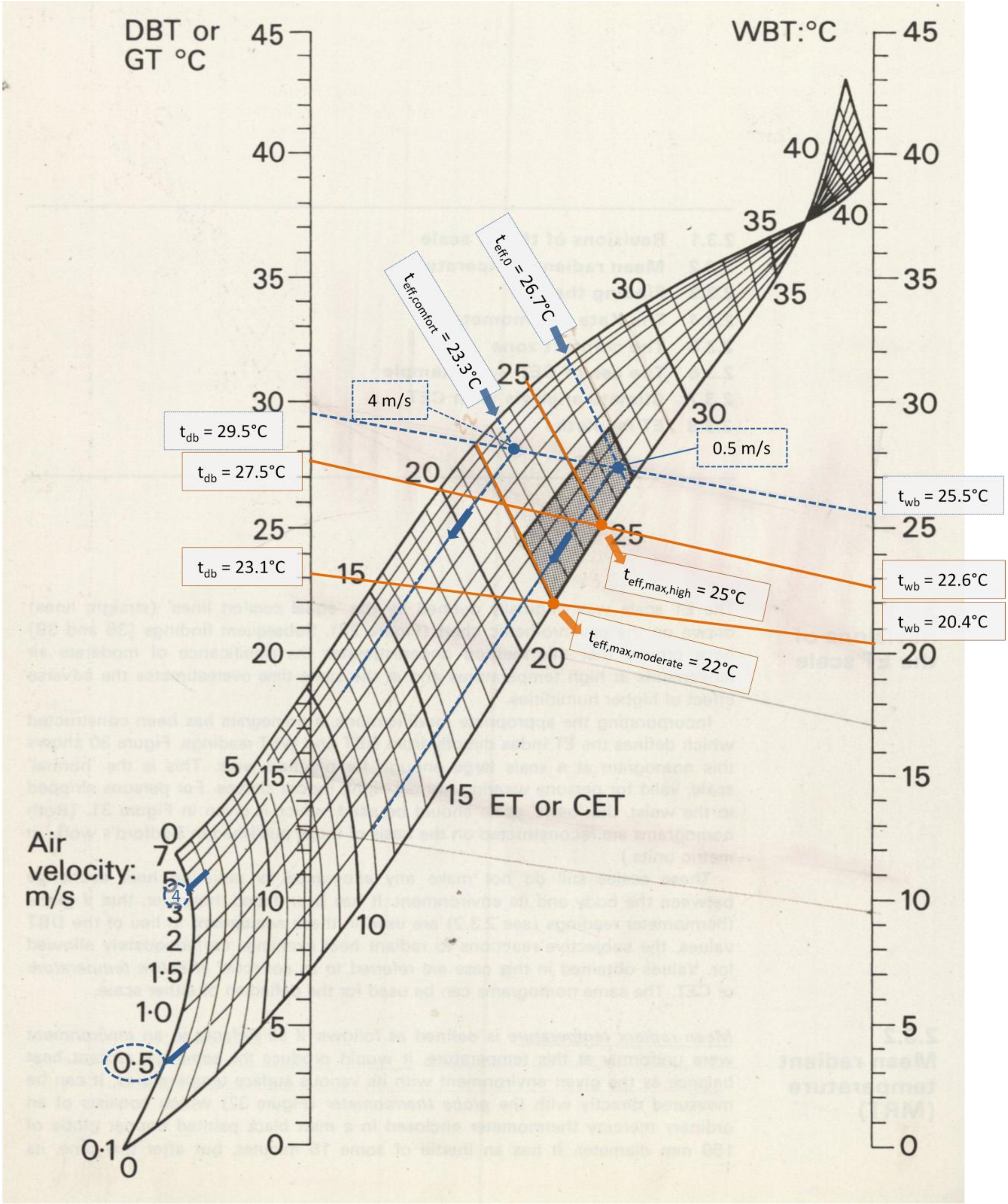


Figure 5-8: Readout of effective temperature and air velocity values by use of nomogram for 1 clo. Source: Koenigsberger, 1978

In summary, the following conditions were derived for the upper limits of thermal comfort, at which the lower border towards being too cold has not been considered:

Table 5-2: Thermal comfort design states elaborated by the diagrams of Szokolay and Koenigsberger

Design state Physical value	Design state 1 (low humidity)	Design state 2 (moderate humidity)	Design state 3 (high humidity)
Dry bulb temperature t_{db} (°C)	28.5	27.5	23.1
Relative humidity R.H. (%)	50	65	78
Wet bulb temperature t_{wb} (°C)	20.8	22.6	20.4
Effective temperature t_{eff} (°C)	24.5	25.0	22.0

5.5.3 Air velocity

The present air velocity is included in the effective temperature values measured by a comfort sensor which was arranged next to a common PT 100 temperature sensor for all three measurement series. Subsequently, the combination of measured room temperature, derived wet bulb temperature and measured effective temperature reveals the particular air velocity by using the nomogram of Figure 5-8 where the dashed lines present an example for the determination of air velocity which adds up to 0.5 m/s in this case.

The required air velocity for thermal comfort is found by defining the upper acceptable limit of the effective temperature. Now the linear interpolation of dry bulb temperature between the neighboring design states as mentioned in section 5.5.1 serves to obtain the effective temperature which is required to provide thermal comfort. By using the nomogram again, the related minimum required air velocity for thermal comfort is determined, in the given example as 4 m/s. Subtracting this new value from present air velocity, reveals the additionally required air velocity for thermal comfort.

5.5.4 Consideration of internal loads

Estimation was required for the obtainment of indoor humidity values given that this variable was not measured directly. First, the enclosed air volumes had to be estimated for the particular room or building (see annex section 5.4).

By multiplying the resulting volumes (saved in the header of Table 5-4) with the density of air, the contained dry air mass was calculated in column E (“Air mass” in kg) of Table 5-4 depending on the present temperature; therefore, the density for dry air was interpolated between the following table values shown in Table 5-3:

Table 5-3: Used table values for density of dry air. Source: Recknagel, 1999

Temperature (°C)	Density dry air (kg/m3)
25	1,184
30	1,164

Reference temperatures are the hourly temperature values in column 2 of Table 5-4 which presents an excerpt of the excel calculation for each hour of the selected day for the case study of Casa Brunner Valdés near Mahahual. The temperature and humidity values are imported from the summary sheet of measurement results by hour. The complete summaries by hour of all measured values are attached for the three series of measurements in annex B (see p. 141 ff.); the complete calculation sheets of indoor humidity for the three selected days are also presented in annex B (see p. 161 ff.).

Table 5-4: Excerpt of the calculation of interior humidity for each hour of the day, based on internal load estimates; case study Casa Brunner Valdés near Mahahual; elaborated by use of MS Excel™

Mahahual Room volume (m^3) 371.8

Hour	t_in2 (°C)	R.H. (%) recalibr.	moisture p. Pers (g)	air mass (kg)	Per-sons	Activity	Add.	Occup. & Activity	add. moisture mass (g)	add. moisture (g/kg air)	sat. vapor press. (mbar)	moisture cont. (g/kg) max.	moisture cont. (g/kg) gross	moisture cont. (g/kg) net	R.H. net (%)
6	26.6	82.8	85	437.87	3	Sleep		1.5	128	0.3	34.8	22.4	18.6	18.8	84.1
7	26.5	82.0	85	437.90	2	Sleep		1	85	0.2	34.7	22.4	18.4	18.5	82.9
8	27.2	73.3	85	436.87	3	Sedentary		3	255	0.6	36.2	23.3	17.1	17.7	75.8
9	28.5	60.8	98	435.03	0			0	0	0.0	38.9	25.2	15.3	15.3	60.8
10	29.4	55.6	98	433.60	1	Sedentary		1	98	0.2	41.1	26.7	14.8	15.1	56.4
11	30.0	50.8	98	432.76	1	Sedentary		1	98	0.2	42.4	27.6	14.0	14.2	51.7
12	30.4	49.2	116	432.22	0			0	0	0.0	43.3	28.2	13.9	13.9	49.2
13	30.4	48.6	116	432.19	3	Sedentary	Cooking	3	398	0.9	43.4	28.2	13.7	14.6	51.9

The exhaust of water vapor is taken from Table 4-3 which applies to humans at sedentary state. Column 4 ("Moisture per person" in g) allocates the corresponding value to the present temperature. For sleeping persons, half of the given table values were assumed.

Based on the given numbers for vapor exhaust and hourly estimates on room occupancy ("Persons") and human activities in the columns 6 to 8 of Table 5-4, the production of water vapor and thus the internal loads on humidity were estimated for the selected day of each case study; column 8 "Add." (Additional) takes cooking activities into account. The subsequent column "Occup. & activity" (Occupancy and activity factor) distinguishes by use of an if-function between the activities Sedentary and Sleeping and assigns the corresponding values to the cells obtained by the number of persons (Sedentary) or half of the same number (Sleeping). Column 10 ("Additional moisture mass" in g) finally determines the internal loads in total numbers by multiplying the occupancy with the derived factor from the antecedent column and by adding a cooking event if applicable, with the aid of an integrated if-function; cooking events rely on the assumptions of 200 g/h vapor exhaust and 0.25 h cooking time. This results in a released water content of 50 g for each cooking event.

The subsequent column ("Additional moisture" in g/kg air) determines the additional moisture caused by the internal loads in reference to the ambient air content; with the quotient of the total number of additional moisture (g) and the air mass (kg), the resulting number was added to the present moisture content of the exterior to finally obtain a value for the total of indoor humidity. For this purpose, it was necessary to translate the measured relative humidity numbers for the exterior into moisture content.

First, in column 12 ("Saturated vapor pressure" in mbar) the saturated water vapor pressure p_s was determined depending on the temperature of the given hour; the following formula was used according to Glück (1991):

$$p_s = 611 \cdot \exp\left(7.257 \cdot 10^{-2} \cdot \mathrm{t} - 2.937 \cdot 10^{-4} \cdot \mathrm{t}^2 + 9.81 \cdot 10^{-7} \cdot \mathrm{t}^3 - 1.901 \cdot 10^{-10} \cdot \mathrm{t}^4\right)$$

With the quotient of dry air and water gas constant of 0.622, the corresponding maximum moisture content X in relation to saturated vapor pressure is defined in column 13 as:

$$X = 0.622 \cdot \frac{p_s}{p - p_s}$$

with $p = p_{ambient}$ = 1000 mbar (ambient pressure).

The product in column 14, consisting of exterior relative humidity and maximum water content at the given temperature converts the exterior relative value into the corresponding water content. Consequently, by adding the estimate for additional moisture content from internal loads (column 11) to the previously derived value, the total indoor moisture content was calculated. In conclusion, the quotient of the derived indoor water content and the maximum water content (column 13) equals the relative indoor humidity written into the ultimate column.

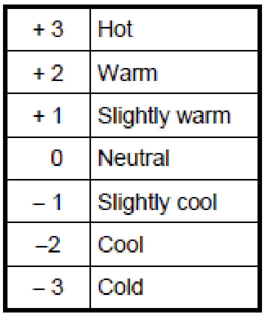
The obtained indoor humidity values are estimated to the maximum, in reality they are supposed to be somewhat lower; due to the high permeability of the building envelopes (given the bioclimatic design of the investigated buildings), the exchange of indoor air with the exterior is very active but has not been considered in the estimation. Furthermore, it is assumed that the building materials do not absorb moisture but delay its transmission to the outside.

5.5.5 Satisfaction with thermal indoor climate

Within the context of a comprehensive alliance of national organizations, a number of countries contribute actively to the creation of knowledge about thermal comfort on international level. International standards obtained are the result from a wellcoordinated process of common consent among the involved countries in order to provide the best internationally agreed methods and data available.

The effective thermal comfort standard ISO 7730 bases on two thermal comfort indices by Fanger established in 1970[11]. The PMV (Predicted Mean Vote) predicts the mean votes of a large group of people on the thermal sensation scale as Table 5-5 shows:

Table 5-5: Seven-point thermal sensation scale of PMV index; Source: ISO 7730, 2005



+ 3	Hot
+ 2	Warm
+ 1	Slightly warm
0	Neutral
– 1	Slightly cool
–2	Cool
– 3	Cold

The human body feels balanced when the internal heat production of the body is equal to the heat loss to the environment; sensed deviation from the equilibrium under influence by human activity, clothing and environmental parameters is expressed as presented in the table.

The PPD (Predicted Percentage of Dissatisfied) estimates the percentage of thermally dissatisfied within a large group of people likely to feel either too cool or too warm.

Further important standards related to the ISO 7730 standard are ISO 8996 for metabolic rate, ISO 9920 for clothing and ISO 7933 for thermal stress, inaccurate estimations of which lead to wider ranges or deviation in the predictions of thermal sensation. ISO 7730 also deals with local discomfort caused by draughts, asymmetric radiation and temperature gradients.

Controversy about the applicability of comfort indices

According to Parsons (2002), the theoretical validity of ISO 7730 has been controversial. The introduction of the PMV/PPD indices in 1970 was followed by enhancements to the human heat balance equation; but approaches using mean skin temperature and sweat rate are supposed to deliver more accurate estimations. Comparably, the use of the principle of thermal load for the PPD prediction has been disputed. It has been recommended to derive the quested deviation from neutrality (towards too cool of too warm) from predictions of body state, such as skin temperature, sweat rate and skin wetness.

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[11] Fanger, P. O. (1970),"Thermal Comfort", Danish Technical Press, Copenhagen

Continuative references in this context are Humphreys (1996)[12] and Gagge (1971)[13].

Another important consideration is the fact that the PMV/PPD index was developed by testing North American and European persons. Correspondingly to the present building characteristics with integrated heating and cooling systems depending on the particular needs, the standard applies to indoor climate with continuous thermal comfort not exceeding moderate deviations from it. As the standard clarifies, deviations may occur because of ethnic and national-geographic variation. Therefore, the application of this standard to naturally ventilated spaces in tropical regions, which are susceptible to higher thermal unsteadiness, is controversial. In those regions, given to the mentioned boundary conditions, people adapt to higher range of temperature and further climatic conditions that complement their culture; correspondingly, an adaptive approach must be opposed to the 'western' approach. (Parsons, 2002; ISO 7730, 2005)

5.5.6 Estimation of PMV and PPD index

Beyond the mentioned external factors, which are obtained by the measured values and their derivatives, internal factors take further decisive influence on the resulting values of thermal satisfaction indices; those internal factors are usually set as parameters. In agreement with the assumptions that the comfort diagram after Szokolay relies on, the metabolism rate was set to 130 W and clothing to 1.0 clo. With these boundary conditions, the calculation tool by ASER (1992) served to determine the index values. Thereby, the following are the decisive parameters and variables involved in the determination of the indices of thermal satisfaction, with the nomenclature according to Table 5-6 in brackets:

- Clothing: 1 clo (Icl);
- Metabolism: 130 W (AU);
- Air temperature (dry bulb): measured value t_{in2} in °C, for Casa Macías Villalobos t_{in4} (T_a);
- Relative humidity (indoor): derived from exterior value and internal loads, in % (U);
- Air velocity: derivative from dry bulb, wet bulb and effective temperature, in m/s (v).

The determination of PMV and PPD values is shown in the example of Table 5-6 which refers to the same state that was shown for the derivation of air velocity in section 5.5.3. However, the applicability of the calculation of the PMV and PPD indices is controversial for higher air velocities, as the air movement included in the calculation seems underrepresented. The impact by variation of air velocity is already low at low velocity

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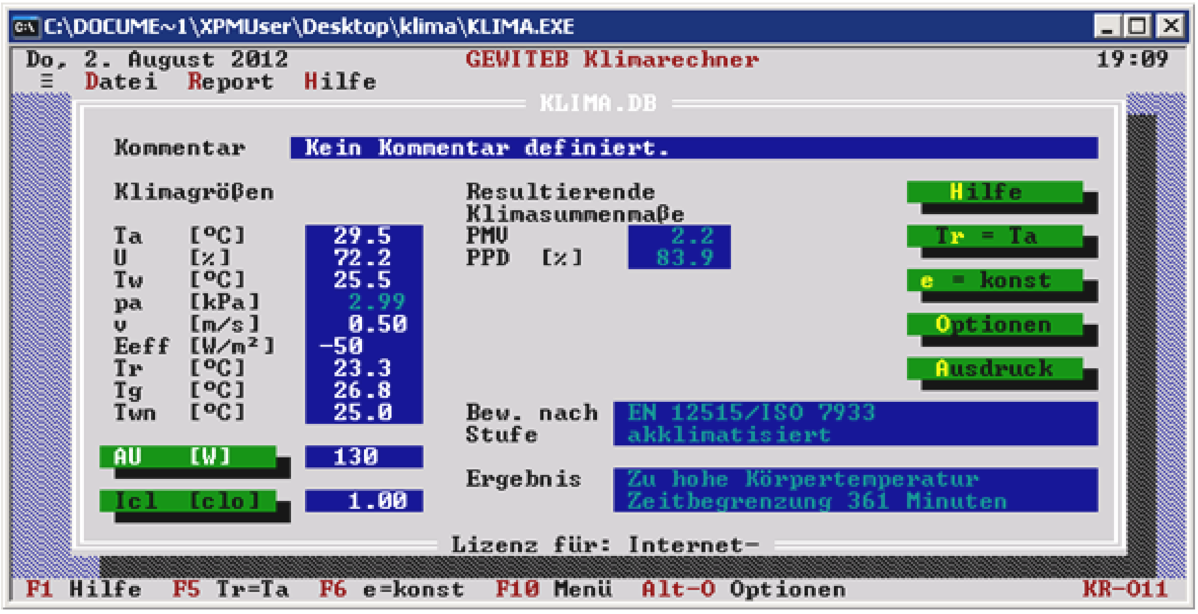
[12] Humphreys, M. A.; Nicol, J. F. (1996), "Conflicting criteria for thermal sensation within the Fanger Predicted Mean Vote equation", Proceedings of CIBSE/ASHRAE Joint National Conference, Harrogate, UK, 1996

[13] Gagge, A. P.; Stolwijk, J. A. J.; Nishi, Y. (1971), "An effective temperature scale based on a single model of human physiological temperature response," ASHRAE Transactions, Vol. 77, pp 247-262

ranges and fades out completely by incrementing the air velocity values toward higher ranges above 2 m/s.

Besides the desired PMV and PPD values, amongst other variables also the wet bulb temperature T_w, derivative from air temperature and relative humidity and determining factor for air velocity, is displayed as a result in the user interface of the calculation tool demonstrated in Table 5-6. The calculations are based on the standard EN 12515/ISO 7933 with the selection of acclimatized (German: *akklimatisiert*) persons, assuming that the involved users are adapted to the specific climatic conditions. The field below states increased body temperatures and corresponding time limits for exposure to the climatic conditions; in this case, the note hints at too high body temperature which allows a maximum exposure of 361 minutes.

Table 5-6: Determination of PMV and PPD index by use of ASER, 1992



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Do, 2. August 2012            GEWITEB Klimarechner                 19:09

  Kommentar     Kein Kommentar definiert.

  Klimagrößen                  Resultierende
                               Klimasummenmaße
  Ta    [°C]      29.5         PMV          2.2
  U     [%]       72.2         PPD   [%]   83.9
  Tw    [°C]      25.5
  pa    [kPa]      2.99
  v     [m/s]      0.50
  Eeff  [W/m²]   -50
  Tr    [°C]      23.3
  Tg    [°C]      26.8
  Twn   [°C]      25.0         Bew. nach   EN 12515/ISO 7933
                               Stufe       akklimatisiert
  AU    [W]       130
                               Ergebnis    Zu hohe Körpertemperatur
  Icl   [clo]      1.00                    Zeitbegrenzung 361 Minuten

                          Lizenz für: Internet-
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An alternative approach for the derivation of the PMV index is offered by Madsen (1984). This publication explored the dependency between air velocity, operative and effective temperature with empirical methods. The resulting diagram is presented in Figure A-7 of the annex. Metabolism of 1.2 met, which is equal 125 W, and clothing of 1 clo are taken as basis for the dependency. However, the relationship of PMV with the named variables is established at constant relative humidity of 50% and at air velocity within the range from 0.1 to 1 m/s; correspondingly, the boundary conditions do not meet the requirements for the climate data of Chetumal. Furthermore, the curves at constant PMV are limited to the values -1, 0 and +1.

6 Case study I: Casa Macías Villalobos, Chetumal

(Bojórquez Báez, 2012; Macías Zapata, 2012)

6.1 Basic information

6.1.1 Specifications about the occupants, construction and the building location

The family Macías Villalobos from Chetumal is a household of four persons, a couple of sociologists with their two sons in preparative school for higher education and in elementary school respectively. The housing complex is divided into two buildings; the investigated building part was constructed in 2006 as extension to the existing building and consists of a living room, an additional kitchen, bathroom, storage room and garage on the first floor and two studies (home office rooms) with bathroom and a balcony on the upper floor. Figure 6-1 shows the view from the courtyard towards the living room and Estudio Martha with balcony on the left and the view from the street towards south and east facade on the right. Mainly the new building part is used in the day and during the afternoon hours, especially as both social scientists work at home to large parts. The elaborated construction plan consisting of ground and lateral views is attached in annex B (see p. 171).

Figure 6-1: Casa Macías Villalobos: north facade from courtyard, south facade from the street. Pictures taken by Moie, 2012

The house is located in the urban district FovISSSTE[14] in the west of the state capital Chetumal (surrounding area map see annex Figure A-8), where state officials can benefit from governmentally supported mortgage housing funds. Chetumal belongs to the municipality Othón P. Blanco, the geographic coordinates of the home are 18° 30’ 57” North and 88° 19’ 17” West (Google Earth, 2012). The main wind direction is east to southeast.

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[14] *Fondo de la Vivienda del Sistema de Seguridad Social de los Trabajadores del Estado* – Combinated low-cost mortgage fund and pension plan program for public-sector employees

6.1.2 Building materials and dimensions

- Walls: blocks, on the wall ends reinforced with steel rods and cement, thickness 15 cm; finish: prefabricated Cemix mortar coating and beige painting on the exterior.
- Roof and ceilings: tie-beam and vent block system (Spanish: *vigueta y bovedilla*), consists of concrete, thickness 15 cm; 5 cm layer of concrete, above: impermeable material Calcreto; vermillion roof tiles on the inclined flanks; mortar coating in the lower part same as for walls.
- Windows: single glazing with solar filter, thickness 6 mm, U-value 5.4 W/(m^2K), frame of aluminum; the windows are movable within the slide of the frame, with exception of the group of six smaller windows on the stairway which are folding (top-hung).
- Floor: flagstones, thickness 3 cm.

The observed building part contains 128 m^2 usable living space, the studies alone account for 19.6 m^2 for Estudio Martha and 18.4 m^2 for Estudio Gabriel, the living hall shares 19 m^2.

With the east window in Estudio Gabriel, 1.0 m^2 of opening is integrated in the east facade (10% share in east facade adjacent to Estudio Gabriel); however, as the window opens by moving it on a frame slide, it only opens up to half of its area. A further east window of 0.8 m^2 is installed in Estudio Martha, but into the elevated part of the living room. Estudio Martha additionally contains a large glazing area of 4.5 m^2 (30%) in the north facade, shared by one window and one balcony door. Shaded by a porch, a large glazing area of 11.6 m^2 is integrated in the first floor of the north facade (45%). The south facade contains 3.2 m^2 of glazing, divided into 2.0 m^2 by the south window of Estudio Gabriel (14%) and in the hallway 1.0 m^2 by the single window and 1.2 m^2 by the group of six windows. High-elevated windows for air exhaust are installed in the central part of the roof; the slide-movable windows add up to 2.0 m^2 towards north in Estudio Gabriel and 0.8 m^2 oriented to the south in Estudio Martha.

6.1.3 Observations

- The change from indoor climate cooled by air conditioning to the warm outside feels uncomfortable and less preferable; therefore, the inhabitants prefer to live in a bioclimatic space.
- Except for rain, the windows in the outside wall are open all day, until the users leave the rooms. However, the windows for exhaust air are located in the center of the building towards the roof; those upper windows require a long rod in order to open or close them. Due to this inconvenience and because of the risk of water entry during precipitation, the windows for both studies (Estudios) are closed most of the time. As a result, sufficient natural ventilation is inhibited.
- The group of small windows in the stairway is installed above body height; they are, however, integrated in the south facade, whereat the large openings beneath the

porch are integrated in the north facade. As a consequence, air exhaust from the living hall which is supposed to exit through the group of small windows, might be repressed because the small windows are oriented to the main wind direction (east to southeast).

- An interior sunblind at the east-oriented window of Estudio Gabriel is used in the mornings, when the sun would radiate directly into the room and on the desk.
- There are several pitch fans (standing) in both studies for the hours of uncomfortable indoor climate, with a higher tendency to use them in Estudio Gabriel: on warm days in the mornings (direct solar irradiation through the east-window) and afternoon/evening (heating of the west-oriented wall); Estudio Martha: usually the ventilator use is restricted to the afternoons/evenings of warm days.
- As treated in subchapter 4.4.1, abundant vegetation and its absorption capacity for solar energy make environments of rural settlements heat up less than larger towns and cities where the denaturalized building and street surfaces made of stone, asphalt and dwellings absorb most of the irradiated solar energy. The collected energy is converted into heat, even reflected fractions are absorbed by surrounding areas of darker color to large parts. This makes urban areas like Chetumal more susceptible to heat periods than single settlements or small villages like for the following study cases.

6.1.4 Influences of user needs, user behavior and economic concerns

Both the budget of the initial investment and particular user needs and behaviors created certain discrepancies between suggested elements and the final building design.

Materials

- A question of costs for transport and production: industrialized materials (cement fabrication and bricks) are more economical than the provision of natural materials.
- As a typical residential area, its urban character promotes the use of industrialized materials again; the increased use of natural materials would cause a strange impression in that zone.
- As typical for the mostly colorful Mexican buildings, the building was painted in beige.

Vegetation

- A palm tree was suggested for the small backyard in the northwest in order to shade Estudio Gabriel and improve the air movement through the east window into the same room; this proposal was dropped for financial reasons.

Further solar protection

- An exterior sun-blind was recommended for the east window where the morning provides high penetration of solar radiation; instead, a very ineffective form of interior sun-blind was chosen.

- Placement of bookshelves next to the west wall was recommended in order to somewhat diminish the thermal input through the heated west wall by the afternoon sun which was neither implemented in Estudio Martha nor in Estudio Gabriel.

6.1.5 Overview of implemented design principles

Table 6-1 reveals that only few of the recommended building design principles are implemented. The contradiction between focus of openings on the north facade and orientation to the prevailing wind direction eliminates the possibility to implement all guidelines. However, the large massive west and east facades and various limitations in the ventilation concept are disadvantageous.

Table 6-1: Building design assessment matrix, applied to Casa Macías Villalobos; elaborated based on Grimme, 2006; Climate Consultant, 2010; Lippsmeier, 1980

Nr.	Recommended design guideline	Statement about application, specifications
1	North-south orientation of the building (long axis reaches from east to west)	**Not applicable**: inclined roof oriented to north and south, resulting in large massive walls facing east and west
2	Open arrangement and low building depth, but protection from hot and cold wind	**Not applicable**: rooms connected by corridor, Estudio Martha with interior window to the living room which reaches over two levels
3	High ceilings and high outlets, preferably operable openings protected by overhangs	**Applicable**: high building depth is balanced by air exhaust at the split roof ridge; openings are operable, but unprotected (no overhangs) and user-unfriendly, therefore barely opened
4	Openings at body height orientated to prevailing breezes (= southeast to east)	**Partly applicable**: windows of Estudio Gabriel and of the stairway are oriented to south and east
5	Large openings (40-80 % of the facade), located on opposite sides of the building	**To a small extent applicable**: north facade Estudio Martha: 30%; Estudio Gabriel: east facade 10%, south facade 14% shaded by overhang; north facade first floor: 45%; no openings in west facade
6	Most of the openings orientated to the north (balance daylighting and enhance cross ventilation)	**Applicable**: openings in the north facade are much larger than any other
7	Shading of exterior rooms, especially on the west facade, and avoidance of direct irradiation through openings without hindering air circulation	**To a small extent applicable**: shading is exclusively supplied in the south facade (overhang above window) and north facade by a tree and a porch
8	Light-weight building with low heat retention	**Not applicable**: concrete is contrary to the recommendation; the enclosed air in the tie-beam and vent blocks system barely produces relief

9	Well-insulated roof, if built with industrialized materials	**Applicable**: impermeable material Calcreto integrated into the exterior layer
10	Light-colored building materials, also roof with high emissivity	**Not applicable**: walls are painted in beige, roof tiles in vermilion, plain roof is cement-gray

6.2 Assessment of thermal comfort

6.2.1 Arrangement of sensors

Figure 6-2 shows the arrangement of indoor temperature sensors at different locations of the building. Sensor 2 (PT 100) recorded the temperature in the living room next to the couch, further PT 100 sensors were installed in each of the studies and additionally the effective temperature was measured by the comfort sensor situated in Estudio Martha.

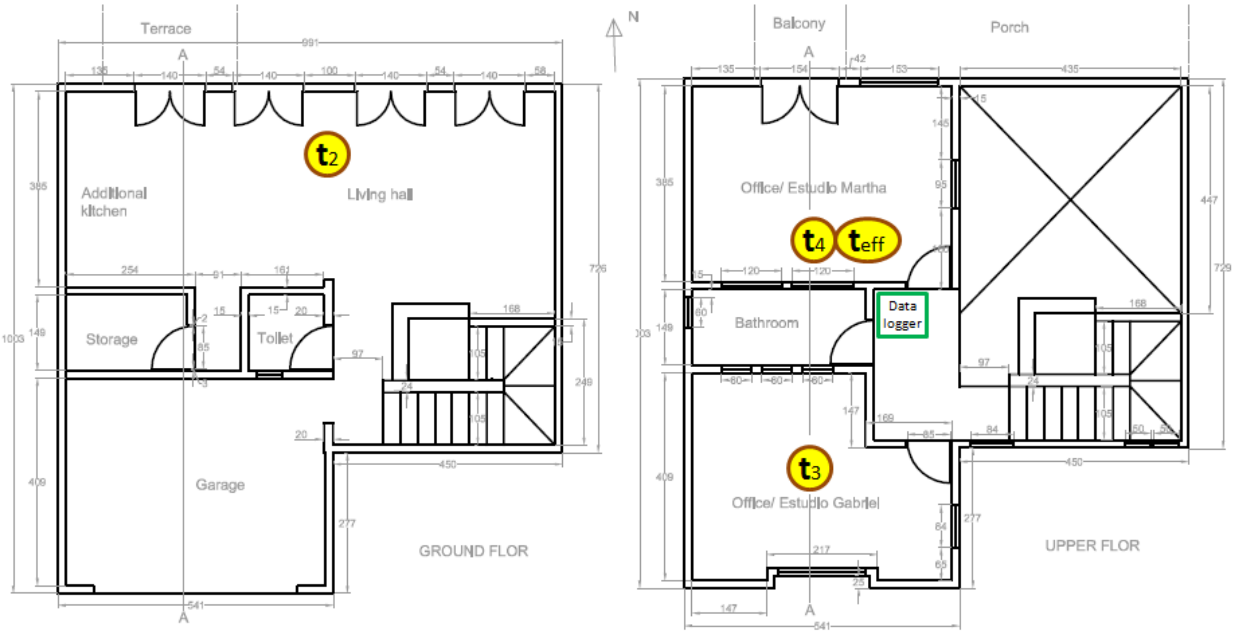


Figure 6-2: Arrangement of indoor PT 100 sensors in Casa Macías Villalobos, excerpt of construction plan

The measurement of temperature t_3 (black globe) in Estudio Gabriel was recorded at an elevation of 1.8 m, the further measurements were taken at elevations around 1 m. The particular elevations of the sensors above floor ground are summarized in section 5.1.3 of the annex, along with further observations about the installation. The wiring for the connection to the data logger, which recorded the measured values, is provided in the annex section 5.1.2.

6.2.2 Thermal performance

All following observations refer to day 8 of the measurement series in Casa Macías Villalobos, recorded on April 27th, 2012. All derivations of further data basing on the measurements are carried out by hourly estimations.

The comparison between measured exterior values and historical climate data by use of high and low mean values is depicted by Table 6-2. The numbers hints at a rather typical day; the range of exterior temperature is somewhat smaller than for the climate data. The humidity, however, is essentially smaller for the measured values; especially the morning is comparably dry. The urban environment with spare vegetation is supposed to play are role in that.

Table 6-2: Comparison between measured and historical climate, April Chetumal. Source: My Forecast, 2012

	t_exterior (°C)		relative humidity (%)	
Casa Macías Villalobos	measured	climate data	measured	climate data
Morning	25.8	24	68.8	91
Afternoon	28.7	29	58.8	68

The line graph in Figure 6-3 contrasts the indoor air temperature with the corresponding exterior values. Also the exterior relative humidity is shown, whose contrary course to temperature stands out clearly; relative humidity drops with rising air temperature and increases when the air temperature falls.

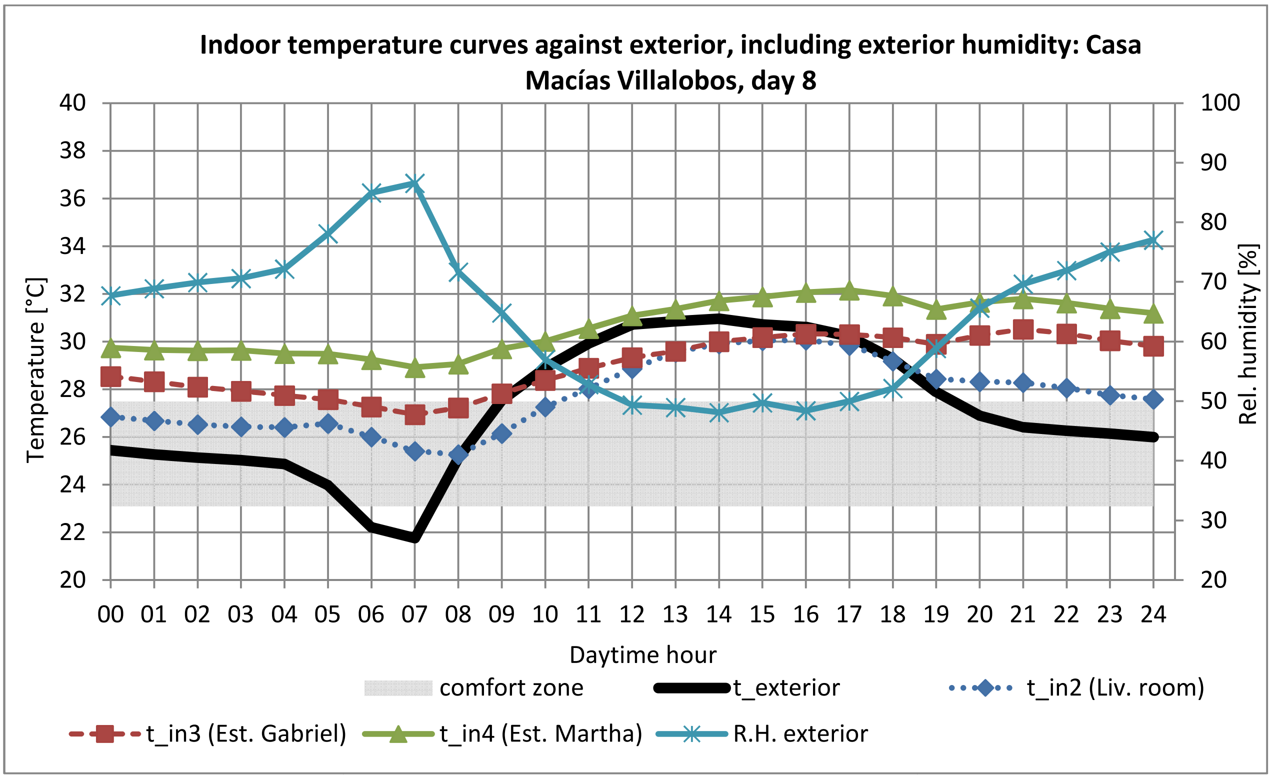


Figure 6-3: Comparison of indoor temperature curves to outdoor temperature and humidity for day 8 of the Casa Macías Villalobos series; rel. humidity values refer to the right scale. Elaborated by Excel™

All displayed variables refer to measured values. It can be observed that the room temperature of Estudio Martha shows low variation and stays extraordinarily high all over the 24 hours, oscillating between 29 and 32°C. Estudio Gabriel performs somewhat better, in an equally small range but by keeping the air temperature continuously 1 to 2

K below the curve of the other study, not exceeding 30.5°C. In comparison, the temperature curve of the living room is characterized by a wider alteration, from 25°C in the morning to 30°C in the afternoon. During the night, cooling of all observed rooms is inhibited by closed windows and the thermal mass of the building which both reduce heat transmission. In contrast, when the delaying effect would be desired, open windows and internal loads make the interior temperatures approximate the outside temperature.

In order to obtain a first estimation on the compliance with thermal comfort, Figure 6-4 presents an exclusive consideration of the measured temperature values. The left scale shows the deviation from the upper comfort limit at 27.5°C which is set as the horizontal neutral axis. However, this simplified approach does not take the variation of thermal comfort with humidity into account, neither air velocity; therefore, it just serves as a first orientation. From the origin, the gray background reaches down to the lower comfort limit which only the exterior temperature falls below for two morning hours. Around 10 a.m., the shift can be observed where most curves cross the origin and thus exceed the outmost level of thermal comfort to stay above it until late at night. As an exception, the indoor temperature t_{in2} of Estudio Martha never crosses the upper border of thermal comfort because it never even reaches the comfort zone; instead, it ranges from 1.5 to 4.5 K above thermal comfort all the 24 hours.

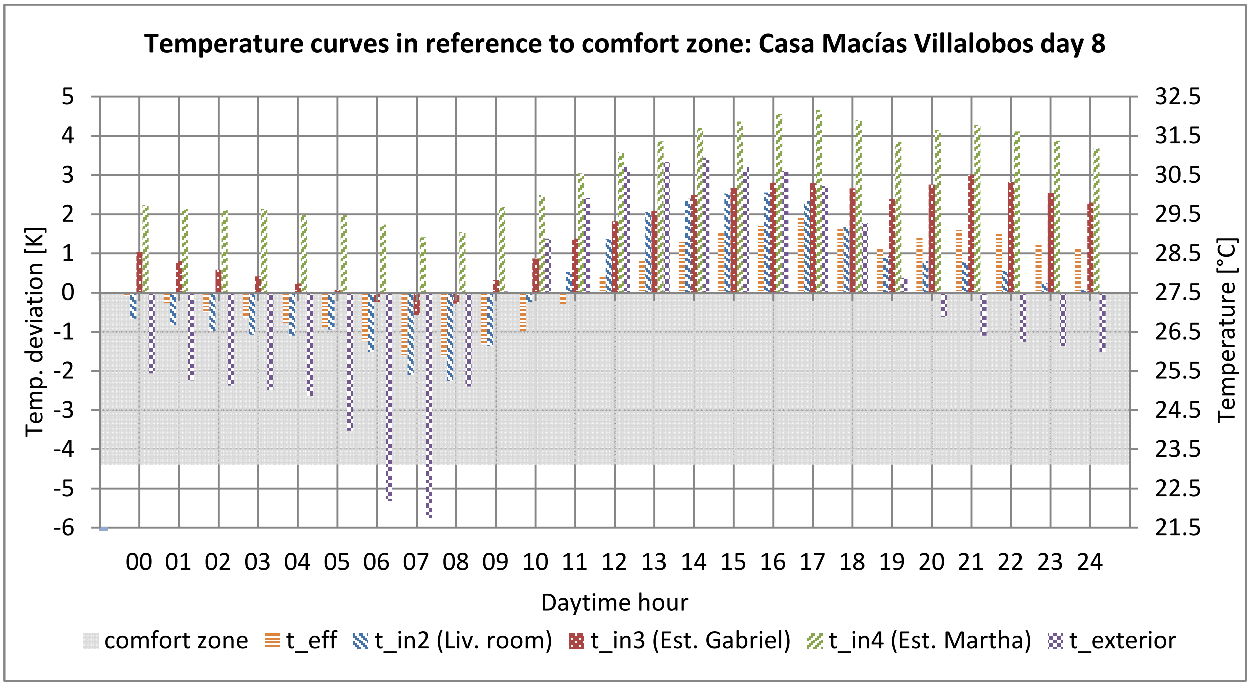


Figure 6-4: Visualization of thermal compliance with the comfort zone, Casa Macías Villalobos. Elaborated by use of Excel™

Significant differences stand out between the three observed rooms; apart from different orientations to sun and wind, this is certainly due to the different internal heat sources (humans, computers and other technical equipment) and different conditions of heat discharge. Although the situation contains a self-regulating effect given that the rooms usually turn unoccupied in the moment when all windows are closed. However, the lacking possibility to cool down over night at closed windows, is a burden passed from day to day and makes already the morning hours critical.

Interpretation of thermal performance

The following factors are identified as reasons for the presented character of the temperature curves:

- Both studies are located beneath the roof and furthermore highly exposed to direct solar irradiation onto the west facade, Estudio Gabriel also onto the east facade.
- Estudio Gabriel has a much better orientation to the windward side but low share of openings in the facade. Some vegetation near Estudio Martha and much larger openings can partly compensate for this; however, the trees are located on the north facade where the influence is minor.
- The ceiling in Estudio Gabriel is significantly higher than in Estudio Martha; accordingly, larger air volumes are available at higher elevation and offer more space for the layers of warmed air to accumulate. Furthermore, the upper openings themselves already have a higher area and the windows have been opened in Estudio Gabriel in the scope of this investigation, in Estudio Martha they were not. Consequently, the discharge of warmed air in Estudio Martha is inhibited and accumulates down to lower air layers – contrary to Estudio Gabriel. But both studies share the limitation that heat dissipation at night is very low when both the upper and lower windows are closed.
- In contrast to the studies, the living room is located at the lower floor and thus is relieved from massive overheating. The heat ascents to leave through the windows in the south facade and to accumulate beneath the dome. When floating into the upper air layers, the air movement might also bring additional heat into the studies upstairs.

6.2.3 Estimation of indoor humidity

For further assessment of thermal comfort, the indoor humidity was estimated; corresponding to the assumptions outlined in section 5.3.4, the estimation of occupancy of the room with persons and particular exerted activities for each hour resulted in the additional moisture content which is demonstrated by the dashed line in Figure 6-5.

Contrary to the temperature loads, the humidity alone seems relatively unproblematic in this case; the indoor relative humidity was here estimated for Estudio Martha with the result of oscillation within a range from 45 to 90%. Instead, the combination of somewhat elevated humidity with the very high temperatures makes it more complicated to avoid massive comfort problems.

6.2.4 Requirement of air velocity

By means of the comfort diagram altered by Szokolay, the applied conditions for thermal comfort with three design states have been defined (see section 5.3).

Generally, the wide uncomfortableness of indoor climate must be countered with air movement at a certain speed; therefore, the existing air velocity is examined and subsequently compared with the actually required velocity. As outlined in section 5.3.3, the present air velocity is included in the effective temperature that was measured by using the comfort sensor; therefore the required velocity was found by defining the upper acceptable limit of the effective temperature.

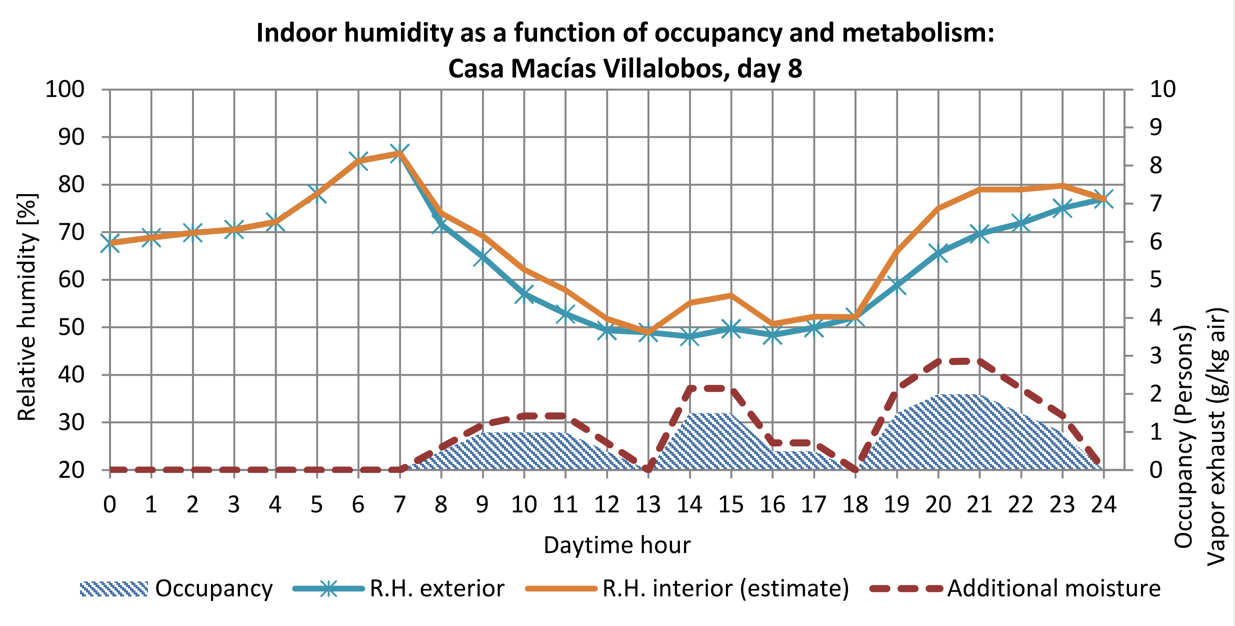


Figure 6-5: Estimated indoor humidity by human activities, Casa Macías Villalobos; both occupancy (number of persons) and vapor exhaust (g/kg air) shown on the right axis. Elaborated by use of Excel™

Figure 6-6 visualizes the relation between effective temperature and air velocity; the PMV index will be treated in section 6.2.5.

The dashed line in the diagram shows the wet bulb temperature which represents the impact of humidity and was required in order to determine the effective temperature. The temperature difference between the measured effective temperature (red line with circular markers) and the effective temperature $t_{eff,comfort}$ on the border of the comfort zone is the gap that must be closed by applying sufficient air movement. The lower dotted area in Figure 6-6 depicts the small share of air velocity provided by natural ventilation. The hatched area above presents the required input of air velocity that must be spent in order to accomplish thermal comfort; this demand has to be covered by ventilators. Consequently, continuous use of a ventilator at medium to high velocity stage is required at all times when the room is used in order to accomplish thermal comfort. According to the nomogram Figure 5-6, a maximum velocity of 7 m/s is permitted for tempering the indoor climate. By this means, the remaining deviations from thermal comfort after the inclusion of ventilator expenses are obtained by the temperature difference between the baseline for thermal comfort ($t_{eff,comfort}$) and the resulting lowest achievable effective temperature $t_{eff,net}$. The discrepancies occur at 6 a.m. and in the evening hours and are strongly driven by high humidity, indicated by the high wet bulb temperature values above 26°C at the given hours (see also prior Figure 6-5 for comparison with relative humidity values). The slight exceeding in the early morning can be neglected as the room is supposed to be empty at that hour; however, the longer-lasting exceeding before midnight of five hours, all of them more than 1 and up to almost 3 K above the upper comfort limit, is assumed to coincide with use and thus signifies a clear grievance that considerably impairs the conditions of work.

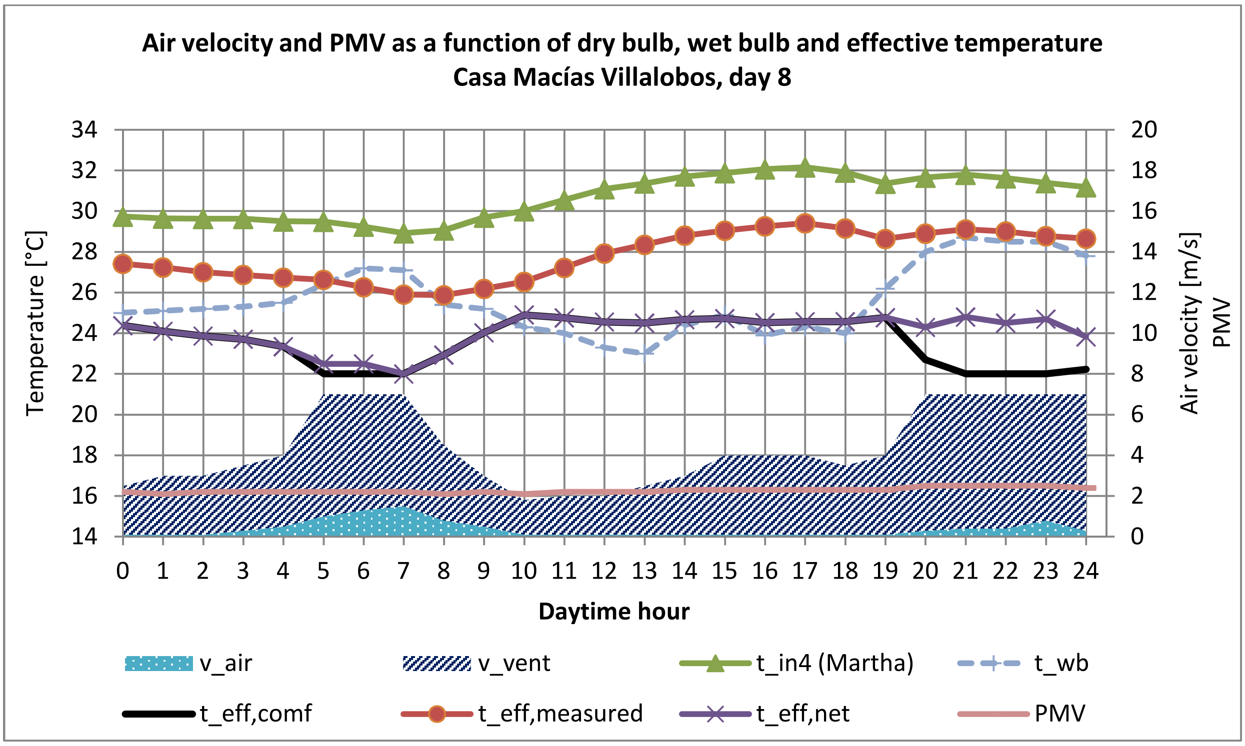


Figure 6-6: Air velocity and PMV in relation to dry bulb, wet bulb and effective temperature, Casa Macías Villalobos. Elaborated by use of Excel™

6.2.5 Indicators for thermal comfort

Included in Figure 6-6 is the course of PMV for the existent indoor climate; it is, however, illustrated in a more precise view in Figure 6-7, together with the PPD index. Within the possible range from -3 to +3, the PMV index varies from 2.1 to 2.5, suggesting a continuous perception of “warm” with the tendency toward “hot” which is already the maximum of the total scale. The PPD index fluctuates within a range of 82 to 94% of dissatisfied. After the morning hours, both indices ascend stepwise; it takes until midnight that a clear falling tendency can be distinguished. Roughly, the selected day can be subdivided into three different stress levels; moderate impact before noon, increased impact in the afternoon and the highest impact after sunset until shortly before midnight. The high stress level at the late hours is certainly due to the coincidence of already high relative humidity at still high temperature levels.

The rather low fluctuation all over the 24 hours, especially of the PMV, can partly be reasoned by the fact that temperature and humidity complement each other: rise of temperature reduces relative humidity and vice versa, so that the total load keeps at a relatively constant level. The graph also shows that PMV and PPD are largely congruent; the higher oscillation of PPD in comparison can be traced back to the selected axis scales for both indices.

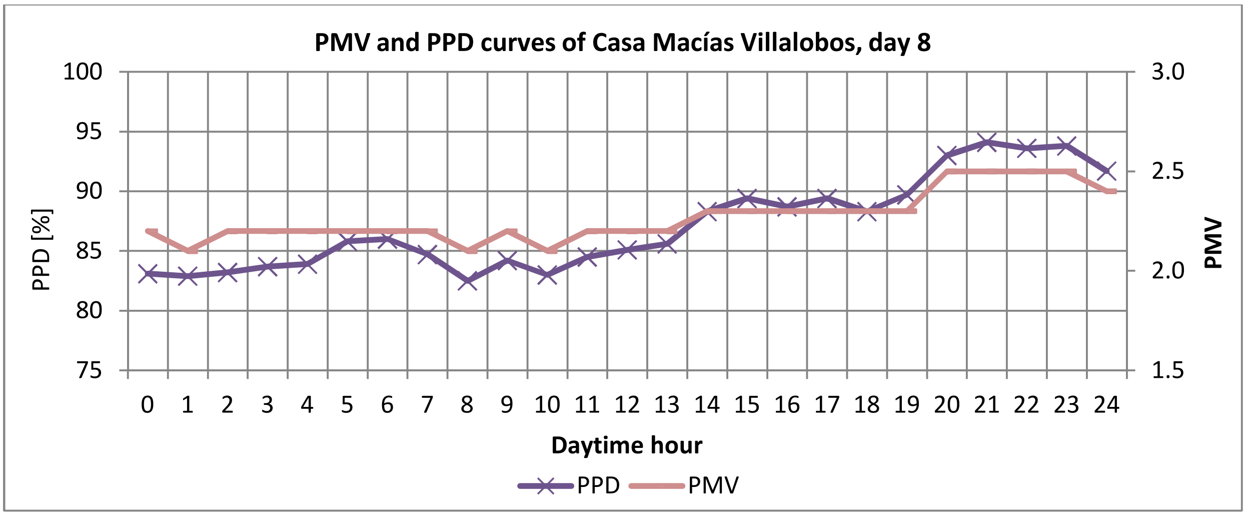


Figure 6-7: Curves of PPD and PMV indices for the present indoor climate, Casa Macías Villalobos. Elaborated by use of Excel™

6.3 Assessment of environmental impact

6.3.1 Analysis of present situation

As a limitation, it must be mentioned that the parameters for material characteristics included in this assessment may vary widely, as it was described in section 5.1.6; consequently, strong deviations from the actual values might occur. Table 6-3 summarizes the expended built-in energy and CO_2 emissions as estimated for the construction of the urban building. With a total building mass of 165 tons, an approximated total of 344 GJ was spent from the fabrication to the delivery of all building materials which caused 63 tons of CO_2 emissions. Occupancy by 4 persons and 128 m^2 living area resulted in the specific values summarized below.

The particular contributions of the building materials to the total numbers are visualized by the left side of Figure 6-8. The main consumer was found to be blocks made of concrete which are responsible for half of the total energy consumption and 60% of CO_2 emissions while it accounts for half of the building's total mass. Limestone powder which was used as component of the concrete composition, the prefabricated ceiling components vent blocks and tie beams and the stone foundation all accounted for significantly less energy consumption and pollution than the average while providing significant masses (except of tie-beams), while especially cement but also cement-based coating, lime and steel accounted for more energy consumption and carbon emissions than the average by mass.

Table 6-3: Embodied energy and CO_2 emissions from the construction of Casa Macías Villalobos, excluding wall paint, framing and glass; data: building materials data collection

Casa Macías Villalobos	Building mass (tons)	Embodied energy (GJ)	Emissions (tons CO_2)
Total numbers:	165	266	20
Specific:		per person:	
4 Persons	41	67	5.1
		per living area:	
128 m^2	1.3	2.1	0.2

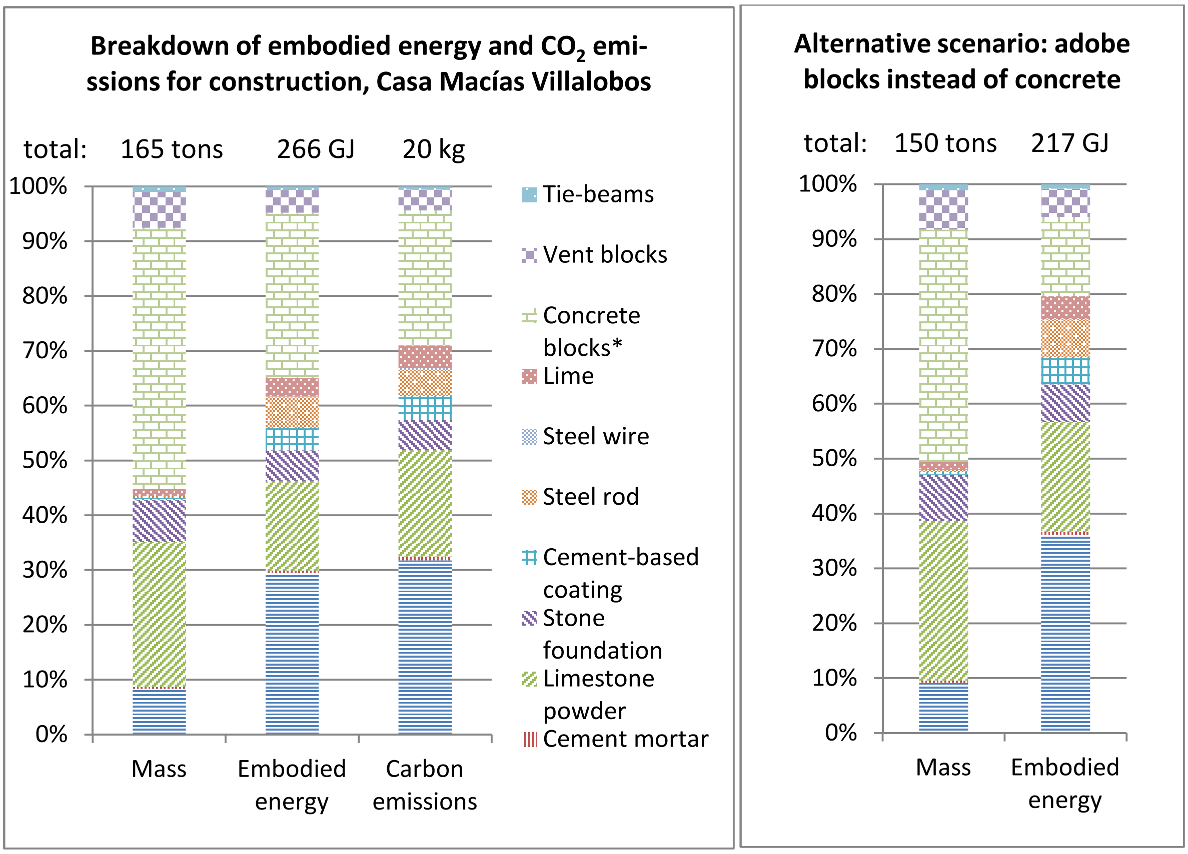


Figure 6-8: Breakdown of embodied energy and CO_2 emissions for the construction of Casa Macías Villalobos (left side), excluding wall paint, framing and glass; alternative scenario (right side) - *concrete blocks are replaced by adobe blocks in the right diagram. Data: building materials data collection

6.3.2 Alternative scenario

Consequently, alternatives for the use of blocks and other cement use offer high potential for reducing the environmental impact. In order to address this point, the right side of Figure 6-8 shows an alternative scenario. Therefore, the concrete blocks have been substituted by adobe blocks. Benefitting from a 19% reduction of mass for the blocks, the much better specific embodied energy parameter facilitated a reduction by almost 50 GJ, corresponding to 61% of the concrete blocks' energy content. The share of the blocks in the right column of the right diagram shrinks accordingly, leaving a slightly extended share to all of the remaining materials. A replacement of the material used for the vent blocks of the combined roofing system by the adobe blocks could bring further relief of embodied energy. Due to abundance in the karst region of Quintana Roo, limestone blocks are another evident option for masonry. However, parameters predict a high content of embodied energy; if short transport routes apply, this may be disputable.

6.4 Recommendations

From the physical observations and the assessment of indoor climate, the following recommendations for Casa Macías Villalobos can be derived:

- Install electric window openers; depending on the disposition of the occupants to participate, the motion devices could be manually controlled or controlled by a small climate station (windows close during precipitation or strong wind).
- More vegetation should be planted; a full tree next to the east window of Estudio Gabriel would improve the ventilation and protect from the morning sun, also ventilation through the window in the hallway towards the stairs would improve. Alternatively, at least an exterior, more effective sunblind should be installed.
- The west facade which is most susceptible to heat gains from solar radiation is completely unprotected; therefore, a new neighboring building or vegetation is urgently needed to enhance this situation.
- As plantation for the south window of Estudio Gabriel would cross the estate borders, a directly attached wind deflector would be a good alternative for that case.
- An ample treetop deflects the dominant east wind into Estudio Martha through the large openings; however, a build-up on the balcony rail could still improve the ventilation.
- Because of the temperature distribution over the building, a partial transfer of activities downstairs might be an option;
- Use of white cement:
    - The lighter color reduces the absorption of heat which penetrates on the east and west facade;
    - Sparing of wall paint which has high content of embodied energy and must be renovated regularly reduces the environmental impact.
- For the dark-red and highly heat-absorbing roof tiles, mounting of solar panels would be a practical solution which converts the disadvantage of direct exposition to irradiation into an advantage. High energy input and high investment cost for the

production and purchase of photovoltaic panels may pay back on the long run. Instead, also solar thermal panels could be mounted for water warming as the more affordable alternative. However, in this specific as in any other case the orientation to the sun and possible shading from surrounding trees must be reviewed.

7 Case study II: Casa Brunner Valdés, Mahahual

(Brunner Morales, 2012)

7.1 Basic information

7.1.1 Specifications about the occupants, construction and the building location

The young family, a couple originally from Mexico City with their 5 years old son, does *Permaculture* farming, an ecological form of agriculture, for a living. They have plans to establish a school for natural agriculture. The construction of their ecological house with limestone and a large straw roof was completed in 2010 after one year of construction. The building is presented from two different angles in Figure 7-1. On the right side, a two-rise annex beyond the large straw roof can be observed. The lower floor of this annex has a separate entrance and is disconnected from the main building. A further extension in form of a new entrance with porch is planned at the west facade. The ground plan and lateral views are attached in annex B (see p. 172).

Figure 7-1: Casa Brunner Valdés from southeast (left side) and north view. Pictures taken by Moie, 2012

Casa Brunner Valdés is located in the tropical forest in the municipality Othón P. Blanco, about 7 km by road from the village Mahahual (also: *Majahual*) and 2.5 km from the coastline (surrounding area map see annex Figure A-9). The geographical coordinates are 18° 42’ 20” North and 87° 44’ 15” West (Google Earth, 2012). The main wind direction is southeast to east.

Due to its location far off the public grid, the house is self-sufficient; the power supply is currently provided by a 2 kW diesel generator with 4 battery blocks of 150 Ah each and an inverter of 400 W. In the medium term, a new concept is aspired in order to become less dependent on fossil fuels. In concern of the particular electricity supply situation, energy is saved as far as possible and especially for lighting, energy-efficient appliances like LED lamps and solar PV lamps are in use. The isolated location also required an adequate solution for wastewater; this is accomplished by a vivid septic dump with decomposition by bacteria. Filter chambers of activated carbon, silica and gravel are in use for the recovery of water.

7.1.2 Observations

Considerations like the influence by magnetic fields (doctrine of *Feng Shui*) were important during the planning and construction process. The beds and with them the whole building were oriented north to south, which means that east and west are the long facades within the elliptic form; the building annex in the north that accommodates the children room and a guest room below.

For the large dimension of the roof, solar irradiation was considered to be more significant onto the roof than onto the walls. The roof in return benefits from its curved form, for this reason less area is directly exposed to vertical radiation during the lower solar altitudes in the morning and before sunset. Concerning the less affected walls beneath the overlaying straw roof, the massive form of construction and the light color of the limestone hold the impact by solar radiation further down. However, due to the dense braiding of the straw and the resulting thickness (two layers one upon the other of 5 cm each) without openings, dissipation of heat is constricted. Moreover, the need to discharge heat is supposed to be very high, due to the high elevations of the roof resulting in strongly heated air layers beneath the upper roof.

Because of the high given volume and elevations of the investigated building, the measurement of temperatures at different heights is of special interest; the elevation profile of the building will be treated within the scope of the measurements.

In 2009, when the construction of the building was already in progress, a forest fire devastated the area; accordingly, the large roof made of straw means risk to anew fires.

The overhang of the straw roof does not seem sufficient for stronger wind; currently, only plastic covers are placed in order to protect from precipitation.

A ventilator is sometimes in use, but it can only be used while the diesel generator is in operation; the inverter has to be exchanged. The estimated usage time for the ventilator ranges from zero to one hour per day.

7.1.3 Building materials and dimensions

- Wall: limestone, thickness 40 cm, height 2.5 m
- Inner wall: limestone, thickness 40 cm, height 2.25 m; two door openings, width 80 cm
- Roof: long grass (Spanish: *zacate*, 1 to 1.5 m long), constructed with bajareque technique
- Floor: polished cement layer, thickness 2 cm (it is planned to replace it by adobe/clay); layer below: compressed sand, 12 to 40 cm
- Door: wood, 2 m height with arc, width 0.9 m
- Openings without glass, only mosquito net, plastic cover mounted for rain protection:
    - Four openings: height 1.7 m with arc, width 1.75 m;
    - One opening: height 2 m with arc, width 1.5 m;
    - One opening to the bathroom (half-open to main indoor space, no roof): 1.5 x 0.9 m;
    - Annex: Pass through to children's room: height 1.8 m, width 0.9 m;
    - Three openings in the children's room: height 1.7 m with arc, width 1.75 m; 1.8 x 0.9 m; 1.0 x 0.9 m.

The examined building contains 105 m^2 of living space; the elliptic main wall includes 8 m^2 of openings both in the east and in the west facade (nearly 30% of the facade each). All outlets in the main wall are protected by overhang from the roof. The building annex contains 1.6 m^2 of openings in the east, 2.3 m^2 in the north and 2.6 m^2 in the west facade (only upper floor, approx. 25% of the facade in average). Exhaust air is facilitated through the gap between wall and roof, but there are no upper outlets.

7.1.4 Quality of materials and economic concerns

In subchapter 4.5.2, the competition for roofing between huano (fan palm leafs) and zacate (long grass) was discussed. Due to the sparse availability of fan palm leafs, grass was more economical for the construction of the new home. However, zacate with a lifetime of just about 10 years has to compete with huano that lasts at least 15 years. A further concern is the fact that younger generations of roofers are not as conversant in their handcraft as their antecessors anymore; the quality of natural roofs decreases correspondingly. Owing to the difficult supply, the construction of the wall with limestone was more expensive than the highly industrialized alternative cement. (Brunner Morales, Canul González)

7.1.5 Overview of implemented design principles

By means of the prepared assessment matrix, Table 7-1 gives an overview of the implementation of recommended design principles. The construction significantly stands out for its immense grass roof, as does the massive limestone wall with its large openings. Instead of north-south orientation, other criteria were prioritized; the oval form of the building whose large roof area is the primal absorber of solar irradiation reduces the impact of exposure to the sun. A distinct weak point is the lack of outlets in the upper roof.

The large openings are well-oriented to prevailing breezes. However, their share in the facades still ranges slightly below the minimum recommendation; a high share is also necessary in order to provide sufficient daylight for the large indoor space. Neglecting structural concerns, which would have to be investigated, the massive limestone wall is contrary to the instruction on light-weight building. The openings in the building annex, not protected by shading devices, should be installed even more abundantly in the north facade but should be reduced in the west facade.

Table 7-1: Building design assessment matrix, applied to Casa Brunner Valdés; elaborated based on Grimme, 2006; Climate Consultant, 2010; Lippsmeier, 1980

Nr.	Recommended design guideline	Statement about application, specifications
1	North-south orientation of the building (long axis reaches from east to west)	**Not applicable**: long axis reaches from south to north; oval form
2	Open arrangement and low building depth, but protection from hot and cold wind	**Applicable**: opposite exterior walls with large openings without interior separation, protected by surrounding vegetation
3	High ceilings and high outlets, preferably operable openings protected by overhangs	**Partly applicable**: very high natural pitched roof, but without upper air exhaust; small gaps between wall and roof serve as outlets; plastic cover used as temporary protection for openings
4	Openings at body height orientated to prevailing breezes (=southeast to east)	**Applicable**: large openings reaching from top to bottom of a standing body; mainly oriented to east and west, in the building annex also to north
5	Large openings (40-80 % of the facade), located on opposite sides of the building	**To a large extent applicable**: east and west facade: 30% each; building annex: 25% in average
6	Most of the openings orientated to the north (balance daylighting and enhance cross ventilation)	**To a small extent applicable**: building annex in the north, except for small passage separated from main area; bathroom window in the northeast
7	Shading of exterior rooms, especially on the west facade, and avoidance of direct irradiation through openings without hindering air circulation	**Partly applicable**: overhang of roof by 1 m (except building annex), dense circumjacent half-height vegetation: on the west facade at about 5 m distance

8	Light-weight building with low heat retention	**Partly applicable**: natural roof but massive limestone wall, loosened by large openings
9	Well-insulated roof, if built with industrialized materials	Natural roof
10	Light-colored building materials, also roof with high emissivity	**Partly applicable**: natural roof (brown but curved); limestone wall has bright color

7.2 Assessment of thermal comfort

7.2.1 Arrangement of sensors

In regard to the high roof, the installation in Casa Brunner Valdés focused on investigating the thermal performance in different elevations; the comfort sensor and the PT 100 temperature sensors for interior measurements were placed centric in reference to the ground area at the following elevations, by allocation of channels:

Channel 4: comfort sensor (Effective temperature): 1 m
Channel 5: Temperature 2 (PT100): 1 m
Channel 6: Temperature 3 (PT100): 2.5 m
Channel 7: Temperature 4 (PT100): 4.8 m

7.2.2 Thermal performance

The hourly data for this evaluation originate from May 7th, which was day 5 of the measurement series of Casa Brunner Valdés. The low and high mean comparison values in Table 7-2 reveal higher temperature but much lower humidity of the measured values in the morning than the typical climate.

Table 7-2: Comparison of measured with historical climate data, May Chetumal.
Source: My Forecast, 2012

	t_exterior (°C)		relative humidity (%)	
Casa Brunner Valdés	measured	climate data	measured	climate data
Morning	28.2	26	71.7	91
Afternoon	30.6	31	62.0	68

This seems surprising and would rather have been expected in the opposite way for a location in the middle of the tropical forest. However, the mounting of the exterior sensor has some impact; for lack of alternatives, the sensor was placed on the roof of the massive limestone building annex.

The line diagram of Figure 7-2 presents the course of measured temperatures and exterior relative humidity with its contrary trend to the exterior temperature. As indicated by the gray area in the background that stands for the comfort zone, all temperatures exceed thermal comfort during the day and only slightly fall into the comfort zone at night. Comparing outdoor with the indoor temperatures shows that heat retention in temporal means is negligible; instead, the heavy building mass reflects in significantly reduced heating in comparison with exterior. In the peak hours of the afternoon, the temperature at medium body height t_{in2} stays around 4 K below outdoors, while the temperature measured at higher elevation t_{in4} maintains around 2.5 to 3 K below the exterior temperature. At night, t_{in2} approximates the exterior temperature and t_{in4} stays around 1.5 K above.

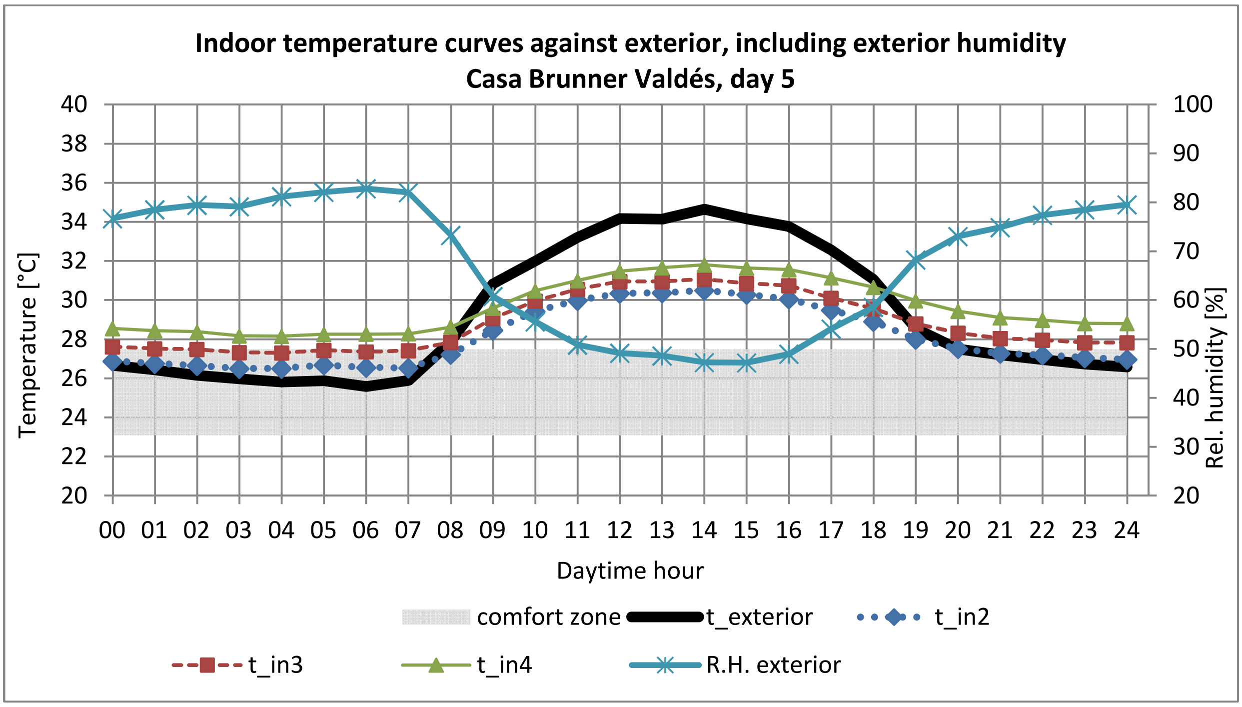


Figure 7-2: Comparison of indoor temperature curves with outdoor temperature and humidity for day 5 of the Casa Brunner Valdés series; rel. humidity values refer to the right scale. Elaborated by Excel™

The indoor temperatures follow very similar patterns during the course of the day, indicating a relatively constant distribution of cooler and heated air in the building. Figure 7-3 looks into this, by depicting the elevation profile of the indoor dry bulb temperature for every third hour of the selected day. From midnight to early morning, the slope is almost constant, while a slight falling tendency can be observed on the upper reach, with total temperature differences between 1.6 and 1.8 K from top to bottom. The greatest unsteadiness resulting in clear bends occurs at 9 a.m. and at noon, when the air layers at body height get heated up rapidly and the ascending air cannot keep track on the fast process. The values between the measuring point 1 m and the one at 2.5 m differ by approximately 0.6 K, measuring between this point and the upper measuring point at 4.8 m registered around 0.5 K difference for the by 0.8 m longer distance. Afternoon and evening are characterized by a largely constant slope, with the total temperature difference between upper layer and body height ranging between 1.4 and 1.9 K. The last point at midnight, still amongst the highest total temperature differences, indicates a slight bend toward the upper layer, suggesting a comparable development for the next day.

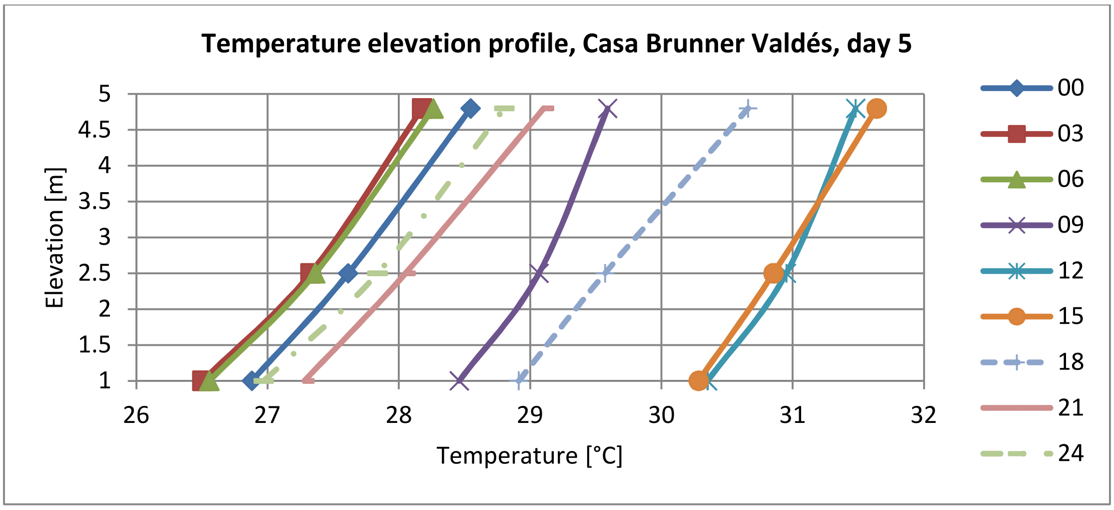


Figure 7-3: Temperature elevation profile for indoor dry bulb temperatures (recorded by PT 100 sensors), Casa Brunner Valdés. Elaborated by use of Excel™

The compliance with thermal comfort in terms of temperature courses is reviewed in Figure 7-4 where the gray background represents the comfort zone.

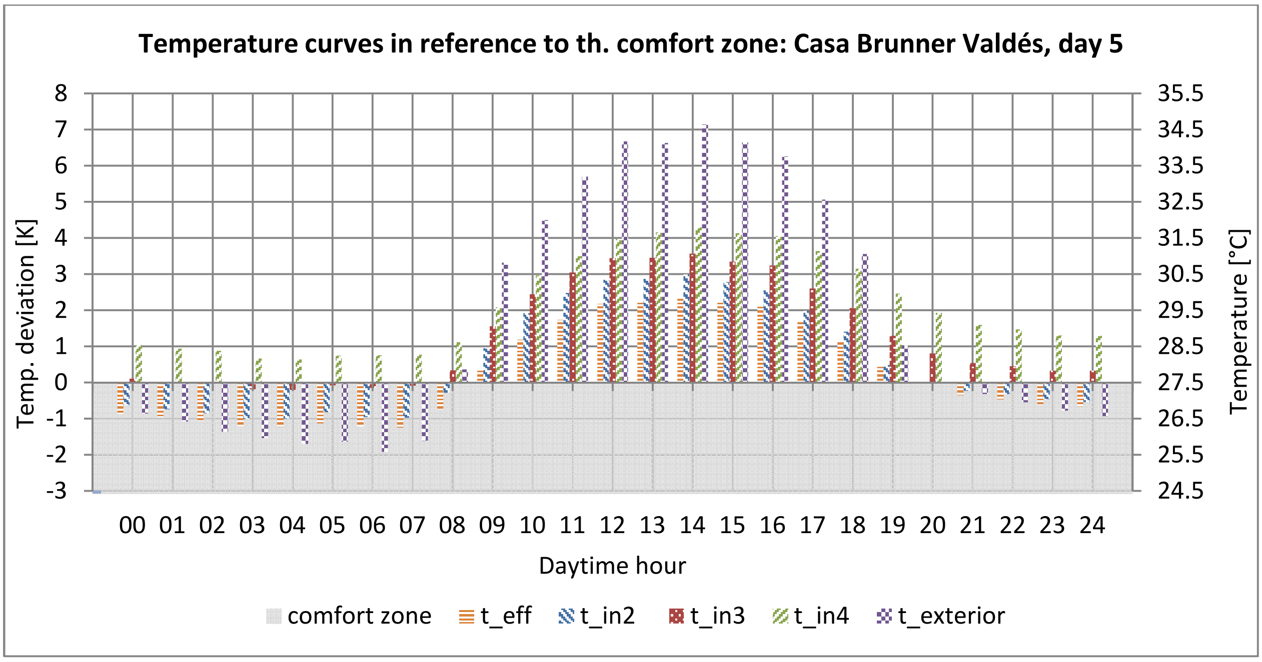


Figure 7-4: Visualization of thermal compliance with the comfort zone, Casa Brunner Valdés. Elaborated by use of Excel™

The temperature at body height t_{in2} crosses the upper comfort limit, which was set at 27.5 °C, at 9 a.m. and returns into the comfort zone at 8 p.m.; in between, it exceeds the comfort limit by 3 K at its maximum at 2 p.m.. In comparison, the temperature of the upper air layer t_{in4} surpasses by 4.2 K and the temperature at medium elevation t_{in3} by 3.5 K at that hour, while the effective temperature at body height exceeds thermal comfort by 2.3 K and the outside temperature by slightly more than 7 K. Air is allowed to leave the building through wall openings, through the gap between roof and wall or by dissipation through the double layer of zacate; this gives few possibilities for heated air in upper layers to leave the building. However, due to the elevated roof and penetration of heat from the ambient air, heated air continuously ascends up to the roof where it accumulates. This causes some form of afflux which affects the temperature development down to the ground; the lack of air exhaust causes an accelerated increase of temperature.

7.2.3 Estimation of indoor humidity

Figure 7-5 establishes the relationship between relative humidity and internal loads which are based on the assumptions made in section 5.3.4. The relatively moderate air temperatures provided for human activities to take place and the immense enclosed air volume, which offers the gained moisture from internal vapor production to spread all over, result in rather low deviation from outdoor humidity; certainly, also the occupancy is rater moderate. In addition, the human organism emits little vapor while sleeping; this condition further reduces the impact by internal loads at night. As a result, the indoor humidity oscillates between 48 and 84%.

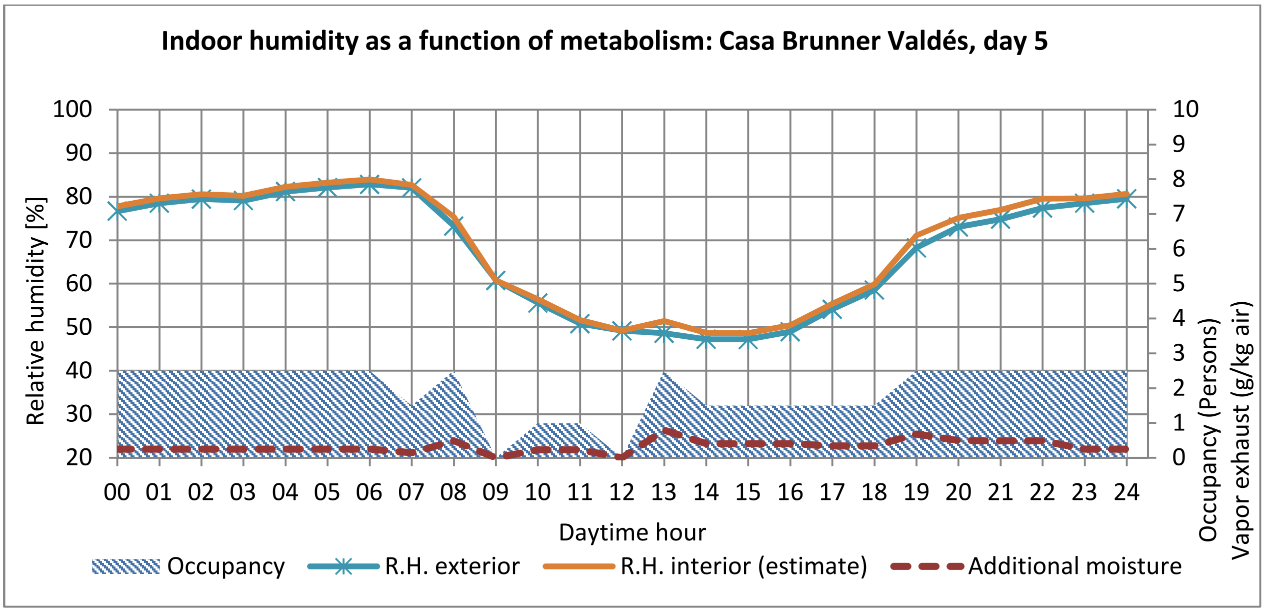


Figure 7-5: Estimated indoor humidity by human activities, Casa Brunner Valdés; both occupancy (number of persons) and vapor exhaust (g/kg air) are shown on the right axis. Elaborated by Excel™

7.2.4 Requirement of air velocity

As treated in section 5.3.3, air velocity was derived from the measured effective temperature $t_{eff,measured}$, measured dry bulb temperature t_{in2} and wet bulb temperature (derivative from dry bulb temperature and relative humidity). As $t_{eff,measured}$ is almost as high as t_{in2} all over the observed period, the resulting measured air velocity v_{air} stays at a constant value of 0.1 m/s and thereby is so small that it is not visible in diagram Figure

7-6. Therein, the mosquito nets in the openings are supposed to have a significant impact of diminishing the cross ventilation.

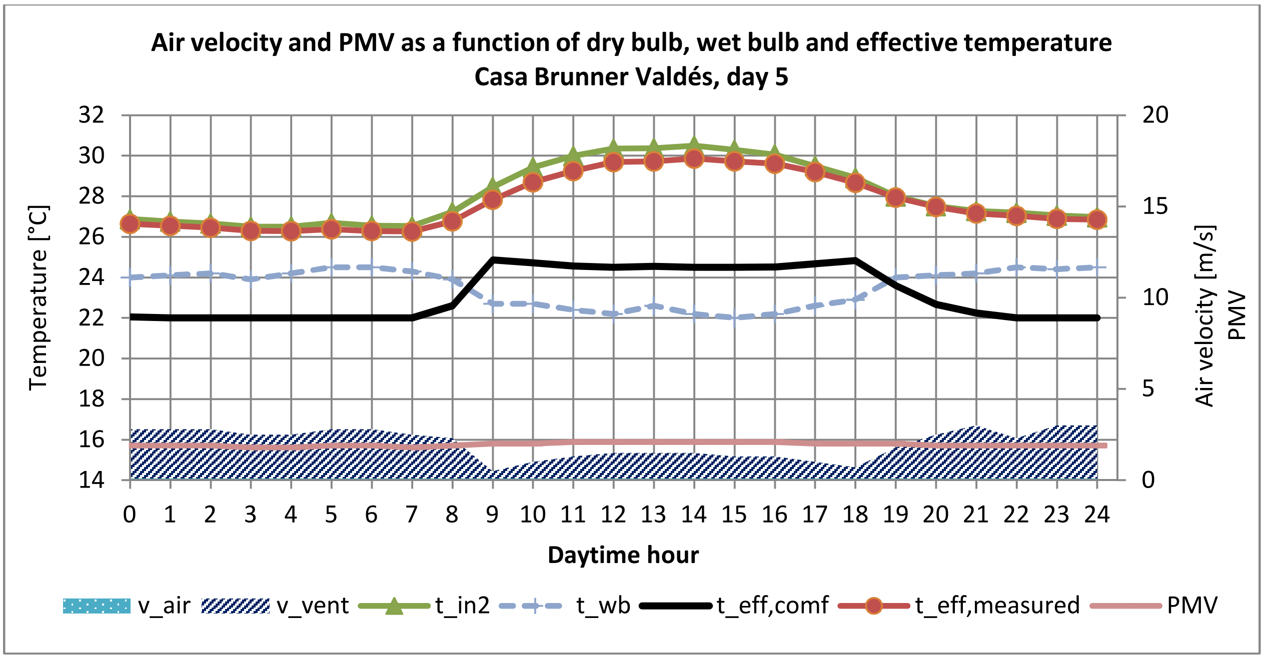


Figure 7-6: Air velocity and PMV in relation to dry bulb, wet bulb and effective temperature, Casa Brunner Valdés. Elaborated by use of Excel™

In order to achieve thermal comfort, the effective temperature must be reduced from the measured state $t_{eff,measured}$ down to $t_{eff,comf}$, the required effective temperature for thermal comfort. The corresponding demand of air movement is indicated as v_{vent} in the diagram whose velocity varies between 0.4 and 3 m/s and thus can be provided by a ventilator without exceeding the maximum permitted speed of 7 m/s for comfortable indoor climate. The resulting effective temperature follows exactly the curve of $t_{eff,comf}$ (therefore, it is not drawn in the diagram as $t_{eff,net}$ as in the prior study case). Thereby, the increased humidity has the higher impact than temperature, which means that the night demands the highest velocity v_{vent}, respectively the effective temperature must be pressed down to the lowest level at these hours. Consequently, auxiliary devices are needed at all hours in order to raise the air velocity to a sufficient level; but low velocity stages are enough during the day, in the evening and at night, when the requirement rises up to 3 m/s, medium stage is required.

7.2.5 Indicators for thermal comfort

With the lower line, Figure 7-6 also contains the PMV index for satisfaction with thermal climate; a closer view with illustration of the courses of PPD and PMV is offered by Figure 7-7. The PPD index varies from 69 to 82% of dissatisfied, while PMV oscillates between 1.8 and 2.1 and thus indicates the thermal sensation "warm" as the dominant stress level. At wide congruency of the two indices, the clear maximum can be distinguished around the early afternoon hours; PPD peaks at 1 p.m., PMV stays at its maximum level from 11 a.m. to 4 p.m. This course with high similarity to the temperature curves suggests a strong influence of air temperature, while the impact by relative humidity seems to be largely eclipsed. This observation stands in strong contrast to the prior case study where the PMV and PPD curves were interpreted as a more complex construct. The oppositeness indicates inconsistency of the thermal comfort indices for their applicability on the present case study.

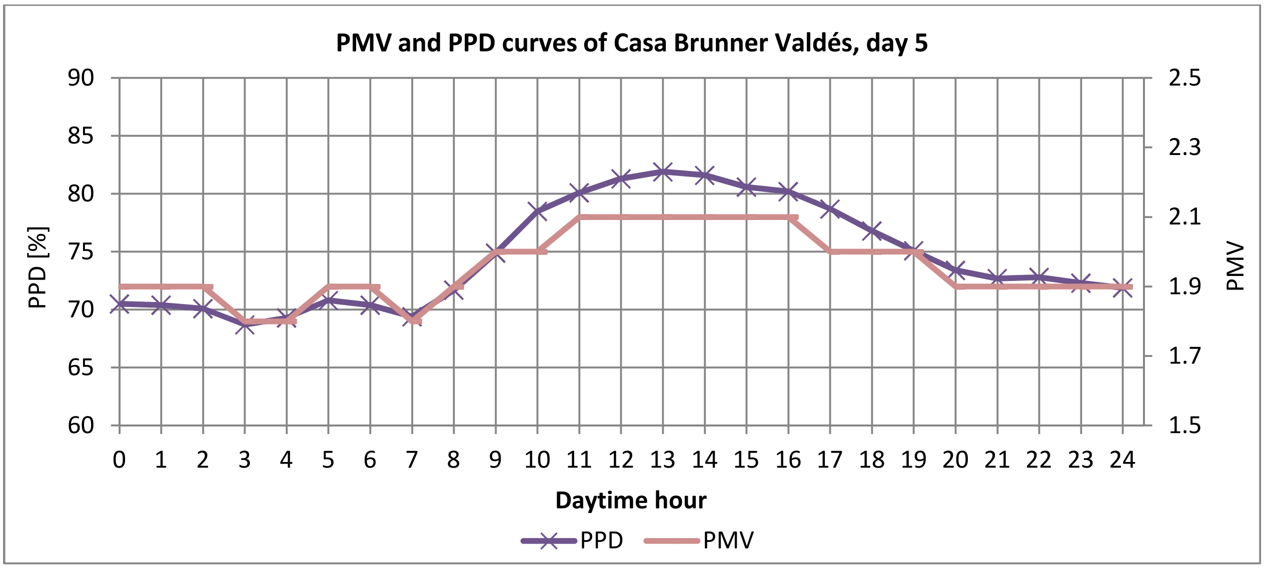


Figure 7-7: Curves of PPD and PMV indices for the present indoor climate, Casa Brunner Valdés. Elaborated by use of Excel™

7.3 Assessment of environmental impact

7.3.1 Analysis of present situation

It is important to consider the possibility of strong deviations from the actual values because parameters of the material characteristics depend on the specific region (see also section 5.1.6). Table 7-3 outlines the total and specific numbers of overall embodied energy and CO_2 emissions as they were estimated for Casa Brunner Valdés. Accordingly, the construction of the building with an estimated 260 tons of building mass was responsible for 266 GJ of energy consumption along with the release of 20 tons CO_2. The specific numbers relate the results to the three inhabitants and to the total living area of 105 m^2.

Table 7-3: Embodied energy and CO_2 emissions from the construction of Casa Brunner Valdés. Data: building materials data collection

Casa Brunner Valdes	Building mass (tons)	Embodied energy (GJ)	Emissions (tons CO_2)
Total numbers:	**260**	**266**	**20**
Specific:		**per person:**	
3 Persons	**87**	**89**	**6.8**
		per living area:	
105 m^2	**2.5**	**2.5**	**0.2**

In Figure 7-8, the total numbers are broken down into the particular materials. It becomes clear that the building wall of limestone, which already accounts for nearly 80% of the total building mass, exceeds this share by the related environmental impact; limestone is responsible for as much as 90% of both the total embodied energy and the total CO_2 emissions. Cement, despite a slight 1% share in the building mass, is responsible for a significant share on the environmental impact with 8% for each of the considered fields. Contrary, compressed sand with a mass share of nearly 20% almost disappears in the total breakdown of environmental impacts by contributing 1% to both embodied energy and carbon emissions. Zacate and wood piles contribute 1% or less to the total building mass and, as natural materials, still have lower shares in the environmental impact.

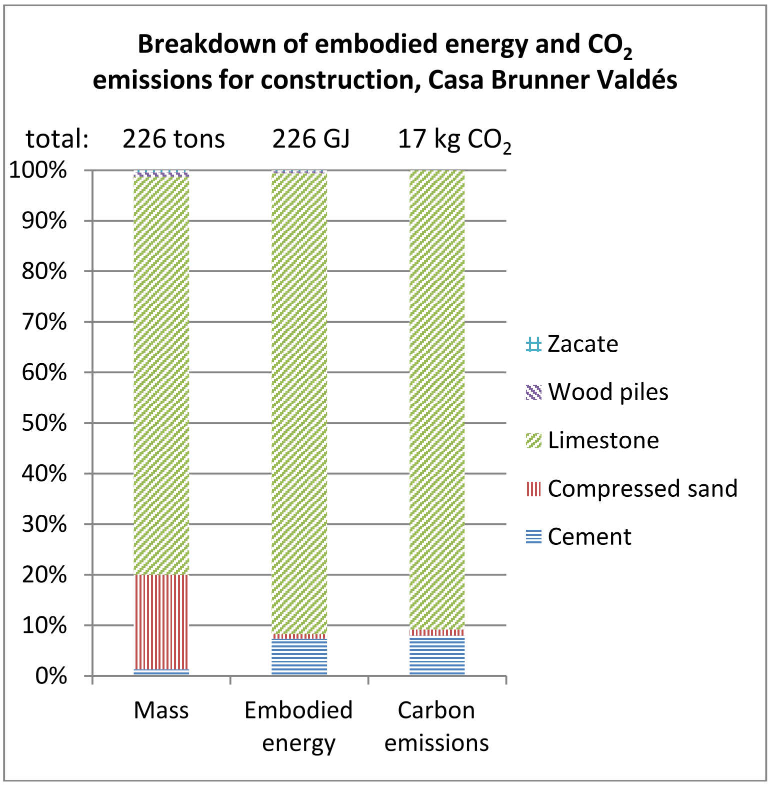


Figure 7-8: Breakdown of embodied energy and CO_2 emissions for the construction of Casa Brunner Valdés. Data: building materials data collection

7.3.2 Alternative scenarios

According to the impacts by the particular materials, variations in the material selection and used amount for the building wall hint at high reduction potential of the environmental impact; therefore, the alternative scenario 1 is dedicated to the limestone wall, by cutting the present thickness of the massive wall in half. In this way, the required mass of limestone decreases by 35% (conditioned by the general perimeter characteristics with openings and the oval form of the limestone wall), with the corresponding mitigation of environmental harm as illustrated by the left diagram in Figure 7-9; this measure would reduce both the embodied energy content and the CO_2

emissions of the total building by more than 30%. Based upon the spatial reduction, the column graph on the right side introduces scenario 2 which replaces limestone by adobe blocks. Facilitated by the much lighter material with good environmental parameters, this substitution saves another 31% of building mass and 67% of embodied energy; this results in total energy savings of 77%.

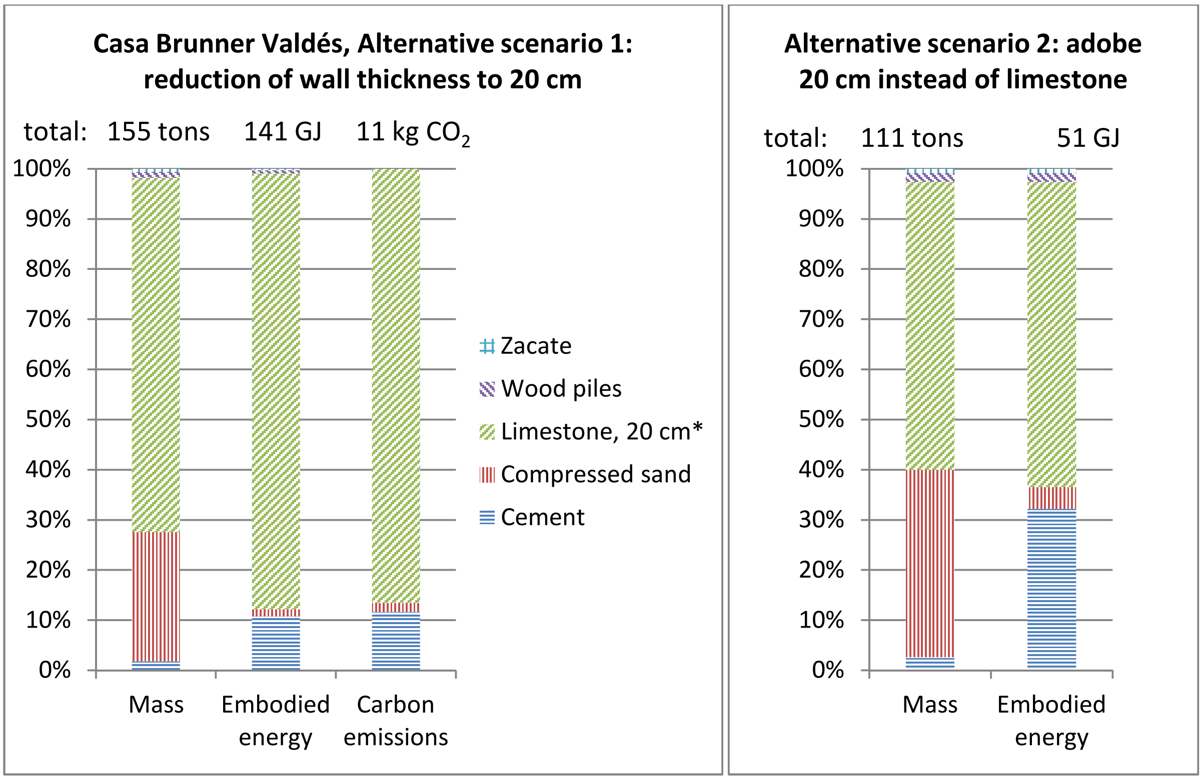


Figure 7-9: Alternative scenarios for Casa Brunner Valdés: shrinking of the limestone wall to 20 cm (left side); *20 cm wall of adobe blocks (right side). Data: building materials data collection

7.3.3 Further considerations

It is worth mentioning once again that on suitable local conditions for processing and delivery of limestone, the environmental impact could be lower than expressed by the given numbers. Another important consideration is the lifetime of different materials; natural materials as in this case the grass roof with zacate and wooden beams are more susceptible to decay. In section 4.5.2, the lifetime of zacate was announced as barely more than 10 years; both grass and wood might rot and lose their durability after several years of mechanical stress and with the impact of moisture, which is growing more acute because of inside cooking. In addition, the roof structure is particularly vulnerable to natural catastrophes like forest fires or hurricanes. Consequently, the roofing has to be renewed more frequently than the firm limestone or even the foundation. In concern of the environmental assessment, however, this deviation seems rather low because of the slight ecological impact that was assigned to the timbering with zacate and wood piles.

7.4 Recommendations

From the described observations and assessment, the following recommendations are concluded:

- Improvement of cross ventilation:
    - Integrate openings in the upper roof in order to facilitate the removal of heated air at higher elevations.
    - Add wind deflectors for enhancing natural ventilation; this can be achieved by vegetation or by the attachment of small construction elements on the air inlets on the windward side.
- In order to disconnect internal loads when possible, it could be considered to build up a partition wall for separating the kitchen. In any case, the kitchen should be orientated to the downwind side of the building in order to improve the air exhaust; in this way, the natural roofing materials are better protected against impacts by moisture, and also cooking events which depend on natural gas (LPG) are better shielded against fluttering cooking flames due to wind. Currently, the opposite is the case – the kitchen is oriented to the windward side.
- Building annex: planting of big trees could help to improve sun protection and natural ventilation; also extensive use of the stone roof for potted plants could produce some relief by giving shadow and absorbing the solar radiation; a more extensive enhancement would foresee the elevation of the roof of the annex and preferably the modification into a pitched roof which could also be achieved by ferrocement if not by another natural roof.
- Robust and sealing-up windows shutters should be integrated for the large openings in order to guard against all wind and weather conditions; this measure also dilutes the cooling in cold nights.
- Both a lower dimension and the use of a lighter material for the wall could bring some relief in terms of the environmental impact.

8 Case study III: Casa Poot Balam, San Roman

(Poot Balam, 2012)

8.1 Basic information

8.1.1 Specifications about the occupants, construction and the building location

The Mayan village San Román is located in the Northwest of the state Quintana Roo, in the municipality Lázaro Cárdenas between El Ideal and Vicente Guerrero (surrounding area see maps Figure A-10 and A-11 in the annex), and close to the border with the state

Yucatan. The distance to Cancun is approximately 200 km and Tulum is about 300 km away. The geographic coordinates are 20° 51’ 37” North and 87° 27’ 48” West.

Casa Poot Balam was constructed in 2004 in rectangular form what means a regression from the originally oval form of Mayan houses. The cottage survived the hurricane Wilma in 2005 without damages, the risen water level from the flood stopped about half a meter below the ground level of the building. Behind the new house, a Mayan house of the original oval form is arranged, but it has a high stone wall (1.2 m stone, 0.9 m wood sticks). It is used as storage and sleeping room for the men and was built about thirty years ago. The women sleep in the front house. A family with the younger son (22 years) and daughter (19 years) lives in the investigated house, the family of the older son with his wife and two young children passes frequently but lives in another part of the small village. Figure 8-1 presents the house from two different angles; on the right picture, the neighbored old Mayan house is situated in front. The ground plan and lateral views are attached in annex B (see p. 173).

Figure 8-1: Casa Poot Balam from southwest (left side) and north view. Pictures taken by Moie, 2012

8.1.2 Observations

Susceptibility to natural disasters

The village San Roman was affected by the hurricane Wilma in 2005, when parts of the village were flooded because of its location in a valley and the immense amounts of precipitation that the karst soils could not absorb within such a short time. Damage that is still visible after the hurricane is shown in Figure 8-2 in the front, while the trend of change towards more solid building materials can be observed in the back.

Culture and social development

Today’s children in Mayan villages mainly grow up with Spanish as their first language, with the intent to also have them taught Mayan; but as it is not their first language, some parts get lost. Recent parents are mostly bilingual as their fathers and forefathers speak Maya, some of whom also learnt Spanish, others and especially many women often did not. Usually, it is the same group of people who did not learn how to read and write neither.

Figure 8-2: Damage after hurricane Wilma and recent trends in San Román. Picture taken by Moie, 2012

For assuring the livelihood of their families, there is an increasing trend that the fathers, although accommodating their families in the native villages, shuttle between their homes and larger towns for work, especially to the economic and touristic center Cancun. Other families already left their home territories for surrounding towns, mainly for touristic destinies where they expect better chances for small businesses and employment. In this manner, the change, barely present for older generations, is undertaken intensively by today's fathers who transfer the new way of living to their children.

The Mayan village San Roman with about 120 inhabitants has its own elementary school. The high school is about 4 km away in the village Tintal, where the federal road 180 passes to connect the regional center Valladolid in the state Yucatan with Cancun, offering frequent bus service to both cities.

Technological and economic development

The former field road that connects San Roman with Tintal was paved a few years ago. About at the same time, shortly after the hurricane Wilma in 2005, the village was electrified. Since that time, watching television has integrated rapidly into the daily habits of the population. Recently, also the water supply is being extended to a public network. Drainage, to date, is limited to the drain of domestic sewage from cooking and from shower places out of the houses and directly into the soil.

Certainly also because of the mentioned impact caused by strong hurricanes and the necessity of safety, the majority of San Roman's inhabitants recently prefer to live in houses of industrialized materials. This trend is supported by the expanding cement industry and even by governmental initiatives. Recently, a private donator also made possible the construction of a new catholic church made of concrete that is still in progress; currently, Christian celebrations take place below a simple palapa roof.

However, the simpler alternative of making adjustments to the current buildings seems to be disregarded. In the course of time, some principles of traditional Mayan homes have rather disappeared; one of those is the oval form that gives the building a better resistance against strong wind.

Preferences

The issue of people's references is closely related to the question of what people are used to. Poorer parts of Mayan population who still use to live in palapas would generally prefer industrialized materials. However, those who had the opportunity to experience industrialized construction methods, recognize that palapas are preferable in times of heat because they stay cooler than industrialized houses, while during cold times industrialized houses are favored for staying warmer.

8.1.3 Building materials and dimensions

- Roof: fan palm leafs (huano), thickness 10 cm, overlapping over wall approximately 0.9 to 1.0 m;
- Low-rise wall-foundation: natural stone, thickness 25 cm, height 65 cm (inside height above floor level: 25 cm);
- Walls: wood sticks (local species), partially supported by paperboard; thickness: approximately 7 cm (effective: assumed as 5 cm), height 1.85 m; further paperboard is installed as upper partition separating space below the roof in a southern and northern half.
- Surrounding wood beam for wall finish at 2.10 m height (includes 25 cm wall foundation), diameter 12 cm;
- Floor and ramp cover of cement:
  - Floor: thickness 7 cm;
  - Ramp: length 140 cm; width 120 and 170 cm, height 15 and 35 cm at lower and upper end respectively;
- Foundation of natural stone;
- Opening without glass, only folding shutter, opening 65 x 60 cm;
- Doors: width 0.9 m, height 1.85 m.

In total, the home provides 30 m^2 of living space. The openings add up to 1.7 m^2 in the east facade (11% of total facade area) and 2.1 m^2 in the west facade (14%), with the main wind direction fluctuating between south and east. Additionally, the permeable building structure including the outlets in the corners of the roof ridge (south and north end) and the gap between wall finish and roof provide ventilation.

8.1.4 Overview of implemented design principles

The balance of design implementations is presented in Table 8-1. The north-south orientation is not applied; in addition, the west facade is strongly exposed. As the originally oval form disappeared, this factor cannot balance out the controversial orientation and lack of shading. The inward-looking doors on opposite sides are open all day but offer few area for air movement together with the small west window; instead, the permeability of the wall produces great relief. Due to the scarce openings, lighting by daylight is at a minimum. Altogether, as a typical traditional building, most of the guidelines are complied with.

Table 8-1: Building design assessment matrix, applied to Casa Poot Balam; elaborated based on Grimme, 2006; Climate Consultant, 2010; Lippsmeier, 1980

Nr.	Recommended design guideline	Statement about application, specifications
1	North-south orientation of the building (long axis reaches from east to west)	**Not applicable**: long axis reaches from south to north
2	Open arrangement and low building depth, but protection from hot and cold wind	**Applicable**: closely opposite exterior walls without interior separation, protected by neighboring building (east) and vegetation (north)
3	High ceilings and high outlets, preferably operable openings protected by overhangs	**Applicable**: permeable pitched roof, air exhaust in the corners of roof ridge with small overhangs; small gaps between roof and wall
4	Openings at body height orientated to prevailing breezes (= south to east)	**Partly applicable**: opposite doors (east and west), small opening with folding shutters on west facade; permeable wall improves ventilation
5	Large openings (40-80 % of the facade), located on opposite sides of the building	**To a small extent applicable**: east facade 11%, west facade 14%
6	Most of the openings orientated to the north (balance daylighting and enhance cross ventilation)	**Not applicable**: no openings in the north facade
7	Shading of exterior rooms, especially on the west facade, and avoidance of direct irradiation through openings without hindering air circulation	**To a small extent applicable**: some shading by neighboring building for the east facade, overhang from roof 1 m
8	Light-weight building with low heat retention	**Applicable**: complete building envelope made of natural materials, high permeability
9	Well-insulated roof, if built with industrialized materials	Natural materials
10	Light-colored building materials, also roof with high emissivity	Natural materials (brown)

8.2 Assessment of thermal comfort

8.2.1 Arrangement of sensors

The interior measurements were installed at the following elevations, with allocation to the particular channel:

Channel 4: Equivalent temperature (comfort sensor): 1 m
Channel 5: Temperature 2 (PT100): 1 m
Channel 6: Globe temperature (PT100): 1.8 m
Channel 7: Temperature 4 (PT100): 3.2 m

The sensors at 1 m height were installed in a shelf on the southeast wall, the elevated sensors were installed relatively centric. However, the upper partition by paperboard separates the space above the living zone and thus affects the measurements; the black globe was installed just below the divider in the very center of the building, but the upper sensor had to be installed on one side and was mounted above the main living zone at the south part, off the kitchen corner.

8.2.2 Thermal performance

The following evaluation is based on day 2 of the measurement series in Casa Poot Balam, recorded on May 16th. As depicted by Table 8-2, the trends of measured values and climate data are somewhat contrary. The measured values imply more moderate temperature while the humidity is very high, the only one of the three series higher than the historical weather data.

Table 8-2: Comparison between measured and historical climate, May Chetumal. Source: My Forecast, 2012

	t_exterior (°C)		relative humidity (%)	
Casa Poot Balam	measured	climate data	measured	climate data
Morning	24.6	26	92.0	91
Afternoon	27.9	31	77.0	68

The temperature curves in Figure 8-3 contrast the indoor temperature courses with exterior for the selected day. Furthermore, the exterior humidity, which runs contrary to the exterior temperature, is shown. Owing to the beginning of the rain season, the humidity was very high on that day and all over the recorded measurement series.

The measured values of indoors basically follow the trend of the exterior temperature t_{ext} but with reduced amplitude in both directions. 15 K of total exterior amplitude stands against 6 to 7 K temperature amplitude for the indoor temperatures; in the peak hours from 2 to 3 p.m., t_{ext} climbs as high as 35°C, the elevated sensors in the house registered up to 32°C and t_{in2} stopped slightly below 31°C.

As the gray area in the background displays, the room temperature at medium body height t_{in2} only exceeds the upper comfort limit at 27.5°C in the afternoon, the indoor values measured at elevated positions surpass the comfort zone shortly before noon to return into thermal comfort before midnight.

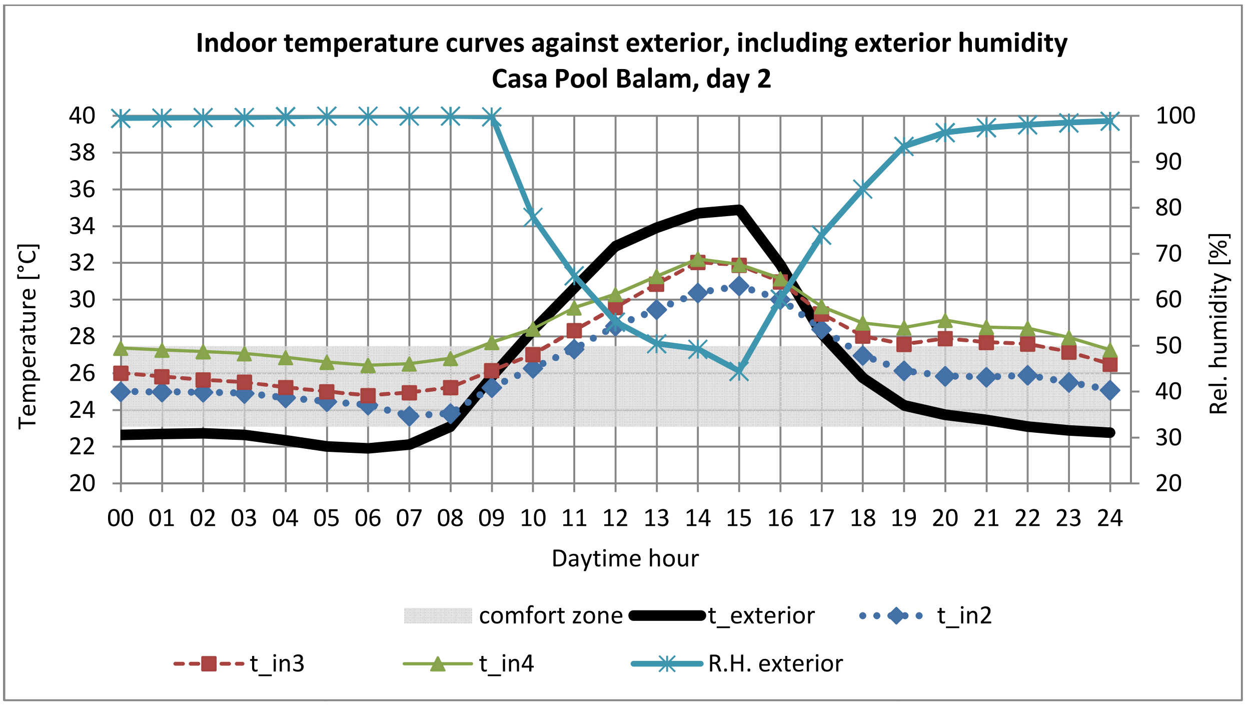


Figure 8-3: Comparison of indoor temperature curves with outdoor temperature and humidity for day 2 of the Casa Poot Balam series; relative humidity values refer to the right scale. Elaborated by Excel™

A closer look supplied by Figure 8-4 suggests that the upper air layers in the palapa roof are subject to relatively turbulent movement. As a consequence both of the highly permeable outdoor wall and of the heat discharge through the openings in the corners of the roof ridge, the heat flow adjusts rapidly to the boundary conditions set by the upper outside temperature above the roof and the temperature streaming in through the door and window openings and the permeable wall. As a result, the fluctuation of the three indoor temperatures is not in line but rather with more individual patterns. Furthermore, the abundant internal loads exert strong influence on the indoor temperature distribution; both high occupancy in the small space (estimated up to 8 persons, see also Figure 8-6) and cooking with wood stove are significant internal heat sources whose horizontal distribution also has effect on the heat flows. Cooking and eating takes place in the northern half, whereas the living zone is concentrated on the south where bench and hammocks are available. In addition, the paperboard partition which divides the upper layers above two mentioned zones affects the distribution of heated air beneath the roof; this could be the decisive reason that at 3 p.m. the temperature registered at 1.8 m height even equals the one at 3.2 m.

The beginning of the selected day at midnight shows an evened out profile; subsequently, the higher spheres cool faster what results in a bend at 3 a.m. and 6 a.m.

where t_{in3} at the middle position is only 0.5 K warmer than at body height t_{in2}. Comparably, the upper layers react faster on the warming in the morning so that the bend is reversed until 9 a.m. and the profile is completely straight. The temperature difference from top to bottom ranges from 4 to 5 K in the first half of the day. After the turning point at 9 a.m., afternoon and evening are dominated by assimilation of the two upper temperatures while at body height a much cooler temperature range is maintained. From 1.5 K temperature difference between t_{in4} and t_{in3} at noon, the difference completely disappears until 3 p.m. and slowly returns after that. In the meantime, the difference between t_{in3} and t_{in2} increases up to 4 K. Especially the comparison between 6 p.m. and 9 p.m. shows rapid cooling at body height, while the elevated layers cool down much slower. It takes until midnight that the reversible trend can be observed; at that moment, the upper layers cool faster than the ground and the bend declines.

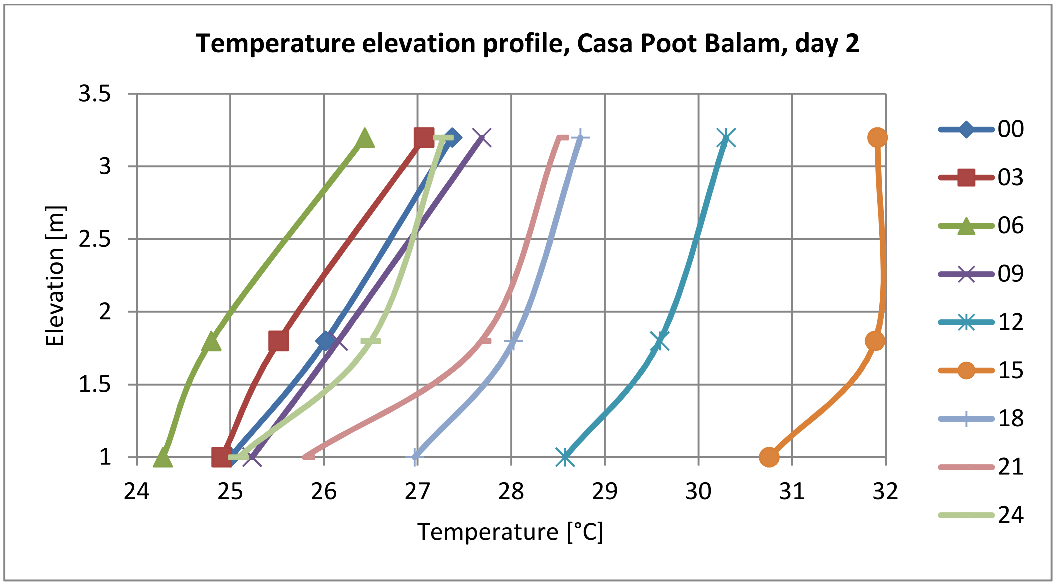


Figure 8-4: Temperature elevation profile for indoor dry bulb temperatures (recorded by PT 100 sensors), Casa Poot Balam. Elaborated by use of Excel™

Figure 8-5 illustrates the thermal performance in reference to the comfort zone. Due to the high temperature ranges, the comfort zone is crossed both on the upper and lower limit. At late night, the measured values taken at medium body height t_{eff} and t_{in2} approach the lower comfort limit, but only t_{ext} falls below by up to 2 K most of the hours; temperature values at the upper layers stay within the medium and upper range of the comfort zone at these hours. All temperatures exceed thermal comfort between 9 and 11 a.m. and return at 6 p.m., except for the two values from the upper layers that take until 11 and 12 p.m. respectively to return to the comfort zone. In the time between, the temperatures at body height reach their maximum at 3 p.m. by 2.4 K (t_{eff}) and 3.3 K (t_{in2}) above the upper limit respectively, t_{ext} rises as high as 7.4 K above, while the upper layers reach their peak one hour earlier with 4.5 K (t_{in3}) and 4.7 K (t_{in4}) above comfort respectively.

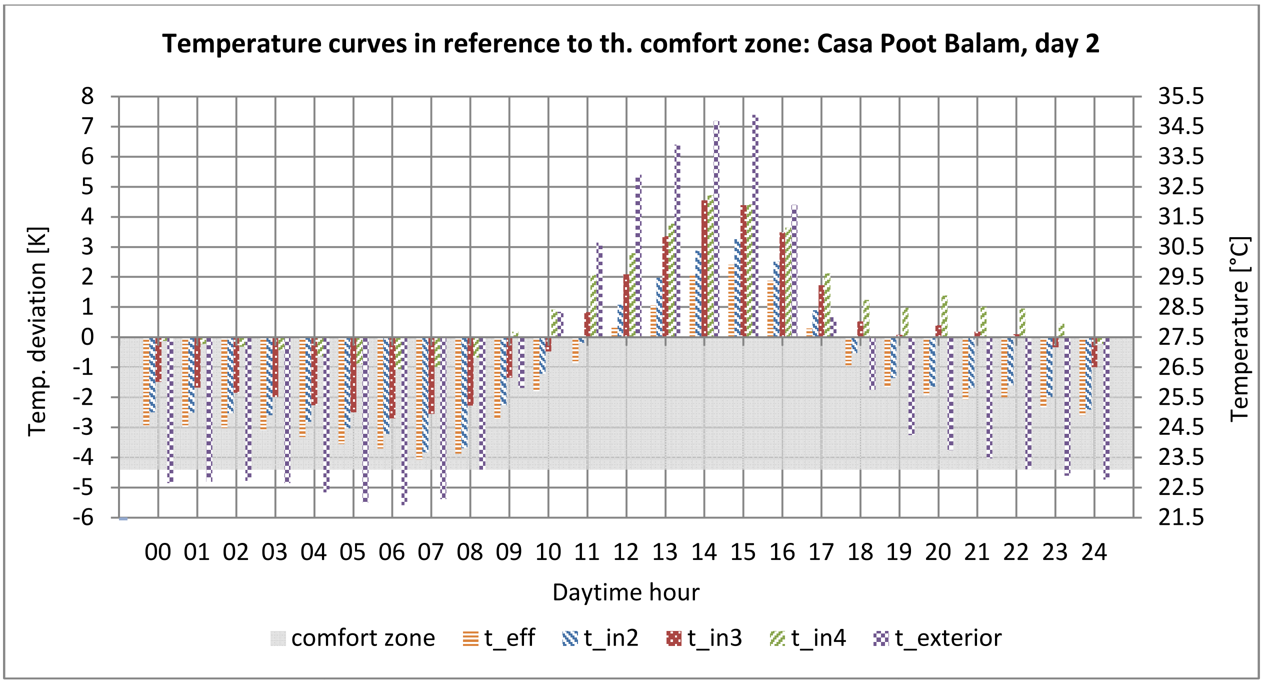


Figure 8-5: Visualization of thermal compliance with the comfort zone, Casa Poot Balam. Use of Excel™

8.2.3 Estimation of indoor humidity

The determination of indoor humidity based on the assumptions from section 5.3.4 is depicted in Figure 8-6.

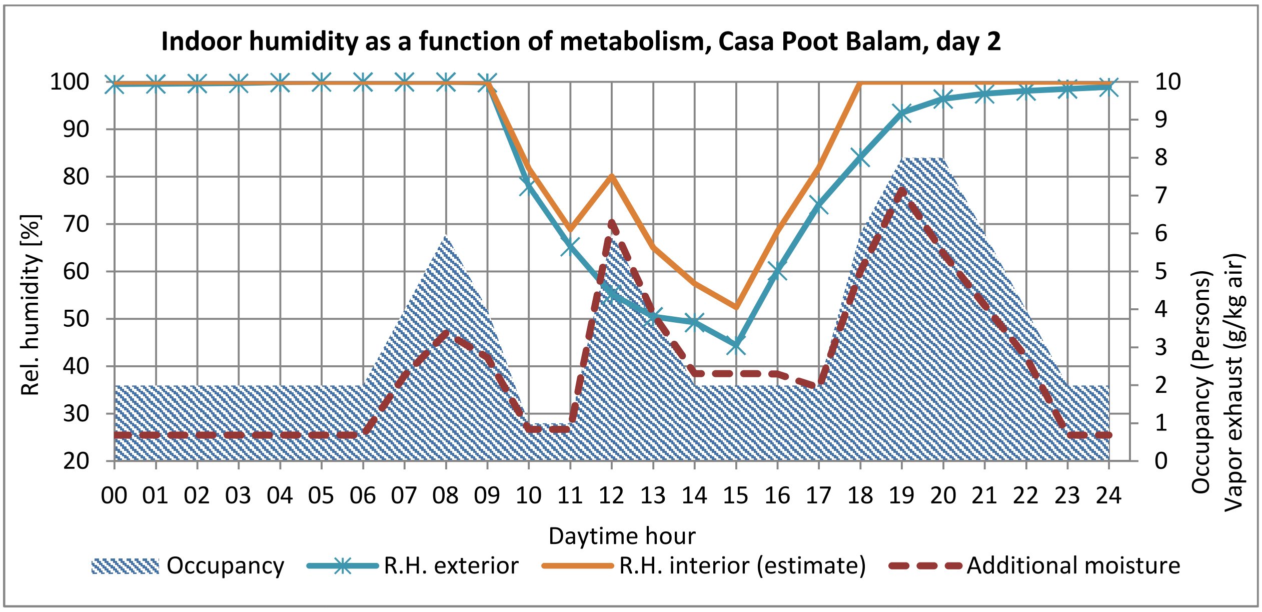


Figure 8-6: Estimated indoor humidity by human activities, Casa Poot Balam; both occupancy (number of persons) and vapor exhaust (g/kg air) are shown on the right axis. Elaborated by use of Excel™

The dashed line illustrates the additional moisture resulting from the high occupancy and cooking; their impact is lowered a bit by the rather moderate room temperature. The primal burden is the very high exterior humidity in the context of the first rainy period of the year; the exterior relative humidity already amounts to 100% from midnight till the morning. The lifting of interior humidity leads to the offset upper line during the day and in the evening, extending the maximum humidity by the space of time from 6 p.m. to midnight.

8.2.4 Requirement of air velocity

Figure 8-7 shows the existent air velocity, which is not amplified by ventilators at any time, and the velocity required for thermal comfort. The decisive temperature values for their determination, according to the proceeding outlined in section 5.3.3, are included in the diagram as line functions, whereat the unmarked central line represents $t_{eff,comf}$, the maximum permitted effective temperature in order to provide thermal comfort; the PMV is treated in the subsequent section. The wet bulb temperature t_{wb} follows the course of the measured temperature at body height t_{in2} during the time span of 100% relative humidity; accordingly, t_{wb} only drops during the day at lower relative humidity. The existent air velocity v_{air} is only visible in the diagram when it amounts to 0.3 m/s, for the remaining time it stays at 0.1 m/s. The required air velocity for thermal comfort v_{vent} is derived from the difference between $t_{eff,measured}$ and $t_{eff,comf}$. According to the results, an auxiliary device would be required for sufficient air velocity at all hours. However, most of the time a medium to low rotation level is sufficient; only at noon and from 5 to 6 p.m., an additional velocity of 4 or above is required; for the remaining hours, v_{vent} ranges from 0.6 to 2.7 m/s.

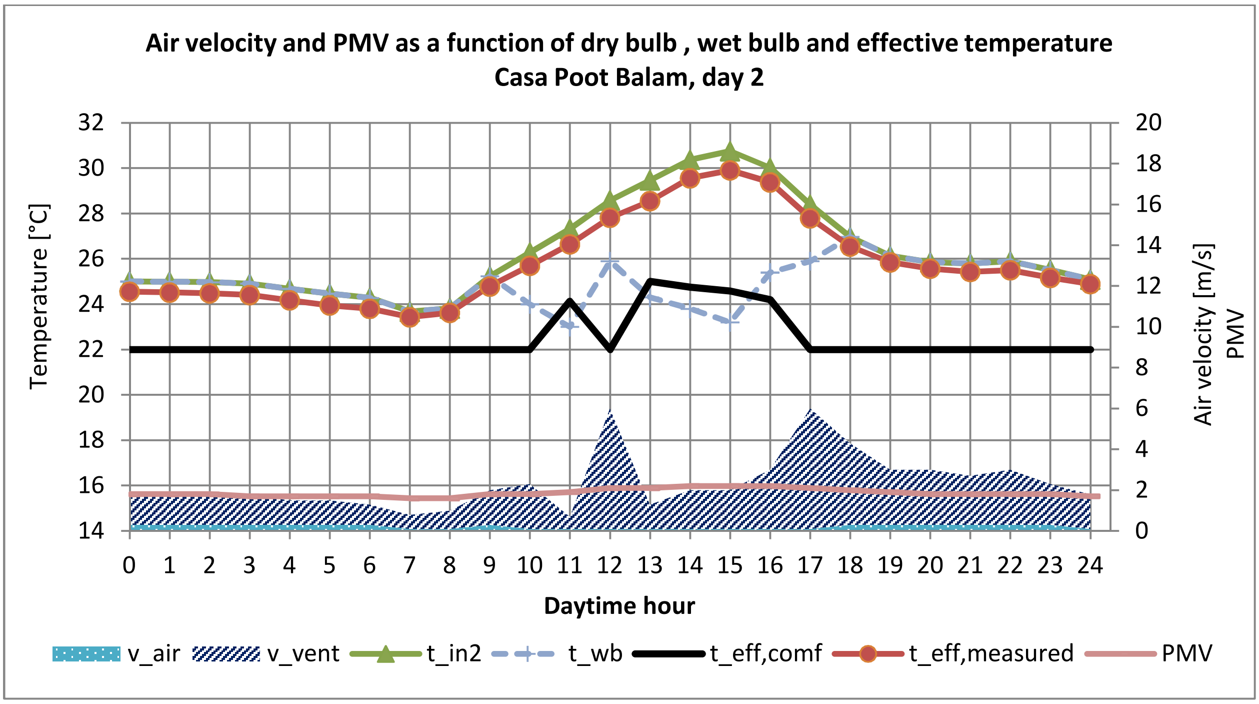


Figure 8-7: Air velocity and PMV in relation to dry bulb, wet bulb and effective temperature, Casa Poot Balam. Elaborated by use of Excel™

8.2.5 Indicators for thermal comfort

The lower line in Figure 8-7 expresses the PMV index for the existent indoor climate. While this diagram presents the index in the whole context, Figure 8-8 permits a more detailed view of the specific course and also includes the PPD index. The PMV varies from 1.6 to 2.2, indicating a predominating perception of “warm” with a low tendency for only “slightly warm”; meanwhile, the PPD index ranges between 56% and 85% of dissatisfied. Both curves reach their distinctive minimum in the early morning from 7 to 8 a.m. and they both peak in the afternoon from 2 to 4 p.m. Again, the curves of both indices are similar to the air temperature curve whereat the influence of humidity is not distinguishable; also the high total range is alike the extraordinarily high temperature span for this case study.

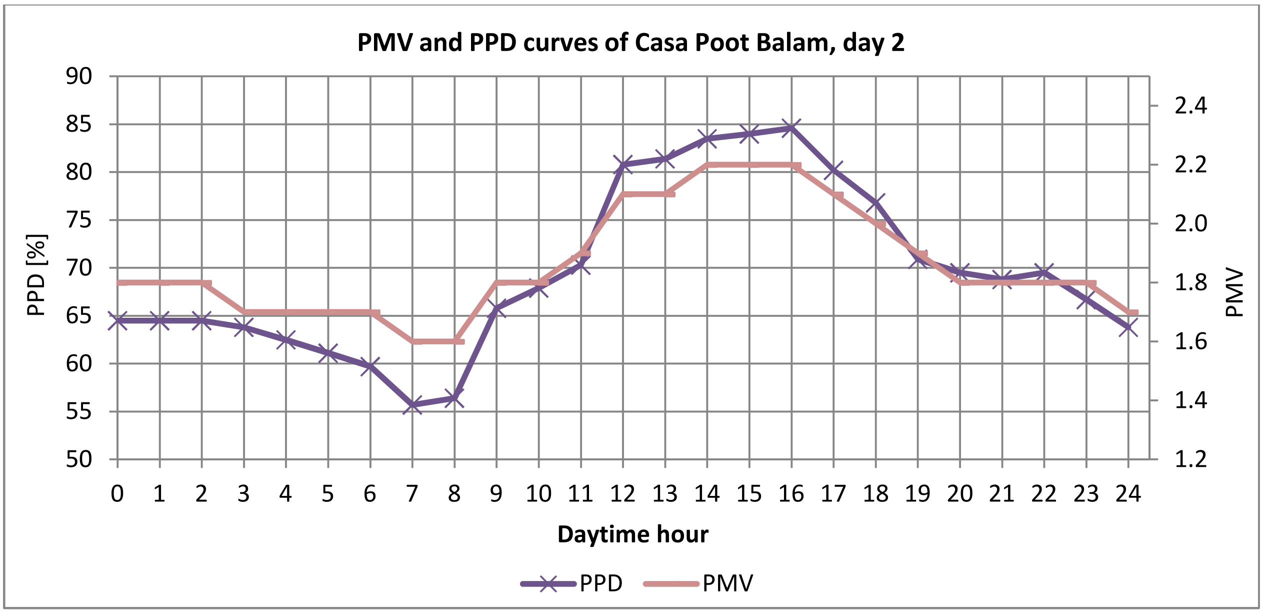


Figure 8-8: Curves of PPD and PMV indices for the present indoor climate, Casa Poot Balam. Elaborated by use of Excel™

8.3 Assessment of environmental impact

8.3.1 Analysis of present situation

As previously mentioned, the used parameters for this assessment might cause deviations owing to regional differences. In reference to 35 tons total building mass, Table 8-3 presents the embodied energy and CO_2 emissions caused by the construction of the Mayan building in total and specific numbers; the specific values refer to the four main inhabitants and the living area of 30 m^2. The low total numbers, due to the prevailing use of natural materials, translate into ordinary area-specific values because of the low floor space.

The left chart of Figure 8-9 illustrates the particular shares of different built-in materials in the total impact. It stands out that cement which amounts to 10% of the total building mass is responsible for a much higher ecological impact by contributing 38% to the embodied energy and 40% to the CO_2 emissions. Due to the high parameters for cement, all remaining materials except paperboard, which is light-weight thus has a negligible mass, share lower impacts than particular building mass. Thereby, limestone which contributes 80% to the total building mass is responsible for no more than 60% of both embodied energy and carbon emissions. The natural materials wood piles and fan palm leafs share the remaining 10% of total building mass, whereat wood piles contribute 2% to the total embodied energy and fan palm leafs less than 1%; CO_2 emissions were not specified but are assumed to be negligible for both. Paperboard contributes around 1% to both kinds of environmental impact.

Table 8-3: Embodied energy and CO_2 emissions from the construction of Casa Poot Balam. Data: building material data collection

Casa Poot Balam	Building mass (tons)	Embodied energy (GJ)	Emissions (tons CO_2)
Total numbers:	**35**	**56**	**4.3**
Specific:		**per person:**	
4 Persons	**8.7**	**14**	**1.1**
		per living area:	
30 m^2	**1.2**	**1.9**	**0.1**

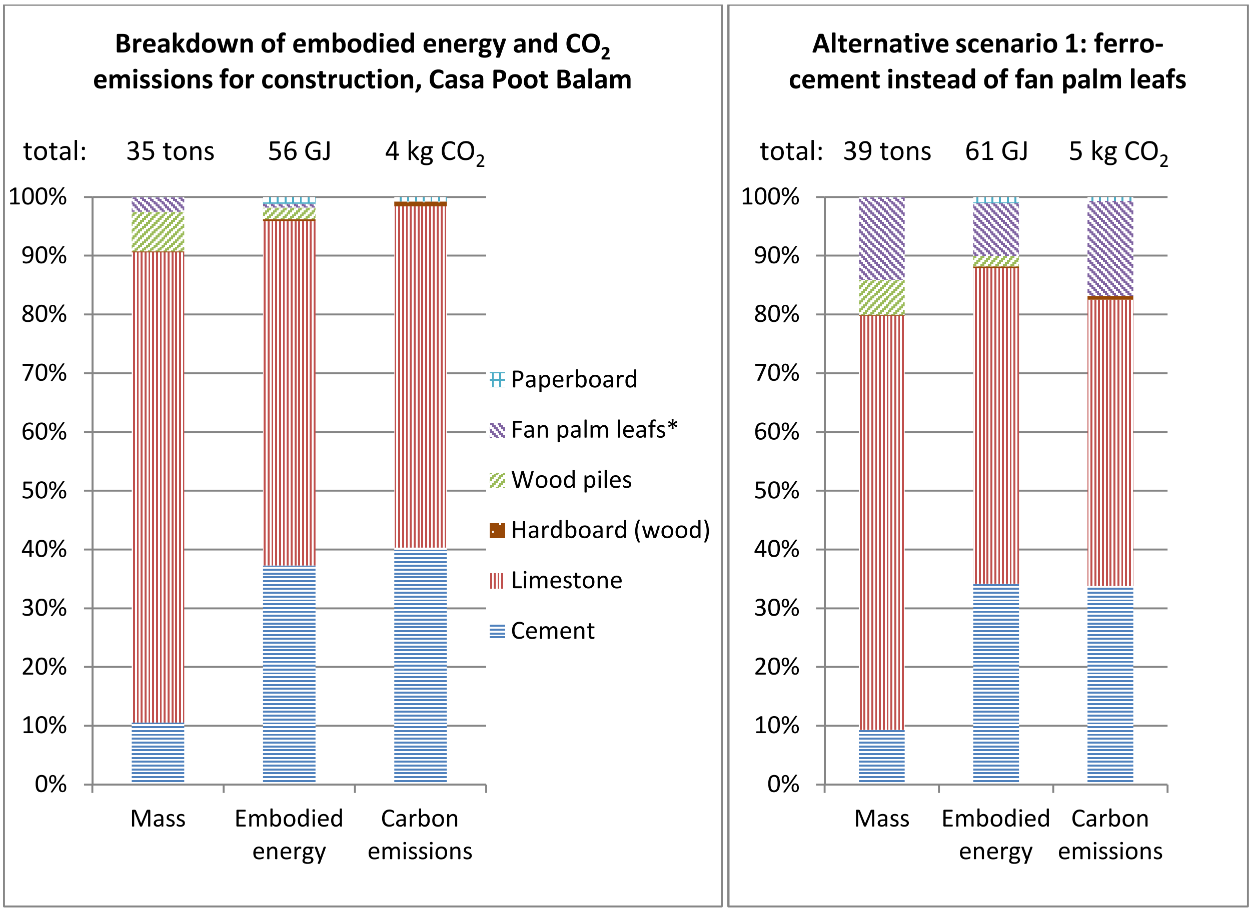


Figure 8-9: Breakdown of embodied energy and CO_2 emissions for the construction of Casa Poot Balam (left side); alternative scenario with ferrocement for roofing. Data: building materials data collection

8.3.2 Alternative scenarios

Evidently, the limestone foundation offers the highest saving potential. However, the selected scenarios focus on recent trends. As concrete construction has increasingly replaced traditional and natural construction methods, a few comparisons of particular elements of the existing building with industrial materials are drawn in order to demonstrate the resulting impacts that would come along with a replacement. The right chart area of Figure 8-9 shows scenario 1 which illustrates the replacement of the traditional palapa roof by 5 cm layer of a ferrocement structure (reinforced concrete), while the original form of pitched rood is maintained.

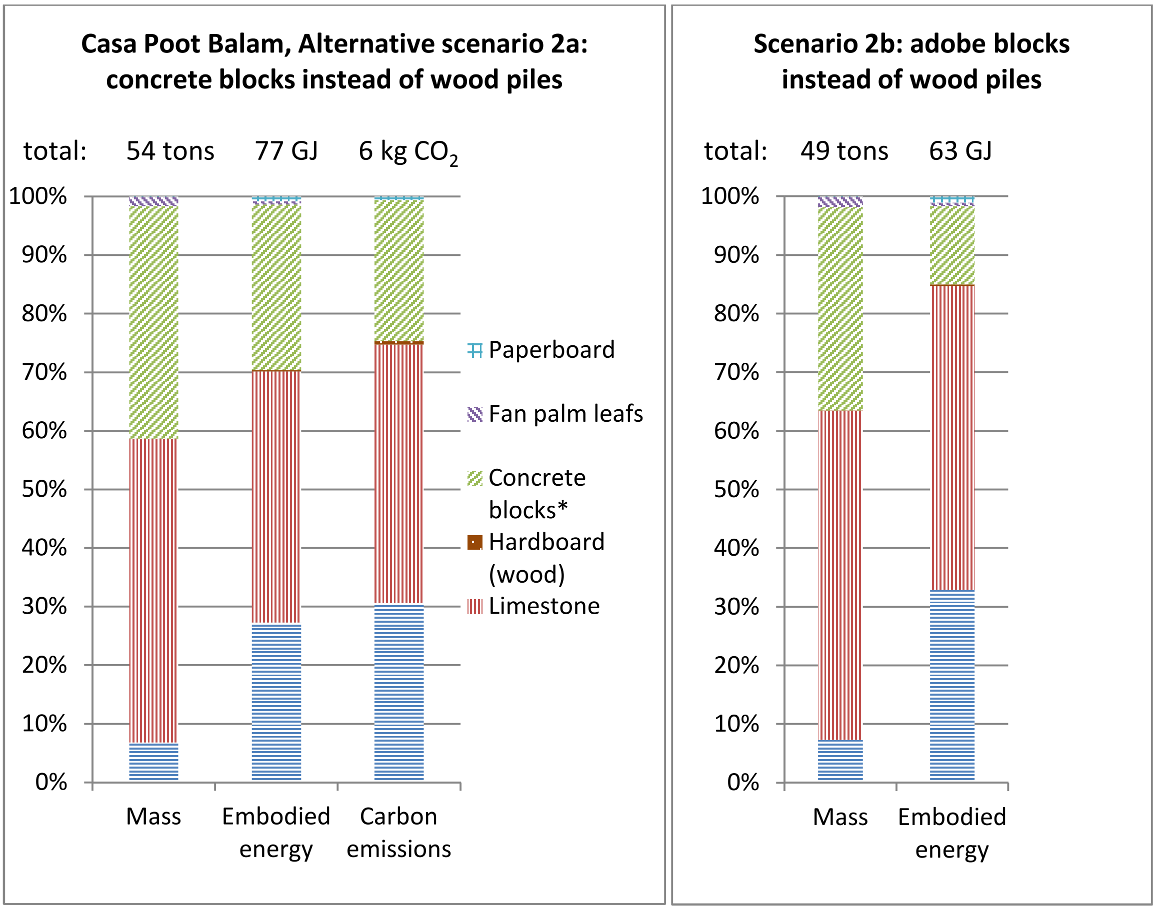


Figure 8-10: Alternative scenarios for wall mounting of Casa Poot Balam: concrete blocks with 20 cm thickness (left side); * adobe blocks, 20 cm (right side). Data: building materials data collection

All three columns show a distinct shifting caused by the much higher weight of ferrocement in comparison, and the corresponding impacts for fabrication and transport. As consequence from the increase of total building mass by 13%, the environmental impact grows by 9% of embodied energy content and 13% of CO_2 emissions. The topic of roofing with ferrocement is deepened in section 9.3.2.

The further scenarios presented in Figure 8-10 deal with the substitution of the wall made of wood piles by massive and hermetic materials; the increased shares of the firm materials provoke a correspondingly strong shifting visible in all columns. Scenario 2a compares the actual case with concrete blocks, representing the most trendy and industry-based alternative. This replacement, raising the total building mass by 55%, would increment the overall environmental impact by as much as 37% of embodied energy and 32% of CO_2 emissions. Scenario 2b considers the substitution of the wooden wall by adobe blocks; this alternative to concrete provokes an increase of the total building mass by 43%, but the gentle production process narrows the overall increase of embodied energy to 13%.

8.3.3 Further considerations

As already traced within the context of the prior case study, it is important to consider the significant differences between the firm industrialized and permeable natural materials in terms of durability and lifetime. The fan palm species huano, which was used for roofing, lasts approximately 15 to 20 years and thus is barely able to compete with solid structures such as ferrocement; the situation about the wood piles and hermetic alternatives is less extreme but goes in the same direction. On the other hand, the implications from the more frequent replacements required for natural materials in comparison with industrial ones are rather low because of the slight environmental impacts that natural materials stand for.

Moreover, apart from the high initial energy input and corresponding release of CO_2, the additional price to pay by selecting massive construction materials is the impairment of ventilation, owing to the hermetic characteristics of the materials. By replacing permeable with hermetic materials, new solutions for adequate building design have to be found. If not, poor ventilation will affect the interior climate decisively.

8.4 Recommendations

The following recommendations are deduced from the specified observations and assessment:

- The orientation should be reconsidered and more shading provided in order to reduce the impact by the afternoon sun. Also a return to the oval building form could improve the situation.
- The use of inside open fire for cooking – usually twice daily – holds a considerable health risk. If the current form of food heating is maintained, a better exhaust is necessary. On the other hand, the inside open fire repels insects.
- A plastic cover is mounted outside on the north wall for protection against cold wind or heavy rain; this layer should be removed when not needed in order to have better discharge of exhaust fumes from the fire place.
- In order to adapt the house to the current season, an approach could be to cover the whole wall from inside with paperboard for the cold season, while dismounting it completely during the warm season.
- Comparably, air outlets could be closed during cold hours within the cold season, but it is important to open them during cooking.

- Natural materials are worth maintaining them both for the good ventilation effect and for the very low environmental impact; if reinforcing of the wooden wall structure is desired or even necessary, first of all an exterior layer of soil material such as adobe should be considered to be applied on both sides. This topic is treated in section 9.3.1 of the following chapter.

9 Further case studies

9.1 Case Study IV: El Arca, Puerto Morelos

(Díaz Barreiro, 2012)

9.1.1 Specifications about the occupants, construction and the building location

Apart from their activities as physician and biologist respectively, Dr. Graciela Díaz Barriero and naturalist Oscar Ramón Canul González have experience in the design of bioclimatic spaces and eco-technology in the tropics. Furthermore, they mill cereals and corn and are engaged in the stabilization of local food markets, promote sustainable food supply free from pesticides, genetic manipulation and economic speculation.

Their new, self-sufficient home El Arca was constructed in two phases, the first of which was completed in 2004, the second one in 2008. Figure 9-1 presents the building from two different angles. Due to failing of the data logger battery and since the house is not connected to the grid (reserves from on-site power generation are usually used up before midnight) it could not be included into the series for full-time measurements.

The building is located in the tropical forest in the back country of the town Puerto Morelos in the municipality Benito Juárez, approximately 2 km off the town center and 4 km off the Caribbean coast. The cities Cancun and Playa del Carmen are both at a distance of about 30 km (surrounding area see map of Figure A-12 in the annex). The geographical coordinates are 20° 51’ 40” North and 86° 55’ 12” West (Google Earth, 2012). The main wind direction changes from east to south in summer towards north in winter.

9.1.2 Specifications about building concepts and observations

<u>Building materials</u>

El Arca was designed in great concern of wind threats and affection by insects; for those reasons, the building is made of cement. A further consideration was the before mentioned high cost for palapa roofs of natural materials and their increasingly unreliable manufacture. Beside tall vegetation (especially on the west facade), the white color of the outside layer are measures against heating of the building through the sun.

In order to avoid frequent repainting for fighting the marks of insects and weather, white cement was chosen for the roof and outside wall.

Figure 9-1: El Arca from south view (left) and the west facade. Pictures taken by Moie, 2012

<u>Supply services and sewage</u>

Electricity is provided by a 400 W wind wheel and five solar panels (four of them inclined and one plain) with a total capacity of 420 W with an inverter of 12 W and six batteries of 225 Ah each; a gasoline generator of 2500 W serves as back-up.

A 35 liter tank that collects rain water from closed roof areas is used for drinking, further domestic water is provided by a well (depth 4 m); water in cases of emergency (water scarcity or forest fire) can be obtained by a deeper well (depth 25 m, water contains sulfur).

Drainage is achieved by dry composting toilets which are fed with wood shavings after use; artificial wetlands are planned for the remaining wastewater which mainly comes from the kitchen and bathroom. All bathrooms have tubes up to the roof for air exhaust in order to remove odor and humidity.

<u>Ventilation concept</u>

On the first floor, small air inlets in the floor and tubes for exhaust air were originally installed in the upper wall. However, they were closed after the hurricane when water had penetrated the rooms through the small openings. Consequently, natural ventilation is provided solely by the door and windows opposite to each other.

For the second floor, a wind deflector on the roof redirects the wind that passes above the treetops into concealable vertical ducts in the walls of the upper floor; the deflector is presented in Figure 9-2 (left side). In order to diminish the mechanical stress at high air velocity, the deflector has an opening; furthermore it is anchored on the roof and fortified with steel scaffolding. Balconies in the corner of the northeast facade and in the west facade serve as further wind deflectors and provide good ventilation of the second floor. Finally, the outer facade is very open and allows ventilation to pass into the central area through doors.

Natural lighting

Abundant use of transparent elements in the roof and outer wall reduces the demand of artificial light, especially in bathrooms and corridors, as Figure 9-2 illustrates (right side).

Figure 9-2: Wind deflector with vent ducts (left), natural lighting in El Arca. Pictures taken by Moie, 2012

9.1.3 Building materials and dimensions

- Walls: concrete blocks, on the ends reinforced with steel rods and cement, 16 cm
    - Outer walls made of white cement
    - Inner walls made of common, gray cement
- Roof/ceiling: tie-beam and vent block system (*vigueta y bovedilla*), 20 cm
- Windows: single glazing with mosquito net (some movable, some folding)
- Transparent elements (roof and outer wall): 18 x 18 cm or individual forms of bottles
- Wind deflector: height at center 2.8 m, height at the flanks 2.35 m, width 2.2 m, height up to the bend 1.6 m, depth 65 cm

- Vent ducts: 55 x 35 cm (living room), 55 x 50 cm (sleeping room), outlet into room at 75 cm height (next to couch and bed respectively)

9.1.4 Overview of implemented design principles

Table 9-1 compares the realized building design with recommended guidelines. As a conclusion, the implications of the massive construction method are rather opposite to the recommendations. The strong ventilation concept with wind catchers and lateral wind deflection in an open building envelope stands for a different approach which therefore does not match exactly with the given criteria within the scope of the compiled guidelines; but the building design is shaped by a coherent concept. The interior (core area of the building) serves as refuge during hurricanes; also under regular conditions the space can be disconnected to a large extent in order to reduce heating from the exterior during the operation of the vertical vent ducts. The vent ducts, which guide the deflected air from the wind catcher, can be opened for the supply of comfortable ventilation during heat stress. By the high amount of operable openings (windows and doors), the building envelope is furnished with high flexibility; this aspect is an important element of the building concept.

Table 9-1: Building design assessment matrix, applied to El Arca; elaborated based on Grimme, 2006; Climate Consultant, 2010; Lippsmeier, 1980

Nr.	Recommended design guideline	Statement about application, specifications
1	North-south orientation of the building (long axis reaches from east to west)	**Partly applicable**: east facade subdivided and more north-oriented, but long west facade
2	Open arrangement and low building depth, but protection from hot and cold wind	**To a small extent applicable**: moderately open exterior wall; inner space subdivided into many rooms, main living zone surrounded by an interior partition but with openings to all wind directions
3	High ceilings and high outlets, preferably operable openings protected by overhangs	**Partly applicable**: ceilings of moderate height; distinct ventilation concept: air inlet from lateral deflectors, in addition from the roof through vent ducts, air outlet through doors and windows
4	Openings at body height orientated to prevailing breezes (= south to east)	**Applicable**: opposite windows and inner doors, open south and west facade and wind deflectors in the northeast corner
5	Large openings (40-80 % of the facade), located on opposite sides of the building	**Partly applicable**: openings below the recommended extent, but located on opposite sides of the building

6	Most of the openings orientated to the north (balance daylighting and enhance cross ventilation)	**Not applicable**: other facades are more open; however, porches and high vegetation protect from direct sunlight
7	Shading of exterior rooms, especially on the west facade, and avoidance of direct irradiation through openings without hindering air circulation	**To a large extent applicable**: high vegetation; air ducts compensate for reduced air movement
8	Light-weight building with low heat retention	**Not applicable**: concrete as main building material
9	Well-insulated roof, if built with industrialized materials	**To a large extent applicable**: insulation effect by tie-beam and vent block system
10	Light-colored building materials, also roof with high emissivity	**Applicable**: use of white cement

9.1.5 Observations and recommendations

- Integrate a vent duct down to the first floor in order to improve the ventilation in that area; due to the seldom need for the elaborate ventilation method in the sleeping room, it would probably be sufficient to prolong the corresponding vent duct from the sleeping room one floor downwards.
- Incline also solar cells in order to prevent dust or impurities from accumulating on the surface easily.

9.2 Case Study V: Urbi Villa Del Rey, Cancun

(Brubeck Gamboa, 2012; Mayagoitia, 2012; REEEP, 2011; Mayagoitia, 2011)

9.2.1 Specifications about the occupants, construction and the building location

Urbi Villa Del Rey consists of 15 housing units on three levels, from 38 to 50 m^2 individual floor space. The aim to have different family constellations was an important consideration for the selection of inhabitants of the building; in this way, diversified usage patterns were obtained.

As a social housing project that involves high-tech components as fundamental energy-efficiency measure, it serves as a showcase in many ways. Completed in 2010, the building complex is the first of its kind by being the first net zero energy home in Mexico of social housing that spans multiple floor levels. A cooperation of the construction company Urbi with the chemical company BASF, the manufacturer of electrical appliances Whirlpool and the national electricity supply company CFE made the way for an integral pilot project. The implementation of this project has created important new knowledge for all participating companies and provides the basis for new market entries. For the given elements, the project is unique amongst a handful of net zero energy projects in the region of Cancun alone and more than a dozen all over Mexico. Figure 9-3 presents Urbi's pilot project in two different views.

Urbi Villa Del Rey is situated in the periphery of Cancun, municipality Benito Juárez (surrounding area see map of Figure A-13 in the annex). The geographical coordinates are 21° 07' 55" North and 86° 55' 28" West (Google Earth, 2012).

Figure 9-3: Urbi Villa Del Rey from southwest (left) and northeast angle. Pictures taken by Moie, 2012

9.2.2 Specifications about the building concept and observations

Power supply

Electricity is supplied by a solar PV field in interconnection with the public grid. Net zero **site** energy is achieved by balancing out between feeding into and consuming from the grid. The solar field has a total installed capacity of 19.6 kW (112 panels of 175 W each, average area 1.4 m^2, expected output for climatic conditions of Cancun 30,000 kWh/a).

Integral cooperation

The balance between electricity production and consumption from the grid was facilitated through a pilot feed-in and usage contract between CFE and the 15 user households. The creation of the contract was a long progress because the algorithms needed to be adapted to each housing unit individually because of different initial situations. Furthermore, it has to be taken into account that electricity cannot be sold to CFE; the limit of profit from on-site generation is to balance out the own consumption, measured on a yearly base. Therefore, any stricter level than net zero **site** energy would mean that the rest after the annual generation-consumption balance would be donated to CFE.

Whirlpool contributed highly energy-efficient electric refrigerators and washing machines. The participation in the pilot project gave the company the opportunity to test their products on user patterns of local consumers before penetrating the Mexican market.

BASF administered insulation material for the building envelope. In this context, the enterprise tested the performance of prepared stucco at high temperatures contrary to its usual use in tempered climate. By this means, the adequacy of the material to fulfill a cooling function instead of heating could be inspected.

For the project leader Urbi, the pilot project was an important element in the testing of concepts for different climatic regions within Mexico. Successful results also helped to initiate new ambitious projects and establish new partnerships.

Involved energy efficiency certificates

- The building complex complies with Nom020, an obligatory Mexican standard for the building envelope; the performance is approximately 50% above base line;
- Electronic appliances from Whirlpool are certified by Fide, a national seal of quality;
- ISV (*Indicator of Sustainable Homes*, Spanish: Índice de Sustentabilidad de Vivienda), an integral seal of quality, is still in development; certificates from other countries (e.g. LEED, Green Star) are not used in Mexico’s residential building sector.

Outlook

Further respectively ongoing activities in the scope of this pilot project are:

- Monitoring of the energy consumption of the housing units;
- Monitoring of the small-scale feed-in contracts in cooperation with CFE;
- Make new financial proposals for electricity tariffs and subsidies of energy use;
- Reconsider infrastructure and building design for new consumption patterns;
- Create public policies that promote the replication of this kind of projects.

9.2.3 Building materials and dimensions

- Walls: pure concrete without blocks, thickness 10 cm.
- Outer walls and roof: exterior insulation and finishing (EIF) system with Neopor (further developed foam based on foam polystyrene): modified expanded polystyrene (EPS) with graphite, used in Mexico for the first time; wax-like material that starts to melt at 23 to 24°C so that thermal energy is absorbed by phase change; thickness 5 cm.
- Roof and ceilings: Elastopor ECO: Polyurethane without emissions of chlorofluorocarbons according to the Montreal protocol; thickness 5 cm.
- Outer walls: Thorostucco Thermo®: Stucco prepared with nanotechnology; two layers of 3 mm.
- Interior of walls: Thorolastic: Elastomeric coating that contributes to reflectance by diminishing the intensity of internal light.

- Outer wall and roof: Masterseal i600: Acrylic waterproof coating that assists to reflectance; two layers of 3 mm.

In order to give a better overview, Figure 9-4 illustrates the composition of the different materials for the wall and roof/ceiling mounting.

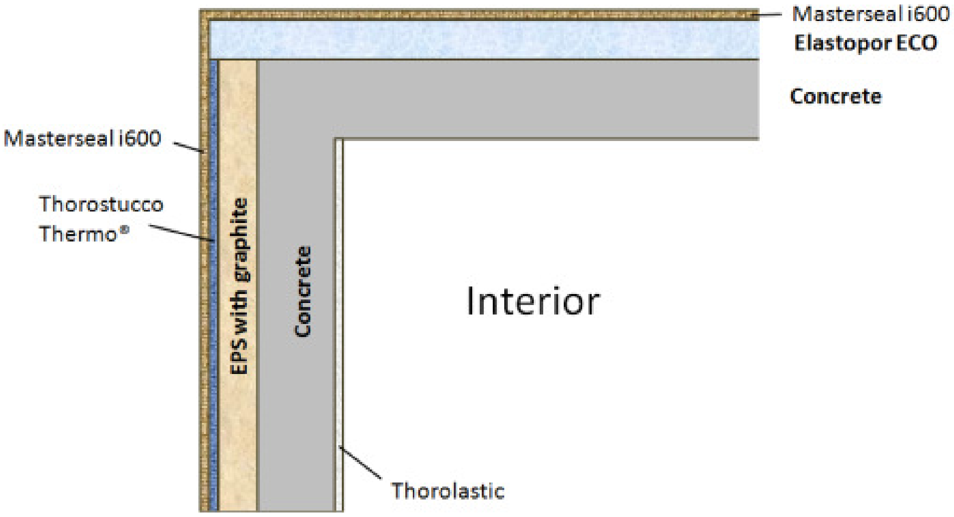


Figure 9-4: Wall and roof/ceiling mounting of Urbi Villa del Rey. Elaborated by means of Mayagoitia, 2012

9.2.4 Previous results of the project

The project was monitored over one year and compared to a northeast neighboring building complex of the same design but without thermal insulation of the building envelope and without a solar field. As a result, energy savings of 55% were registered by means of the energy efficiency measures; the remaining 45% were provided by the solar PV power production in interchange with consumption from the grid.

Thermal monitoring revealed that the wall mounting with particular thermal stucco and polystyrene maintained the indoor temperature 4 to 7 K below the exterior temperature.

As the price for low consumption during operation owing to highly energy-efficient building components and the solar PV cells, the environmental impact during the construction phase of the building is extremely high.

9.2.5 Individual observations and recommendations

As a very different approach to traditional building design in warm-humid climate, the presented project URBI Villa Del Rey does not share many criteria with the recommended guidelines from section 5.4.4. However, by exposing the long facade to south-southeast, the orientation to the sun is largely complied with. The following observations and recommendations were formulated based on the short insight into the project:

- For the design of three-level construction (ceilings at 2.7 m height), a worsening of inner air circulation is accepted; three-step ceiling ventilators (at 24, 28 and 42 W) are built-in supportive devices in all housing units.
- On the other hand, the combination of multiple housing units to one complex lowers the demand for material and construction costs significantly.
- The nanotechnology targets to maintain a low surface temperature; the building is not completely sealed from exterior climate, cross ventilation for improvement of indoor climate is desired; as a consequence, Urbi Villa Del Rey represents a combination between technological and bioclimatic design.
- Shading:
    - West facade: vegetation was planted for the windowless facade but still needs to grow; thick trees or bushes are recommended.
    - East facade: sun roofs are installed above the windows; however, the protection for the second floor is only partially achieved (lamellar device); in general, the sun protection should be improved.
- Wind deflectors and ducts/towers could improve the interior air circulation.

9.3 Further approaches and concepts

9.3.1 Wall mounting of Cottages in the Lagoon of Bacalar

(Rodríguez Elizarrarás, 2012)

In the Lagoon of Bacalar, Dr. Rodríguez Elizarrarás built two cottages (Spanish: *cabañas*) under the consideration of Mayan construction methods, by use of the bahareque technique. The palapa roofs maintained the typical oval form but the curved front endings are designed as terraces so that the elevated wall finish is rectangular. One of the two cottages is shown in Figure 9-5.

Figure 9-5: Cottage in the Lagoon of Bacalar from southeast angle. Picture taken by Moie, 2012

In contrast to the usual case that one finds in Quintana Roo, the wood piles are covered by earth inside and outside. The result is a more robust wall than the simple bahareque construction. Obviously, the wall of covered wood is less permeable, but it has good thermal properties. Furthermore, wide openings as air inlets beneath the roof endings provide a good cooling effect by natural ventilation. Due to the location next to the lagoon and the corresponding exposition to strong winds, good indoor climate is obtained without greater difficulties; for the same reason, the situation is understood as essentially different from the study cases, therefore the Cottages in the Lagoon of Bacalar were not considered as being included in the series of measurements.

9.3.2 Ferrocement roofing in Puerto Morelos

(Díaz Barreiro, 2012)

The high-elevated circular roof in Figure 9-6 is spanned by would beam. But instead of using natural materials as for a typical palapa, a fine web of steel serves as skeleton and is covered with cement. The solid cement and steel structure, ferrocement, gives the roof a robust character and a long lifetime. The high elevations towards the center and the large air outlet improve the interior air flow and thereby should facilitate acceptable conditions for the indoor climate. Evidently, the durable alternative causes a much higher environmental impact than the use of natural materials.

Figure 9-6: Ferrocement roof (reinforced concrete), Puerto Morelos. Picture taken by Moie, 2012

10 Conclusion

In addition to general literature statements, the Mahoney calculation table and Climate Consultant 5.2® have been consulted as supportive tools for recommended building design guidelines in warm-humid climate, and have therefore been linked to the specific climate data of Chetumal. Different types of bioclimatic buildings in the region of Quintana Roo have been physically inspected in order to obtain a representative overview of present local construction methods and trends. Three buildings thereof have been included in measurement series of indoor climate over minimum one week each and during the high temperature season; therefore the test results can be assumed as maximum loads.

Moreover, the thermal comfort assessment was subject to very strict boundary conditions:

1. The limits of the comfort zone rely on moderate adaption of users on climatic conditions.
2. The estimates for indoor humidity are very high as exchange with the exterior was neglected.
3. The measured values of all case studies tend towards the higher limits of the total scope of climatic conditions (owing to the points in time of the measurement series and May being amongst the hottest months).
4. The resulting PMV values are pessimistic, mainly due to the high indoor humidity (see point 2.) and the partial neglect or underestimation of air movement.

Discussion of results

The hypothesis was partly complied with. Thermal comfort for the measured case studies can be accomplished by support of ventilators in addition to natural ventilation; the summer season requires frequent use of forced ventilation. In Casa Macías Villalobos, thermal comfort can only partially be accomplished during summer. Theoretic and measured results agree that thermal comfort with its strict boundaries, as they were defined within the scope of this work, cannot be provided exclusively by natural means the entire year. Theoretic calculations by Climate Consultant 5.2® estimate that natural ventilation is able to provide thermal comfort for 44% of the year. The measured values indicate the requirement for continuous use of ventilators at different speed levels during the warm months. However, exclusive consideration of temperature for thermal comfort hints at tolerable climate at night and partly already from the early evening. For exclusive consideration of temperature for thermal comfort, approximately two thirds of the year is tolerable according to Climate Consultant 5.2®.

Furthermore, the test results confirmed the adequacy of traditional pitched roofs for the warmer months; the permeable light-weight wall made of wood allows for good air inlet, while the elevation toward the top of the roof with openings on the endings of the roof ridge promotes stack ventilation. As a result, the indoor temperature at medium body height (living zone) stayed more than 4 K below the exterior in the afternoon. On the other hand, the opinion of inhabitants revealed discontent for the thermal performance in winter.

The massive spacious construction made of limestone with large openings in the wall and highly elevated natural roof but without upper air outlets is competitive and keeps the interior at body height around 4 K below. Certainly, also the oval form contributes to the good thermal performance, as the curved building envelope offers a smaller target for solar irradiation and undesired strong wind. The construction has potential for still better results by integrating upper air outlets.

The massive urban building with inclined roof at moderate height appears clearly less preferable, whereat measurements were conducted in different rooms due to the building composition. The study (home office) facing downwind even exceeded the exterior temperature already in the afternoon, the windward study as well as the living room downstairs ranged from 2 K below to meeting the exterior temperature in the late afternoon. The poor performance is certainly based on limited ventilation, due to relatively small openings, lacking deflection of wind and user-unfriendly upper air exhaust windows so that they are barely opened. But also the massive construction makes a significant contribution with the effect that large parts of the heated air accumulate inside. The glazed facade of Estudio Martha is oriented to the north so that the inlet of air is limited. Due to the better orientation to the prevailing wind direction and because the upper exhaust windows were opened during parts of the presented measurements, the thermal performance in Estudio Gabriel is somewhat less critical.

Moreover, ventilators are in relatively frequent use in the studies. The rank order within the measured case studies explicitly confirms the expectations according to the implementation of recommended guidelines.

Despite the demand for additional, forced ventilation, building concepts aimed at natural ventilation are preferable; this is pointed up by the strong contrast of energy consumption between air-conditioning systems and ventilators: an AC system consumes minimum ten times the energy of a ventilator at full speed.

Hurricanes, forest fires, moisture and insects are typical harmful agents of the region; responding to such concern over the resistance against the force of nature, the desire for more durable construction materials is common. An alternative material for pitched roofs is ferrocement, providing higher resistance and durability. For the wall, wood piles could be covered by adobe on both sides as alternative; concrete blocks and adobe blocks have been investigated as further options. However, the effect of permeability gets lost by those replacements. Therefore, it is important to install wide openings and include measures for deflection of wind if the orientation of main openings to prevailing breezes is not assured. In this aspect, wind deflectors are a worthwhile consideration. If ground winds are sufficient, wind catchers installed on the roof with deflection into air ducts can transport considerable breezes down to the subjacent rooms and thus provide pleasant cooling for indoors.

By achieving indoor temperature levels of 4 to 7 K below exterior, the technological approach for the building envelope offers great potential for provision of thermal comfort. However, the numerous assemblies of high-technology components for thermal insulation result in the by far highest environmental impact. In addition, the selected materials are difficult to access and involve high investment costs; therefore, large scale is required for profitable implementation.

As the price for higher material resistance, all mentioned substitutions cause significant increase of environmental impact, by reason of strong increase both of building mass and of the efforts for the fabrication of materials. As a result, the ferrocement roof embodies 14 times the energy of the roof made of fan palm leafs; partly due to the higher wall thickness, which was set as 15 cm, adobe blocks embody 8 times and concrete blocks 20 times the energy of wood piles.

For solid exterior construction components, a further recommendable measure is the integration of transparent elements in order to improve natural lighting.

Outlook

The future trend of the residential building sector is of increasing concern in Mexico, amongst others owing to the advanced spread of industrialized building materials which have already replaced traditional materials to a large extent, and with it promote the installation of air-conditioning systems. In agreement with the concept of bioclimatic construction, comfortable indoor climate should be provided by natural means without air-conditioning and by use of construction materials with low environmental impact. In this way, overall ecological impacts are kept relatively low and thus make a contribution to sustainable development of local construction methods.

Regulations on energy efficiency of residential buildings in Mexico are still in the development stage to date. No compulsory, comprehensive regulation is in effect that covers all subject areas of construction in the residential building sector. In order to have guidelines take considerable effect in the construction sector, the adoption of obligatory building regulations is a basic requirement. Only in this way, the overall structure can adapt to new conditions that the obligatory requirements are directed to, from needs of individual private persons to the large distribution of products. In general, the regulation needs to have integral character. Therein, an essential factor that must be integrated into all considerations of building design is the climatic diversity of Mexico; in order to assure that generated building guidelines or even regulations apply to the conditions of a specific location, a distinction between the different climate zones is fundamental.

Requirements and restrictions need to be clearly indicated for all included measures so that users know exactly where they apply and what else has to be considered.

The key for sustainable development is identified in education and support of local knowledge; region-specific building techniques and building materials should be well understood by all involved persons. Furthermore, crafts such as roofing should be assisted adequately and the reforestation of used natural materials (e.g. wood, fan palms) is essential for continuous and well-balanced use of resources in the state Quintana Roo.

Specific recommendable design guidelines

Consequently, guiding design principles should be strongly tied to residential building planning in Quintana Roo; on the basis of the compilation of recommendable design guidelines from subchapter 5.4.4, the primal criteria were reassessed based on the findings from the case studies:

- **North-south orientation with small west and east facades;** important element to reduce the impact by solar irradiation. Oval form is preferable for further relief.
- **High ceilings and elevated roof with sufficient outlets for air exhaust, preferably operable openings with protection by overhangs;** the air exhaust should be oriented in opposite of and more elevated than air inlets. For amplification, cool towers can be integrated for higher elevation of air exhaust so that warmed indoor air is extracted by means of a stronger updraft effect. Related to the operability of openings, **flexibility of the building envelope** is a further important element (treated below this compilation).
- **Low building depth,** especially in the main wind direction, to facilitate cross ventilation.
- **Permeable building envelope <u>or</u> sufficient openings at body height oriented to prevailing breezes;** this is often contradictory to the north-south orientation of the building and should be resolved by applying the following point:
- **Integration of wind deflection elements** (planting or constructive measures like salient components in the envelope or wind catchers); wind catchers, which capture ground winds and carry them down into the living zones through ducts, are the most elaborate option, and should be especially considered if ground winds are not strong enough or the ventilation concept is poor.
- **Shading of exterior rooms, mainly on the west facade;** this measure can significantly impair air movement and therefore has to be considered individually for each facade.
- **Light-weight building with low heat retention, preferably made of local and natural materials;** light materials are in favor both of permeability, which facilitates air movement, and of low environmental impact. By trend, it can be assumed that the more natural the used materials are the better is the bioclimatic approach.

- **Light-colored building envelope and integration of transparent elements, if industrialized materials are used;** the poorer the shading the more significance has this measure, because it reduces the absorption of solar irradiation and thus diminishes heating of the building.

Flexible design of building envelope (and of the interior subdivision of space); in order to minimize the deviation from thermal comfort both for warm and for colder months but also for short-term changes of outdoor climate, more flexibility is in demand. Therefore, the building envelope should be able to adjust to the current climatic conditions. Therefore, a large share of openings with good sealing-up closing function or even openable walls would be an adequate solution. El Arca gave a good example for an adaptable envelope by integrating numerous windows and inner doors. In this specific case, disconnection of the building's core area was facilitated in order to benefit adequately from the use of the wind catcher. On the other hand, as it was outlined for Casa Brunner Valdés, sealable window shutters should be added to the large openings in order to be prepared for colder climate and strong wind and weather. For a suitable distribution of indoor air, a combined approach could be achieved by separating elevated roofs by an extendible intermediate ceiling; the additional ceiling can be pulled out for the cold season in order to reduce heat losses and will be retracted for the warm season in order to facilitate proper air circulation.

General recommendations

From the entire physical investigation, the following recommendations were concluded as further important principles for sustainable building in Quintana Roo:

- Encourage the use of local materials and their cultivation, reforestation and manufacture (e.g. support professional roofers).
- Take considerations not only in regard of the indoor climate in general (form, material, thickness, insulation/gaps etc.) but also related to precautions against catastrophes like hurricanes, forest fires etc. The decisive measures need to be taken within the construction process – measures taken afterwards, during operation, have minor effect.
- Conduct the planning process of buildings in a firm collaboration and exchange with the users, owners and further stakeholders.
- Shift subsidies from the use of electricity and air-conditioning towards components required for the implementation of elaborate building design (e.g. insulation, natural materials, refurbishments for energy efficiency measures) in order to promote sustainable building design. Due to very unequal distribution of wealth, many people do not have access to investment in sustainable solutions; this grievance needs to be tackled by adequate governance of subsidies.
- Improve the interaction between humans and their environment; as Quintana Roo's diverse population consists of many migrants from other climate zones who are

barely adapted to the given conditions, education on climate adaption and building design is a key element to prepare the inhabitants for their handling with this unfamiliar matter.

- The previous point is also important for investors; technologies have lost the relation to the land and their users what is certainly influenced by tourism. On the other hand, ecological tourism is an emerging trend which should be promoted. The complexity of the matter must be identified in order to achieve sustainable development, continuously and at all levels.
- Distribution of activities/rooms for housing units that range over multiple floor levels:
    - Building with calm air movement and poor shading (Casa Macías Villalobos): it would be preferable to carry out activities in the afternoon on the lower floor and use the upper floor(s) at late night and in the morning.
    - Building with strong natural ventilation (El Arca): it is rather preferable to stay on the upper floor(s) in the afternoon.
- Frame slide windows, despite good anchorage, are not recommendable as they only open up to half of their area. Folding windows are strongly recommended in order to benefit from the total opening area for ventilation; furthermore, the bent window casement facilitates the entry of air.
- The accumulation of single housing units to a larger complex is controversial; indeed, the combination to a larger complex saves building material and consequently reduces the initial investment. However, it is very important to maintain low building depth in the main wind direction, from air inlet to air exhaust. And in any case, the mutual influence of single units is undesirable and extends heat retention; building design is then especially challenged in order to generate adequate solutions.

In order to make natural building materials more attractive for urban construction, the following approaches could lead to good compromises:

- Walls made of wood could be covered by a layer of earth (see example in 9.3.1).
- Roofs should be elevated but could be made of ferrocement as alternative (see example in 9.3.2).
- Finally, also new, more creative ways should be considered in order to promote natural materials and products; innovative solutions could provide a new identity for a diverse population as present in Quintana Roo.

BIBLIOGRAPHY

Notes:

Chapter 5: Secondary literature sources are declared in footnotes.

Chapter 6-8: The reference declared as *building materials data collection* comprehends the following sources: Hammond, 2011, Baird, 1997; Milne, 2008; Grimme, 2000; Bojórquez, 2010; Häkkinen, 1999; Chamber Southeast, 2012

1) Anderson, E.N. & B. (2011), "Development and the Yucatec Maya in Quintana Roo: some successes and failures", Journal of Political Ecology Vol. 18. http://jpe.library.arizona.edu/volume_18/Anderson.pdf

2) ASER (1992), „GEWITEB Klima-Rechner" - *climate calculator*, version 2.70, Institut für Arbeitsmedizin, Sicherheitstechnik und Ergonomie e.V., Wuppertal, Germany http://www.institut-aser.de/out.php?idart=502

3) Baird, G.; Alcorn, A.; Haslam, P. (1997), "The energy embodied in building materials - updated New Zealand coefficients and their significance", IPENZ Transactions Vol. 24, No. 1/CE, Institution of Professional Engineers New Zealand, 1997. http://www.ipenz.org.nz/ipenz/publications/transactions/Transactions97/civil/7baird.PDF

4) Blaine, R. (2004), "Humidity Fixed Points", TA Instruments, New Castle, Delaware, U.S.A. http://www.tainstruments.co.jp/application/pdf/Thermal_Library/Applications_Notes/TN056.PDF

5) Bojórquez Báez, I.; Castillo, S.; Moen, M. (2010), "Propiedades Térmicas de maderas tropicales utilizadas en la vivienda" – *thermal properties of tropical woods used in residential buildings*, Semana Nacional de Energía Solar No. 34, SNES2010-ABC-008

6) Bojórquez Báez, I.: Personal meetings on March 21, 28, 30, April 18, 24, May 4, 2012, Chetumal, Mexico

7) Brubeck Gamboa, J.: Personal meeting on May 22, 2012, Cancun, Mexico

8) Brunner Morales, R.; Valdés Eguía Lis, L.: Personal meetings with physical investigation on 29 April, 2, 3, 10-12 May 2012, Mahahual, Mexico

Building materials data collection: see footnote above, Chapter 6-8

9) Bull, K. (2006), "Methods of accurately measuring capacitive RH sensors", 5th International Symposium on Humidity and Moisture, Veriteq Instruments Inc., Richmond BC, Canada.

http://www.vaisala.com/Vaisala%20Documents/White%20Papers/lsh-Methods-of-Accurately-Measuring-Capacitive-RH-Sensors.pdf

10) CFE (2009), “Estadísticas de venta: Quintana Roo” – Comisión Federal de Energía. http://app.cfe.gob.mx/Aplicaciones/QCFE/EstVtas/Historico.aspx
11) CFE (2011), “Listado de centrales generadoras” – *General listing of generator plants*, Comisión Federal de Electricidad, Estadística, Mexico http://www.cfe.gob.mx/QuienesSomos/estadisticas/listadocentralesgeneradoras/Paginas/Turbogas.aspx
12) Camber Southeast (2012), “Engineering Resources – Bulk Density Chart”, Camber Southeast Inc., Jacksonville Beach, Florida, U.S.A. http://www.powderandbulk.com/resources/bulk_density/material_bulk_density_chart_l.htm
13) Campbell Scientific (2012), “Black Globe: Temperature Sensor for Heat Stress, Instruction Manual”, Campbell Scientific Canada Corp., Edmonton, Canada. http://www.campbellsci.ca/Catalogue/BlackGlobe_Man.pdf
14) Claussen, E.; Johansson, T.; Loftness, V.E.; Tanabe, S.-I.; Yi, J. (2008), “Energy Efficiency in Buildings: Business Realities and Opportunities” – World Business Council for Sustainable Development (WBCSD).
15) Climate Consultant (2011), “Climate Consultant 5.1®” – Milne, M., Energy Design Tools, University of California, Los Angeles, U.S.A. http://www.energy-design-tools.aud.ucla.edu/
16) CONAPO (2005), “Indicadores demográficos básicos 1990-2030” – Consejo Nacional de Población. http://www.conapo.gob.mx/index.php?option=com_content&view=article&id=125&Itemid=203
17) De Anahí Ay Robertos, F.: Personal meeting on 16 March 2012, Cancun, Mexico
18) Díaz Barreiro, Graciela; Canul González, Oscar Ramón: Personal meetings with physical investigation on May 9, 15-18, 2012, Puerto Morelos, Mexico
19) ECEEE – European Council for an Energy efficient Economy (2009), “Steering through the maze # 2: Net zero energy buildings: definitions, issues and experience”. http://www.eceee.org/buildings/MazeGuide2-NetzeroEnergyBldgs.pdf
20) Energy Plus (2010), “Meteonorm Weather Files: North and Central America and Caribbean”, Energy Plus®, Yahoo Group Energy Plus Support. http://groups.yahoo.com/group/EnergyPlus_Support/
21) Engineering Toolbox (2012), “Dry Bulb, Wet Bulb and Dew Point Temperature”, The Engineering Toolbox. http://www.engineeringtoolbox.com/dry-wet-bulb-dew-point-air-d_682.html
22) Fuentes Freixanet, V; Álvarez García, G. (2002), “Arquitectura Bioclimática – *Bioclimatic Architecture*”, XXVI Semana Nacional de Energía Solar, Chetumal, Quintana Roo, Mexico
    – see translation below for relevant paragraphs.

23) Gjoksi, N. (2011), “Rebound effects and the ecological rucksack in the light of resource policies”, ESDN Case Study No. 7, European Sustainable Development Network. http://www.sd-network.eu/pdf/case%20studies/ESDN%20Case%20study_7_rebound%20effect_final.pdf
24) Glück, B. (1991), Zustands- und Stoffwerte: Wasser - Dampf - Luft; Verbrennungsrechnung (Reihe: Bausteine der Heizungstechnik), 2. überarbeitete und erweiterte Auflage, Verlag für Bauwesen, Berlin, Germany. http://berndglueck.de/stoffwerte.php
25) Google (2012), “Google Earth” – U.S. Department of State Geographer, INEGI. http://www.google.com/earth/index.html
26) Grimme, F.W. (2000), “Baustoff-Primäreenergieinhalte” – *Primary energy contents of construction materials*, compilation from various references, lecture notes, Institute for Technology and Resources Management in the Tropics and Subtropics, Cologne University of Applied Sciences, Germany.
27) Grimme, F.W. (2006), “Mahoney-Table for Decision Support”, calculation tool by MS Excel™, lecture notes, Institute for Technology and Resources Management in the Tropics and Subtropics, Cologne University of Applied Sciences, Germany. Elaborated based on Koenigsberger, 1978.
28) Grimme, F.W.: Personal meetings and frequent E-Mail correspondence, year 2012
29) Grupo Joben (2011), “Vigueta y Bovedilla”, Grupo Joben, Tultitlán, Mexico. http://www.grupojoben.com/concreto/viguet.html
30) Häkkinen, T.; Ahola, P.; Vanhatalo, L.; Merra, A. (1999), “Environmental Impact of Coated Exterior Wooden Cladding”, Technical Research Centre of Finland, VTT. http://virtual.vtt.fi/virtual/proj6/environ/env_woodclad.pdf
31) Hammond, G.; Jones, C. (2011), “Inventory of Carbon & Energy (ICE)”, Version 2.0, Sustainable Energy Research Team (SERT), University of Bath.
http://www.naturalstonespecialist.com/documents/ICEV2.0-Jan2011.xls
http://www.greenspec.co.uk/embodied-energy.php
32) Hussain, I. (2003), “Reactivation of a Silica Gel Moist Air Dehumidifier Using Solar Heat”, Islamic University of Technology (IUT), Gazipur, Bangladesh. http://www.lged-rein.org/archive_file/01059.pdf
33) IEA (2008), “Mexico: Statistics”, Related Graphs, International Energy Agency, Paris, France. http://www.iea.org/stats/countryresults.asp?COUNTRY_CODE=MX&Submit=Submit
34) IEC 60751 (2008), “Industrial platinum resistance thermometers and platinum temperature sensors (IEC 60751:2008)”, International Electrotechnical Commission, Geneva, Switzerland; German version DIN EN 60751:2009-15.
35) INEGI (2009), “Prontuario de información geográfica municipal de los Estados Unidos Mexicanos: Othón P. Blanco, Quintana Roo”, Instituto Nacional de Estadística y Geografía – *National Statistics and Geography Institute*, Aguascalientes, Mexico.

http://www.inegi.org.mx/sistemas/mexicocifras/datos-geograficos/23/23004.pdf

36) INEGI (2010), “División municipal: Quintana Roo”, Instituto Nacional de Estadística y Geografía. http://cuentame.inegi.org.mx/monografias/informacion/qroo/territorio/div_municipal.aspx?tema=me&e=23

37) INEGI (2011), “México en Cifras: Información Nacional, por Entidad federativa y municipios” – Instituto Nacional de Estadística y Geografía. http://www.inegi.org.mx/sistemas/mexicocifras/Default.aspx?i=i&

38) INEGI (2011)-A, “Anuario estadístico de los Estados Unidos Mexicanos” – Instituto Nacional de Estadística y Geografía. Cuadro 2.2, p. 71 ff. http://www.inegi.org.mx/prod_serv/contenidos/espanol/bvinegi/productos/integracion/pais/aeeum/2011/Aeeum11_1.pdf

39) INEGI (2011)-B, “Anuario de Estadísticas por Entidad Federativa”, Instituto Nacional de Estadística y Geografía. http://www.inegi.org.mx/prod_serv/contenidos/espanol/bvinegi/productos/integracion/pais/aepef/2011/Aepef2011.pdf

40) INEGI (2011)-C, “Anuario Estadístico de Quintana Roo 2011”, Instituto Nacional de Estadística y Geografía. http://www.inegi.org.mx/est/contenidos/espanol/sistemas/aee11/estatal/qroo/default.htm

41) IMF (2010), “World Economic and Financial Surveys: World Economic Outlook Database”, International Monetary Fund, Washington D.C., U.S.A. http://www.imf.org/external/pubs/ft/weo/2010/02/weodata/index.aspx

42) ISO 7730 (2005), “Ergonomics of the thermal environment: Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria”, International Organization for Standardization, Geneva, Switzerland. http://ntm.ru/UserFiles/File/document/Microklimat/Norm/ISO_7730_2005.pdf

43) Jarnagin, R.E. et al. (2008), “ASHRAE Vision 2020: Producing Net Zero Energy Buildings”, American Society of Heating, Refrigerating and Air-Conditioning Engineers. http://www.google.de/url?sa=t&rct=j&q=ashrae%20definition%20net%20zero%20energy%20&source=web&cd=6&ved=0CFgQFjAF&url=http%3A%2F%2Fwww.ashrae.org%2FFile%2520Library%2FdocLib%2FPublic%2F20080226_ashraevision2020.pdf&ei=6ns2T5zOD8nKsga6p_CzDA&usg=AFQjCNGDKEt4gCFzo8CKWJ58a_d1TGSEhw&cad=rja

44) Johnson, T.M.; Alatorre, C.; Romo, Z.; Liu, F. (2010), “Low-Carbon Development for Mexico”, Low Carbon Growth Country Studies Program, World Bank. http://sdwebx.worldbank.org/climateportalb/doc/ESMAP/FINAL_LCCGP_MX_BriefingNote003_10.pdf

45) Kaltschmitt, M.; Streicher, W.; Wiese, A. (2007), “Renewable Energy: Technology, Economics, Environment“ – Springer-Verlag, Berlin, Germany; p. 103 ff., p. 385 ff.

46) Kennedy, Jos.F. et al. (2004), “Building without Borders”, New Society Publishers, Canada. http://books.google.de/books?id=kXWQa2NkYoMC&printsec=frontcover&hl=de&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

47) Kim, J-J.; Rigdon, B. (1998) Sustainable Architecture Module: Qualities, Use, and Examples of Sustainable Building, University of Michigan, U.S.A. http://www.umich.edu/~nppcpub/resources/compendia/ARCHpdfs/ARCHsbmIntro.pdf

48) Koenigsberger, O.H.; Ingersoll, T.G.; Mayhew, A.; Szokolay, S.V. (1978), “Manual of tropical housing and building – Part one: Climatic design”, Longman Group Ltd., London, U.K.

49) Laustsen, J. (2008), “Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings”, International Energy Agency, Paris, France; p. 71 ff. http://www.iea.org/g8/2008/Building_Codes.pdf

50) Lippsmeier, G.; Mukerji, K. (1980), “Building in the Tropics”, Callwey-Verlag Munich, Germany

51) Liu, F.; Meyer, A.S.; Hogan, J.F. (2010), “Mainstreaming Building Energy Efficiency Codes in Developing Countries: Global Experiences and Lessons from Early Adopters” – World Bank Paper # 204. http://www.esmap.org/esmap/sites/esmap.org/files/WP_204_GBL_Mainstreaming%20Building%20Energy%20Efficiency%20Codes%20in%20Developing%20Countries.pdf

52) Lutz, W.; Prieto, L.; Sanderson, W. (2000), “Population, Development, and Environment on the Yucatan Peninsula: From Ancient Maya to 2030”, International Institute for Applied Systems Analysis, Laxenburg, Austria. http://www.iiasa.ac.at/Admin/PUB/Documents/RR-00-014.pdf

53) Macías Zapata, Gabriel Aarón; Villalobos, Martha Herminia: Personal meetings with physical investigation on April 19, 23, May 2, 5, 2012; Chetumal, Mexico

54) Madsen, T.L.; Olesen, B.W.; Kristensen, N.K. (1984), Comparison between Operative and Equivalent Temperature under Typical Indoor Conditions, Report No. 160, ASHRAE Meeting Atlanta January 1984, Thermal Insulation Laboratory, Technical University of Denmark http://www.byg.dtu.dk/upload/institutter/byg/publications/rapporter/lfv-160.pdf

55) Map 1: http://www.pickatrail.com/jupiter/location/north_america/mexico/quintana_roo.html

56) Map 2: http://www.explorandomexico.com/photos/maps/full-quintanaroo_l.gif

57) Mayagoitia, F.; Armstrong, J. (2011), “Exporting energy efficient building technology and services: the opportunity for EU business”, Renewable energy and energy

efficiency partnership, European Union Sustainable Energy Week, 11 to 15 April 2011. http://www.reeep.org/file_upload/7217_tmpphpKOgPCP.pdf

58) Mayagoitia, F.; Amaya Mayagoitia, E.G.: Personal meeting on May 29, 2012, Mexico City, Mexico
59) Milne, G.; Reardon, C. (2008), "Your Home Technical Manual – Australia's guide to environmentally sustainable homes", Commonwealth of Australia. http://www.yourhome.gov.au/technical/index.html, subchapter "Embodied Energy": http://www.yourhome.gov.au/technical/pubs/fs52.pdf
60) My Forecast (2011), "Almanac: Historical Information – Chetumal, Mexico" – Custom-Weather Inc. http://www.myforecast.com/bin/climate.m?city=70040&metric=true
61) Olgyay, V. & A. (1973), "Design with Climate: Bioclimatic Approach to Architectural Regionalism", 4th edition, Princeton University Press, New Jersey, U.S.A.; original press release in 1963.
62) Parsons, K. C. (2002), "Introduction to thermal comfort standards". Loughborough University, U.K. http://www.utci.org/cost/publications/ISO%20Standards%20Ken%20Parsons.pdf
63) Poot Balam, José Enrique: Personal meetings with physical investigation on April 25, May 13-15, 23, 2012, San Román, Mexico
64) Recknagel, H.; Sprenger, E.; Schramek, E.-R. (1999), "Taschenbuch für Heizung und Klimatechnik" – *Pocketbook for heating and air-conditioning technology*, Oldenbourg Verlag Munich, Germany. p. 49.
65) REEEP – Renewable energy and energy efficiency partnership (2011), "Low-energy housing for low incomes Cancun", Interview with Ing. Fernando Mayagoitia, 28 January 2011, REEEP International Secretariat. http://www.reeep.org/index.php?assetType=news&assetId=494
66) Rodríguez Elizarrarás, Gustavo: Personal meeting on 19 March 2012, Bacalar, Mexico
67) SAGARPA (2012), "Daily solar radiation of Mexico in daily average", Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA) - *Secretary of Agriculture, Cattle breeding, Rural Development, Fishery and Nutrition*, Mexico.
68) Torcellini, P.; Pless, S.; Deru, M. (2006), "Zero Energy Buildings: A Critical Look at the Definition", National Renewable Energy Laboratory, U.S. Department of Energy. http://www.nrel.gov/docs/fy06osti/39833.pdf
69) Van Lengen, J. (2007), "The Barefoot Architect – A Handbook for Green Building", Rio de Janeiro; Shelter Publications, Calinfornia, U.S.A.
70) Van Wie McGrory, L.; Harris, J.; Breceda Lapeyre, M.; Campbell, S. et al. (2002) "Market Leadership by Example: Government Sector Energy Efficiency in Developing Countries". p. 9-15. http://www.pepsonline.org/publications/Market%20Leadership%20by%20Example.pdf

71) Viel, L. (2004), “Datalogger MODAS 1632: English manual”, NES Measuring Systems, Erlensee, Germany. http://www.nerc.gov.jo/wind/instruments/5-%20LH/M1632_Manual_uk02.pdf
72) Wehner, S.; Krey, M.; Gusmao, F; Hayashi, D.; Michaelowa, A.; Sam, N. (2010), “Supported NAMA Design Concept for Energy-Efficiency Measures in the Mexican Residential Building Sector – Final Draft Working Paper”. p. 11 ff., p. 42 f. http://www.perspectives.cc/home/groups/7/Publications/NAMA_Design_Mexico_Working_Paper.pdf
73) World Energy Council (2011), “Energy Efficiency Policies around the World: Review and Evaluation”. http://www.worldenergy.org/publications/energy_efficiency_policies_around_the_world_review_and_evaluation/1_introduction/1175.asp

Translation:

Fuentes Freixanet, V; Álvarez García, G. (2002), “Arquitectura Bioclimática”, XXVI Semana Nacional de Energía Solar, Chetumal, Quintana Roo, México

Capítulo 5, Confort – Spanish original:

Confort lumínico

El confort lumínico se refiere a la percepción a través del sentido de la vista. Se hace notar que el confort lumínico difiere del confort visual, ya que el primero se refiere de manera preponderante a los aspectos físicos, fisiológicos y psicológicos relacionados con la percepción espacial y de los objetos que rodean al individuo.

La radiación solar tiene dos componentes, la térmica y la lumínica; de tal forma la luz natural es uno de los recursos más abundantes en nuestro planeta, en contraste con otras fuentes de energía convencional; sin embargo ésta se encuentra disponible sólo durante el día. Prácticamente desde que el hombre descubrió el fuego descubrió, al mismo tiempo, la iluminación artificial. Antorchas, velas, lámparas de aceite y posteriormente de petróleo y gas fueron utilizados durante cientos de años hasta que Thomas A. Edison, a finales del siglo pasado, inventó la bombilla eléctrica. Desde entonces el hombre ha inventado una gran variedad de lámparas y sistemas de alumbrado, utilizando la iluminación eléctrica de manera intensiva, obteniendo de esta forma la posibilidad de ampliar su horario de actividades a las 24 horas del día. Esto evidentemente acarrea consigo la ruptura o alteración de los ciclos biológicos naturales (sueño-vigilia, entre otros), pero además puede provocar otras alteraciones fisiológicas y psicológicas.

Suele asumirse que si se provee una cantidad suficiente de luz, según algunas normas, se puede desarrollar cualquier tipo de trabajo; sin embargo es necesario considerar la calidad de la luz además de la simple cantidad. La calidad se relaciona con las características de iluminación que facilitan la visión. Normalmente todas estas características están interrelacionadas: Calidad de luz (…), Cantidad de luz (…), Aspectos psicológicos (…)

Chapter 5, Comfort –translation into English:

Luminous comfort

Luminous comfort refers to the perception by the visual senses. It must be mentioned that differs from visual comfort, since luminous comfort mainly refers to physical, physiological and psychological aspects, related with the spatial perception and the object which surround the individual person.

Solar radiation contains two components, thermal and luminous radiation; natural light is one of the most abundant resources on our planet, in contrast to other conventional energy sources; however, this resource is only available during the day. Almost with the same time that humans explored fire, they also invented artificial light. Flares, candles, oil lamps and after oil gas was used for hundreds of years until Thomas A. Edison invented the light bulb in the end of the past century. Since then humans invented a great variety of lamps and lighting systems, making intensive use of electric lighting, and in this way the chance has been given to extend the time schedule up to the 24 hours of the day. This evidently also caused the rupture and alteration of biological cycles (sleep/wake amongst others), but it can also provoke other physical or psychological alterations.

We tend to assume that it is possible to obtain sufficient quantity of light, according to certain standards any work can be carried out; but it is necessary to consider the quality of light beside the simple quantity. The quality is related to the characteristics of light that facilitate the vision. Usually, all of the following characteristics are interrelated: Quality of light (…), Quantity of light (…), Psychological aspects (…)

ANNEX

Excel tables (measured values, calculations) and drawings are attached in Annex B.

Headings correspond to the structure of the main text; *no annex pertinent to chapters 1 and 2.*

3 Antecedents and climatic conditions of Quintana Roo

3.1 Division of municipalities in the state Quintana Roo

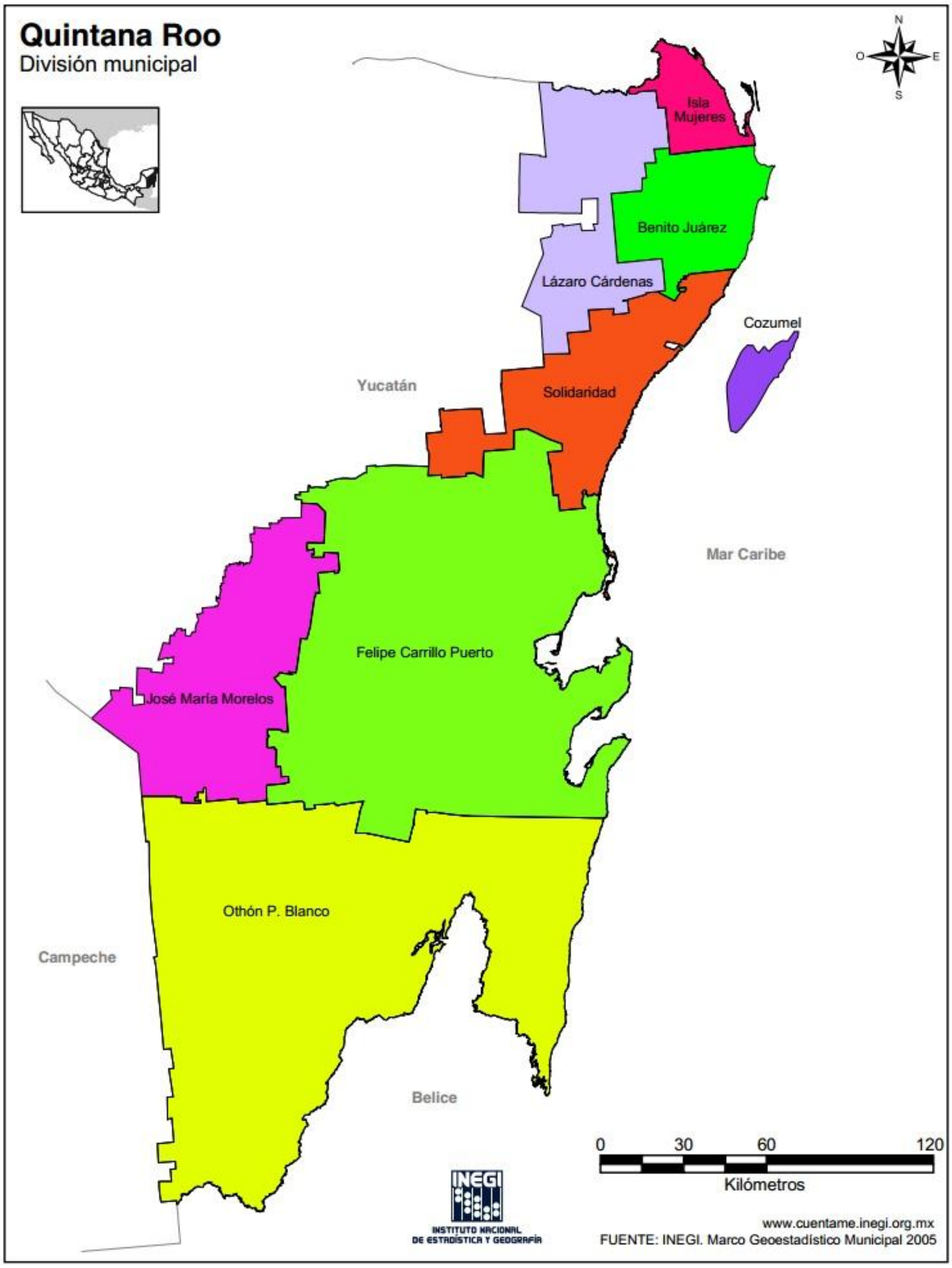


Figure A-1: Map of the municipalities in Quintana Roo; the new municipality Tulum was separated out from Solaridad after 2010. Source: INEGI, 2010

3.2 Climate maps of the municipalities Benito Juárez and Othón P. Blanco

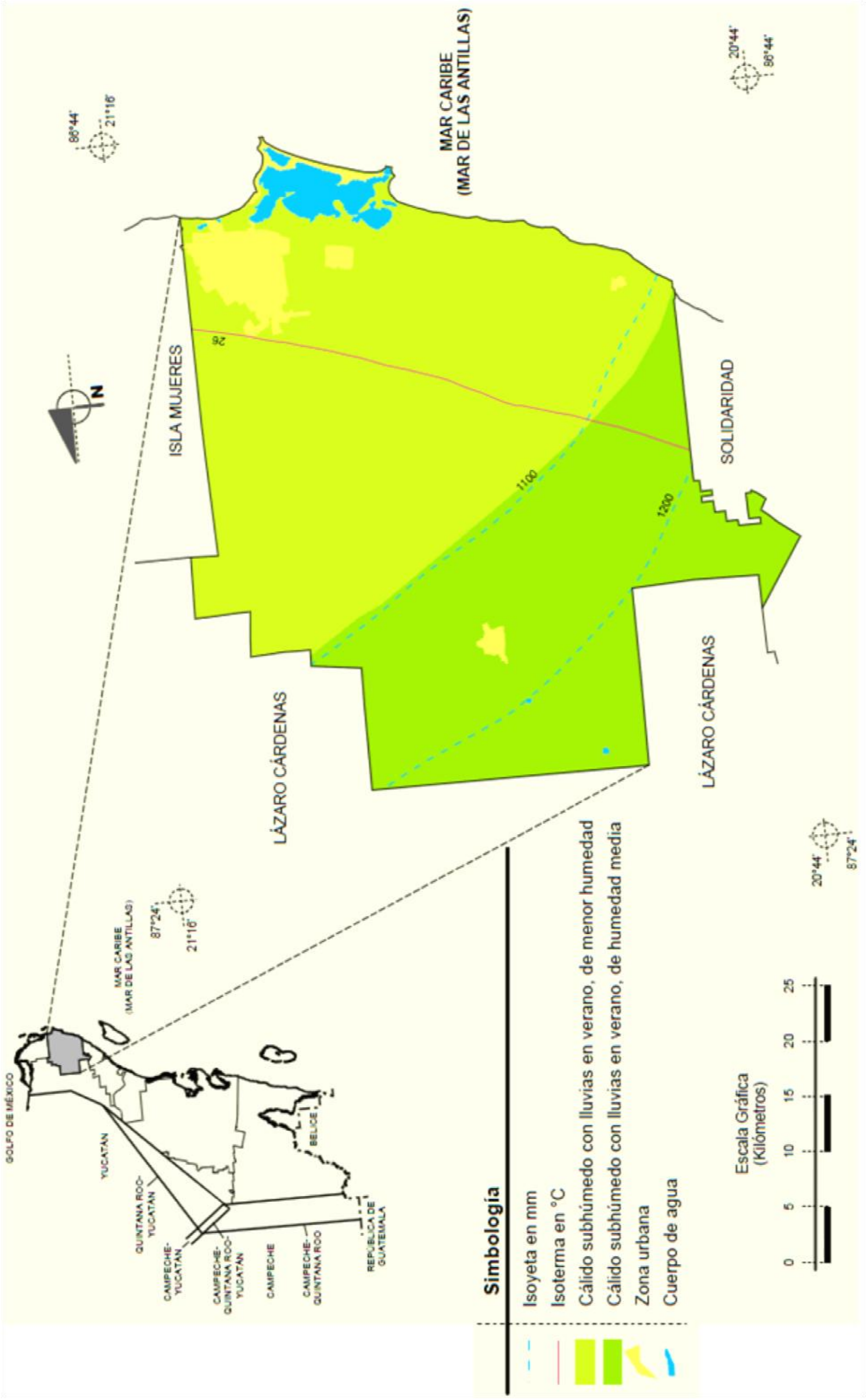


Figure A-2: Climate map of the municipality Benito Juárez, Quintana Roo. Source: INEGI, 2009

Amongst others, the municipality Benito Juárez contains the Cancun and Puerto Morelos.

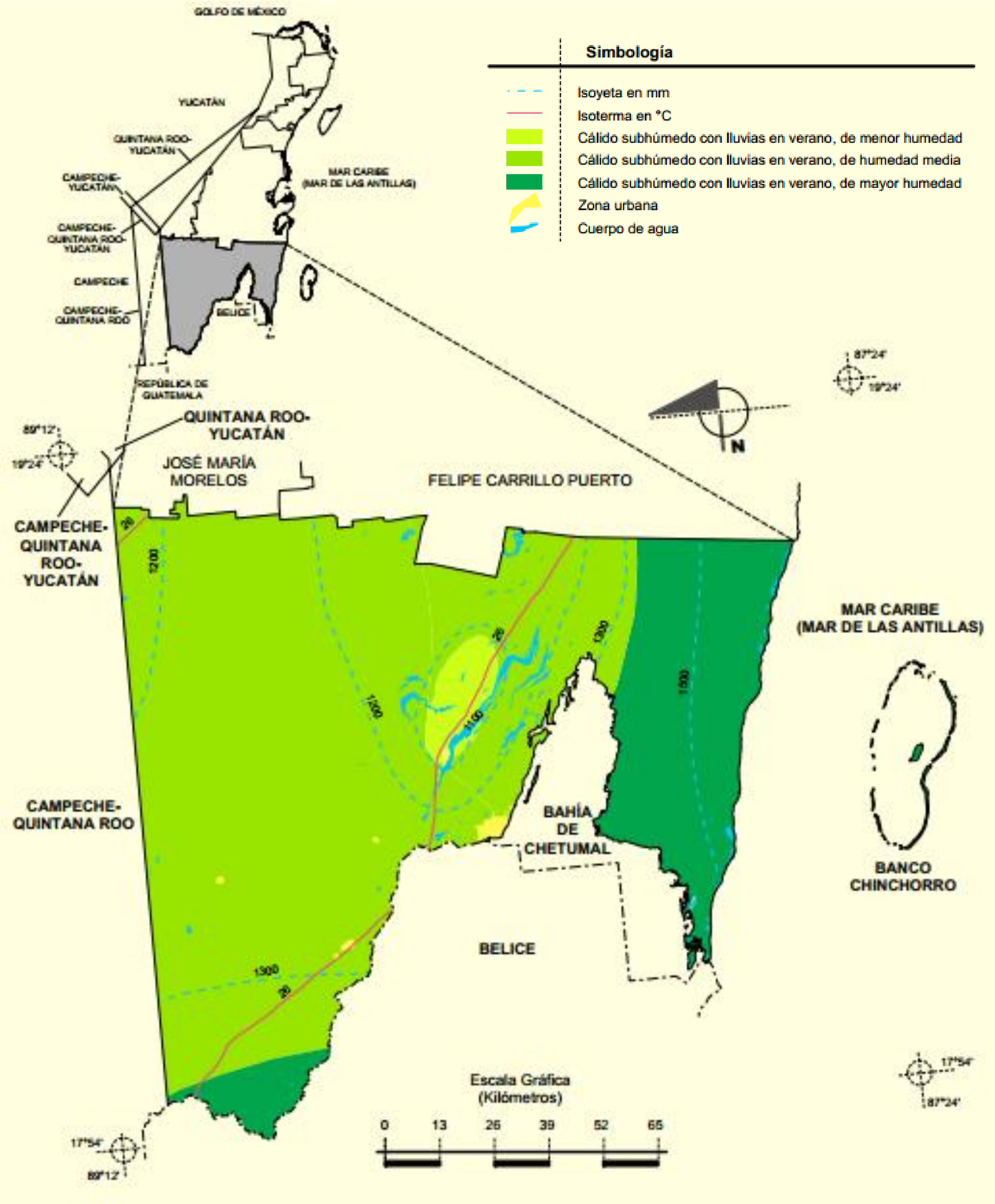


Figure A-3: Climate map of the municipality Othón P. Blanco, Quintana Roo. Source: INEGI, 2009

Amongst others, the municipality Othón P. Blanco contains the capital Chetumal, and the settlements Bacalar and Mahahual.

Legend for Figure A-2 and Figure A-3:

Dashed blue line: isohyetal line in mm (line that joins points of equal precipitation)
Red line: isothermal line in °C
Light green area: warm sub-humid with summer rains, of minor humidity (only in the small central area next to the Lagoon of Bacalar at mark 1100)
Medium green area: warm sub-humid with summer rains, of medium humidity (major area)
Dark green area: warm sub-humid with summer rains, of high humidity (area in the coastal region in the west)
Beige area: Urban zone
Blue area: Water body

3.3 Solar irradiation map for Mexico

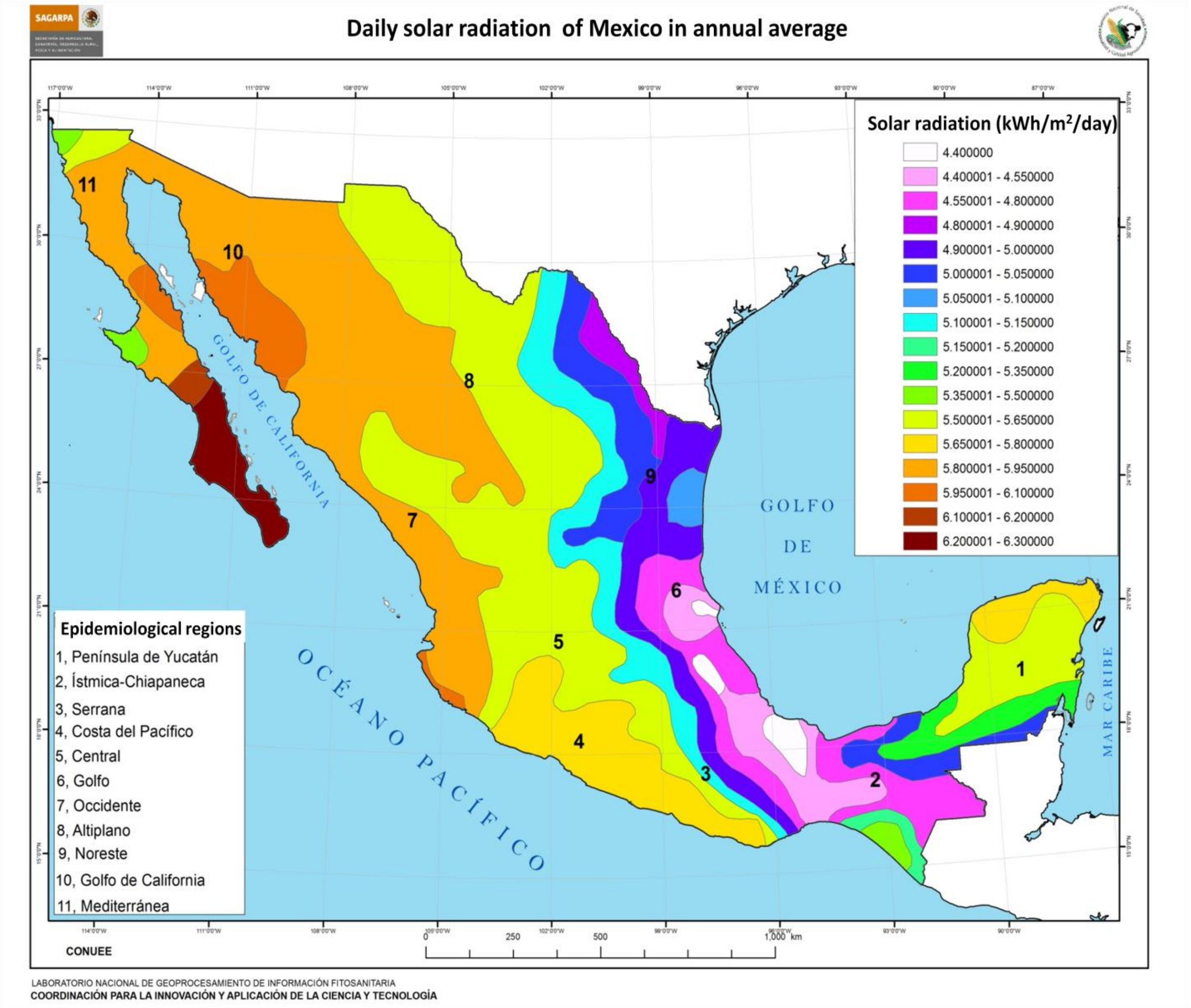


Figure A-4: Solar radiation map of Mexico and Central America. Source: SAGARPA, 2012

4 Building in the tropics and building technologies

- No annex included –

5 Fundamentals for the evaluation of thermal comfort

5.1 Conduction of measurements and collecting of values for thermal evaluation

5.1.1 Complications at the use of the measuring equipment

University-owned equipment from the inventory of Cologne University of Applied Sciences was used for the implementation of the series of measurements. Thereby, the following complications occurred during the preparation and installation of the measurement equipment.

The data logger

The data logger is required in order to record the measurements over longer periods without the need to read them directly from a display for every registration of values. After the transport from Germany to Mexico, the different voltage required to place a repeat order that had to be shipped all the way from Germany.

Additional equipment

Most of the carried equipment was originally used for another data logger and has digital outlets – in contrast to the working one but which requires connecting the different wires individually to the terminal block of the data logger. In addition to the complex issue of finding the correct connection arrangements, various details about the calibration of different sensors have been unknown, complicated by the fact that most of the manufacturers do not exist anymore. After long trials of testing specific wiring combinations for each sensor, the decision was made to exclusively use the equipment originally used for the present data logger for the investigation, and therein sensors which reasonable test results have been obtained for; therefore, the measurement was limited to the PT 100 sensors and the combined exterior temperature and humidity sensor. This decision was taken after the conclusion that the received values by the data logger had not been plausible (mostly because of very constant values). This impeded the use of hygrometers for interior, one anemometer, luxmeters, pyranometers and additional temperature sensors.

Battery

After the installation at the second investigated building was already completed, it resulted that the battery of the data logger was not working. It was agreed with the house owner to keep the measurement running around the clock for a little more than a week by accepting a low extra cost for the steady power supply.

5.1.2 Installation of measurement equipment

Wiring plan

For the scheme of the wiring plan please see the separate pdf-file “wiring scheme”.

The allocation of wiring connections from the different sensors to the terminal block of the data logger is also listed in Table A-1. The notes “+” and “–“refer to the particular poles; the wires indicated with “*” are not connected directly to the terminal block, but are connected in series.

Table A-1: Allocation of wires from the different sensors to the connection to the data logger terminal block

Wiring		**Data Logger**	
Color	**Color (Prolongation)**	**Channel / block**	**Measure-ment**
Combined Humidity and Temperature Sensor (13 + 14)			
Grey	(Brown-White)	Earth	
Brown	(Brown)	13 (+)	R.H.
White	(Green-White)	Earth	
Green	(Green)	+5 V	R.H.
Red	(Orange)	+1 mA	Temp.
Yellow	(Orange-White)	14 (+)	Temp.
Pink	(Blue-White)	14 (-)	Temp.
Blue	(Blue)	-1 mA *	Temp.
PT100 Temp. Sensors (5 + 6 + 7)			
Cable 1	Red	+1 mA *	Temp.
Cable 2	Red	7, 6, 5 (+)	Temp.
Cable 2	Red-black	7, 6, 5 (-)	Temp.
Cable 1	Red-black	-1 mA *	Temp.
Comfort sensor (Equivalent Temperature) (4)			
White		+1 mA *	Temp.
Brown		4 (+)	Temp.
Yellow		4 (-)	Temp.
Green		-1 mA	Temp.
Grey		Earth	

5.1.3 Mounting of sensors and observations

In the following, the arrangements of the measurements above floor level for the different case studies are summarized, along with particular observations and comments about each measurement series.

Case Study 1: Casa Macías Villalobos:

Channels and their arrangements with elevations

4: Equivalent temperature (comfort sensor): Estudio Martha, 1.1 m
5: Temperature 2 (PT100): Living room/ TV couch, 0.7 m
6: Globe temperature (PT100 in black globe): Estudio Gabriel, 1.8 m
7: Temperature 4 (PT100): Estudio Martha, 1.1 m
13: Outside relative humidity
14: Outside temperature (PT100)

Observations/Interpretation of measurement data

- Since 24/03/2012, Gabriel opened the upper windows (for exhaust air) during the day, and closed it at night.
- High temporary jumps of PT100 sensor (measurement of Temperature 4, channel 7) in Estudio Martha: the cause could not be resolved; however, the following interrelations are supposed to be linked to the incident:
    - Interference between with the adjacent comfort sensor (channel 4);
    - Opening/closing the door which causes air turbulence close to the entry;
    - Increased internal loads, for example by physical activities, or direct solar irradiation; none of those could be proved.

Case Study 2: Casa Brunner Valdés:

Channels and their arrangements with elevations

4: Equivalent temperature (comfort sensor): 1 m
5: Temperature 2 (PT100): 1 m
6: Temperature 3 (PT100; until 03/05/12 in black globe!!): 2.5 m
7: Temperature 4 (PT100): 4.8 m
13: Relative humidity (outside)
14: Outside temperature (PT100)

Observations/Interpretation of measurement data

- Irrigation on 12/05/2012 approximately from 4:00 pm to 4:30 pm;
- Ventilator used on 12/05/2012 from approximately 4:40 pm to 6:10 pm;
- More persons (5 instead of 3) for the last period of measurements, from 10 to 12/05/2012.

Case Study 3: Casa Poot Balam:

Channels and their arrangements with elevations

4: Equivalent temperature (comfort sensor): 1.0 m
5: Temperature 2 (PT100): 1.0 m
6: Globe temperature (PT100): 1.8 m

7: Temperature 4 (PT100): 3.2 m
13: Relative humidity (outside)
14: Outside temperature (PT100)

Observations/Interpretation of measurement data

- Window and doors are opened virtually all day;
- High occupancy in the evenings but also at noon: approx. 5 to 8 persons.

5.2 Recalibration

5.2.1 Black globe

Figure A-5 shows the re-calibration of the black globe.

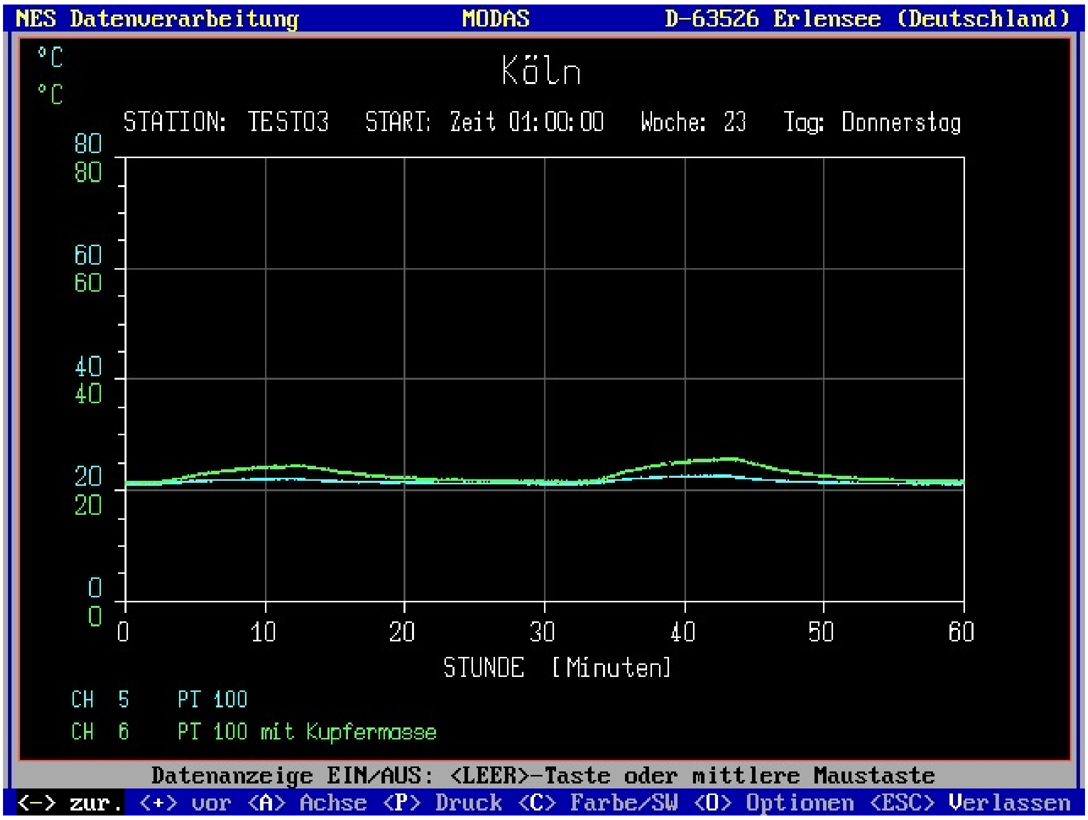


Figure A-5: Test series for re-calibration of black globe. Interface from NES data logger software; Viel, 2006

For the test series, the globe was beamed by a desk lights in two tests of ten minutes each. The lamp, however, was switched on in two different tunable levels. The upper line shows the curve of the PT 100 sensor enclosed in the globe. As reference, the temperature was measured nearby by a simple PT 100 sensor. The short deviation only for the time of irradiation and a short fade-out time allows for the conclusion that the black globe emits a comparable value to a usual PT 100, when it is not irradiated. The slightly stronger amplitude for the second test is due to the higher illumination stage of the lamp.

5.2.2 Humidity sensor

Recalibration of the humidity sensor

Various kinds of sensors deviate from the correct measuring values over the years owing to the strain exerted by external influences such as exposition to heat or direct sunlight; this is also the case for the hygrometer integrated in the sensor for exterior measurements of temperature and relative humidity. In order to be able to derive the correct values, the hygrometer was recalibrated by the use of two fixed states which were obtained by exposing the hygrometer to saturated aqueous saline solutions. For convenience in terms of availability and unproblematic handling with the chemicals, the saturated aqueous solutions magnesium chloride ($MgCl_2$) and sodium chloride (NaCl) were chosen as the fixed points. The test series of the saline solutions for recalibration are presented in the annex, summarized to 10 minute-values (see separate flies “saline solution test series). Table A-2 shows the respective resulting values for the two saline solutions and their assignment to the variables x_0, f_0, x_1 and f_1. Assuming that the relation is entirely linear, the relative humidity values of the series of measurements are rectified by use of the formula for linear interpolation, where x stands for the original value obtained from the measurement series.

$$f(x) = f_0 + \frac{x - x_0}{x_1 - x_0} \cdot (f_1 - f_0)$$

Table A-2: Measured and set values of the fixed points of magnesium chloride $MgCl_2$ and NaCl at 20 °C. Source of measured values: Moie, 2012; source of set values: Blaine, 2004

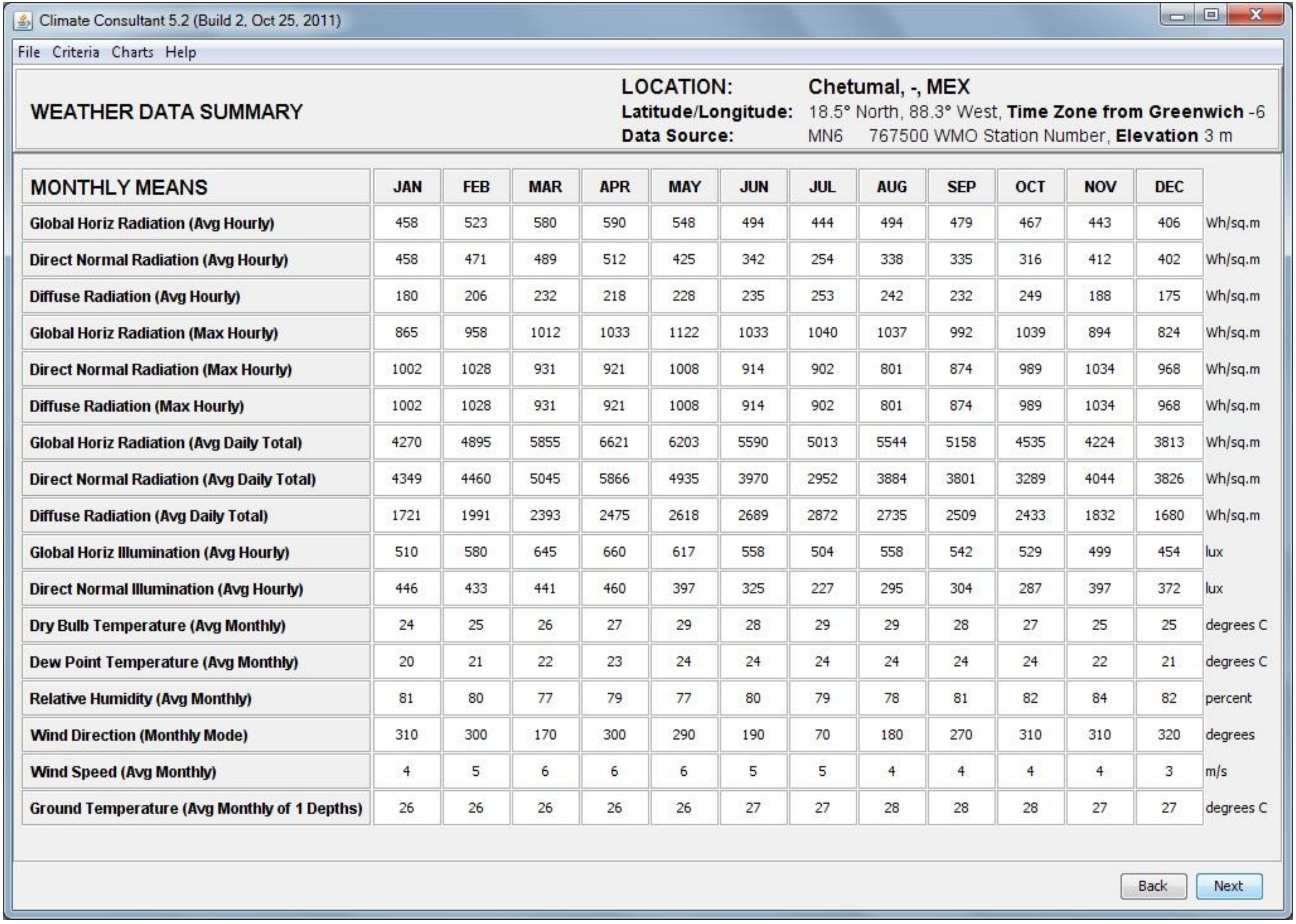
Values for recalibration (Relative humidity in %) *Nomenclature of variables*		Measured x	Set value f
MgCl2 (magnesium chloride)	*0*	**34,890**	**33,1**
NaCl (sodium chloride)	*1*	**74,642**	**75,5**

An if-function is integrated into the excel calculation for the corrected humidity values in order to cut resulting numbers exceeding 100% down to the 100% relative humidity.
The sheet with measured values within the scope of the recalculation of the humidity sensor is attached in annex B.

5.3 Climate Consultant 5.2®

5.3.1 Summary of climate data for Chetumal

Table A-3: Summary of climate data of Chetumal; interface: Climate Consultant, 2011; climate data: Energy Plus, 2010



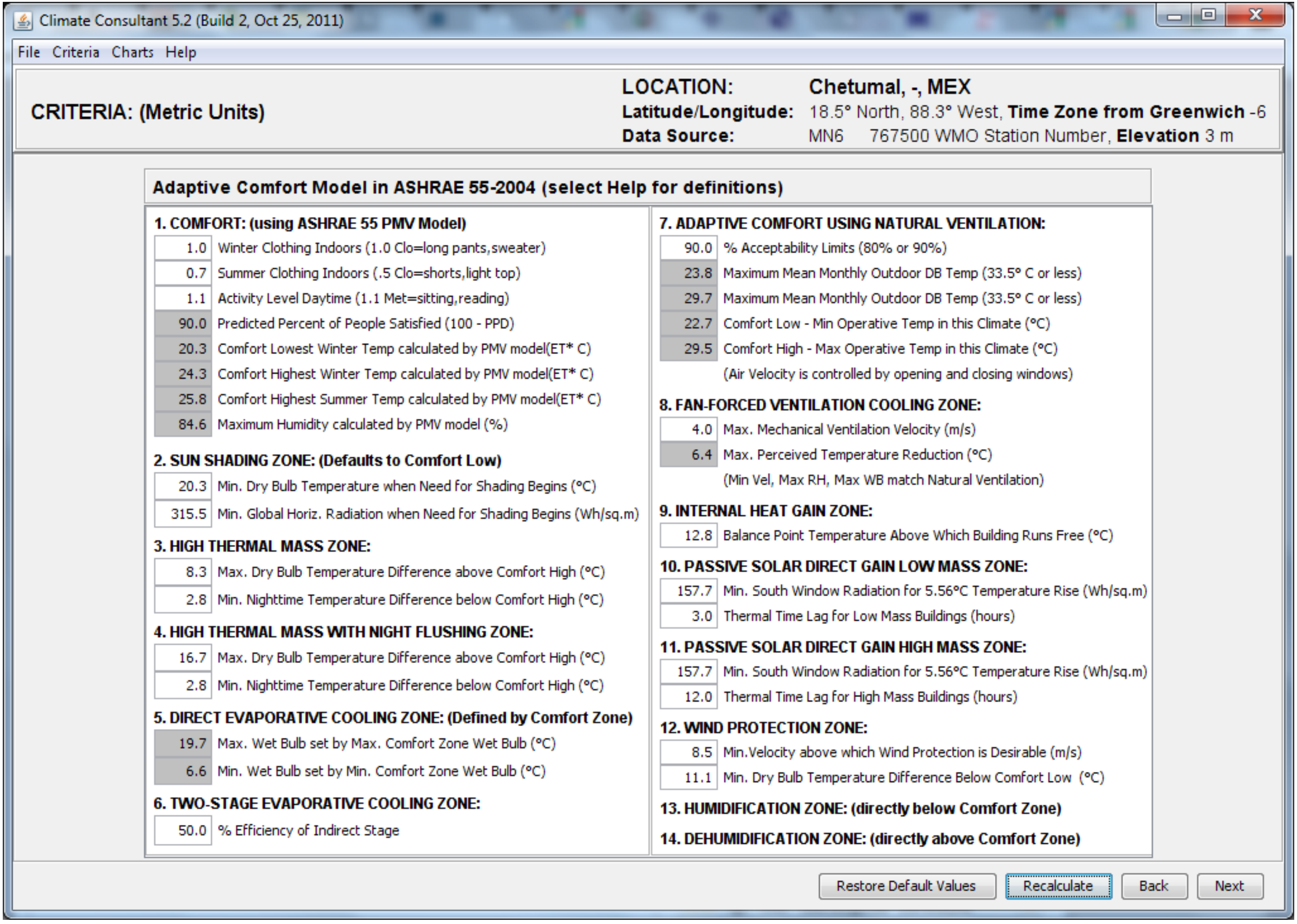
WEATHER DATA SUMMARY

LOCATION: Chetumal, -, MEX
Latitude/Longitude: 18.5° North, 88.3° West, **Time Zone from Greenwich** -6
Data Source: MN6 767500 WMO Station Number, **Elevation** 3 m

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	458	523	580	590	548	494	444	494	479	467	443	406	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	458	471	489	512	425	342	254	338	335	316	412	402	Wh/sq.m
Diffuse Radiation (Avg Hourly)	180	206	232	218	228	235	253	242	232	249	188	175	Wh/sq.m
Global Horiz Radiation (Max Hourly)	865	958	1012	1033	1122	1033	1040	1037	992	1039	894	824	Wh/sq.m
Direct Normal Radiation (Max Hourly)	1002	1028	931	921	1008	914	902	801	874	989	1034	968	Wh/sq.m
Diffuse Radiation (Max Hourly)	1002	1028	931	921	1008	914	902	801	874	989	1034	968	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	4270	4895	5855	6621	6203	5590	5013	5544	5158	4535	4224	3813	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	4349	4460	5045	5866	4935	3970	2952	3884	3801	3289	4044	3826	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	1721	1991	2393	2475	2618	2689	2872	2735	2509	2433	1832	1680	Wh/sq.m
Global Horiz Illumination (Avg Hourly)	510	580	645	660	617	558	504	558	542	529	499	454	lux
Direct Normal Illumination (Avg Hourly)	446	433	441	460	397	325	227	295	304	287	397	372	lux
Dry Bulb Temperature (Avg Monthly)	24	25	26	27	29	28	29	29	28	27	25	25	degrees C
Dew Point Temperature (Avg Monthly)	20	21	22	23	24	24	24	24	24	24	22	21	degrees C
Relative Humidity (Avg Monthly)	81	80	77	79	77	80	79	78	81	82	84	82	percent
Wind Direction (Monthly Mode)	310	300	170	300	290	190	70	180	270	310	310	320	degrees
Wind Speed (Avg Monthly)	4	5	6	6	6	5	5	4	4	4	4	3	m/s
Ground Temperature (Avg Monthly of 1 Depths)	26	26	26	26	26	27	27	28	28	28	27	27	degrees C

5.3.2 Parameters of comfort model in Climate Consultant 5.2®

Table A-4: Set of parameters for 55 PMV Comfort Model; interface: Climate Consultant, 2011



CRITERIA: (Metric Units)

LOCATION: Chetumal, -, MEX
Latitude/Longitude: 18.5° North, 88.3° West, **Time Zone from Greenwich** -6
Data Source: MN6 767500 WMO Station Number, **Elevation** 3 m

Adaptive Comfort Model in ASHRAE 55-2004 (select Help for definitions)

1. COMFORT: (using ASHRAE 55 PMV Model)
1.0 Winter Clothing Indoors (1.0 Clo=long pants,sweater)
0.7 Summer Clothing Indoors (.5 Clo=shorts,light top)
1.1 Activity Level Daytime (1.1 Met=sitting,reading)
90.0 Predicted Percent of People Satisfied (100 - PPD)
20.3 Comfort Lowest Winter Temp calculated by PMV model(ET* C)
24.3 Comfort Highest Winter Temp calculated by PMV model(ET* C)
25.8 Comfort Highest Summer Temp calculated by PMV model(ET* C)
84.6 Maximum Humidity calculated by PMV model (%)

2. SUN SHADING ZONE: (Defaults to Comfort Low)
20.3 Min. Dry Bulb Temperature when Need for Shading Begins (°C)
315.5 Min. Global Horiz. Radiation when Need for Shading Begins (Wh/sq.m)

3. HIGH THERMAL MASS ZONE:
8.3 Max. Dry Bulb Temperature Difference above Comfort High (°C)
2.8 Min. Nighttime Temperature Difference below Comfort High (°C)

4. HIGH THERMAL MASS WITH NIGHT FLUSHING ZONE:
16.7 Max. Dry Bulb Temperature Difference above Comfort High (°C)
2.8 Min. Nighttime Temperature Difference below Comfort High (°C)

5. DIRECT EVAPORATIVE COOLING ZONE: (Defined by Comfort Zone)
19.7 Max. Wet Bulb set by Max. Comfort Zone Wet Bulb (°C)
6.6 Min. Wet Bulb set by Min. Comfort Zone Wet Bulb (°C)

6. TWO-STAGE EVAPORATIVE COOLING ZONE:
50.0 % Efficiency of Indirect Stage

7. ADAPTIVE COMFORT USING NATURAL VENTILATION:
90.0 % Acceptability Limits (80% or 90%)
23.8 Maximum Mean Monthly Outdoor DB Temp (33.5° C or less)
29.7 Maximum Mean Monthly Outdoor DB Temp (33.5° C or less)
22.7 Comfort Low - Min Operative Temp in this Climate (°C)
29.5 Comfort High - Max Operative Temp in this Climate (°C)
(Air Velocity is controlled by opening and closing windows)

8. FAN-FORCED VENTILATION COOLING ZONE:
4.0 Max. Mechanical Ventilation Velocity (m/s)
6.4 Max. Perceived Temperature Reduction (°C)
(Min Vel, Max RH, Max WB match Natural Ventilation)

9. INTERNAL HEAT GAIN ZONE:
12.8 Balance Point Temperature Above Which Building Runs Free (°C)

10. PASSIVE SOLAR DIRECT GAIN LOW MASS ZONE:
157.7 Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
3.0 Thermal Time Lag for Low Mass Buildings (hours)

11. PASSIVE SOLAR DIRECT GAIN HIGH MASS ZONE:
157.7 Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
12.0 Thermal Time Lag for High Mass Buildings (hours)

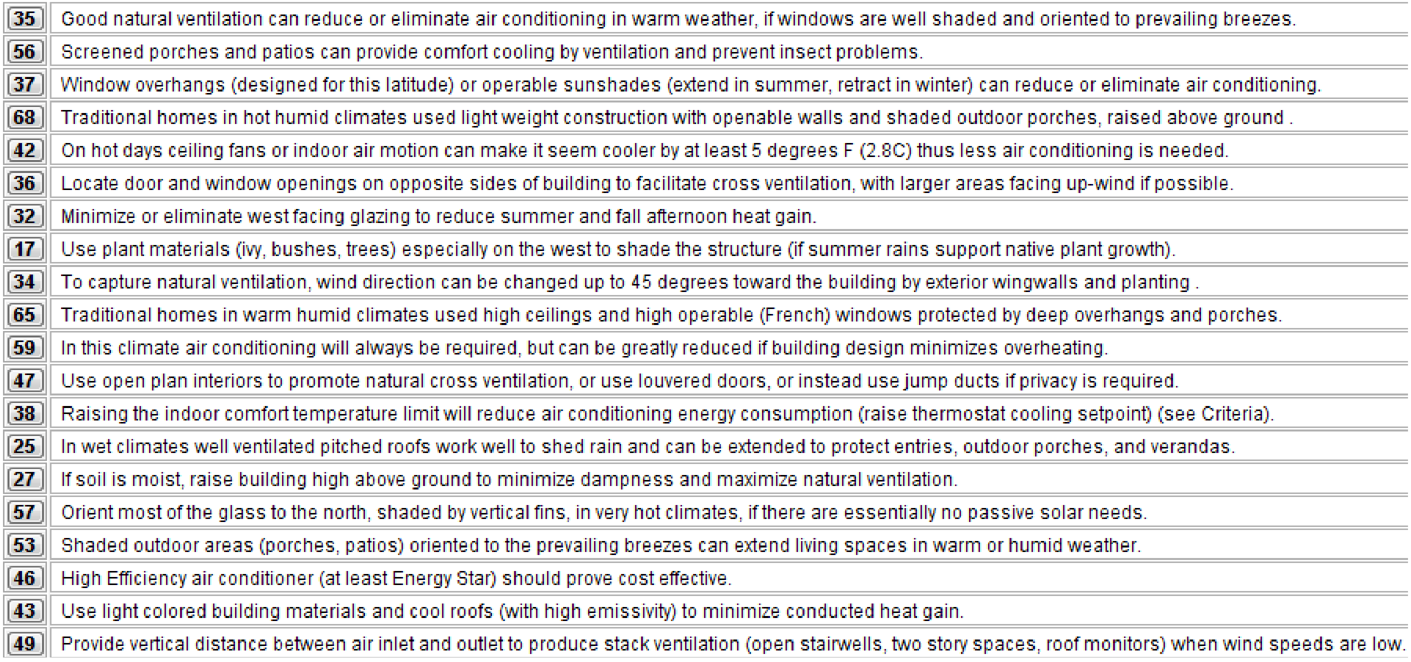
12. WIND PROTECTION ZONE:
8.5 Min.Velocity above which Wind Protection is Desirable (m/s)
11.1 Min. Dry Bulb Temperature Difference Below Comfort Low (°C)

13. HUMIDIFICATION ZONE: (directly below Comfort Zone)

14. DEHUMIDIFICATION ZONE: (directly above Comfort Zone)

5.3.3 List of guidelines at combined Adaptive Comfort/55 PMV Model

Table A-5: List of design guidelines in the combined Adaptive Comfort/55 PMV Model for the climatic conditions of Chetumal; Source of user interface: Climate Consultant, 2011; climate data: Energy Plus, 2010



35	Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes.
56	Screened porches and patios can provide comfort cooling by ventilation and prevent insect problems.
37	Window overhangs (designed for this latitude) or operable sunshades (extend in summer, retract in winter) can reduce or eliminate air conditioning.
68	Traditional homes in hot humid climates used light weight construction with openable walls and shaded outdoor porches, raised above ground .
42	On hot days ceiling fans or indoor air motion can make it seem cooler by at least 5 degrees F (2.8C) thus less air conditioning is needed.
36	Locate door and window openings on opposite sides of building to facilitate cross ventilation, with larger areas facing up-wind if possible.
32	Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain.
17	Use plant materials (ivy, bushes, trees) especially on the west to shade the structure (if summer rains support native plant growth).
34	To capture natural ventilation, wind direction can be changed up to 45 degrees toward the building by exterior wingwalls and planting .
65	Traditional homes in warm humid climates used high ceilings and high operable (French) windows protected by deep overhangs and porches.
59	In this climate air conditioning will always be required, but can be greatly reduced if building design minimizes overheating.
47	Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required.
38	Raising the indoor comfort temperature limit will reduce air conditioning energy consumption (raise thermostat cooling setpoint) (see Criteria).
25	In wet climates well ventilated pitched roofs work well to shed rain and can be extended to protect entries, outdoor porches, and verandas.
27	If soil is moist, raise building high above ground to minimize dampness and maximize natural ventilation.
57	Orient most of the glass to the north, shaded by vertical fins, in very hot climates, if there are essentially no passive solar needs.
53	Shaded outdoor areas (porches, patios) oriented to the prevailing breezes can extend living spaces in warm or humid weather.
46	High Efficiency air conditioner (at least Energy Star) should prove cost effective.
43	Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain.
49	Provide vertical distance between air inlet and outlet to produce stack ventilation (open stairwells, two story spaces, roof monitors) when wind speeds are low.

5.4 Indoor humidity: Determination of interior enclosed air volumes

Because of incompatibilities in the measurement equipment, the interior humidity had to be estimated. Therefor, the air volumes enclosed in each of the measured buildings needed to be determined. Inclined roofs are included by talking the middle value between upper and lower end. Furthermore, the following formulas are used for the geometric circular bodies in the case study Casa Brunner Valdés in Mahahual:

Circular area: $A_{circle} = \pi \cdot r^2$
Cone volume: $V_{cone} = \frac{1}{3} \cdot \pi \cdot r^2 \cdot h$

According to the specific dimensions as they are also presented in the construction plans (see pdf-files in the separate annex), the following interior volumes were calculated for being filled by air:

<u>Case Study 1: Casa Macías Villalobos</u>

$$V_{air} = 3.85\, m \cdot 5.1\, m \cdot \frac{2.35+4.8}{2} m = 70.2\, m^3$$

Room width (north – south): 3.85 m

Room length (east – west): 5.1 m
Lower interior wall finish: 2.35 m
Upper interior wall finish: 4.8 m

Case Study 2: Casa Brunner Valdés

$$V_{air} = 5.0\,m \cdot 7.6\,m \cdot \frac{2.2+4.0}{2} m + \pi \cdot (3.8\,m)^2 \cdot \frac{2.2+4.0}{3} m + [2.5\,m \cdot 2.0\,m + \pi \cdot (2.3\,m)^2] \cdot 2.2\,m = \quad = 367.5\,m^3$$

Straight horizontal wall length: 5.0 m
Interior width between straight walls: 7.6 m
Interior wall height: 2.2 m
Roof height from wall finish: 4.0 m
Mathematical constant π: 3.141592654
Interior radius of circular endings: 3.8 m
Annex interior straight wall length (north facade): 2.5 m
Annex interior wall length (east facade): 2.0 m
Interior radius of annex northwest end: 2.3 m
Annex interior wall height: 2.2 m

Case Study 3: Casa Poot Balam

$$V_{air} = 4.0\,m \cdot 7.1\,m \cdot 2.1\,m + \frac{7.1+4.4}{2} m \cdot \frac{4.0}{2}\,m \cdot 2.35\,m = 86.7\,m^3$$

Interior wall width (east – west): 4.0 m
Interior wall length (north – south): 7.1 m
Interior wall height: 2.1 m
Length of roof peak: 4.4 m
Roof height from wall finish: 2.35 m

Furthermore, the following formulas are used for the geometric circular bodies in the case study Casa Brunner Valdés in Mahahual:

Circular area: $A_{circle} = \pi \cdot r^2$

Cone volume: $V_{cone} = \frac{1}{3} \cdot \pi \cdot r^2 \cdot h$

Please also review the construction plans in annex B for the specific dimensions.

5.5 Psychrometric diagram

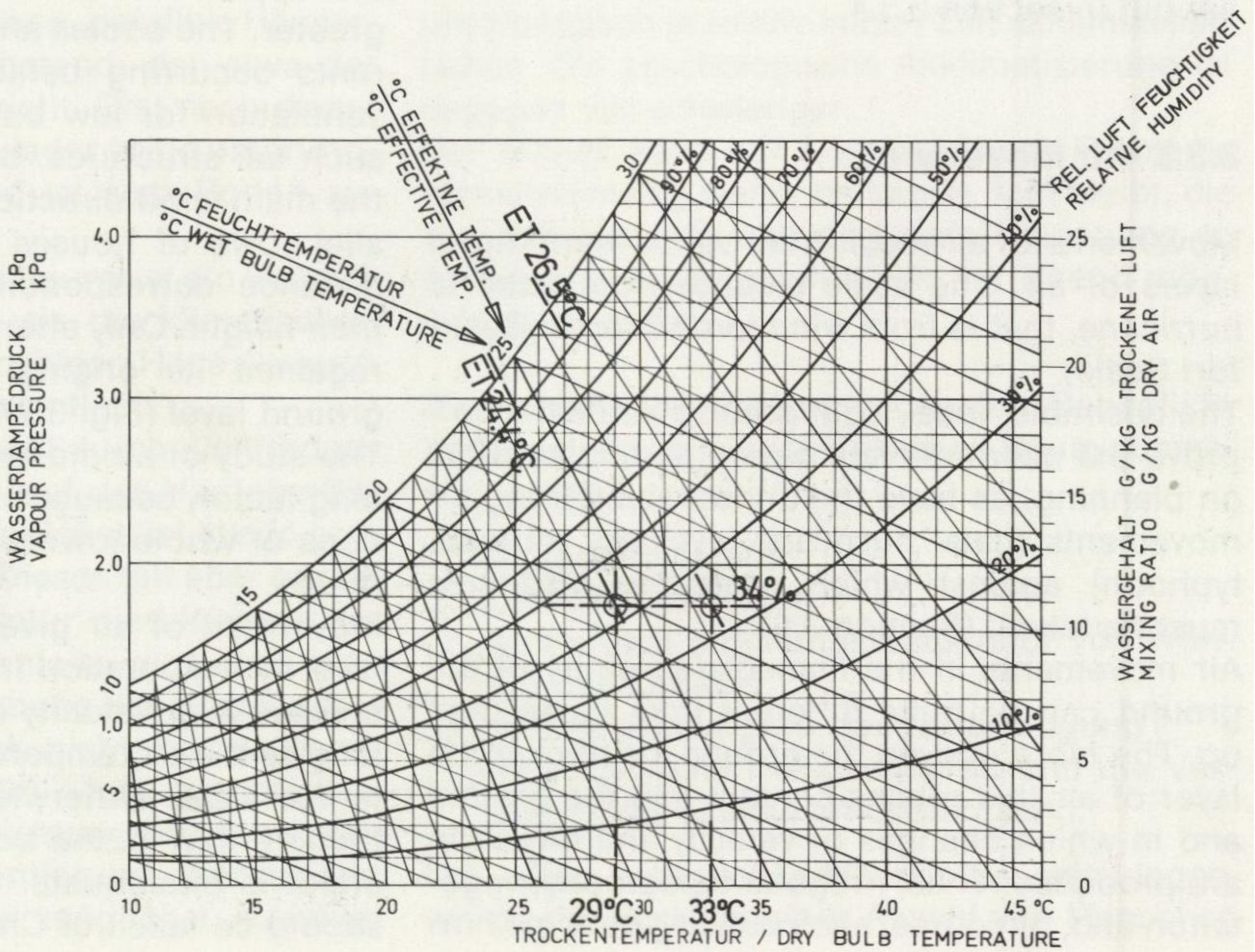


Figure A-6: Psychrometric diagram including dry and wet bulb temperature and relative humidity. Source: Lippsmeier, 1980

5.6 Derivation of PMV values from temperature characteristics and air velocity

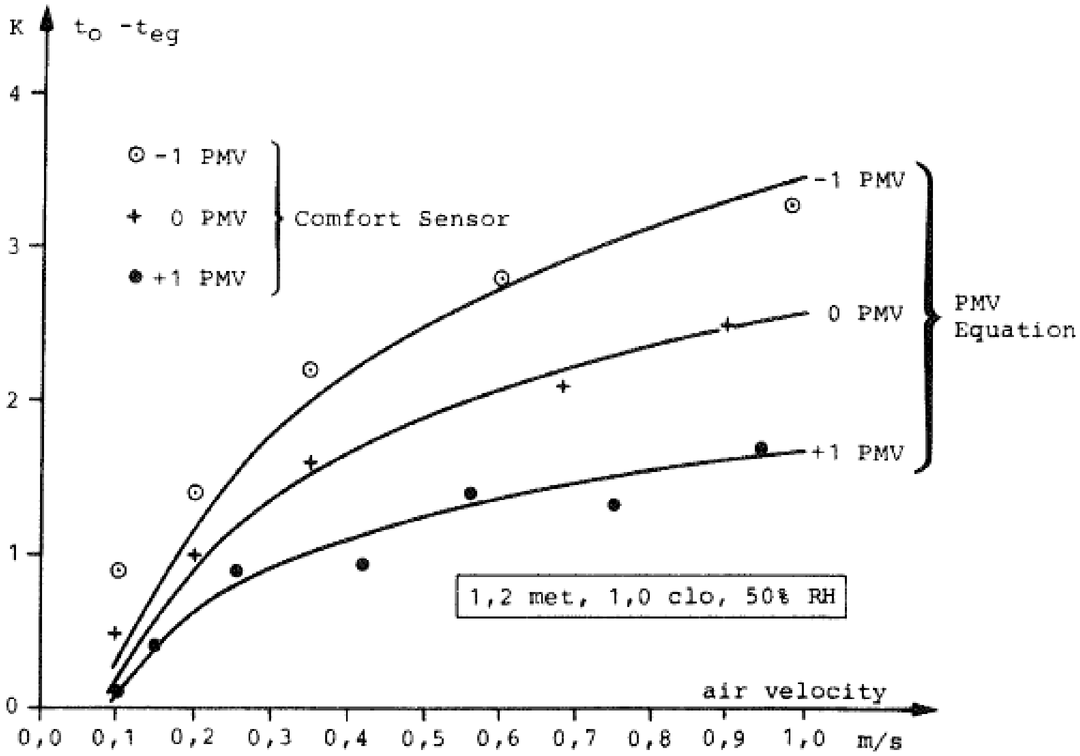


Figure A-7: Air velocity in dependence of operative temperature t_o and effective temperature t_{eq} at constant PMV index; effective temperature is here named equivalent temperature.
Source: Madsen, 1984

6 Introduction of case studies: surrounding area maps

Figure A-8: Surrounding area map of the colony FovISSSTE, Chetumal with the investigated building encircled in red. Source: Google Maps, 2012

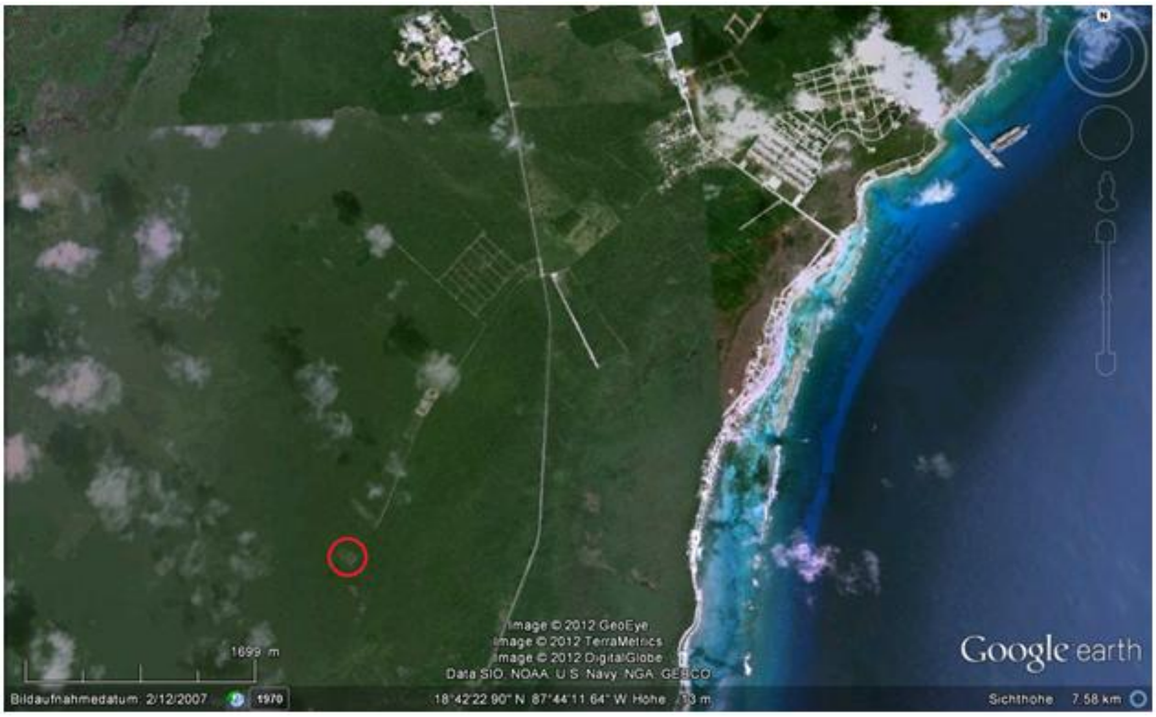


Figure A-9: Surrounding area of Finca la Abundancia near Mahahual, building location encircled in red. Source: Google Maps, 2012

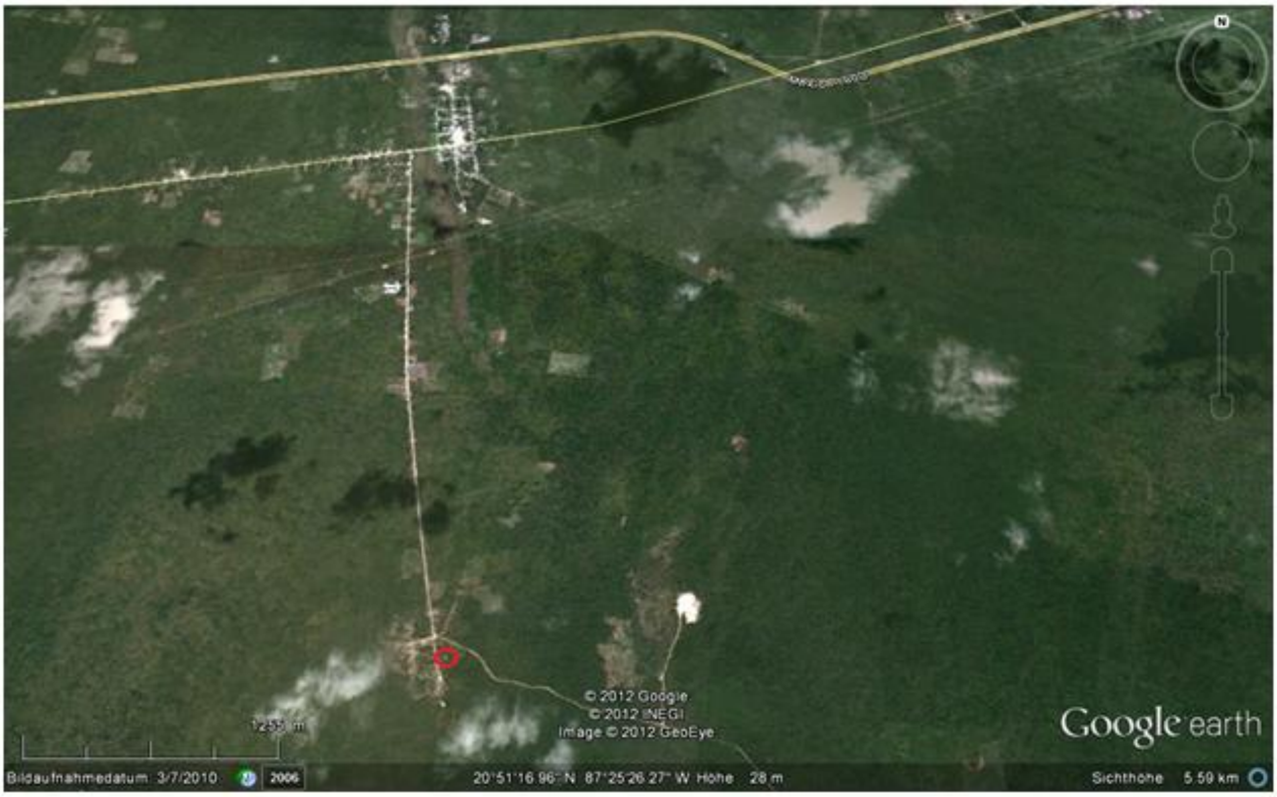


Figure A-10: Surrounding area of San Román with the location of Casa Poot Balam encircled in red. Source: Google Maps, 2012

Figure A-11: Surrounding area of Casa Poot Balam, San Román with the building location encircled in red. Source: Google Maps, 2012

Figure A-12: Surrounding area of El Arca, Puerto Morelos with the building location encircled in red. Source: Google Maps, 2012

Figure A-13: Surrounding area of Urbi Villa Del Rey, Cancun with the building location encircled in red. Source: Google Maps, 2012

ANNEX B

a) Wiring scheme

- 1 page

b) Recalibration of humidity sensor

- 2 pages

c) Measured values (1 hour-intervals)

- Casa Maciás Villalobos – 6 pages
- Casa Brunner Valdés – 4 pages
- Casa Poot Balam – 5 pages

d) Mahoney calculation table

- 5 pages

e) Estimation of indoor humidity, air velocity and PMV

- 4 pages (large)

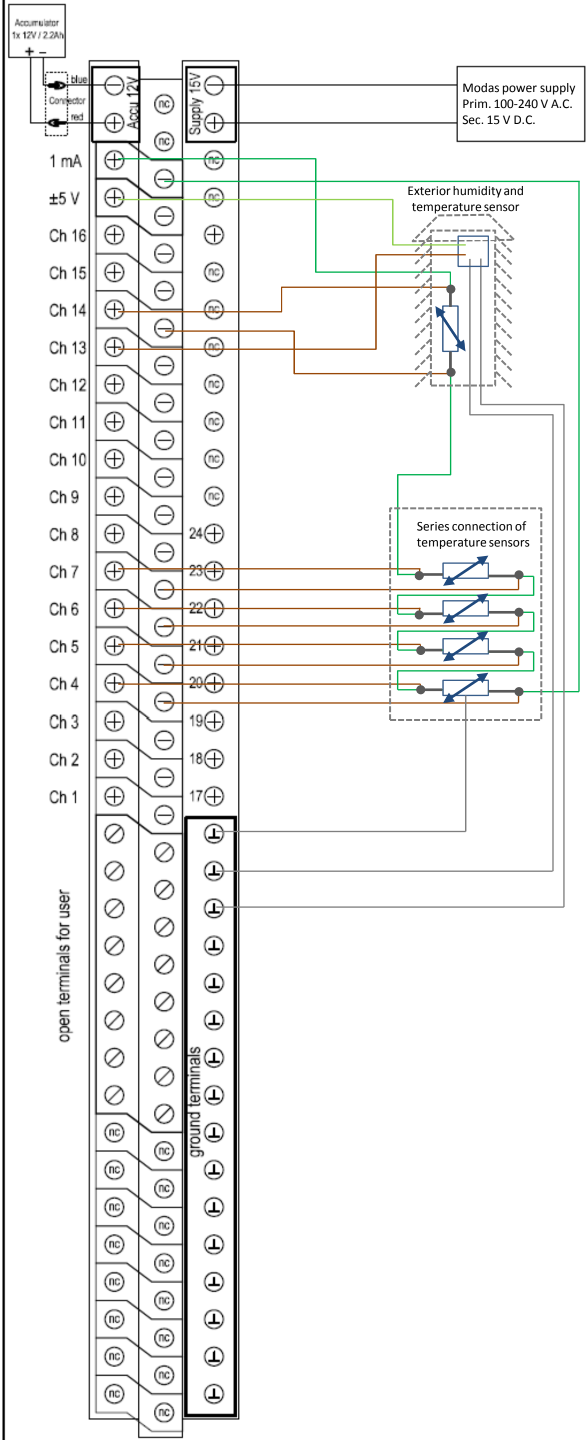
f) Assessment of environmental impact

Excel calculation sheets, content:

- Estimation of building materials
  - Casa Maciás Villalobos (excerpt) – 2 pages (large)
  - Casa Brunner Valdés and Casa Poot Balam – 1 page (large)
- Data references – 1 page (large)
- Summary (Calculation of embodied energy and CO_2 emissions from particular building masses) – 2 pages (large)

g) CAD plans of case studies

- Casa Maciás Villalobos
- Casa Brunner Valdés
- Casa Poot Balam


Accumulator
1x 12V / 2.2Ah
+ –
blue
Connector
red
Accu 12V
Supply 15V
Modas power supply
Prim. 100-240 V A.C.
Sec. 15 V D.C.
1 mA
±5 V
Ch 16
Ch 15
Ch 14
Ch 13
Ch 12
Ch 11
Ch 10
Ch 9
Ch 8
Ch 7
Ch 6
Ch 5
Ch 4
Ch 3
Ch 2
Ch 1
nc
24
23
22
21
20
19
18
17
Exterior humidity and
temperature sensor
Series connection of
temperature sensors
open terminals for user
ground terminals

Saturated NaCl solution - Sodium chloride

Measurement period:		**Average value**	
6/12/2012		R.H. (%)	Temp (°C)
13:40 to 00:0		CH 13	CH 14
		74.641	**19.005**
Date	Time	R.H. (%)	Temp (°C)
dd.mm.yy	hh:mm:ss	CH 13	CH 14

****

6/12/2012	13:45:00	74.1	19.0
6/12/2012	13:55:00	74.4	19.0
6/12/2012	14:05:00	74.6	19.0
6/12/2012	14:15:00	74.6	19.0
6/12/2012	14:25:00	74.6	19.1
6/12/2012	14:35:00	74.7	19.1
6/12/2012	14:45:00	74.7	19.1
6/12/2012	14:55:00	74.6	19.2
6/12/2012	15:05:00	74.6	19.2
6/12/2012	15:15:00	74.6	19.2
6/12/2012	15:25:00	74.6	19.2
6/12/2012	15:35:00	74.6	19.2
6/12/2012	15:45:00	74.6	19.2
6/12/2012	15:55:00	74.6	19.2
6/12/2012	16:05:00	74.6	19.2
6/12/2012	16:15:00	74.6	19.2
6/12/2012	16:25:00	74.6	19.2
6/12/2012	16:35:00	74.6	19.2
6/12/2012	16:45:00	74.6	19.2
6/12/2012	16:55:00	74.6	19.2
6/12/2012	17:05:00	74.6	19.2
6/12/2012	17:15:00	74.6	19.2
6/12/2012	17:25:00	74.6	19.2
6/12/2012	17:35:00	74.6	19.2
6/12/2012	17:45:00	74.6	19.2
6/12/2012	17:55:00	74.6	19.2
6/12/2012	18:05:00	74.6	19.2
6/12/2012	18:15:00	74.6	19.2
6/12/2012	18:25:00	74.6	19.1
6/12/2012	18:35:00	74.6	19.1
6/12/2012	18:45:00	74.6	19.1
6/12/2012	18:55:00	74.6	19.1
6/12/2012	19:05:00	74.6	19.1
6/12/2012	19:15:00	74.6	19.1
6/12/2012	19:25:00	74.6	19.1
6/12/2012	19:35:00	74.6	19.0
6/12/2012	19:45:00	74.6	19.0
6/12/2012	19:55:00	74.6	19.0
6/12/2012	20:05:00	74.6	19.0
6/12/2012	20:15:00	74.6	18.9
6/12/2012	20:25:00	74.6	18.9

Saturated MgCl2 solution - Magnesium chloride

Measurement period:		**Average value**	
6/13/2012		R.H. (%)	Temp (°C)
12:00 to 20:3		CH 13	CH 14
		34.890	**18.886**
Date	Time	R.H. (%)	Temp (°C)
dd.mm.yy	hh:mm:ss	CH 13	CH 14

****

6/13/2012	12:05:00	35.1	18.6
6/13/2012	12:15:00	35.1	18.6
6/13/2012	12:25:00	35.1	18.6
6/13/2012	12:35:00	35.1	18.6
6/13/2012	12:45:00	35.1	18.6
6/13/2012	12:55:00	35.1	18.7
6/13/2012	13:05:00	35.1	18.7
6/13/2012	13:15:00	35.1	18.7
6/13/2012	13:25:00	35.1	18.7
6/13/2012	13:35:00	35.0	18.8
6/13/2012	13:45:00	35.0	18.8
6/13/2012	13:55:00	35.0	18.8
6/13/2012	14:05:00	34.9	18.8
6/13/2012	14:15:00	34.9	18.9
6/13/2012	14:25:00	34.9	18.9
6/13/2012	14:35:00	34.8	18.9
6/13/2012	14:45:00	34.8	18.9
6/13/2012	14:55:00	34.8	18.9
6/13/2012	15:05:00	34.8	18.9
6/13/2012	15:15:00	34.8	18.9
6/13/2012	15:25:00	34.8	18.9
6/13/2012	15:35:00	34.8	18.9
6/13/2012	15:45:00	34.8	18.9
6/13/2012	15:55:00	34.8	19.0
6/13/2012	16:05:00	34.8	18.9
6/13/2012	16:15:00	34.8	19.0
6/13/2012	16:25:00	34.8	19.0
6/13/2012	16:35:00	34.8	19.0
6/13/2012	16:45:00	34.8	19.0
6/13/2012	16:55:00	34.8	19.0
6/13/2012	17:05:00	34.8	19.0
6/13/2012	17:15:00	34.8	19.0
6/13/2012	17:25:00	34.8	19.0
6/13/2012	17:35:00	34.8	19.0
6/13/2012	17:45:00	34.8	19.0
6/13/2012	17:55:00	34.8	19.0
6/13/2012	18:05:00	34.8	19.0
6/13/2012	18:15:00	34.8	19.0
6/13/2012	18:25:00	34.8	19.0
6/13/2012	18:35:00	34.8	19.0
6/13/2012	18:45:00	34.9	19.0

6/12/2012	20:35:00	74.6	18.9
6/12/2012	20:45:00	74.6	18.9
6/12/2012	20:55:00	74.7	18.9
6/12/2012	21:05:00	74.7	18.9
6/12/2012	21:15:00	74.7	18.8
6/12/2012	21:25:00	74.7	18.9
6/12/2012	21:35:00	74.7	18.9
6/12/2012	21:45:00	74.7	18.8
6/12/2012	21:55:00	74.7	18.8
6/12/2012	22:05:00	74.7	18.8
6/12/2012	22:15:00	74.7	18.8
6/12/2012	22:25:00	74.8	18.8
6/12/2012	22:35:00	74.8	18.7
6/12/2012	22:45:00	74.8	18.7
6/12/2012	22:55:00	74.8	18.7
6/12/2012	23:05:00	74.8	18.7
6/12/2012	23:15:00	74.8	18.7
6/12/2012	23:25:00	74.8	18.7
6/12/2012	23:35:00	74.8	18.7
6/12/2012	23:45:00	74.8	18.7
6/12/2012	23:55:00	74.8	18.7

6/13/2012	18:55:00	34.9	19.0
6/13/2012	19:05:00	34.9	19.0
6/13/2012	19:15:00	34.9	18.9
6/13/2012	19:25:00	34.9	18.9
6/13/2012	19:35:00	34.9	18.9
6/13/2012	19:45:00	34.9	18.9
6/13/2012	19:55:00	34.9	19.0
6/13/2012	20:05:00	34.9	18.9
6/13/2012	20:15:00	34.9	19.0
6/13/2012	20:25:00	34.9	18.9

Timline Day	 Hour	dd.mm.yy	hh:mm:ss	CH 4 t_eff	CH 5 t_in2	CH 6 t_in3	CH 7 t_in4	CH 14 t_ext	CH 13 R.H. measured	**R.H. ext.**	**R.H. indoor (estimate)**
1	00	4/19/2012	24:00:00	26.8	26.7	**28.2**	27.8	26.3	78.9	80.0	
	01	4/20/2012	1:00:00	26.6	26.6	**28.0**	27.7	26.3	77.8	78.9	
	02	4/20/2012	2:00:00	26.5	26.4	**27.8**	27.6	26.1	78.7	79.8	
	03	4/20/2012	3:00:00	26.6	26.6	**27.7**	27.7	26.1	79.5	80.7	
	04	4/20/2012	4:00:00	26.6	26.7	**27.6**	27.7	25.6	82.2	83.6	
	05	4/20/2012	5:00:00	26.5	26.7	**27.5**	27.6	23.9	89.2	91.0	
	06	4/20/2012	6:00:00	26.5	26.6	**27.3**	27.5	23.2	93.8	95.9	
	07	4/20/2012	7:00:00	26.3	26.4	**27.2**	27.4	23.4	94.3	96.5	
	08	4/20/2012	8:00:00	26.3	26.0	**27.4**	27.4	25.4	88.6	90.4	
	09	4/20/2012	9:00:00	26.4	26.5	**27.7**	27.5	28.5	70.7	71.3	
	10	4/20/2012	10:00:00	26.8	27.5	**28.7**	28.0	29.5	65.4	65.7	
	11	4/20/2012	11:00:00	27.4	28.4	**29.2**	28.7	30.6	60.6	60.6	
	12	4/20/2012	12:00:00	28.2	29.5	**29.9**	29.6	31.9	54.8	54.4	
	13	4/20/2012	13:00:00	28.7	30.0	**30.0**	30.1	31.7	57.1	56.7	
	14	4/20/2012	14:00:00	29.1	30.5	**30.6**	31.4	32.3	52.9	52.3	
	15	4/20/2012	15:00:00	29.3	30.7	**30.8**	38.0	32.1	52.9	52.3	
	16	4/20/2012	16:00:00	29.6	30.7	**30.9**	35.9	31.8	54.2	53.7	
	17	4/20/2012	17:00:00	29.6	30.3	**30.7**	86.8	30.6	62.7	62.8	
	18	4/20/2012	18:00:00	29.4	29.8	**30.4**	134.4	29.7	67.6	68.0	
	19	4/20/2012	19:00:00	29.2	29.2	**29.8**	36.3	28.5	70.0	70.6	
	20	4/20/2012	20:00:00	28.4	28.4	**28.9**	32.0	27.7	72.9	73.6	
	21	4/20/2012	21:00:00	28.6	28.4	**29.2**	30.6	27.6	74.8	75.6	
	22	4/20/2012	22:00:00	28.3	28.1	**29.4**	30.3	27.4	74.6	75.5	
	23	4/20/2012	23:00:00	28.1	28.1	**29.5**	30.1	27.3	76.0	76.9	
2	00	4/20/2012	24:00:00	28.3	28.2	**29.3**	30.3	27.1	76.6	77.6	
	01	4/21/2012	1:00:00	28.2	28.2	**29.1**	30.2	27.1	77.9	79.0	
	02	4/21/2012	2:00:00	28.1	28.0	**28.9**	30.1	26.9	78.4	79.5	
	03	4/21/2012	3:00:00	27.9	28.0	**28.7**	30.0	26.7	78.9	80.1	
	04	4/21/2012	4:00:00	27.8	27.9	**28.6**	29.9	26.4	80.9	82.2	
	05	4/21/2012	5:00:00	27.7	27.8	**28.4**	29.8	25.6	84.7	86.2	
	06	4/21/2012	6:00:00	27.6	27.7	**28.3**	29.7	24.9	88.2	90.0	
	07	4/21/2012	7:00:00	27.4	27.0	**28.2**	29.4	24.7	88.6	90.4	
	08	4/21/2012	8:00:00	27.2	26.6	**28.4**	29.3	26.6	79.1	80.3	
	09	4/21/2012	9:00:00	27.3	27.4	**28.6**	29.3	29.8	66.0	66.3	
	10	4/21/2012	10:00:00	27.7	28.4	**29.5**	29.8	31.1	57.0	56.7	
	11	4/21/2012	11:00:00	28.5	28.9	**29.8**	30.6	33.9	47.8	46.9	
	12	4/21/2012	12:00:00	29.9	29.8	**30.3**	32.3	35.1	44.7	43.5	
	13	4/21/2012	13:00:00	30.7	30.4	**31.0**	34.5	35.8	40.5	39.1	
	14	4/21/2012	14:00:00	31.6	31.0	**31.5**	35.2	36.3	36.7	35.0	
	15	4/21/2012	15:00:00	32.1	31.4	**31.8**	34.8	35.7	37.0	35.3	
	16	4/21/2012	16:00:00	31.0	31.5	**32.0**	33.4	34.9	40.5	39.0	
	17	4/21/2012	17:00:00	31.0	32.4	**32.3**	33.2	36.1	31.4	29.4	
	18	4/21/2012	18:00:00	31.0	32.3	**32.3**	33.2	34.4	34.2	32.4	
	19	4/21/2012	19:00:00	30.8	31.7	**32.1**	33.1	32.6	37.9	36.4	
	20	4/21/2012	20:00:00	30.2	30.7	**31.6**	33.0	30.7	43.1	41.8	
	21	4/21/2012	21:00:00	29.1	29.8	**31.0**	32.0	29.2	44.9	43.8	
	22	4/21/2012	22:00:00	27.9	29.1	**30.5**	30.6	27.6	50.2	49.5	

	23	4/21/2012	23:00:00	27.0	28.6	**30.1**	29.4	26.4	56.2	55.8	
3	00	4/21/2012	24:00:00	26.0	27.7	**29.5**	27.9	25.4	61.5	61.5	
	01	4/22/2012	1:00:00	27.6	28.2	**29.5**	29.3	24.6	64.4	64.6	
	02	4/22/2012	2:00:00	27.7	27.9	**29.2**	29.4	23.7	64.2	64.3	
	03	4/22/2012	3:00:00	27.6	27.7	**28.8**	29.3	22.7	67.7	68.1	
	04	4/22/2012	4:00:00	27.3	27.3	**28.4**	29.0	21.8	73.9	74.7	
	05	4/22/2012	5:00:00	27.0	27.0	**28.1**	28.8	20.9	76.4	77.4	
	06	4/22/2012	6:00:00	26.7	26.5	**27.6**	28.5	20.3	77.0	78.1	
	07	4/22/2012	7:00:00	26.2	25.5	**27.2**	27.8	20.8	71.4	72.0	
	08	4/22/2012	8:00:00	25.8	25.0	**27.2**	27.4	22.6	63.7	63.9	
	09	4/22/2012	9:00:00	25.6	25.3	**27.1**	27.2	24.9	51.8	51.1	
	10	4/22/2012	10:00:00	25.5	26.0	**27.4**	27.3	27.0	42.4	41.1	
	11	4/22/2012	11:00:00	25.7	26.7	**27.5**	30.8	29.0	35.6	33.9	
	12	4/22/2012	12:00:00	26.4	27.4	**27.9**	30.3	30.3	33.5	31.6	
	13	4/22/2012	13:00:00	27.0	28.0	**28.6**	28.9	31.8	31.9	29.9	
	14	4/22/2012	14:00:00	27.0	28.2	**28.6**	28.6	32.0	31.5	29.5	
	15	4/22/2012	15:00:00	27.4	29.1	**29.2**	29.0	33.1	29.6	27.5	
	16	4/22/2012	16:00:00	27.8	29.4	**29.5**	29.3	33.3	29.5	27.4	
	17	4/22/2012	17:00:00	28.2	29.7	**29.8**	29.6	32.8	30.5	28.4	
	18	4/22/2012	18:00:00	28.7	29.7	**30.1**	30.4	32.1	33.0	31.1	
	19	4/22/2012	19:00:00	28.8	29.3	**30.0**	30.7	30.3	37.9	36.3	
	20	4/22/2012	20:00:00	28.4	28.9	**29.9**	30.1	28.8	44.1	43.0	
	21	4/22/2012	21:00:00	28.4	28.5	**29.7**	30.1	27.8	48.1	47.2	
	22	4/22/2012	22:00:00	28.2	28.3	**29.5**	29.8	27.1	51.7	51.0	
	23	4/22/2012	23:00:00	27.9	27.9	**29.2**	29.4	26.0	55.7	55.2	
4	00	4/22/2012	24:00:00	27.8	27.5	**28.9**	29.1	25.0	58.4	58.2	
	01	4/23/2012	1:00:00	27.5	27.1	**28.6**	28.9	23.9	61.0	60.9	
	02	4/23/2012	2:00:00	27.2	26.6	**28.3**	28.6	22.8	64.7	64.8	
	03	4/23/2012	3:00:00	26.9	26.1	**28.0**	28.4	21.7	69.5	70.0	
	04	4/23/2012	4:00:00	26.6	25.6	**27.6**	28.1	20.8	73.6	74.4	
	05	4/23/2012	5:00:00	26.3	25.1	**27.2**	27.7	20.1	75.6	76.5	
	06	4/23/2012	6:00:00	25.9	24.7	**26.8**	27.4	19.5	78.5	79.6	
	07	4/23/2012	7:00:00	25.4	24.4	**26.6**	26.8	19.9	76.2	77.2	
	08	4/23/2012	8:00:00	24.6	23.3	**26.5**	26.1	21.8	67.4	67.8	
	09	4/23/2012	9:00:00	24.1	23.8	**26.4**	25.7	24.4	55.7	55.3	
	10	4/23/2012	10:00:00	24.4	24.8	**26.7**	26.3	26.4	48.2	47.3	
	11	4/23/2012	11:00:00	25.1	25.8	**27.3**	27.0	28.8	40.0	38.6	
	12	4/23/2012	12:00:00	26.1	26.7	**27.8**	27.7	30.5	35.2	33.5	
	13	4/23/2012	13:00:00	27.0	27.4	**28.3**	30.3	32.4	30.6	28.5	
	14	4/23/2012	14:00:00	28.0	28.4	**29.3**	36.3	33.7	27.9	25.7	
	15	4/23/2012	15:00:00	28.0	28.8	**29.4**	33.0	31.7	37.0	35.3	
	16	4/23/2012	16:00:00	28.4	29.2	**29.8**	32.9	32.0	34.3	32.4	
	17	4/23/2012	17:00:00	29.3	29.3	**30.4**	32.8	33.5	28.4	26.1	
	18	4/23/2012	18:00:00	29.5	29.3	**30.7**	36.2	32.5	27.8	25.5	
	19	4/23/2012	19:00:00	29.3	28.8	**30.2**	39.8	29.9	42.3	41.0	
	20	4/23/2012	20:00:00	28.4	27.9	**29.6**	30.9	26.9	59.3	59.1	
	21	4/23/2012	21:00:00	27.9	27.4	**29.8**	29.4	26.3	62.4	62.4	
	22	4/23/2012	22:00:00	27.6	27.0	**29.5**	29.8	25.9	63.7	63.9	
	23	4/23/2012	23:00:00	27.5	26.7	**29.3**	29.6	25.7	65.3	65.5	
5	00	4/23/2012	24:00:00	26.6	25.9	**29.0**	29.0	24.2	72.2	72.9	

	01	4/24/2012	1:00:00	27.0	26.0	**28.7**	29.3	22.6	75.6	76.5	
	02	4/24/2012	2:00:00	26.9	25.8	**28.3**	28.9	21.6	59.3	59.1	
	03	4/24/2012	3:00:00	26.7	25.8	**27.9**	29.0	20.9	58.6	58.4	
	04	4/24/2012	4:00:00	26.4	25.6	**27.5**	29.2	20.1	61.8	61.8	
	05	4/24/2012	5:00:00	26.1	25.3	**27.1**	29.3	19.2	66.7	67.0	
	06	4/24/2012	6:00:00	25.8	24.7	**26.7**	29.5	18.6	69.4	69.9	
	07	4/24/2012	7:00:00	25.4	24.1	**26.4**	30.2	18.8	67.5	67.9	
	08	4/24/2012	8:00:00	25.1	23.6	**26.4**	30.6	21.0	60.3	60.2	
	09	4/24/2012	9:00:00	24.9	23.7	**26.1**	30.2	24.7	51.9	51.2	
	10	4/24/2012	10:00:00	24.9	25.0	**26.7**	30.0	27.5	42.9	41.7	
	11	4/24/2012	11:00:00	25.5	26.1	**27.5**	32.0	29.2	36.2	34.5	
	12	4/24/2012	12:00:00	26.3	26.8	**28.0**	33.4	30.8	29.7	27.5	
	13	4/24/2012	13:00:00	26.9	27.6	**28.1**	30.4	29.8	38.2	36.7	
	14	4/24/2012	14:00:00	27.2	28.3	**28.4**	30.2	29.6	37.4	35.8	
	15	4/24/2012	15:00:00	27.6	28.7	**28.8**	29.9	29.9	35.7	34.0	
	16	4/24/2012	16:00:00	27.9	28.9	**29.2**	29.8	30.0	34.7	32.9	
	17	4/24/2012	17:00:00	28.4	29.0	**29.6**	31.4	30.2	34.1	32.3	
	18	4/24/2012	18:00:00	28.1	28.2	**28.8**	31.4	27.9	52.8	52.2	
	19	4/24/2012	19:00:00	27.7	27.6	**28.5**	29.9	27.1	54.8	54.3	
	20	4/24/2012	20:00:00	27.3	27.0	**28.2**	28.9	26.4	53.1	52.5	
	21	4/24/2012	21:00:00	27.2	26.9	**28.6**	28.8	26.0	54.3	53.8	
	22	4/24/2012	22:00:00	27.2	26.7	**28.8**	28.7	25.7	55.7	55.3	
	23	4/24/2012	23:00:00	27.2	26.6	**28.6**	28.7	25.5	57.6	57.3	
6	00	4/24/2012	24:00:00	27.2	26.7	**28.3**	28.8	25.1	58.1	57.8	
	01	4/25/2012	1:00:00	27.1	26.5	**28.1**	28.6	24.9	56.7	56.3	
	02	4/25/2012	2:00:00	26.9	26.5	**27.9**	28.4	24.5	58.7	58.5	
	03	4/25/2012	3:00:00	26.7	26.2	**27.6**	28.3	21.7	73.7	74.5	
	04	4/25/2012	4:00:00	26.5	26.2	**27.4**	28.2	21.0	81.3	82.6	
	05	4/25/2012	5:00:00	26.3	26.1	**27.1**	28.1	21.2	81.0	82.3	
	06	4/25/2012	6:00:00	26.1	25.8	**26.8**	28.0	20.4	83.2	84.7	
	07	4/25/2012	7:00:00	25.8	25.4	**26.6**	27.7	20.8	79.1	80.3	
	08	4/25/2012	8:00:00	25.7	25.1	**26.9**	27.8	23.5	68.0	68.4	
	09	4/25/2012	9:00:00	25.6	25.3	**27.1**	28.1	25.6	63.6	63.7	
	10	4/25/2012	10:00:00	25.7	26.1	**27.4**	28.6	27.2	56.0	55.6	
	11	4/25/2012	11:00:00	26.2	26.8	**27.7**	28.9	28.2	49.0	48.1	
	12	4/25/2012	12:00:00	26.7	27.3	**28.1**	29.3	28.8	46.2	45.2	
	13	4/25/2012	13:00:00	27.2	27.7	**28.6**	29.7	29.4	45.8	44.8	
	14	4/25/2012	14:00:00	27.5	28.0	**28.7**	29.9	29.3	45.1	44.0	
	15	4/25/2012	15:00:00	27.9	28.5	**29.1**	29.8	29.9	42.9	41.7	
	16	4/25/2012	16:00:00	28.2	28.7	**29.2**	29.8	29.8	44.8	43.6	
	17	4/25/2012	17:00:00	28.3	28.7	**29.4**	29.9	29.5	44.0	42.8	
	18	4/25/2012	18:00:00	28.1	28.1	**29.2**	29.8	28.3	46.4	45.3	
	19	4/25/2012	19:00:00	27.7	27.4	**28.6**	31.6	27.1	47.1	46.1	
	20	4/25/2012	20:00:00	27.2	26.8	**28.0**	31.3	26.2	51.6	51.0	
	21	4/25/2012	21:00:00	27.5	26.6	**28.8**	30.5	25.7	57.5	57.2	
	22	4/25/2012	22:00:00	27.3	26.5	**28.9**	29.9	25.4	60.2	60.1	
	23	4/25/2012	23:00:00	26.9	26.3	**28.6**	29.5	25.2	60.9	60.8	
7	00	4/25/2012	24:00:00	26.6	26.0	**28.3**	29.2	25.1	60.9	60.9	
	01	4/26/2012	1:00:00	26.5	25.9	**28.1**	29.1	24.9	62.3	62.4	
	02	4/26/2012	2:00:00	26.9	26.5	**27.9**	29.5	24.5	69.2	69.7	

	03	4/26/2012	3:00:00	26.8	26.5	**27.7**	29.4	24.1	72.9	73.6	
	04	4/26/2012	4:00:00	26.6	26.4	**27.5**	29.2	22.6	78.2	79.3	
	05	4/26/2012	5:00:00	26.4	26.3	**27.3**	29.0	21.6	81.5	82.9	
	06	4/26/2012	6:00:00	26.3	26.1	**27.1**	28.7	20.8	84.8	86.3	
	07	4/26/2012	7:00:00	25.9	24.9	**26.9**	28.3	20.1	86.1	87.7	
	08	4/26/2012	8:00:00	25.6	24.2	**26.8**	27.9	23.0	75.3	76.1	
	09	4/26/2012	9:00:00	25.6	25.2	**27.0**	27.8	26.6	64.1	64.3	
	10	4/26/2012	10:00:00	26.0	26.2	**27.6**	28.2	28.0	59.4	59.2	
	11	4/26/2012	11:00:00	26.6	27.2	**28.1**	28.8	28.9	54.8	54.3	
	12	4/26/2012	12:00:00	27.2	27.8	**28.3**	29.3	29.5	53.0	52.5	
	13	4/26/2012	13:00:00	27.7	28.4	**28.7**	29.7	29.9	49.4	48.6	
	14	4/26/2012	14:00:00	28.0	28.7	**29.1**	29.8	29.9	50.2	49.4	
	15	4/26/2012	15:00:00	28.0	28.4	**29.3**	29.7	29.4	49.3	48.5	
	16	4/26/2012	16:00:00	28.1	28.5	**29.3**	29.8	29.1	49.4	48.6	
	17	4/26/2012	17:00:00	28.1	28.2	**29.1**	29.9	28.4	57.0	56.7	
	18	4/26/2012	18:00:00	28.1	28.0	**29.2**	29.9	27.9	56.9	56.6	
	19	4/26/2012	19:00:00	27.9	27.7	**29.0**	29.8	27.2	59.5	59.3	
	20	4/26/2012	20:00:00	27.6	27.2	**28.7**	29.5	26.5	61.9	61.9	
	21	4/26/2012	21:00:00	27.5	26.9	**28.7**	29.7	26.1	64.1	64.3	
	22	4/26/2012	22:00:00	27.6	26.8	**28.7**	29.9	25.9	65.2	65.4	
	23	4/26/2012	23:00:00	27.6	27.0	**28.7**	29.9	25.6	66.2	66.5	
8	00	4/26/2012	24:00:00	27.4	26.8	**28.5**	29.7	25.4	67.3	67.7	67.7
	01	4/27/2012	1:00:00	27.2	26.7	**28.3**	29.6	25.3	68.4	68.9	68.9
	02	4/27/2012	2:00:00	27.0	26.5	**28.1**	29.6	25.1	69.4	69.9	69.9
	03	4/27/2012	3:00:00	26.9	26.4	**27.9**	29.6	25.0	70.0	70.6	70.6
	04	4/27/2012	4:00:00	26.7	26.4	**27.7**	29.5	24.9	71.5	72.2	72.2
	05	4/27/2012	5:00:00	26.6	26.6	**27.6**	29.5	24.0	77.1	78.1	78.1
	06	4/27/2012	6:00:00	26.3	26.0	**27.3**	29.2	22.2	83.5	85.0	85.0
	07	4/27/2012	7:00:00	25.9	25.4	**26.9**	28.9	21.8	85.0	86.6	86.6
	08	4/27/2012	8:00:00	25.9	25.3	**27.2**	29.1	25.1	71.0	71.7	74.0
	09	4/27/2012	9:00:00	26.2	26.1	**27.8**	29.7	27.5	64.6	64.8	69.2
	10	4/27/2012	10:00:00	26.5	27.3	**28.4**	30.0	28.9	57.3	57.0	62.1
	11	4/27/2012	11:00:00	27.2	28.0	**28.9**	30.6	29.9	53.4	52.8	57.8
	12	4/27/2012	12:00:00	27.9	28.9	**29.3**	31.1	30.7	50.1	49.4	51.8
	13	4/27/2012	13:00:00	28.4	29.6	**29.6**	31.4	30.8	49.8	49.0	49.0
	14	4/27/2012	14:00:00	28.8	29.9	**30.0**	31.7	31.0	49.0	48.1	55.1
	15	4/27/2012	15:00:00	29.0	30.0	**30.2**	31.9	30.7	50.5	49.7	56.7
	16	4/27/2012	16:00:00	29.3	30.1	**30.3**	32.1	30.6	49.2	48.4	50.7
	17	4/27/2012	17:00:00	29.4	29.8	**30.3**	32.2	30.2	50.7	50.0	52.3
	18	4/27/2012	18:00:00	29.2	29.2	**30.2**	31.9	29.3	52.7	52.1	52.1
	19	4/27/2012	19:00:00	28.6	28.4	**29.9**	31.4	27.9	59.0	58.9	66.0
	20	4/27/2012	20:00:00	28.9	28.3	**30.3**	31.7	26.9	65.4	65.6	75.0
	21	4/27/2012	21:00:00	29.1	28.3	**30.5**	31.8	26.4	69.2	69.7	79.0
	22	4/27/2012	22:00:00	29.0	28.1	**30.3**	31.6	26.3	71.3	71.9	79.0
	23	4/27/2012	23:00:00	28.8	27.8	**30.0**	31.4	26.1	74.2	75.0	79.8
9	24	4/27/2012	24:00:00	28.7	27.6	**29.8**	31.2	26.0	76.1	77.0	77.0
	01	4/28/2012	1:00:00	28.4	27.4	**29.6**	31.0	25.9	77.1	78.1	
	02	4/28/2012	2:00:00	28.3	27.4	**29.4**	30.8	25.8	78.0	79.1	
	03	4/28/2012	3:00:00	28.1	27.2	**29.2**	30.6	25.8	76.8	77.8	
	04	4/28/2012	4:00:00	27.9	27.1	**28.9**	30.5	25.6	77.6	78.6	

	05	4/28/2012	5:00:00	27.8	26.9	**28.7**	30.4	25.5	78.8	79.9	
	06	4/28/2012	6:00:00	27.6	26.8	**28.6**	30.2	25.3	79.9	81.2	
	07	4/28/2012	7:00:00	27.5	26.8	**28.4**	30.0	25.4	78.4	79.5	
	08	4/28/2012	8:00:00	27.4	26.8	**28.6**	29.9	26.5	71.9	72.6	
	09	4/28/2012	9:00:00	27.5	27.3	**29.0**	30.0	28.2	65.6	65.9	
	10	4/28/2012	10:00:00	27.7	28.0	**29.2**	30.1	29.1	63.1	63.2	
	11	4/28/2012	11:00:00	28.0	28.8	**29.5**	30.4	29.7	60.6	60.5	
	12	4/28/2012	12:00:00	28.5	29.4	**29.7**	30.9	30.1	58.6	58.4	
	13	4/28/2012	13:00:00	28.9	29.9	**29.9**	31.1	30.4	57.8	57.5	
	14	4/28/2012	14:00:00	29.2	30.2	**30.3**	31.3	30.6	57.3	57.0	
	15	4/28/2012	15:00:00	29.4	30.4	**31.0**	31.5	30.7	56.8	56.4	
	16	4/28/2012	16:00:00	29.6	30.3	**31.3**	31.7	30.5	58.0	57.7	
	17	4/28/2012	17:00:00	29.7	30.1	**31.5**	31.7	29.9	60.5	60.4	
	18	4/28/2012	18:00:00	29.6	29.6	**31.6**	31.6	29.1	64.4	64.5	
	19	4/28/2012	19:00:00	29.3	29.1	**31.5**	31.3	28.2	65.8	66.1	
	20	4/28/2012	20:00:00	29.1	28.5	**31.3**	31.2	27.7	67.9	68.3	
	21	4/28/2012	21:00:00	28.9	28.1	**31.1**	31.0	27.2	72.1	72.8	
	22	4/28/2012	22:00:00	28.6	27.9	**30.8**	30.8	26.9	73.1	73.8	
	23	4/28/2012	23:00:00	29.0	28.4	**30.6**	31.1	26.7	73.0	73.8	
10	00	4/28/2012	24:00:00	28.9	28.4	**30.4**	31.0	26.5	73.7	74.5	
	01	4/29/2012	1:00:00	28.8	28.3	**30.1**	30.9	26.3	74.3	75.1	
	02	4/29/2012	2:00:00	28.6	28.1	**29.9**	30.7	26.2	74.0	74.8	
	03	4/29/2012	3:00:00	28.5	28.0	**29.7**	30.6	26.1	74.8	75.7	
	04	4/29/2012	4:00:00	28.3	27.9	**29.4**	30.5	25.8	76.2	77.1	
	05	4/29/2012	5:00:00	28.2	27.8	**29.2**	30.3	25.7	75.5	76.5	
	06	4/29/2012	6:00:00	28.0	27.7	**29.0**	30.2	25.7	75.3	76.2	
	07	4/29/2012	7:00:00	27.6	27.2	**28.8**	29.7	26.1	74.5	75.3	
	08	4/29/2012	8:00:00	27.5	27.2	**28.7**	29.7	27.1	71.1	71.8	
	09	4/29/2012	9:00:00	27.6	27.7	**29.0**	29.8	28.5	65.4	65.7	
	10	4/29/2012	10:00:00	27.9	28.3	**29.4**	30.0	29.3	61.6	61.6	
	11	4/29/2012	11:00:00	28.2	29.0	**29.6**	30.3	30.2	58.1	57.8	
	12	4/29/2012	12:00:00	28.6	29.7	**30.1**	30.7	31.1	52.4	51.8	
	13	4/29/2012	13:00:00	29.1	30.2	**30.5**	31.0	31.5	50.9	50.2	
	14	4/29/2012	14:00:00	29.5	30.6	**30.9**	31.5	32.0	51.0	50.3	
	15	4/29/2012	15:00:00	29.9	30.8	**31.1**	31.8	31.9	52.2	51.6	
	16	4/29/2012	16:00:00	30.1	30.9	**31.3**	32.0	31.4	52.2	51.6	
	17	4/29/2012	17:00:00	30.3	30.7	**31.2**	32.1	30.8	55.5	55.1	
	18	4/29/2012	18:00:00	30.1	30.1	**30.7**	32.0	29.4	62.2	62.2	
	19	4/29/2012	19:00:00	29.9	29.6	**30.4**	31.8	28.8	64.2	64.4	
	20	4/29/2012	20:00:00	29.6	28.9	**30.2**	31.2	27.9	68.0	68.4	
	21	4/29/2012	21:00:00	29.2	28.3	**30.0**	30.9	27.2	72.5	73.2	
	22	4/29/2012	22:00:00	29.0	28.0	**29.8**	30.6	26.9	74.6	75.4	
	23	4/29/2012	23:00:00	29.0	28.1	**30.0**	30.6	26.7	76.0	76.9	
11	00	4/29/2012	24:00:00	29.3	28.6	**30.3**	31.0	26.6	76.7	77.7	
	01	4/30/2012	1:00:00	29.2	28.6	**30.1**	30.9	26.5	77.8	78.9	
	02	4/30/2012	2:00:00	29.1	28.5	**30.0**	30.8	26.4	79.0	80.1	
	03	4/30/2012	3:00:00	28.9	28.4	**29.8**	30.7	26.2	79.7	80.9	
	04	4/30/2012	4:00:00	28.8	28.3	**29.6**	30.5	26.0	80.0	81.2	
	05	4/30/2012	5:00:00	28.6	28.3	**29.5**	30.4	26.0	80.4	81.7	
	06	4/30/2012	6:00:00	28.5	28.2	**29.3**	30.3	25.4	82.2	83.6	

	07	4/30/2012	7:00:00	28.3	27.9	**29.2**	30.1	24.9	84.6	86.2	
	08	4/30/2012	8:00:00	28.1	27.5	**29.4**	29.8	26.3	79.2	80.4	
	09	4/30/2012	9:00:00	28.1	28.1	**29.5**	29.8	28.8	68.4	68.8	
	10	4/30/2012	10:00:00	28.4	28.7	**29.7**	30.1	29.8	62.6	62.6	
	11	4/30/2012	11:00:00	28.8	29.4	**30.0**	30.5	30.8	59.2	59.0	
	12	4/30/2012	12:00:00	29.3	30.2	**30.5**	30.9	31.5	54.4	53.9	
	13	4/30/2012	13:00:00	29.8	30.9	**30.9**	31.4	32.2	49.4	48.6	
	14	4/30/2012	14:00:00	30.2	31.2	**31.3**	31.8	32.0	51.1	50.4	
	15	4/30/2012	15:00:00	30.5	31.2	**31.4**	32.1	31.9	52.1	51.4	
	16	4/30/2012	16:00:00	30.6	31.1	**31.4**	32.1	31.3	56.0	55.6	
	17	4/30/2012	17:00:00	30.7	30.9	**31.3**	32.2	30.8	58.7	58.5	
	18	4/30/2012	18:00:00	30.5	30.5	**31.0**	31.9	29.9	62.1	62.1	
	19	4/30/2012	19:00:00	30.8	30.5	**31.8**	32.9	29.1	65.0	65.2	
	20	4/30/2012	20:00:00	30.9	30.1	**32.1**	33.1	28.3	68.7	69.2	
	21	4/30/2012	21:00:00	30.7	29.8	**32.0**	32.9	27.7	72.6	73.3	
	22	4/30/2012	22:00:00	30.5	29.6	**31.7**	33.1	27.5	74.1	74.9	
	23	4/30/2012	23:00:00	29.7	29.1	**31.3**	32.9	27.3	74.9	75.8	
12	00	4/30/2012	24:00:00	29.6	28.8	**30.3**	32.8	27.1	76.3	77.3	
	01	5/1/2012	1:00:00	29.8	28.8	**30.8**	33.1	26.8	76.8	77.8	
	02	5/1/2012	2:00:00	29.6	28.6	**30.5**	33.0	26.6	77.7	78.8	
	03	5/1/2012	3:00:00	29.5	28.6	**30.4**	32.9	26.6	77.5	78.5	
	04	5/1/2012	4:00:00	29.3	28.4	**30.2**	32.7	26.5	78.0	79.1	
	05	5/1/2012	5:00:00	29.1	28.3	**30.0**	32.6	26.5	77.2	78.2	
	06	5/1/2012	6:00:00	29.0	28.2	**29.8**	32.5	26.4	77.9	79.0	
	07	5/1/2012	7:00:00	28.9	28.2	**29.8**	32.4	27.0	75.7	76.6	
	08	5/1/2012	8:00:00	28.6	28.2	**29.7**	32.1	28.0	70.8	71.5	
	09	5/1/2012	9:00:00	28.6	28.6	**29.8**	32.2	29.2	66.3	66.6	
	10	5/1/2012	10:00:00	28.9	29.1	**30.0**	32.3	29.9	62.4	62.4	
	11	5/1/2012	11:00:00	29.2	29.8	**30.3**	32.4	30.7	57.7	57.4	
	12	5/1/2012	12:00:00	29.6	30.5	**30.8**	32.9	31.8	51.1	50.4	
	13	5/1/2012	13:00:00	30.1	31.1	**31.2**	33.1	32.3	48.4	47.5	
	14	5/1/2012	14:00:00	30.5	31.5	**31.5**	35.1	32.3	47.2	46.3	
	15	5/1/2012	15:00:00	30.9	31.7	**31.8**	35.0	32.4	49.1	48.2	
	16	5/1/2012	16:00:00	31.0	31.4	**31.6**	34.4	31.4	55.1	54.7	
	17	5/1/2012	17:00:00	30.8	31.0	**31.3**	34.2	30.6	59.3	59.2	
	18	5/1/2012	18:00:00	30.6	30.5	**31.0**	34.1	29.7	62.9	63.0	
	19	5/1/2012	19:00:00	30.3	29.9	**30.5**	33.8	28.8	66.8	67.1	
	20	5/1/2012	20:00:00	30.0	29.6	**30.3**	33.7	28.3	69.5	70.0	
	21	5/1/2012	21:00:00	29.7	29.2	**30.0**	33.6	28.0	71.8	72.4	
	22	5/1/2012	22:00:00	30.2	29.3	**31.1**	34.2	27.8	72.4	73.1	
	23	5/1/2012	23:00:00	30.2	29.1	**31.0**	34.0	27.7	70.2	70.8	
13	00	5/1/2012	24:00:00	30.0	28.8	**30.8**	33.7	27.4	71.9	72.5	

Timline Day	Hour	dd.mm.yy	hh:mm:ss	CH 4 t_eff	CH 5 t_in2	CH 6 t_in3	CH 7 t_in4	CH 14 t_ext	CH 13 R.H. measured	**R.H. ext.**	**R.H. indoor (estimate)**
1	00	5/2/2012	24:00:00	26.6	26.8	27.8	30.3	26.3	80.7	82.1	
	01	5/3/2012	1:00:00	26.5	26.7	27.7	29.2	26.3	80.8	82.3	
	02	5/3/2012	2:00:00	26.4	26.7	27.7	28.9	26.2	80.3	81.8	
	03	5/3/2012	3:00:00	26.4	26.6	27.6	28.8	26.0	80.8	82.3	
	04	5/3/2012	4:00:00	26.3	26.6	27.5	28.6	26.0	80.5	82.0	
	05	5/3/2012	5:00:00	26.3	26.6	27.5	28.5	26.0	80.9	82.4	
	06	5/3/2012	6:00:00	26.2	26.4	27.4	28.4	25.8	80.9	82.4	
	07	5/3/2012	7:00:00	26.3	26.6	27.5	28.4	26.5	78.6	79.9	
	08	5/3/2012	8:00:00	27.2	27.7	28.3	29.1	28.9	69.4	70.1	
	09	5/3/2012	9:00:00	28.1	28.8	29.4	30.2	30.5	63.7	64.0	
	10	5/3/2012	10:00:00	28.8	29.4	30.1	30.9	31.5	60.2	60.2	
	11	5/3/2012	11:00:00	29.5	30.2	30.9	31.6	32.8	56.5	56.3	
	12	5/3/2012	12:00:00	29.8	30.5	31.3	32.3	33.3	54.9	54.6	
	13	5/3/2012	13:00:00	30.0	30.6	31.4	32.7	33.6	54.5	54.1	
	14	5/3/2012	14:00:00	30.1	30.6	31.4	32.6	34.1	53.0	52.5	
	15	5/3/2012	15:00:00	29.9	30.5	31.3	32.6	33.5	54.6	54.2	
	16	5/3/2012	16:00:00	29.7	30.1	30.9	32.0	33.0	56.2	55.9	
	17	5/3/2012	17:00:00	29.2	29.5	30.4	31.6	31.5	61.0	61.1	
	18	5/3/2012	18:00:00	28.5	28.7	29.7	30.8	29.8	67.3	67.8	
	19	5/3/2012	19:00:00	27.9	28.0	28.9	30.2	28.4	72.0	72.9	
	20	5/3/2012	20:00:00	27.5	27.6	28.3	29.7	27.5	74.8	75.9	
	21	5/3/2012	21:00:00	27.3	27.4	28.1	29.5	27.2	77.5	78.7	
	22	5/3/2012	22:00:00	27.0	27.2	27.9	29.0	27.0	77.1	78.3	
	23	5/3/2012	23:00:00	26.9	27.1	27.7	28.7	26.9	78.1	79.4	
2	00	5/3/2012	24:00:00	26.8	27.0	27.7	28.6	26.8	79.0	80.4	
	01	5/4/2012	1:00:00	26.7	26.9	27.6	28.4	26.6	79.8	81.2	
	02	5/4/2012	2:00:00	26.5	26.8	27.4	28.2	26.5	79.4	80.8	
	03	5/4/2012	3:00:00	26.4	26.7	27.4	28.1	26.4	79.6	81.0	
	04	5/4/2012	4:00:00	26.3	26.6	27.3	27.9	26.2	79.4	80.8	
	05	5/4/2012	5:00:00	26.2	26.5	27.2	27.8	26.1	79.6	81.0	
	06	5/4/2012	6:00:00	26.2	26.5	27.2	27.8	26.0	80.4	81.9	
	07	5/4/2012	7:00:00	26.3	26.7	27.3	27.9	26.6	77.1	78.3	
	08	5/4/2012	8:00:00	26.9	27.4	27.9	28.5	28.5	70.9	71.7	
	09	5/4/2012	9:00:00	27.9	28.6	29.1	29.7	30.6	64.0	64.3	
	10	5/4/2012	10:00:00	28.6	29.2	29.8	30.5	31.3	62.2	62.4	
	11	5/4/2012	11:00:00	29.5	30.2	30.8	31.6	32.7	57.6	57.4	
	12	5/4/2012	12:00:00	29.8	30.4	31.0	32.2	32.9	57.8	57.6	
	13	5/4/2012	13:00:00	30.0	30.7	31.2	32.7	33.4	56.4	56.2	
	14	5/4/2012	14:00:00	30.0	30.5	31.1	32.9	33.2	56.3	56.1	
	15	5/4/2012	15:00:00	29.8	30.3	30.8	32.5	33.0	56.1	55.8	
	16	5/4/2012	16:00:00	29.5	29.9	30.4	31.9	32.9	55.7	55.4	
	17	5/4/2012	17:00:00	29.0	29.3	29.8	31.2	31.9	58.7	58.6	
	18	5/4/2012	18:00:00	28.4	28.6	29.2	30.6	30.4	63.6	63.9	
	19	5/4/2012	19:00:00	27.8	27.9	28.7	30.1	28.3	72.0	72.9	
	20	5/4/2012	20:00:00	27.3	27.4	28.3	29.6	27.5	75.5	76.6	
	21	5/4/2012	21:00:00	27.1	27.2	28.0	29.3	27.1	76.3	77.5	
	22	5/4/2012	22:00:00	27.0	27.1	27.9	29.1	26.9	78.7	80.0	

	23	5/4/2012	23:00:00	26.8	26.9	27.7	28.8	26.7	78.8	80.2	
3	00	5/4/2012	24:00:00	26.8	26.9	27.7	28.8	26.6	79.6	81.0	
	01	5/5/2012	1:00:00	26.7	26.9	27.7	28.7	26.4	80.4	81.8	
	02	5/5/2012	2:00:00	26.5	26.7	27.6	28.6	26.0	80.5	82.0	
	03	5/5/2012	3:00:00	26.5	26.7	27.5	28.5	25.8	81.1	82.6	
	04	5/5/2012	4:00:00	26.3	26.5	27.4	28.4	25.4	81.9	83.4	
	05	5/5/2012	5:00:00	26.1	26.3	27.3	28.2	25.2	82.0	83.6	
	06	5/5/2012	6:00:00	25.9	26.1	27.0	28.0	25.0	82.7	84.3	
	07	5/5/2012	7:00:00	26.1	26.4	27.2	28.1	26.0	78.9	80.3	
	08	5/5/2012	8:00:00	26.9	27.5	28.0	28.7	29.2	66.1	66.5	
	09	5/5/2012	9:00:00	27.9	28.6	29.2	29.9	30.4	62.4	62.5	
	10	5/5/2012	10:00:00	28.7	29.4	30.0	30.7	31.7	57.7	57.6	
	11	5/5/2012	11:00:00	29.3	30.0	30.6	31.4	32.8	54.3	53.9	
	12	5/5/2012	12:00:00	29.7	30.3	31.0	32.0	33.7	51.9	51.3	
	13	5/5/2012	13:00:00	29.9	30.5	31.1	32.3	33.8	51.5	50.9	
	14	5/5/2012	14:00:00	30.0	30.5	31.1	32.4	34.2	50.7	50.0	
	15	5/5/2012	15:00:00	29.8	30.3	30.9	32.2	33.7	52.0	51.4	
	16	5/5/2012	16:00:00	29.6	30.0	30.6	31.9	33.4	53.0	52.5	
	17	5/5/2012	17:00:00	28.9	29.2	29.8	31.2	32.2	55.8	55.5	
	18	5/5/2012	18:00:00	28.4	28.5	29.2	30.6	30.8	60.6	60.7	
	19	5/5/2012	19:00:00	27.6	27.6	28.4	29.9	28.1	71.3	72.1	
	20	5/5/2012	20:00:00	27.1	27.2	28.0	29.3	27.1	74.7	75.8	
	21	5/5/2012	21:00:00	26.9	27.0	28.0	29.2	26.8	75.1	76.2	
	22	5/5/2012	22:00:00	26.7	26.8	27.7	28.9	26.6	75.3	76.4	
	23	5/5/2012	23:00:00	26.6	26.7	27.6	28.7	26.4	77.0	78.2	
4	00	5/5/2012	24:00:00	26.4	26.5	27.4	28.5	26.2	78.1	79.4	
	01	5/6/2012	1:00:00	26.4	26.5	27.5	28.5	26.1	78.7	80.1	
	02	5/6/2012	2:00:00								
	03	5/6/2012	3:00:00								
	04	5/6/2012	4:00:00								
	05	5/6/2012	5:00:00								
	06	5/6/2012	6:00:00								
	07	5/6/2012	7:00:00	26.2	26.6	27.3	28.1	26.5	75.8	76.9	
	08	5/6/2012	8:00:00	26.9	27.4	28.1	28.8	29.2	65.3	65.7	
	09	5/6/2012	9:00:00	27.8	28.4	29.0	29.6	30.9	59.7	59.7	
	10	5/6/2012	10:00:00	28.7	29.4	30.0	30.4	32.4	55.5	55.2	
	11	5/6/2012	11:00:00	29.1	29.8	30.4	30.8	33.0	51.9	51.3	
	12	5/6/2012	12:00:00	29.4	30.1	30.7	31.2	33.9	49.6	48.9	
	13	5/6/2012	13:00:00	29.7	30.3	30.9	31.6	34.5	48.0	47.2	
	14	5/6/2012	14:00:00	29.9	30.5	31.1	31.8	34.6	47.3	46.4	
	15	5/6/2012	15:00:00	29.8	30.3	30.8	31.7	34.2	49.5	48.7	
	16	5/6/2012	16:00:00	29.6	30.0	30.6	31.5	33.7	50.5	49.8	
	17	5/6/2012	17:00:00	29.0	29.3	29.9	30.9	32.5	53.9	53.5	
	18	5/6/2012	18:00:00	28.4	28.6	29.3	30.4	31.2	58.5	58.4	
	19	5/6/2012	19:00:00	27.8	27.9	28.7	29.8	28.5	66.7	67.2	
	20	5/6/2012	20:00:00	27.3	27.4	28.3	29.4	27.4	73.8	74.8	
	21	5/6/2012	21:00:00	27.1	27.3	28.1	29.2	27.2	75.6	76.7	
	22	5/6/2012	22:00:00	27.0	27.1	27.9	28.9	27.1	75.4	76.5	
	23	5/6/2012	23:00:00	26.8	27.0	27.7	28.7	26.9	75.8	76.9	
5	00	5/6/2012	24:00:00	26.6	26.9	27.6	28.5	26.7	75.6	76.7	77.8

	01	5/7/2012	1:00:00	26.5	26.8	27.5	28.4	26.4	77.3	78.5	79.6
	02	5/7/2012	2:00:00	26.5	26.7	27.5	28.4	26.2	78.1	79.4	80.5
	03	5/7/2012	3:00:00	26.3	26.5	27.3	28.2	26.0	77.8	79.1	80.2
	04	5/7/2012	4:00:00	26.3	26.5	27.3	28.2	25.8	79.8	81.2	82.3
	05	5/7/2012	5:00:00	26.4	26.7	27.4	28.3	25.9	80.6	82.1	83.2
	06	5/7/2012	6:00:00	26.3	26.6	27.4	28.3	25.6	81.3	82.8	83.9
	07	5/7/2012	7:00:00	26.3	26.5	27.4	28.3	25.9	80.6	82.0	82.7
	08	5/7/2012	8:00:00	26.8	27.2	27.8	28.6	27.9	72.4	73.3	75.4
	09	5/7/2012	9:00:00	27.8	28.5	29.1	29.6	30.8	60.7	60.8	60.8
	10	5/7/2012	10:00:00	28.7	29.4	30.0	30.5	32.0	55.9	55.6	56.4
	11	5/7/2012	11:00:00	29.2	30.0	30.6	31.0	33.2	51.4	50.8	51.7
	12	5/7/2012	12:00:00	29.7	30.4	31.0	31.5	34.2	49.9	49.2	49.2
	13	5/7/2012	13:00:00	29.7	30.4	31.0	31.7	34.1	49.4	48.6	51.4
	14	5/7/2012	14:00:00	29.9	30.5	31.1	31.8	34.6	48.1	47.3	48.7
	15	5/7/2012	15:00:00	29.7	30.3	30.9	31.6	34.2	48.0	47.2	48.6
	16	5/7/2012	16:00:00	29.6	30.1	30.8	31.6	33.8	49.7	49.0	50.5
	17	5/7/2012	17:00:00	29.2	29.5	30.1	31.1	32.6	54.5	54.1	55.4
	18	5/7/2012	18:00:00	28.7	28.9	29.6	30.7	31.1	58.7	58.6	59.9
	19	5/7/2012	19:00:00	27.9	28.0	28.8	30.0	28.5	67.7	68.2	71.0
	20	5/7/2012	20:00:00	27.5	27.5	28.3	29.4	27.5	72.2	73.0	75.1
	21	5/7/2012	21:00:00	27.2	27.3	28.1	29.1	27.2	73.9	74.9	77.0
	22	5/7/2012	22:00:00	27.0	27.2	28.0	29.0	27.0	76.2	77.4	79.5
	23	5/7/2012	23:00:00	26.9	27.1	27.8	28.8	26.7	77.3	78.5	79.6
6	24	5/7/2012	24:00:00	26.9	27.0	27.8	28.8	26.6	78.2	79.5	80.6
	01	5/8/2012	1:00:00	26.7	26.9	27.7	28.6	26.5	77.8	79.1	
	02	5/8/2012	2:00:00	26.6	26.8	27.6	28.5	26.4	77.7	79.0	
	03	5/8/2012	3:00:00	26.6	26.8	27.5	28.4	26.2	78.1	79.4	
	04	5/8/2012	4:00:00	26.5	26.7	27.4	28.3	26.1	78.5	79.8	
	05	5/8/2012	5:00:00	26.4	26.6	27.3	28.2	25.8	78.7	80.1	
	06	5/8/2012	6:00:00	26.2	26.4	27.2	28.0	25.7	78.7	80.1	
	07	5/8/2012	7:00:00	26.3	26.7	27.3	28.0	26.6	75.7	76.9	
	08	5/8/2012	8:00:00	27.2	27.8	28.2	28.9	29.2	65.8	66.2	
	09	5/8/2012	9:00:00	28.0	28.7	29.2	29.8	30.5	61.8	62.0	
	10	5/8/2012	10:00:00	28.9	29.7	30.3	30.7	32.1	56.4	56.2	
	11	5/8/2012	11:00:00	29.7	30.5	31.0	31.5	33.6	52.6	52.1	
	12	5/8/2012	12:00:00	30.0	30.6	31.3	32.1	33.9	52.0	51.4	
	13	5/8/2012	13:00:00	30.2	30.8	31.4	32.4	34.5	50.8	50.2	
	14	5/8/2012	14:00:00	30.4	31.0	31.6	32.6	34.7	50.4	49.7	
	15	5/8/2012	15:00:00	30.3	30.8	31.3	32.5	34.3	52.4	51.9	
	16	5/8/2012	16:00:00	30.1	30.6	31.1	32.3	33.5	54.3	53.9	
	17	5/8/2012	17:00:00	29.7	30.1	30.6	31.8	33.0	55.3	55.0	
	18	5/8/2012	18:00:00	28.9	29.2	29.7	31.0	31.4	60.6	60.6	
	19	5/8/2012	19:00:00	28.2	28.3	29.0	30.4	28.7	71.3	72.2	
	20	5/8/2012	20:00:00	27.8	27.9	28.6	29.9	27.8	75.1	76.2	
	21	5/8/2012	21:00:00	27.5	27.6	28.3	29.6	27.4	77.3	78.6	
	22	5/8/2012	22:00:00	27.4	27.5	28.2	29.4	27.3	78.7	80.1	
	23	5/8/2012	23:00:00	27.2	27.4	28.0	29.1	27.1	78.1	79.4	
7	00	5/8/2012	24:00:00	27.2	27.4	28.0	29.0	27.1	79.3	80.7	
9	00	5/10/2012	24:00:00	27.0	27.1	27.9	29.0	26.5	77.9	79.2	
	01	5/11/2012	1:00:00	26.9	27.0	27.8	28.8	26.5	78.9	80.2	

	02	5/11/2012	2:00:00	26.9	27.1	27.8	28.8	26.5	79.5	80.9	
	03	5/11/2012	3:00:00	26.8	27.0	27.7	28.6	26.5	79.4	80.8	
	04	5/11/2012	4:00:00	26.7	27.0	27.6	28.4	26.5	77.7	79.0	
	05	5/11/2012	5:00:00	26.7	27.0	27.5	28.3	26.6	78.4	79.7	
	06	5/11/2012	6:00:00	26.7	27.0	27.5	28.3	26.6	78.5	79.8	
	07	5/11/2012	7:00:00	26.7	27.2	27.6	28.3	27.0	75.6	76.8	
	08	5/11/2012	8:00:00	27.2	27.7	28.1	28.8	28.3	72.2	73.0	
	09	5/11/2012	9:00:00	28.1	28.8	29.3	29.8	30.3	63.9	64.2	
	10	5/11/2012	10:00:00	29.1	29.8	30.3	30.7	31.7	58.5	58.4	
	11	5/11/2012	11:00:00	29.8	30.5	31.0	31.6	32.8	54.9	54.5	
	12	5/11/2012	12:00:00	29.9	30.6	31.0	32.0	33.2	54.3	53.9	
	13	5/11/2012	13:00:00	30.4	31.0	31.5	32.5	34.0	52.1	51.6	
	14	5/11/2012	14:00:00	30.4	30.9	31.4	32.5	34.2	52.2	51.7	
	15	5/11/2012	15:00:00	30.4	31.0	31.5	32.5	34.4	51.5	50.9	
	16	5/11/2012	16:00:00	30.0	30.4	30.8	32.0	32.3	58.4	58.3	
	17	5/11/2012	17:00:00	29.5	29.9	30.3	31.4	32.1	58.6	58.5	
	18	5/11/2012	18:00:00	29.0	29.3	29.7	31.0	30.8	63.6	63.9	
	19	5/11/2012	19:00:00	28.4	28.5	29.2	30.5	28.9	70.4	71.2	
	20	5/11/2012	20:00:00	27.9	28.1	28.8	29.9	28.1	71.7	72.6	
	21	5/11/2012	21:00:00	27.6	27.8	28.4	29.5	27.5	70.9	71.7	
	22	5/11/2012	22:00:00	27.3	27.5	28.1	29.2	27.3	72.5	73.4	
	23	5/11/2012	23:00:00	27.2	27.4	28.1	29.0	27.2	74.4	75.5	
10	00	5/11/2012	24:00:00	27.3	27.5	28.1	29.0	27.2	75.9	77.0	
	01	5/12/2012	1:00:00	27.2	27.5	28.1	29.0	27.2	77.1	78.3	
	02	5/12/2012	2:00:00	27.1	27.4	28.0	28.9	27.0	77.8	79.1	
	03	5/12/2012	3:00:00	27.0	27.3	27.9	28.9	26.8	78.6	80.0	
	04	5/12/2012	4:00:00	27.1	27.4	27.9	28.8	27.0	79.3	80.7	
	05	5/12/2012	5:00:00	27.1	27.3	28.0	28.8	27.0	80.4	81.9	
	06	5/12/2012	6:00:00	27.1	27.4	28.0	28.8	27.1	81.1	82.6	
	07	5/12/2012	7:00:00	27.4	27.8	28.3	29.1	27.6	80.0	81.5	
	08	5/12/2012	8:00:00	27.6	28.1	28.5	29.2	28.7	74.1	75.1	
	09	5/12/2012	9:00:00	28.7	29.4	29.8	30.4	30.8	66.1	66.6	
	10	5/12/2012	10:00:00	29.0	29.7	30.1	30.8	31.3	63.2	63.5	
	11	5/12/2012	11:00:00	28.7	29.3	29.7	30.6	30.8	64.8	65.2	
	12	5/12/2012	12:00:00	29.8	30.4	30.9	31.9	32.5	61.4	61.5	
	13	5/12/2012	13:00:00	29.3	29.7	30.2	31.5	31.1	66.1	66.6	
	14	5/12/2012	14:00:00	29.6	30.1	30.6	31.8	31.8	63.5	63.8	
	15	5/12/2012	15:00:00	30.0	30.6	31.1	32.1	33.0	59.1	59.1	
	16	5/12/2012	16:00:00	30.1	30.6	31.1	32.1	33.1	59.4	59.4	
	17	5/12/2012	17:00:00	28.6	28.4	29.4	30.9	28.0	84.3	86.0	
	18	5/12/2012	18:00:00	28.3	28.5	29.2	30.6	28.1	81.5	83.1	
	19	5/12/2012	19:00:00	27.8	27.8	28.6	30.0	27.7	81.6	83.2	
	20	5/12/2012	20:00:00	27.6	27.7	28.4	29.7	27.3	82.2	83.8	
	21	5/12/2012	21:00:00	27.5	27.7	28.4	29.5	27.2	82.7	84.4	
	22	5/12/2012	22:00:00	27.3	27.6	28.2	29.3	27.2	82.6	84.2	
	23	5/12/2012	23:00:00	27.2	27.5	28.1	29.2	27.1	82.2	83.8	
11	00	5/12/2012	24:00:00	27.1	27.4	28.0	29.0	27.0	81.3	82.9	

Timline				CH 4	CH 5	CH 6	CH 7	CH 14	CH 13		
Day	Hour	dd.mm.yy	hh:mm:ss	t_eff	t_in2	t_in3	t_in4	t_ext	R.H. measured	**R.H. ext.**	**R.H. indoor (estimate)**
1	00	5/14/2012	24:00:00	24.5	24.8	27.2	31.2	22.1	91.9	93.9	
	01	5/15/2012	1:00:00	24.5	24.7	26.2	30.2	21.8	92.6	94.6	
	02	5/15/2012	2:00:00	24.0	24.2	25.4	29.5	21.3	93.1	95.2	
	03	5/15/2012	3:00:00	23.5	23.7	24.8	28.9	20.9	93.7	95.8	
	04	5/15/2012	4:00:00	23.3	23.5	24.4	28.4	20.7	94.3	96.5	
	05	5/15/2012	5:00:00	23.4	23.7	24.5	28.4	21.5	94.4	96.6	
	06	5/15/2012	6:00:00	23.1	23.3	24.2	28.3	20.8	94.7	96.8	
	07	5/15/2012	7:00:00	23.4	23.6	24.4	29.2	22.2	93.2	95.3	
	08	5/15/2012	8:00:00	24.0	24.4	25.4	30.2	24.6	81.6	82.9	
	09	5/15/2012	9:00:00	24.8	25.2	26.0	30.9	26.8	72.4	73.1	
	10	5/15/2012	10:00:00	26.5	27.1	27.6	31.4	30.2	59.7	59.6	
	11	5/15/2012	11:00:00	28.2	28.9	29.9	32.7	32.4	53.4	52.9	
	12	5/15/2012	12:00:00	29.2	29.9	31.5	33.5	33.1	51.3	50.6	
	13	5/15/2012	13:00:00	30.2	30.9	32.7	34.4	34.6	46.0	45.0	
	14	5/15/2012	14:00:00	30.7	31.5	33.1	34.6	34.5	46.2	45.2	
	15	5/15/2012	15:00:00	28.9	29.3	30.4	31.5	29.5	64.8	64.9	
	16	5/15/2012	16:00:00	27.4	27.7	28.8	30.2	25.3	88.3	90.1	
	17	5/15/2012	17:00:00	25.0	25.4	26.4	27.9	23.0	95.0	97.3	
	18	5/15/2012	18:00:00	24.5	24.8	26.3	28.0	23.3	95.8	98.1	
	19	5/15/2012	19:00:00	24.7	25.0	26.4	28.0	23.5	96.1	98.3	
	20	5/15/2012	20:00:00	24.7	25.1	26.5	28.0	23.0	96.5	98.8	
	21	5/15/2012	21:00:00	25.1	25.5	27.5	28.7	22.8	96.7	99.0	
	22	5/15/2012	22:00:00	24.9	25.4	27.0	28.3	22.7	96.9	99.2	
	23	5/15/2012	23:00:00	24.4	24.7	26.4	27.7	22.5	97.0	99.4	
2	00	5/15/2012	24:00:00	24.6	25.0	26.0	27.4	22.7	97.1	99.5	100.0
	01	5/16/2012	1:00:00	24.5	25.0	25.8	27.3	22.7	97.2	99.6	100.0
	02	5/16/2012	2:00:00	24.5	25.0	25.7	27.2	22.7	97.3	99.7	100.0
	03	5/16/2012	3:00:00	24.4	24.9	25.5	27.1	22.6	97.4	99.7	100.0
	04	5/16/2012	4:00:00	24.2	24.7	25.2	26.9	22.3	97.5	99.9	100.0
	05	5/16/2012	5:00:00	24.0	24.5	25.0	26.6	22.0	97.7	100.0	100.0
	06	5/16/2012	6:00:00	23.8	24.3	24.8	26.4	21.9	97.9	100.0	100.0
	07	5/16/2012	7:00:00	23.4	23.7	25.0	26.5	22.1	98.2	100.0	100.0
	08	5/16/2012	8:00:00	23.6	23.8	25.2	26.8	23.1	98.2	100.0	100.0
	09	5/16/2012	9:00:00	24.8	25.2	26.2	27.7	25.8	98.0	99.8	100.0
	10	5/16/2012	10:00:00	25.7	26.3	27.0	28.4	28.3	77.0	78.0	81.8
	11	5/16/2012	11:00:00	26.6	27.3	28.3	29.6	30.6	65.0	65.2	68.8
	12	5/16/2012	12:00:00	27.8	28.6	29.6	30.3	32.9	55.6	55.2	80.0
	13	5/16/2012	13:00:00	28.6	29.5	30.9	31.3	33.9	51.2	50.5	65.0
	14	5/16/2012	14:00:00	29.6	30.4	32.0	32.2	34.7	50.0	49.3	57.4
	15	5/16/2012	15:00:00	29.9	30.8	31.9	31.9	34.9	45.5	44.5	52.4
	16	5/16/2012	16:00:00	29.4	30.0	31.0	31.1	31.9	60.3	60.2	68.5
	17	5/16/2012	17:00:00	27.8	28.4	29.2	29.6	28.2	73.3	74.1	81.8
	18	5/16/2012	18:00:00	26.5	27.0	28.0	28.7	25.8	82.7	84.1	100.0
	19	5/16/2012	19:00:00	25.8	26.1	27.6	28.5	24.2	91.4	93.4	100.0
	20	5/16/2012	20:00:00	25.6	25.9	27.9	28.9	23.7	94.2	96.4	100.0
	21	5/16/2012	21:00:00	25.4	25.8	27.7	28.5	23.5	95.2	97.5	100.0
	22	5/16/2012	22:00:00	25.5	25.9	27.6	28.5	23.1	95.8	98.1	100.0

	23	5/16/2012	23:00:00	25.2	25.5	27.2	28.0	22.9	96.2	98.5	100.0
3	24	5/16/2012	24:00:00	24.9	25.1	26.5	27.3	22.8	96.6	98.9	100.0
	01	5/17/2012	1:00:00	24.5	24.7	26.1	26.9	22.6	96.8	99.1	
	02	5/17/2012	2:00:00	24.3	24.7	25.9	26.6	22.5	97.0	99.3	
	03	5/17/2012	3:00:00	24.4	24.8	25.7	26.5	22.6	97.1	99.4	
	04	5/17/2012	4:00:00	24.3	24.7	25.6	26.3	22.4	97.2	99.6	
	05	5/17/2012	5:00:00	24.1	24.5	25.4	26.2	22.3	97.3	99.7	
	06	5/17/2012	6:00:00	24.0	24.4	25.1	26.0	22.1	97.4	99.8	
	07	5/17/2012	7:00:00	23.9	24.2	25.1	25.9	22.4	97.5	99.9	
	08	5/17/2012	8:00:00	24.0	24.3	25.5	26.3	23.8	97.2	99.6	
	09	5/17/2012	9:00:00	24.8	25.3	26.2	26.9	26.1	88.2	89.9	
	10	5/17/2012	10:00:00	25.8	26.4	27.0	27.6	28.9	70.3	70.9	
	11	5/17/2012	11:00:00	26.5	27.2	27.7	28.3	30.5	63.3	63.4	
	12	5/17/2012	12:00:00	27.7	28.4	29.2	29.6	32.6	56.1	55.7	
	13	5/17/2012	13:00:00	28.0	28.7	30.0	30.2	31.0	63.3	63.4	
	14	5/17/2012	14:00:00	26.9	27.5	29.0	29.2	27.2	80.1	81.3	
	15	5/17/2012	15:00:00	27.4	28.2	29.0	29.3	30.3	64.6	64.8	
	16	5/17/2012	16:00:00	27.9	28.7	29.4	29.6	31.5	57.9	57.7	
	17	5/17/2012	17:00:00	27.7	28.4	29.1	29.4	30.0	64.0	64.2	
	18	5/17/2012	18:00:00	27.3	28.0	28.7	29.2	28.5	70.1	70.7	
	19	5/17/2012	19:00:00	26.5	27.1	28.3	29.2	26.3	80.6	81.8	
	20	5/17/2012	20:00:00	25.8	26.4	27.7	28.5	24.8	87.4	89.1	
	21	5/17/2012	21:00:00	25.2	25.8	27.1	28.0	23.9	91.2	93.1	
	22	5/17/2012	22:00:00	25.3	26.0	26.9	27.7	23.8	92.3	94.3	
	23	5/17/2012	23:00:00	25.1	25.7	26.9	27.7	23.6	92.5	94.6	
4	00	5/17/2012	24:00:00	25.0	25.6	26.5	27.4	23.6	92.9	95.0	
	01	5/18/2012	1:00:00	25.0	25.4	26.2	27.1	23.5	93.1	95.2	
	02	5/18/2012	2:00:00	24.7	25.2	25.9	26.8	23.1	94.1	96.2	
	03	5/18/2012	3:00:00	24.6	25.1	25.7	26.7	23.2	94.6	96.8	
	04	5/18/2012	4:00:00	24.5	25.1	25.6	26.6	23.2	94.8	97.0	
	05	5/18/2012	5:00:00	24.4	24.9	25.5	26.4	23.1	94.7	96.9	
	06	5/18/2012	6:00:00	24.3	24.8	25.4	26.4	22.9	94.9	97.1	
	07	5/18/2012	7:00:00	24.3	24.8	25.3	26.4	23.2	95.2	97.4	
	08	5/18/2012	8:00:00	24.4	24.8	25.9	26.7	24.9	88.1	89.9	
	09	5/18/2012	9:00:00	25.0	25.6	26.4	27.1	27.2	75.8	76.8	
	10	5/18/2012	10:00:00	26.5	27.2	28.1	28.6	30.6	60.7	60.7	
	11	5/18/2012	11:00:00	27.8	28.5	29.4	29.7	32.7	53.8	53.3	
	12	5/18/2012	12:00:00	29.0	29.7	31.0	31.0	33.8	50.5	49.8	
	13	5/18/2012	13:00:00	27.7	28.1	29.9	30.0	27.3	80.0	81.2	
	14	5/18/2012	14:00:00	27.4	27.9	29.4	29.8	27.5	82.1	83.5	
	15	5/18/2012	15:00:00	27.1	27.8	28.7	29.2	29.0	70.8	71.4	
	16	5/18/2012	16:00:00	27.3	28.0	28.7	29.1	28.7	72.8	73.5	
	17	5/18/2012	17:00:00	27.0	27.6	28.3	28.8	28.7	72.0	72.7	
	18	5/18/2012	18:00:00	26.7	27.4	28.3	28.7	29.1	68.4	68.8	
	19	5/18/2012	19:00:00	26.1	26.6	27.9	28.3	26.2	80.5	81.8	
	20	5/18/2012	20:00:00	25.3	25.7	27.6	28.3	24.2	88.8	90.6	
	21	5/18/2012	21:00:00	24.7	25.3	27.3	28.2	23.5	92.6	94.6	
	22	5/18/2012	22:00:00	24.9	25.4	26.8	27.7	23.2	93.4	95.5	
	23	5/18/2012	23:00:00	24.8	25.3	26.6	27.3	23.0	94.4	96.5	
5	00	5/18/2012	24:00:00	24.7	25.3	26.3	27.0	22.8	94.9	97.1	

	01	5/19/2012	1:00:00	24.5	25.1	25.8	26.5	22.6	95.3	97.5	
	02	5/19/2012	2:00:00	24.3	24.9	25.5	26.3	22.4	95.6	97.9	
	03	5/19/2012	3:00:00	24.1	24.7	25.2	26.1	22.3	96.0	98.2	
	04	5/19/2012	4:00:00	24.0	24.6	25.1	26.0	22.2	96.2	98.5	
	05	5/19/2012	5:00:00	23.8	24.4	24.8	25.7	21.9	96.5	98.9	
	06	5/19/2012	6:00:00	23.8	24.4	24.8	25.7	22.0	96.6	99.0	
	07	5/19/2012	7:00:00	23.8	24.4	24.9	25.7	22.6	96.7	99.0	
	08	5/19/2012	8:00:00	24.6	25.2	26.2	26.9	25.5	90.5	92.4	
	09	5/19/2012	9:00:00	26.1	26.7	27.5	28.3	30.3	65.7	65.9	
	10	5/19/2012	10:00:00	27.2	27.8	28.8	29.6	30.7	63.3	63.4	
	11	5/19/2012	11:00:00	29.0	29.6	31.0	31.3	33.8	52.7	52.1	
	12	5/19/2012	12:00:00	29.1	29.7	31.4	31.4	31.8	60.4	60.3	
	13	5/19/2012	13:00:00	28.3	28.8	30.7	30.7	29.3	71.2	71.8	
	14	5/19/2012	14:00:00	29.4	30.1	31.8	31.5	31.9	60.3	60.2	
	15	5/19/2012	15:00:00	29.4	30.2	31.3	31.2	31.9	59.9	59.8	
	16	5/19/2012	16:00:00	29.3	30.1	31.0	30.9	32.1	57.7	57.5	
	17	5/19/2012	17:00:00	29.2	29.9	30.6	30.6	31.6	59.6	59.4	
	18	5/19/2012	18:00:00	28.4	29.1	29.7	29.8	30.2	64.6	64.8	
	19	5/19/2012	19:00:00	27.3	27.8	28.6	28.8	27.1	75.1	76.0	
	20	5/19/2012	20:00:00	26.5	26.9	28.4	28.8	25.6	82.0	83.4	
	21	5/19/2012	21:00:00	25.9	26.2	28.1	28.5	24.6	87.0	88.6	
	22	5/19/2012	22:00:00	25.4	25.8	27.4	27.9	24.1	89.5	91.3	
	23	5/19/2012	23:00:00	25.4	25.9	27.1	27.5	24.3	88.7	90.5	
6	00	5/19/2012	24:00:00	25.6	26.2	26.9	27.2	24.3	89.0	90.8	
	01	5/20/2012	1:00:00	25.5	26.1	26.7	27.1	24.2	89.6	91.5	
	02	5/20/2012	2:00:00	25.3	25.9	26.4	26.8	23.8	91.8	93.8	
	03	5/20/2012	3:00:00	25.2	25.8	26.2	26.7	23.9	92.5	94.6	
	04	5/20/2012	4:00:00	25.2	25.8	26.2	26.8	24.1	92.5	94.6	
	05	5/20/2012	5:00:00	25.2	25.7	26.1	26.7	24.0	93.7	95.8	
	06	5/20/2012	6:00:00	25.1	25.7	26.1	26.7	24.0	94.1	96.2	
	07	5/20/2012	7:00:00	25.1	25.7	26.1	26.6	24.1	94.2	96.4	
	08	5/20/2012	8:00:00	25.4	25.9	26.6	27.1	25.5	90.2	92.1	
	09	5/20/2012	9:00:00	26.4	27.0	27.7	27.9	28.1	78.1	79.2	
	10	5/20/2012	10:00:00	27.1	27.7	28.2	28.4	29.2	74.5	75.4	
	11	5/20/2012	11:00:00	27.5	28.2	28.5	28.7	29.8	71.7	72.3	
	12	5/20/2012	12:00:00	27.4	27.9	28.5	28.6	28.2	80.1	81.3	
	13	5/20/2012	13:00:00	27.1	27.6	28.3	28.4	27.1	85.2	86.8	
	14	5/20/2012	14:00:00	25.6	26.0	27.6	27.7	24.2	94.0	96.1	
	15	5/20/2012	15:00:00	26.0	26.6	28.0	28.4	25.1	95.2	97.5	
	16	5/20/2012	16:00:00	26.2	26.7	27.9	28.2	25.7	94.7	96.9	
	17	5/20/2012	17:00:00	26.2	26.7	27.7	28.1	26.1	91.1	93.0	
	18	5/20/2012	18:00:00	26.0	26.6	27.4	27.9	25.8	91.1	93.0	
	19	5/20/2012	19:00:00	25.3	25.9	27.0	27.5	23.8	94.7	96.9	
	20	5/20/2012	20:00:00	25.0	25.8	26.7	27.2	23.1	96.1	98.4	
	21	5/20/2012	21:00:00	24.9	25.6	26.8	27.2	23.1	96.7	99.0	
	22	5/20/2012	22:00:00	25.0	25.7	26.5	27.1	23.1	96.9	99.2	
	23	5/20/2012	23:00:00	24.9	25.5	26.2	26.8	23.1	97.1	99.5	
7	00	5/20/2012	24:00:00	24.7	25.2	26.1	26.6	23.0	97.2	99.6	
	01	5/21/2012	1:00:00	24.6	25.2	25.8	26.3	22.9	97.3	99.7	
	02	5/21/2012	2:00:00	24.4	25.2	25.5	26.0	22.7	97.5	99.8	

	03	5/21/2012	3:00:00	24.2	25.0	25.3	25.9	22.7	97.6	100.0	
	04	5/21/2012	4:00:00	24.1	24.8	25.1	25.6	22.8	97.6	100.0	
	05	5/21/2012	5:00:00	24.0	24.7	25.0	25.5	22.6	97.7	100.0	
	06	5/21/2012	6:00:00	23.8	24.5	24.8	25.4	22.3	97.9	100.0	
	07	5/21/2012	7:00:00	23.8	24.5	24.8	25.4	22.8	97.9	100.0	
	08	5/21/2012	8:00:00	24.5	25.0	25.8	26.3	24.3	97.7	100.0	
	09	5/21/2012	9:00:00	25.1	25.7	26.5	26.8	25.8	93.7	95.4	
	10	5/21/2012	10:00:00	25.4	26.0	26.9	27.4	26.8	82.8	84.2	
	11	5/21/2012	11:00:00	26.2	26.8	28.0	28.4	28.3	76.4	77.3	
	12	5/21/2012	12:00:00	26.6	27.2	28.5	28.8	28.9	73.5	74.2	
	13	5/21/2012	13:00:00	27.5	28.2	29.7	29.6	30.7	66.0	66.3	
	14	5/21/2012	14:00:00	27.7	28.4	29.3	29.3	30.8	65.0	65.3	
	15	5/21/2012	15:00:00	28.1	28.8	29.6	29.6	31.5	62.4	62.4	
	16	5/21/2012	16:00:00	28.4	29.1	29.6	29.7	31.9	61.5	61.4	
	17	5/21/2012	17:00:00	27.7	28.1	29.0	29.2	28.4	80.8	82.1	
	18	5/21/2012	18:00:00	27.1	27.8	28.6	29.0	28.1	81.3	82.6	
	19	5/21/2012	19:00:00	26.3	27.0	27.8	28.2	26.0	86.0	87.6	
	20	5/21/2012	20:00:00	25.8	26.6	27.9	28.5	24.3	92.7	94.8	
	21	5/21/2012	21:00:00	25.9	26.7	27.8	28.3	23.9	94.1	96.3	
	22	5/21/2012	22:00:00	25.9	26.6	28.0	28.3	23.8	94.5	96.7	
	23	5/21/2012	23:00:00	25.8	26.5	27.6	27.9	23.5	95.3	97.5	
8	00	5/21/2012	24:00:00	25.4	25.9	27.2	27.4	23.2	96.0	98.2	
	01	5/22/2012	1:00:00	24.7	25.2	26.5	26.9	23.0	96.5	98.8	
	02	5/22/2012	2:00:00	24.6	25.1	26.1	26.5	22.7	97.0	99.4	
	03	5/22/2012	3:00:00	24.3	24.7	25.6	26.0	22.1	97.2	99.6	
	04	5/22/2012	4:00:00	23.9	24.3	25.2	25.5	21.7	97.5	99.9	
	05	5/22/2012	5:00:00	23.5	23.8	24.7	25.1	21.3	97.9	100.0	
	06	5/22/2012	6:00:00	23.4	23.8	24.4	24.9	21.2	98.2	100.0	
	07	5/22/2012	7:00:00	23.6	24.1	24.6	25.1	22.2	97.9	100.0	
	08	5/22/2012	8:00:00	24.4	24.9	25.7	26.1	24.6	95.8	98.1	
	09	5/22/2012	9:00:00	25.6	26.3	27.1	27.6	28.8	72.3	73.0	
	10	5/22/2012	10:00:00	26.8	27.4	28.0	28.3	30.5	62.7	62.8	
	11	5/22/2012	11:00:00	28.2	28.8	29.4	29.6	32.6	54.7	54.2	
	12	5/22/2012	12:00:00	28.5	29.1	29.7	29.8	32.1	57.0	56.6	
	13	5/22/2012	13:00:00	29.2	29.9	31.6	31.4	32.2	57.5	57.3	
	14	5/22/2012	14:00:00	30.0	30.8	32.6	31.9	33.1	52.8	52.2	
	15	5/22/2012	15:00:00	30.5	31.3	32.6	32.1	33.4	51.9	51.3	
	16	5/22/2012	16:00:00	30.2	31.0	31.9	31.7	33.1	52.0	51.3	
	17	5/22/2012	17:00:00	29.4	30.1	30.9	30.8	31.3	56.9	56.5	
	18	5/22/2012	18:00:00	28.3	28.9	29.5	29.6	29.6	63.5	63.6	
	19	5/22/2012	19:00:00	27.3	27.9	28.7	28.8	27.4	72.3	73.0	
	20	5/22/2012	20:00:00	26.7	27.0	28.6	29.1	26.0	80.3	81.6	
	21	5/22/2012	21:00:00	26.0	26.2	28.9	29.5	24.8	87.8	89.5	
	22	5/22/2012	22:00:00	25.8	26.2	28.5	28.8	24.0	91.4	93.3	
	23	5/22/2012	23:00:00	25.6	26.1	27.7	27.9	23.3	93.3	95.4	
9	00	5/22/2012	24:00:00	25.4	25.8	27.1	27.3	22.7	94.5	96.7	
	01	5/23/2012	1:00:00	24.9	25.4	26.4	26.5	22.2	95.5	97.7	
	02	5/23/2012	2:00:00	24.4	24.9	25.8	25.9	21.7	96.7	99.1	
	03	5/23/2012	3:00:00	23.9	24.3	25.1	25.3	21.1	97.0	99.4	
	04	5/23/2012	4:00:00	23.4	23.7	24.6	24.8	20.7	97.9	100.0	

	05	5/23/2012	5:00:00	23.0	23.3	24.1	24.4	20.4	98.2	100.0	
	06	5/23/2012	6:00:00	22.7	23.0	23.8	24.0	20.1	98.4	100.0	
	07	5/23/2012	7:00:00	22.7	23.0	23.7	24.0	20.8	98.4	100.0	
	08	5/23/2012	8:00:00	23.9	24.2	25.2	25.5	24.6	93.3	95.4	
	09	5/23/2012	9:00:00	25.7	26.3	27.2	27.6	29.4	68.8	69.3	
	10	5/23/2012	10:00:00	27.3	27.9	28.8	29.4	31.8	58.5	58.3	
	11	5/23/2012	11:00:00	28.3	28.9	30.8	31.5	32.9	54.2	53.7	
	12	5/23/2012	12:00:00	29.2	30.0	31.8	31.9	34.4	48.9	48.0	
	13	5/23/2012	13:00:00	30.5	31.3	32.9	32.9	35.5	45.4	44.3	
	14	5/23/2012	14:00:00	31.5	32.5	34.4	33.9	36.8	41.5	40.1	
	15	5/23/2012	15:00:00	30.9	31.7	33.2	33.0	34.6	49.5	48.7	
	16	5/23/2012	16:00:00	31.2	32.0	33.1	32.9	34.6	48.9	48.0	
	17	5/23/2012	17:00:00	30.8	31.6	32.6	32.4	34.2	49.6	48.7	
	18	5/23/2012	18:00:00	29.5	30.1	30.9	31.0	30.8	59.8	59.7	
	19	5/23/2012	19:00:00	28.2	28.5	29.8	30.2	28.0	68.9	69.3	
	20	5/23/2012	20:00:00	27.2	27.4	29.8	30.2	26.0	77.7	78.7	
	21	5/23/2012	21:00:00	26.4	26.6	29.2	29.7	24.5	85.3	86.8	
	22	5/23/2012	22:00:00	25.5	25.5	27.8	28.3	23.3	90.5	92.4	
	23	5/23/2012	23:00:00	25.0	25.1	26.9	27.3	22.6	92.9	95.0	
10	00	5/23/2012	24:00:00	24.6	24.8	26.0	26.3	21.8	94.1	96.2	

Mahoney-Table for Decision Support

@ F. W. Grimme

Input values

0. Place Indication

Location	Chetumal, Mexico
Longitude	88.3° West
Latitude	18.5° North
Altitude	7 m

Highest monthly mean temperature		Yearly high mean temperature	
31.0	°C →	**26.0**	°C
21.0	°C →	10.0	°C
Lowest monthly mean temperatur		Yearly low mean temperature	

1. Air Temperature °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean maximum	27	27	28	29	31	31	30	30	30	29	28	27
Monthly mean minimum	21	22	23	24	26	26	26	26	25	24	23	22
Monthly mean deviation	6	5	5	5	5	5	4	4	5	5	5	5

2. Relative Humidity %

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean maximum 12 o´clock	95	95	93	91	91	92	92	94	96	96	96	96
Monthly mean minimum 6 o´clock	72	71	68	68	69	76	75	74	75	76	74	74
Monthly mean	83.5	83	80.5	79.5	80	84	83.5	84	85.5	86	85	85
Humidity group	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**

Group 1	< 30 %	Group 3	50 < 70 %
Group 2	30 < 50 %	Group 4	> 70 %

Rainfall mm	64	36	28	38	128	199	146	142	205	168	91	68

Total Rainfall in the Year **1312.50 mm**

Wind, prevailing	E	E	E	E	E	E	E	E	E	E	E	E
Wind, secondary												

in accordance: yearly mean temperature **26.0** °C

4. Comfort Limits

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean max.	**27**	**27**	**28**	**29**	**31**	**31**	**30**	**30**	**30**	**29**	**28**	**27**
Humidity group	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Day Comfort upper value	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**
Day Comfort lower value	**22**	**22**	**22**	**22**	**22**	**22**	**22**	**22**	**22**	**22**	**22**	**22**
Monthly mean minimum	**21**	**22**	**23**	**24**	**26**	**26**	**26**	**26**	**25**	**24**	**23**	**22**
Night comfort upper value	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**	**21**
Night comfort lower value	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**
Therm. Stress at day	**Neutr.**	**neutr.**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**	**neutr.**
at night	**neutr.**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**	**hot**

Day upper Comfort Limits		yearly mean temperature (see above)		
		>20	>15<20	<15
Humidity group	1	34	32	30
	2	31	30	27
	3	29	28	26
	4	27	25	24

Night upper Comfort Limits	yearly mean temperature (see above)		
	> 20	>15<20	<15
	25	23	21
	24	22	20
	23	21	19
	21	20	18

Day lower Comfort Limits		>20	>15<20	<15
Humidity group	1	26	23	21
	2	25	22	20
	3	23	21	19
	4	22	20	18

Night lower Comfort Limits	>20	>15<20	<15
	17	14	12
	17	14	12
	17	14	12
	17	14	12

5. Indicators

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Humid F1			**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**		**9**
F2	**+**	**+**										**+**	**3**
F3									+				**1**
Arid T1													**0**
T2													**0**
T3													**0**

Indicators for general measures		Thermal Stress		Rainfall	Humidity Group	Mon. Mean Range	für den Standort empfohlene Lösungen
		Day	Night				
Humid	F1a	Hot			4		Air movement important
	F1b	Hot			2, 3	<10°C	Air movement important
	F2	Neutr.			4		Air movement important
	F3			> 200 mm			Rain protection necessary
Arid	T1				1, 2, 3	>10°C	Thermal capacity nescessary
	T2a		Hot		1, 2		Outdoor sleeping desirable
	T2b	Hot	Neutr.		1, 2	>10°C	Outdoor sleeping desirable
	T3	Cold					Protection from cold

Recommendations

after total indicator number

						for the site
Layout	T1	0-10			Orientation N-S/long axis O-W	+
	T1	11, 12	T3	5-12	Orientation N-S/long axis O-W	
	T1	11, 12	T3	0-4	Compact courtyard house	
Spacing	F1	11, 12			Open spacing for ventilation; building distance > 5* building hight	
	F2	2-10			Open spacing for ventilation; but protection from hot and cold wind	+
	F3	0-1			Compact village layout, because ventilation is unimportant	+

Air Movement	F1	3-12			Single-row rooms , continuous measures for air movement	+
	F2	1-2	T1	0-5	Single-row rooms , continuous measures for air movement	
	F2	1-2	T1	6-12	Double-row rooms, temporary measures for air movement	
	F3	0	F2	2-12	Double-row rooms, temporary measures for air movement	
	F3	0	F2	0-1	No ventilation requirement	
Openings	T1	0-1	T3	0	Large openings, 40 - 80 %	+
	T1	0-1	T3	11-12	Very small openings, 10 - 20 %	
	T1	2-5			Medium openings, 25 - 40 %	
	T1	6-10			Small openings, 15 - 25 %	
	T1	11-12	T3	0-3	Very small openings, 10 - 20 %	
	T1	11-12	T3	4-12	Medium openings, 25 - 40 %	
	F1	3-12			N/S-windows in wind direction at body hight	+
	F1	1-2	T1	0-5	N/S-windows in wind direction at body hight	
	F1	1-2	T1	6-12	as above, openings also in inner walls	
	F1	0	F2	2-12	as above, openings also in inner walls	
	T3	0-2			Windwos: exclude direct sun from windows	+
	F3	2-12			Windows: provide rain protection	
Walls	T1	0-2			Light walls, short time-lag	+
	T1	3-12			Heavy external and internal walls with >8 h time-lag	

Roofs	**T1**	**0-5**			**Light, but well insulated**	**+**
	T1	**6-12**			**Heavy roof with >8 h time-lag**	
Outdoor sleeping	**T2**	**2-12**			**Place for outdoor sleeping required**	
Rain Protection	**F3**	**3-12**			**Protection from heavy rain necessary**	

after Mahoney; modified after Koenigberger/Ingersoll et al.

Source of climate data

Temperature in °C - Windspeed in km/h - Relative Humidity R.H. In % . Source: http://www.myforecast.com/bin/climate.m?city=70040&metric=true

Averaged Data	Jan	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
High Temp	27	27	28	29	31	31	30	30	30	29	28	27
Low Temp	21	22	23	24	26	26	26	26	25	24	23	22
MeanTemp	24	24	26	27	28	28	28	28	28	27	26	24
DewPoint	21	21	22	23	24	24	24	24	24	24	22	22
Windspeed	13	11	13	15	15	15	15	13	13	11	11	13
WindDirect.	E	E	E	E	E	E	E	E	E	E	E	E
Morn. R.H.	95	95	93	91	91	92	92	94	96	96	96	96
Afnoon R.H.	72	71	68	68	69	76	75	74	75	76	74	74
Averaged R.H.	64	36	27.5	38.3	128.1	199.1	145.7	142.4	204.6	167.9	90.9	68
Rainfall *												

* *Rainfall in mm.* Source: Comision Nacional del Agua - *National Water Comission*

Water vapor exhalation by sedentary man

Still air, humidity 30..70%

Normal clothing and light activity **Assumption for sleeping persons:** **half** of the given values!

Air temp. (°C)	Vapor exhaust (g/h)
20	38
22	47
24	58
26	70
28	85
30	98
32	116

Source: Recknagel/Sprenger*; Honghten et al., "Heat and moisture losses from men at work, ASHVE Research Report Nr. 930"

*Recknagel, H.; Sprenger, E.; Schramek, E.-R. (1999), "Taschenbuch für Heizung und Klimatechnik", Oldenbourg Verlag München **- p.49**

Assumption for Cooking

Vapor exhaust (g/h)	Cooking time (h)	Released water content (g)
200	0.25	50

Temperature (°C)	Density dry air (kg/m3)
25	1.184
30	1.164

Chetumal, day 8 Room volume (m3) 70.2 **Estudio Martha**

Hour	t_in4 (°C)	R.H. exterior recalibr. (%)	moisture p. Pers (g)	air mass (kg)	Occupancy (Persons)	Activity	Add.	Occup. & activity	Additional moisture mass (g)	Additional moisture (g/kg air)	Sat. Vapor press. (mbar)	moisture cont. (g/kg) max.	gross	net
0	29.7	67.7	98	81.78	0			0	0	0.0	41.9	27.2	18.4	18.4
1	29.6	68.9	98	81.81	0			0	0	0.0	41.6	27.0	18.6	18.6
2	29.6	69.9	98	81.81	0			0	0	0.0	41.6	27.0	18.9	18.9
3	29.6	70.6	98	81.81	0			0	0	0.0	41.6	27.0	19.1	19.1
4	29.5	72.2	98	81.85	0			0	0	0.0	41.3	26.8	19.3	19.3
5	29.5	78.1	98	81.85	0			0	0	0.0	41.2	26.8	20.9	20.9
6	29.2	85.0	98	81.92	0			0	0	0.0	40.7	26.4	22.4	22.4
7	28.9	86.6	98	82.01	0			0	0	0.0	39.9	25.9	22.4	22.4
8	29.1	71.7	98	81.97	0.5	Sedentary		0.5	49	0.6	40.2	26.1	18.7	19.3
9	29.7	64.8	98	81.79	1	Sedentary		1	98	1.2	41.7	27.1	17.6	18.8
10	30.0	57.0	116	81.71	1	Sedentary		1	116	1.4	42.5	27.6	15.7	17.2
11	30.6	52.8	116	81.55	1	Sedentary		1	116	1.4	43.8	28.5	15.1	16.5
12	31.1	49.4	116	81.40	0.5	Sedentary		0.5	58	0.7	45.2	29.5	14.5	15.3
13	31.4	49.0	116	81.32	0			0	0	0.0	45.9	30.0	14.7	14.7
14	31.7	48.1	116	81.23	1.5	Sedentary		1.5	174	2.1	46.8	30.6	14.7	16.9
15	31.9	49.7	116	81.18	1.5	Sedentary		1.5	174	2.1	47.3	30.9	15.4	17.5
16	32.1	48.4	116	81.13	0.5	Sedentary		0.5	58	0.7	47.8	31.2	15.1	15.8
17	32.2	50.0	116	81.10	0.5	Sedentary		0.5	58	0.7	48.1	31.4	15.7	16.4
18	31.9	52.1	116	81.17	0			0	0	0.0	47.4	31.0	16.1	16.1
19	31.4	58.9	116	81.33	1.5	Sedentary		1.5	174	2.1	45.9	29.9	17.6	19.8
20	31.7	65.6	116	81.24	2	Sedentary		2	232	2.9	46.7	30.5	20.0	22.9
21	31.8	69.7	116	81.20	2	Sedentary		2	232	2.9	47.1	30.7	21.4	24.3
22	31.6	71.9	116	81.25	1.5	Sedentary		1.5	174	2.1	46.6	30.4	21.9	24.0
23	31.4	75.0	116	81.32	1	Sedentary		1	116	1.4	46.0	30.0	22.5	23.9
24	31.2	77.0	116	81.37	0			0	0	0.0	45.5	29.6	22.8	22.8

Comfort diagram by Szokolay

50.0	28.5	**20.8**	24.5	Design state 1 (low humidity)
65.0	27.5	**22.6**	25.0	Design state 2 (moderate humidity)
78.0	23.1	**20.4**	22.0	Design state 3 (high humidity)

							Comfort requirements					**Klimarechner** measured	
R.H. interior ((%)	t_in4 (Martha) °C	t_wb °C	t_eff,meas. °C	v_air (m/s)	switch	t_eff,comf	v_a,min (m/s)	v_vent (m/s)	t_exceed. °C	t_eff,net °C	t_in4–t_eff (K)	PMV	PPD (%)
67.7	29.7	25.0	27.4	0.1	24.4	24.4	**2.5**	2.4		24.4	2.3	2.2	83.1
68.9	29.6	25.1	27.2	0.1	24.1	24.1	**3.0**	2.9		24.1	2.4	2.1	82.9
69.9	29.6	25.2	27.0	0.1	23.9	23.9	**3.0**	2.9		23.9	2.6	2.2	83.2
70.6	29.6	25.3	26.9	0.3	23.7	23.7	**3.5**	3.2		23.7	2.8	2.2	83.7
72.2	29.5	25.5	26.7	0.5	23.3	23.3	**4.0**	3.5		23.3	2.8	2.2	83.9
78.1	29.5	26.4	26.6	1.0	22.0	22.0	**7.0**	6.0	0.5	22.5	2.9	2.2	85.8
85.0	29.2	27.2	26.3	1.3	22.0	22.0	**7.0**	5.7	0.5	22.5	3.0	2.2	86.0
86.6	28.9	27.1	25.9	1.5	22.0	22.0	**7.0**	5.5	0	22.0	3.0	2.2	84.7
74.0	29.1	25.4	25.9	0.8	22.9	22.9	**4.5**	3.7		22.9	3.2	2.1	82.5
69.2	29.7	25.2	26.2	0.5	24.0	24.0	**3.0**	2.5		24.0	3.5	2.2	84.2
62.1	30.0	24.3	26.5	0.1	switch	24.9	**1.8**	1.7		24.9	3.5	2.1	83.0
57.8	30.6	24.0	27.2	0.1	switch	24.8	**2.0**	1.9		24.8	3.3	2.2	84.5
51.8	31.1	23.3	27.9	0.1	switch	24.6	**2.0**	1.9		24.6	3.2	2.2	85.1
49.0	31.4	23.0	28.4	0.1	switch	24.5	**2.5**	2.4		24.5	3.0	2.2	85.6
55.1	31.7	24.4	28.8	0.1	switch	24.7	**3.0**	2.9		24.7	2.9	2.3	88.3
56.7	31.9	24.9	29.0	0.1	switch	24.7	**4.0**	3.9		24.7	2.8	2.3	89.4
50.7	32.1	23.9	29.3	0.1	switch	24.5	**4.0**	3.9		24.5	2.8	2.3	88.7
52.3	32.2	24.3	29.4	0.1	switch	24.6	**4.0**	3.9		24.6	2.8	2.3	89.4
52.1	31.9	24.0	29.2	0.1	switch	24.6	**3.5**	3.4		24.6	2.8	2.3	88.3
66.0	31.4	26.2	28.6	0.1	24.8	24.8	**4.0**	3.9		24.8	2.7	2.3	89.7
75.0	31.7	28.0	28.9	0.3	22.7	22.7	**7.0**	6.7	1.6	24.3	2.8	2.5	93.0
79.0	31.8	28.7	29.1	0.4	22.0	22.0	**7.0**	6.6	2.8	24.8	2.7	2.5	94.1
79.0	31.6	28.5	29.0	0.4	22.0	22.0	**7.0**	6.6	2.5	24.5	2.6	2.5	93.6
79.8	31.4	28.5	28.8	0.8	22.0	22.0	**7.0**	6.2	2.7	24.7	2.6	2.5	93.8
77.0	31.2	27.8	28.7	0.3	22.2	22.2	**7.0**	6.7	1.6	23.8	2.5	2.4	91.7

bypass for limited if-function

Mahahual, day 5 Room volume (m3) 367.5

Hour	t_in4 (°C)	R.H. exterior recalibr. (%)	moisture p. Pers (g)	air mass (kg)	Occupancy (Persons)	Activity	Add.	Occup. & activity	Additional moisture mass (g)	(g/kg air)	Sat. Vapor press. (mbar)	moisture cont. (g/kg) max.	gross	net
0	26.9	76.7	85	432.30	2.5	Sleep		1.25	106	0.2	35.4	22.8	17.5	17.8
1	26.8	78.5	85	432.47	2.5	Sleep		1.25	106	0.2	35.2	22.7	17.8	18.1
2	26.7	79.4	85	432.62	2.5	Sleep		1.25	106	0.2	35.0	22.5	17.9	18.2
3	26.5	79.1	85	432.85	2.5	Sleep		1.25	106	0.2	34.6	22.3	17.7	17.9
4	26.5	81.2	85	432.85	2.5	Sleep		1.25	106	0.2	34.7	22.3	18.1	18.4
5	26.7	82.1	85	432.58	2.5	Sleep		1.25	106	0.2	35.0	22.6	18.5	18.8
6	26.6	82.8	85	432.77	2.5	Sleep		1.25	106	0.2	34.8	22.4	18.6	18.8
7	26.5	82.0	85	432.81	1.5	Sleep		0.75	64	0.1	34.7	22.4	18.4	18.5
8	27.2	73.3	85	431.79	2.5	Sedentary		2.5	213	0.5	36.2	23.3	17.1	17.6
9	28.5	60.8	98	429.98	0			0	0	0.0	38.9	25.2	15.3	15.3
10	29.4	55.6	98	428.55	1	Sedentary		1	98	0.2	41.1	26.7	14.8	15.1
11	30.0	50.8	98	427.73	1	Sedentary		1	98	0.2	42.4	27.6	14.0	14.3
12	30.4	49.2	116	427.19	0			0	0	0.0	43.3	28.2	13.9	13.9
13	30.4	48.6	116	427.16	2.5	Sedentary	Cooking	2.5	340	0.8	43.4	28.2	13.7	14.5
14	30.5	47.3	116	426.98	1.5	Sedentary		1.5	174	0.4	43.7	28.4	13.4	13.8
15	30.3	47.2	116	427.30	1.5	Sedentary		1.5	174	0.4	43.2	28.1	13.3	13.7
16	30.1	49.0	116	427.62	1.5	Sedentary		1.5	174	0.4	42.6	27.7	13.6	14.0
17	29.5	54.1	98	428.46	1.5	Sedentary		1.5	147	0.3	41.2	26.8	14.5	14.8
18	28.9	58.6	98	429.31	1.5	Sedentary		1.5	147	0.3	39.9	25.9	15.1	15.5
19	28.0	68.2	98	430.65	2.5	Sedentary	Cooking	2.5	295	0.7	37.8	24.5	16.7	17.4
20	27.5	73.0	85	431.36	2.5	Sedentary		2.5	213	0.5	36.8	23.8	17.4	17.8
21	27.3	74.9	85	431.71	2.5	Sedentary		2.5	213	0.5	36.3	23.4	17.5	18.0
22	27.2	77.4	85	431.84	2.5	Sedentary		2.5	213	0.5	36.1	23.3	18.0	18.5
23	27.1	78.5	85	432.04	2.5	Sleep		1.25	106	0.2	35.8	23.1	18.1	18.4
24	27.0	79.5	85	432.17	2.5	Sleep		1.25	106	0.2	35.6	23.0	18.3	18.5

San Roman, day 2 Room volume (m3) 86.7

Hour	t_in4 (°C)	R.H. exterior recalibr. (%)	moisture p. Pers (g)	air mass (kg)	Occupancy (Persons)	Activity	Add.	Occup. & activity	Additional moisture mass (g)	(g/kg air)	Sat. Vapor press. (mbar)	moisture cont. (g/kg) max.	gross	net
0	25.0	99.5	70	102.61	2	Sleep		1	70	0.7	31.7	20.4	20.3	20.9
1	25.0	99.6	70	102.61	2	Sleep		1	70	0.7	31.7	20.3	20.3	20.9
2	25.0	99.7	70	102.62	2	Sleep		1	70	0.7	31.6	20.3	20.3	20.9
3	24.9	99.7	70	102.64	2	Sleep		1	70	0.7	31.5	20.2	20.2	20.9
4	24.7	99.9	70	102.72	2	Sleep		1	70	0.7	31.1	20.0	19.9	20.6
5	24.5	100.0	70	102.80	2	Sleep		1	70	0.7	30.7	19.7	19.7	20.4
6	24.3	100.0	70	102.86	2	Sleep		1	70	0.7	30.3	19.5	19.5	20.2
7	23.7	100.0	58	103.07	4	Sedentary		4	232	2.3	29.3	18.8	18.8	21.0
8	23.8	100.0	58	103.02	6	Sedentary		6	348	3.4	29.5	18.9	18.9	22.3
9	25.2	99.8	70	102.53	4	Sedentary		4	280	2.7	32.1	20.7	20.6	23.4
10	26.3	78.0	85	102.17	1	Sedentary		1	85	0.8	34.2	22.0	17.2	18.0
11	27.3	65.2	85	101.81	1	Sedentary		1	85	0.8	36.3	23.5	15.3	16.1
12	28.6	55.2	98	101.37	6	Sedentary	Cooking	6	638	6.3	39.1	25.3	14.0	20.3
13	29.5	50.5	98	101.06	4	Sedentary		4	392	3.9	41.2	26.7	13.5	17.4
14	30.4	49.3	116	100.75	2	Sedentary		2	232	2.3	43.4	28.2	13.9	16.2
15	30.8	44.5	116	100.62	2	Sedentary		2	232	2.3	44.4	28.9	12.8	15.1
16	30.0	60.2	116	100.87	2	Sedentary		2	232	2.3	42.5	27.6	16.6	18.9
17	28.4	74.1	98	101.43	2	Sedentary		2	196	1.9	38.7	25.1	18.6	20.5
18	27.0	84.1	85	101.93	6	Sedentary		6	510	5.0	35.6	23.0	19.3	24.3
19	26.1	93.4	85	102.22	8	Sedentary	Cooking	8	730	7.1	33.9	21.8	20.4	27.5
20	25.9	96.4	70	102.32	8	Sedentary		8	560	5.5	33.3	21.5	20.7	26.2
21	25.8	97.5	70	102.34	6	Sedentary		6	420	4.1	33.2	21.4	20.8	24.9
22	25.9	98.1	70	102.30	4	Sedentary		4	280	2.7	33.4	21.5	21.1	23.8
23	25.5	98.5	70	102.43	2	Sleep		1	70	0.7	32.7	21.0	20.7	21.4
24	25.1	98.9	70	102.58	2	Sleep		1	70	0.7	31.9	20.5	20.2	20.9

							Comfort requirements					Klima-rechner	
R.H. interior ((%)	t_in2 °C	t_wb °C	t_eff,meas. °C	v_air (m/s)	switch	t_eff,comf	v_a,min (m/s)	v_vent (m/s)	t_exceed. °C	t_eff,net °C	t_in4–t_eff (K)	PMV	PPD (%)
77.8	26.9	24.0	26.6	0.1	22.1	22.1	2.8	2.7		22.1	0.24	1.9	70.5
79.6	26.8	24.1	26.5	0.1	22.0	22.0	2.8	2.7		22.0	0.22	1.9	70.4
80.5	26.7	24.2	26.5	0.1	22.0	22.0	2.8	2.7		22.0	0.21	1.9	70.1
80.2	26.5	23.9	26.3	0.1	22.0	22.0	2.5	2.4		22.0	0.21	1.8	68.7
82.3	26.5	24.2	26.3	0.1	22.0	22.0	2.5	2.4		22.0	0.22	1.8	69.3
83.2	26.7	24.5	26.4	0.1	22.0	22.0	2.8	2.7		22.0	0.31	1.9	70.8
83.9	26.6	24.5	26.3	0.1	22.0	22.0	2.8	2.7		22.0	0.27	1.9	70.4
82.7	26.5	24.3	26.3	0.1	22.0	22.0	2.5	2.4		22.0	0.27	1.8	69.4
75.4	27.2	23.9	26.8	0.1	22.6	22.6	2.3	2.2		22.6	0.46	1.9	71.7
60.8	28.5	22.7	27.8	0.1	switch	24.9	0.5	0.4		24.9	0.63	2.0	74.9
56.4	29.4	22.7	28.7	0.1	switch	24.7	1.0	0.9		24.7	0.73	2.0	78.5
51.7	30.0	22.4	29.2	0.1	switch	24.6	1.3	1.2		24.6	0.74	2.1	80.1
49.2	30.4	22.2	29.7	0.1	switch	24.5	1.5	1.4		24.5	0.67	2.1	81.3
51.4	30.4	22.6	29.7	0.1	switch	24.5	1.5	1.4		24.5	0.65	2.1	81.9
48.7	30.5	22.2	29.9	0.1	switch	24.5	1.5	1.4		24.5	0.64	2.1	81.6
48.6	30.3	22.0	29.7	0.1	switch	24.5	1.3	1.2		24.5	0.56	2.1	80.6
50.5	30.1	22.2	29.6	0.1	switch	24.5	1.3	1.2		24.5	0.45	2.1	80.2
55.4	29.5	22.6	29.2	0.1	switch	24.7	1.0	0.9		24.7	0.29	2.0	78.7
59.9	28.9	22.9	28.7	0.1	switch	24.8	0.7	0.6		24.8	0.24	2.0	76.8
71.0	28.0	24.0	27.9	0.1	23.6	23.6	1.8	1.7		23.6	0.06	2.0	75.1
75.1	27.5	24.1	27.5	0.1	22.7	22.7	2.5	2.4		22.7	0.04	1.9	73.4
77.0	27.3	24.2	27.2	0.1	22.2	22.2	3.0	2.9		22.2	0.12	1.9	72.7
79.5	27.2	24.5	27.0	0.1	22.0	22.0	2.3	2.2		22.0	0.16	1.9	72.8
79.6	27.1	24.4	26.9	0.1	22.0	22.0	3.0	2.9		22.0	0.16	1.9	72.3
80.6	27.0	24.5	26.9	0.1	22.0	22.0	3.0	2.9		22.0	0.12	1.9	71.9

							Comfort requirements					Klima-rechner	
R.H. interior ((%)	t_in2 °C	t_wb °C	t_eff,meas. °C	v_air (m/s)	switch	t_eff,comf	v_a,min (m/s)	v_vent (m/s)	t_exceed. °C	t_eff,net °C	t_in4–t_eff (K)	PMV	PPD (%)
100.0	25.0	25.0	24.6	0.3	22.0	22.0	1.8	1.5		22.0	0.45	1.8	64.5
100.0	25.0	25.0	24.5	0.3	22.0	22.0	1.8	1.5		22.0	0.47	1.8	64.5
100.0	25.0	25.0	24.5	0.3	22.0	22.0	1.8	1.5		22.0	0.49	1.8	64.5
100.0	24.9	24.9	24.4	0.3	22.0	22.0	1.8	1.5		22.0	0.50	1.7	63.8
100.0	24.7	24.7	24.2	0.3	22.0	22.0	1.5	1.2		22.0	0.50	1.7	62.5
100.0	24.5	24.5	24.0	0.3	22.0	22.0	1.5	1.2		22.0	0.52	1.7	61.1
100.0	24.3	24.3	23.8	0.3	22.0	22.0	1.3	1.0		22.0	0.48	1.7	59.7
100.0	23.7	23.7	23.4	0.1	22.0	22.0	0.8	0.7		22.0	0.24	1.6	55.7
100.0	23.8	23.8	23.6	0.1	22.0	22.0	1.0	0.9		22.0	0.19	1.6	56.4
100.0	25.2	25.2	24.8	0.3	22.0	22.0	2.0	1.7		22.0	0.45	1.8	65.8
81.8	26.3	24.0	25.7	0.1	22.0	22.0	2.3	2.2		22.0	0.58	1.8	67.9
68.8	27.3	23.0	26.6	0.1	24.1	24.1	0.7	0.6		24.1	0.67	1.9	70.3
80.0	28.6	25.9	27.8	0.1	22.0	22.0	6.0	5.9		22.0	0.76	2.1	80.8
65.0	29.5	24.3	28.6	0.1	switch	25.0	1.3	1.2		25.0	0.92	2.1	81.4
57.4	30.4	23.8	29.6	0.1	switch	24.7	2.0	1.9		24.7	0.82	2.2	83.5
52.4	30.8	23.2	29.9	0.1	switch	24.6	2.0	1.9		24.6	0.85	2.2	84.0
68.5	30.0	25.4	29.4	0.1	24.2	24.2	3.0	2.9		24.2	0.64	2.2	84.6
81.8	28.4	25.9	27.8	0.1	22.0	22.0	6.0	5.9		22.0	0.60	2.1	80.2
100.0	27.0	27.0	26.5	0.3	22.0	22.0	4.3	4.0		22.0	0.43	2.0	76.8
100.0	26.1	26.1	25.8	0.3	22.0	22.0	3.0	2.7		22.0	0.29	1.9	70.9
100.0	25.9	25.9	25.6	0.3	22.0	22.0	3.0	2.7		22.0	0.28	1.8	69.5
100.0	25.8	25.8	25.4	0.3	22.0	22.0	2.7	2.4		22.0	0.37	1.8	68.8
100.0	25.9	25.9	25.5	0.3	22.0	22.0	3.0	2.7		22.0	0.39	1.8	69.5
100.0	25.5	25.5	25.2	0.3	22.0	22.0	2.3	2.0		22.0	0.34	1.8	66.7
100.0	25.1	25.1	24.9	0.1	22.0	22.0	1.8	1.7		22.0	0.20	1.7	63.8

Material	Cement		Mortar (cement)		Plaster		Plaster (fine)	
	Cemento (gris)		Cemento mortar		Polvo		Polvo fino	
Content of 1 unit (kg)	50		50					
Content of 1 unit (m3)							0.018	
Source, also see bottom	Dr. Bojorquez		Convention					
Tot. weight (kg)	**13700**		**650**					
Tot. volume (m3)					**39**		**1.0**	
Count-Functions	**Amount**	**Price**						

RELACION DE MATERIALES

Relation of Materials

OBRA: MV0106

PERIODO	FECHA	UNIDAD	CANTIDAD	DESCRIPCION	PROVEEDOR	P.U	IMPORTE	TOTAL	**Total**	**274**	**25507**	**13**	**754**	**39**	**8970**	**58**	**1740**
Period	*Date*	*Unit*	*Amount*	*Description*	*Distributor*	*Unit price*	*Cost*	*Total*		Bags		bags		m3		pouch	
1(19/25 FEB)	23-Feb-06	KG	3	CLAVO 2"	ISRAEL ESTRADA	14.00	42.00			0	0	0	0	0	0	0	0
		KG	1	CLAVO 4"	ISRAEL ESTRADA	14.00	14.00			0	0	0	0	0	0	0	0
		KG	3	CLAVO	ISRAEL ESTRADA	14.00	42.00	98.00		0	0	0	0	0	0	0	0
1(19/25 FEB)	23-Feb-06									0	0	0	0	0	0	0	0
	24-Feb-06	BULTO	10	CEMENTO	ISRAEL ESTRADA	92.00	920.00			10	920	0	0	0	0	0	0
		M3	6	POLVO	ISRAEL ESTRADA	230.00	1380.00			0	0	0	0	6	1380	0	0
		BULTO	10	CAL	ISRAEL ESTRADA	35.00	350.00	2650.00		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0
	23-Feb-06		2	LAMINA DE CARTON ASFALTAD/	FERRETERIA CONT.	200.00		400.00		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0
	23-Feb-06	PZA		MADERA DE MONTE	SIN NOMBRE			480.00		0	0	0	0	0	0	0	0
								3628.00		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0
2(26 FEB/4 MAR)										0	0	0	0	0	0	0	0
	27-Feb-06	M3	3	GRAVA	ISRAEL ESTRADA	230.00	690.00			0	0	0	0	0	0	0	0
		PZA	12	ARMEX CASTILLO	ISRAEL ESTRADA	73.00	876.00			0	0	0	0	0	0	0	0
		PZA	10	ARMEX CADENA	ISRAEL ESTRADA	73.00	730.00			0	0	0	0	0	0	0	0
		PZA	8	VARILLAS 3/8	ISRAEL ESTRADA	55.00	440.00			0	0	0	0	0	0	0	0
		PZA	2	VARILLAS 1/2	ISRAEL ESTRADA	95.00	190.00			0	0	0	0	0	0	0	0
		PZA	6	VARILLAS 1/4	ISRAEL ESTRADA	95.00	570.00			0	0	0	0	0	0	0	0
		KG	25	ALAMBRON	ISRAEL ESTRADA	10.00	250.00			0	0	0	0	0	0	0	0
		KG	10	ALAMBRE	ISRAEL ESTRADA	14.00	140.00	3886.00		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0
	27-Feb-06	BULTOS	4	CEMENTO	ISRAEL ESTRADA	93.00	372.00			4	372	0	0	0	0	0	0
		BULTOS	3	CALFIN	ISRAEL ESTRADA	35.00	105.00	477.00		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0
	27-Feb-06	PZA	3	BISAGRAS 3*3	FERRETERIA WILBURZ	9.00	27.00			0	0	0	0	0	0	0	0
		PZA	1	CANDADO	FERRETERIA WILBURZ	40.00	40.00	67.00		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0
	28-Feb-06	ML	6	TUBO SANITARIO	CORP. MATS	39.06	234.36	234.36		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0
	2-Mar-06	VIAJES	2	PIEDRA PARA CIMENTACION		800.00	1600.00	1600.00		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0
	3-Mar-06	PZA	40	BLOCKS	ISRAEL ESTRADA	5.70	228.00	228.00		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0
	3-Mar-06	M3	3	POLVO	ISRAEL ESTRADA	230.00	690.00			0	0	0	0	3	690	0	0
		PZA	300	BLOCKS	ISRAEL ESTRADA	5.70	1710.00	2400.00		0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0

Sources

1) http://www.construrama.com/content/public/sitio/comprom

Chalk (lime)		**Steel rod**		**Steel rod**		**Steel rod**		**Stone foundation**		**Concrete blocks**		**Cement-based coating**		**Vent blocks**		**Tie-beams**		**Tie-beams**		**Tie-beams**		**Tie-beams**		**Tie-beams**		**Wire netting**	
Cal(fin)		varilla(s) 3/8		varilla(s) 1/2		varilla(s) 1/4		Piedra para cimentacion		block(s)		Uniblock gris		Bovedillas		Vigueta 1.7		Vigueta 3.2		Vigueta 5.0		Vigueta 5.3		Vigueta 6.5		Malla	
40		0.557 /m		0.996 /m		0.251 /m		3		0.016		20 1649 kg/m3		14.2 0.0168		9.8 /m 0.0054 /m		9.8 /m 0.0054 /m		9.8 /m 0.0054 /m		9.8 /m 0.0054 /m		9.8 /m 0.0054 /m		0.14 /m	
Dr. Bojorquez		see 1)						Dr. Bojorquez				see 2)		Dr. Bojorquez		Grupo Joben		Grupo Joben		Grupo Joben		Grupo Joben		Grupo Joben		see 3)	
2160		**368**		**131**		**18.1**		**6**		**54**		**700** **424**		**10735** **12.7**		**100** **0.055**		**62.7** **0.035**		**343** **0.19**		**727** **0.40**		**446** **0.25**		**22.6**	
54	**1920**	**55**	**3645**	**11**	**1265**	**6**	**570**	**2**	**1600**	**3390**	**20238**	**35**	**3500**	**756**	**10584**	**6**	**479**	**2**	**301**	**7**	**1645**	**14**	**3487**	**7**	**2139**	**160**	**2240**
Bags		Pieces		Pieces		Pieces		Cargo		Pieces		Bags		Pieces		Pieces		Pieces		Pieces		Pieces		Pieces		m	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	8	440	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	6	570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	2	1600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	40	228	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	300	1710	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

iso/cat_prd_20_73_39.htm

2) http://www.cemix.com/CEMIX_Adeblok.aspx

3) http://portal.infonavit.org.mx/lic26/04FICHASTECNICAS/004_Malla_electrosoldada.pdf

Casa Brunner Valdes, Mahahual

			Dimensions (m)											Alternative scenario		
		Volume (m3)	Thickness	Height (from upper earth level)	Total perimeter (as per area)	Radius 1	Circumference - for annex only half	Length 1	Length 2	Openings: (circular) width	Openings: height (average)	Openings: particular amount		Volume (m3)	Thickness	total perimeter
Limestone	wall - main area	**35.1**	0.4	2.5	35.1	4.0	25.1	5.0	8.0	0.9	1.8	3	4.9	17.6	0.2	
	wall - annex	**22.6**	0.4	4.5	12.6	2.5	7.85	2.5	2.2	1.75	1.5	5	13.1	11.3	0.2	
	floor, ceiling and roof - annex	**17.6**	0.2		28.4	surface area	14.1	0.2	border height	1.5	1.85	1	2.8	16.6	0.2	26.7
	inner wall	**4.5**	0.4	2.25				5.0		1.5	0.9	1	1.4	2.3	0.2	
	foundation	**28.7**			97.4	surface area		0.24	0.84	1.8	0.9	3	4.9	26.7	0.2	93.8
		-27.0											27.0	-27.0		
	SUM Limestone:	**81.6**		surface area	surface area - annex									**47.5**		
Floor	**SUM Cement layer:**	**2.2**	0.02	83.4	28.4											
	SUM Compressed sand:	**21.7**	0.26	83.4				0.12	0.4							
				curved surface area - endings		Radius 1	Inclined roof length	Horizontal roof length	Inclined roof length -annex							
Roof	**Zacate***	**11.1**	0.1	79.3		4.5	6.36	5.0	3.68	*** 2 layers of 5 cm on top of each other**						
	Wood sticks				Length		Number of beams									
		2.9	0.12	0.0113	6.4		40	inclined plane								
		0.2	0.12	0.0113	3.0		6	cross beams								
		0.1	0.12	0.0113	5.0		1	roof top								
		0.2	0.03	0.0007	351			circumferential, for braiding: every 40 cm								
		0.03	0.06	0.0028	9.4	3.0		upper circumferential (carrier beam)								
	SUM Wood sticks:	**3.4**			Perimeter	Diameter										

Casa Poot Balam, San Roman

			Dimensions (m)										
		Volume (m3)	Thickness	Height (from earth)	Perimeter	Door width (incl. frame)	Length 1	Length 2	Length 3	Length 4	Length 5		
Floor layer	Cement layer	**2.0**	0.07				7.1	4					
Ramp	Cement layer	**0.4**	0.07				2.5	1.5	1.4	1.7	1.2		
	SUM Cement:	**2.4**										**Alternative scenario: wall**	
									Length 3 (annex)	Length 4 (annex)	Height from earth	Volume (m3)	Thickness
	Natural stone	**0.7**	0.15	0.35									
Foundation	Natural stone	**9.6**		0.33			7.1	4.0	1.2	1.4	0.15		0.15
Wall	Natural stone	**3.0**	0.25	0.65	21.2	1.1	7.4	4.3					
	SUM Natural stone:	**13.3**											
	SUM Paperboard:	**0.056**	0.005	1.85			3.0	3.0					
	Wood	**2.1**	0.05	1.85	21.2							**6.2**	
			Diameter	Cross sect. (m2)									
	Wood beam (wall finish)	**0.26**	0.12	0.0113	23.4								
	Wood beam (wall finish)	**0.07**	0.06	0.0028	23.4								
					(incl.) length		Number of beams						
Roof	Wood (carrier beams)	**0.14**	0.06	0.0028	4.0		6	on each small plane					
		0.46	0.06	0.0028	4.5		18	on each large plane					
		0.02	0.06	0.0028	1.9		4	annex					
		0.29	0.12	0.0113	4.3		6	cross beams					
		0.07	0.12	0.0113	6.6		1	roof top					
		0.08	0.03	0.0007	117	circumferential, for braiding: every 40 cm							
	SUM Wood pegs:	**3.5**										**Alternative scenario: roof**	
		one side	Thickness	Area of inclined roof (m2)	Inclined roof length	Horizontal roof length (lower)	Horizontal roof length (roof top)	Horizontal roof length (annex)	Add. inclined roof length (annex)			Volume (m3)	Thickness
	large plane (east+west)	**5.9**	0.1	29.7	4.48	8.7	4.55						0.05
	small plane (north+south)	**2.5**	0.1	11.7	4.0	5.85		2.18	0.94				
	SUM Fan palm leafs:	**8.5**										**4.2**	
			Thickness		Height	Width		Perimeter					
	Doors	0.0648	0.02		1.8	0.9							
	Window	0.0078	0.02		0.6	0.65							
	Door frame	0.018	0.02			0.1		4.5					
	Window frame	0.005	0.02			0.1		2.5					
	SUM Wood hardboard:	**0.096**											

	Averaged values			*Source*		Data		*Source*	Data	*Source*	Data	*Source*				*Source*			
Materials	Density (kg/m3)	Embodied energy (MJ/kg)	Carbon (kg CO2/kg)	***ICE, UK*****	Density (kg/m3)	Carbon (kg CO2/kg)	Embodied energy (MJ/kg)	***Baird, New Zealand******	Embodied energy (MJ/kg)	***Milne, Australia*******	Embodied energy (MJ/kg)	***Grimme, various***	Embodied energy (MJ/kg)	Carbon (kg CO2/kg)	Density (kg/m3)	***Häkkinen ********	Embodied energy (MJ/kg)	Carbon (kg CO2/kg)	Density (kg/m3)
Cement (Portland)	1523	5.7	0.475		1860	0.95	5.5		7.8		5.6	*Cement (Portld.)*	4.0	0	1200				1510
Cement mortar	1820	1.7	0.208	*1:3*	1820	0.208	1.33		2.0										
Limestone powder	1090	1.0	0.091														1	0.091	1090
Stone foundation	2090	1.2	0.09	*limestone*	2180	0.09	1.5					*est.: limestone*	0.871		2000				
Cement-based coating	#DIV/0!	15.3	1.28			1.28	15.3												
Steel rod	7835	28.7	1.8835		7800	1.95	22.3	*general*	35					*1.817*	*7870*				
Steel wire	#DIV/0!	19.4	3			3	36	*wire rod*	12.5			*wired steel*	*9.6*						
Chalk / lime	800	4.2	0.39044			0.78	5.30					*Chalk (lime)*	*3.06*	*0.00088*	*800*				
Concrete block (bricks)	1450	1.0	0.063996		1450	0.073	0.67		0.97		1.5	*Concrete bricks*	0.95	0.055					
Vent blocks	1450	1.0	0.073		1450	0.073	0.67		0.94		1.5								
Tie-beams	1450	1.0	0.073		1450	0.073	0.67		0.94		1.5								
Compressed sand	2240	0.05	0.0051		2240	0.0051	0.0081		0.1										
Limestone	2090	1.2	0.09		2180	0.09	1.5					*lime-sand brick*	*0.87*		*2000*				
Local wood, hardwood 1)	679	3.7	0.72	*sawn hardwood*		0.72	10.0	*air-dried softwood*	0.5	*air-dried sawn hardwood*	0.5								
Local wood, recollected	500	0.46																	
Fan palm leafs 2)	100	0.46																	
Zacate	100	0.46		*straw bale*	100		0.91	*baled straw*	0.24	*baled straw*	0.24								
Paperboard	480	23.9	1.29		480	1.29	24.8	*recycled*	23.4	*recycled*	23.4								
Limestone bricks	2180	0.85			2180		0.85												
Adobe blocks, bitumen stabilized	1170	0.5							0.29	*stabilized earth*	0.7								1170
Ferrocement	1300	1.0	0.15		1300	0.15	1												

1)average value, Boj, 2010:*

2) straw was assumed.

Jabín	904
Tsalam	655
Caboa	477

***http://www.greenspec.co.uk/embodied-ene ***http://www.ipenz.org.nz/ipenz/publications/transactions/Transactions97/civil/7baird.PDF*

***www.naturalstonespecialist.com/documents/ICEV2.0-Jan2011.xls ****http://www.yourhome.gov.au/technical/pubs/fs52.pdf*

**Bojórquez, I.; Castillo, S.; Moen, M. (2010), Propiedades Térmicas of tropical woods used in residential buildings, SNES2010-ABC-008*

******http://virtual.vtt.fi/virtual/proj6/environ/env_woodclad.pdf*

****** http://www.powderandbulk.com/resources/bulk_density/material_bulk_density_chart_l.htm

Case study		**Casa Macías Villalobos**	**Building mass (tons)**	**Embodied energy (GJ)**	**Emissions (tons CO_2)**	**Casa Brunner Valdes**	**Building mass (tons)**	**Embodied energy (GJ)**	**Emissions (tons CO_2)**	**Casa Poot Balam**	**Building mass (tons)**
Total numbers		Total numbers:	**165**	**266**	**20**	Total numbers:	**226**	**226**	**17**	Total numbers:	**35**
		Specific:	**per person:**			Specific:	**per person:**			Specific:	
per person	Occupants	4 Persons	**41**	**67**	**5.1**	3 Persons	**75**	**75**	**5.7**	4 Persons	**8.7**
			per living area:				**per living area:**				
per living space	Living space	128 m^2	**1.3**	**2.1**	**0.2**	105 m^2	**2.1**	**2.1**	**0.2**	30 m^2	**1.2**

Material	**Density (kg/m3)**	**Mass-spec. embodied energy (MJ/kg)**	**Mass-specific carbon emission (kg CO2/kg)**	**Volume (m3)**	**Mass (kg)**	**Embodied energy (MJ)**	**Carbon em. (kg CO2)**	**Volume (m3)**	**Mass (kg)**	**Embodied energy (MJ)**	**Carbon em. (kg CO2)**	**Volume (m3)**	**Mass (kg)**
Cement	1523	5.7	0.48	*9.0*	13700	78590	6508	2.2	*3405*	19534	1617	2.4	*3645*
Cement mortar	1820	1.7	0.21		650	1082	135			0	0		
Limestone powder	1090	1.0	0.09	40	*43648*	43648	3972			0	0		
Stone foundation	2090	1.2	0.09	6.0	*12540*	14866	1129			0	0		
Cement-based coating		15.3	1.28	424.5	700	10710	896			0	0		
Steel rod	7835	28.7	1.88		517	14817	974			0	0		
Steel wire		19.4	3.00		23	437	68			0	0		
Lime	800	4.2	0.39	*2.7*	2160	9029	843			0	0		
Concrete blocks	1450	1.0	0.06	54.2	*78648*	80342	5033			0	0		
Vent blocks	1450	1.0	0.07	12.7	10735	11129	784			0	0		
Tie-beams	1450	1.0	0.07	0.93	1679	1740	123			0	0		
Compressed sand	2240	0.054	0.005			0	0	21.7	*48552*	2624	248		
Limestone	2090	1.2	0.09			0	0	81.6	*170465*	202086	15342	13.3	*27712*
Local wood, treated	500	3.7	0.72			0	0			0	0	0.096	*48*
Local wood, pegs	679	0.5				0	0	3.4	*2315.8*	1073	0	3.5	*2342*
Fan palm leafs	100	0.46				0	0			0	0	8.5	*848*
Zacate	100	0.46				0	0	11.1	*1111.3*	515	0		
Paperboard	480	23.9	1.29			0	0			0	0	0.06	*27*
					165000	**266391**	**20464**	**120**	**225849**	**225832**	**17207**	**28**	**34622**
Alternative scenarios													
Limestone blocks	2180	0.85		54.2	118243	100507	0	*reduced volume, 15 cm wall thickness*				14.6	*31935*
Adobe blocks, bitumen stabilized	1170	0.5		54.2	63461	31413	0	47.5	55575	27510		14.6	*17139*
Concrete blocks	1450	1.0	0.06									14.6	*21241*
Ferrocement (reinforced concrete)	1300	1	0.15									4.2	*5513*

Embodied energy (GJ)	Emissions (tons CO$_2$)
56	4.3
per person:	
14	1.1
per living area:	
1.9	0.1

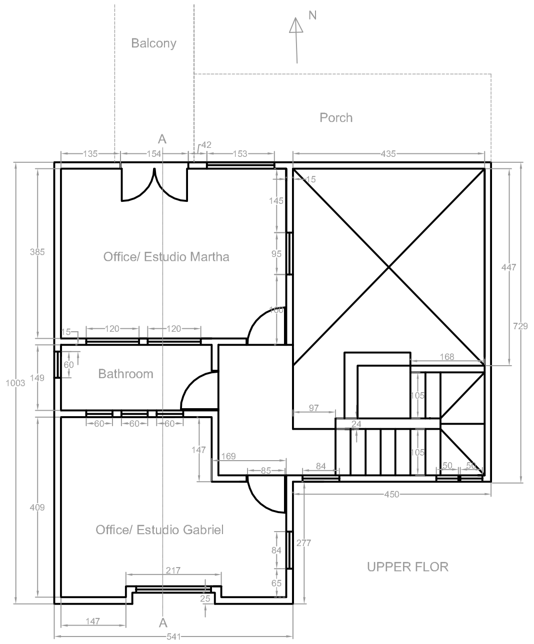
Embodied energy (MJ)	Carbon em. (kg CO2)
20908	1731
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
32853	2494
175	34
1085	0
393	0
0	0
636	34
56050	**4294**
27144	0
8484	0
21699	1359
5513	827

Casa Macias Villalobos	Volume	Mass	Embodied energy	Carbon emissions
Material	**Volume (m3)**	**Mass (to)**	**Embodied energy (GJ)**	**CO$_2$ emissions**
Cement	9	14	79	7
Cement mortar	0	0.7	1.1	0.1
Limestone powder	40	44	44	4.0
Stone foundation	6	13	15	1.1
Cement-based coating	424	0.7	11	0.9
Steel rod		0.5	15	1.0
Steel wire		0.0	0.4	0.1
Lime	3	2.2	9.0	0.8
Concrete blocks*	54	79	80	5
Vent blocks	13	11	11	0.8
Tie-beams	1	1.7	1.7	0.1
total		**165**	**266**	**20**
Alternative: new wall material				
Adobe blocks	54	63	31	0
	100%	81%	39%	
	0%	-19%	-61%	
total		150	217	

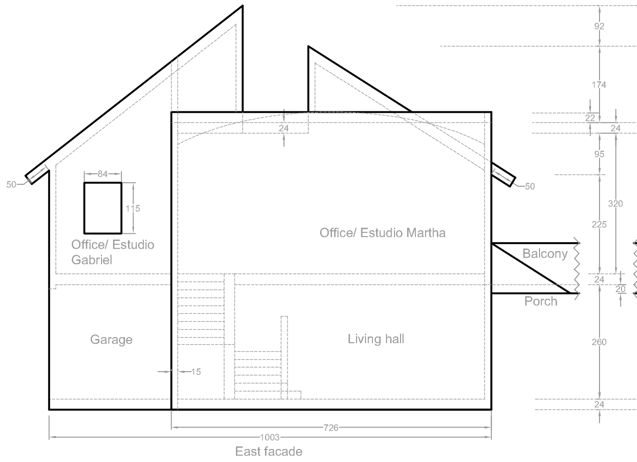
Casa Brunner Valdes	Volume	Mass	Embodied energy	Carbon emissions
Material	**Volume (m3)**	**Mass (to)**	**Embodied energy (GJ)**	**CO$_2$ emissions**
Cement	2.2	3.4	20	1.6
Compressed sand	22	49	2.6	0.2
Limestone	82	170	202	15
Wood piles	3.4	2.3	1.1	0
Zacate	11	1.1	0.5	0
total	**120**	**226**	**226**	**17**
Alternative 1: reduction of original wall thickness				
Limestone, 20 cm*	48	99	118	8.9
	58%	58%		
		32%	37%	37%
total	86	155	141	11
Alternative 2: new wall material (20 cm)				
Adobe blocks	48	56	28	0
	100%	56%	23%	
		28%	64%	
			77%	
total	86	111	51	

Casa Poot Balam	Volume	Mass	Embodied energy	Carbon emissions
Material	**Volume (m3)**	**Mass (to)**	**Embodied energy (GJ)**	**CO$_2$ emissions**
Cement	2.4	3.6	21	1.7
Limestone	13.3	28	33	2.5
Hardboard (wood)	0.1	0.05	0.2	0.03
Wood piles	3.5	2.3	1.1	0
Fan palm leafs	8.5	0.8	0.4	0
Paperboard	0.1	0.03	0.6	0.03
total	**28**	**35**	**56**	**4**
alternative 1: new wall material, thickness 15 cm				
Limestone	15	32	27	
total	39	64	82	
Adobe blocks	15	17	8.5	
total	39	49	63	
Concrete blocks*	15	21	22	1
total	39	54	77	6
alternative 2: new roof material, thickness 5 cm				
Ferrocement	4.2	5.5	5.5	0.8
total	23	39	61	5

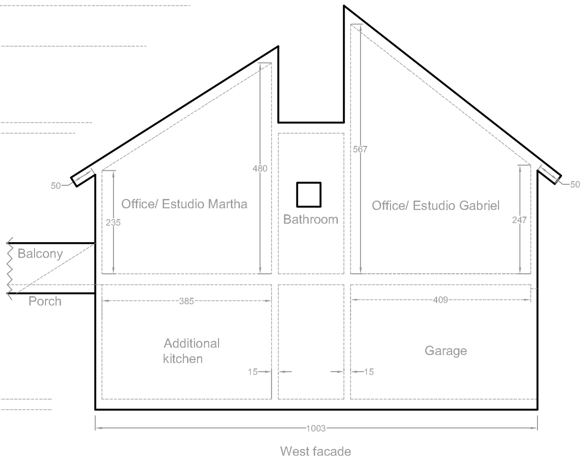
Construction plan: Casa Macías Villalobos, FovISSSTE, Chetumal



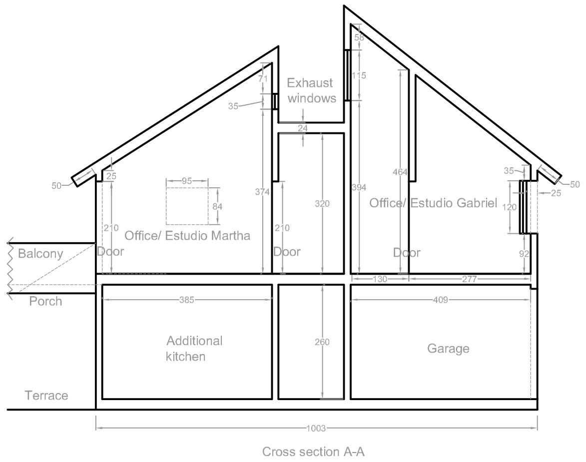
UPPER FLOR



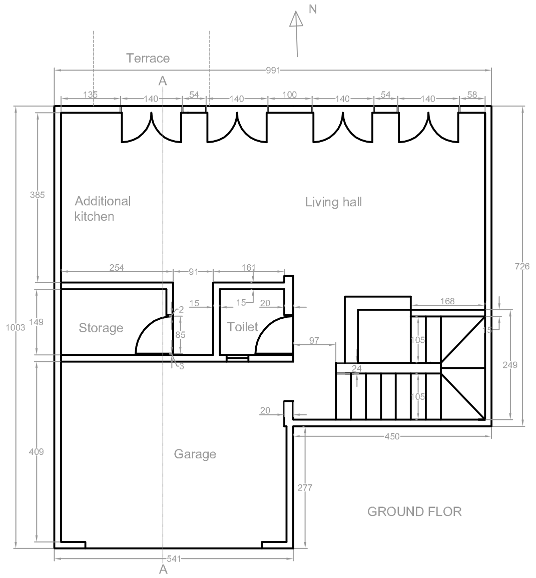
East facade



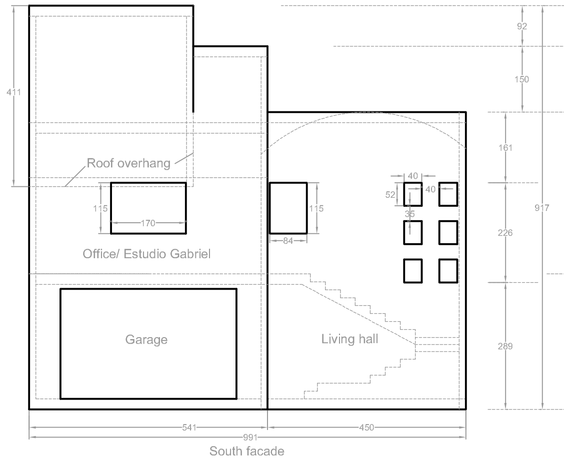
West facade



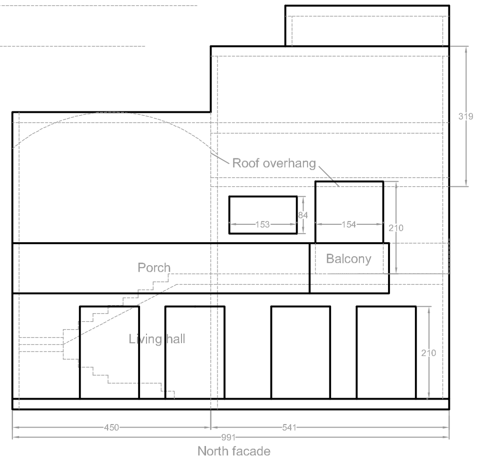
Cross section A-A



GROUND FLOR

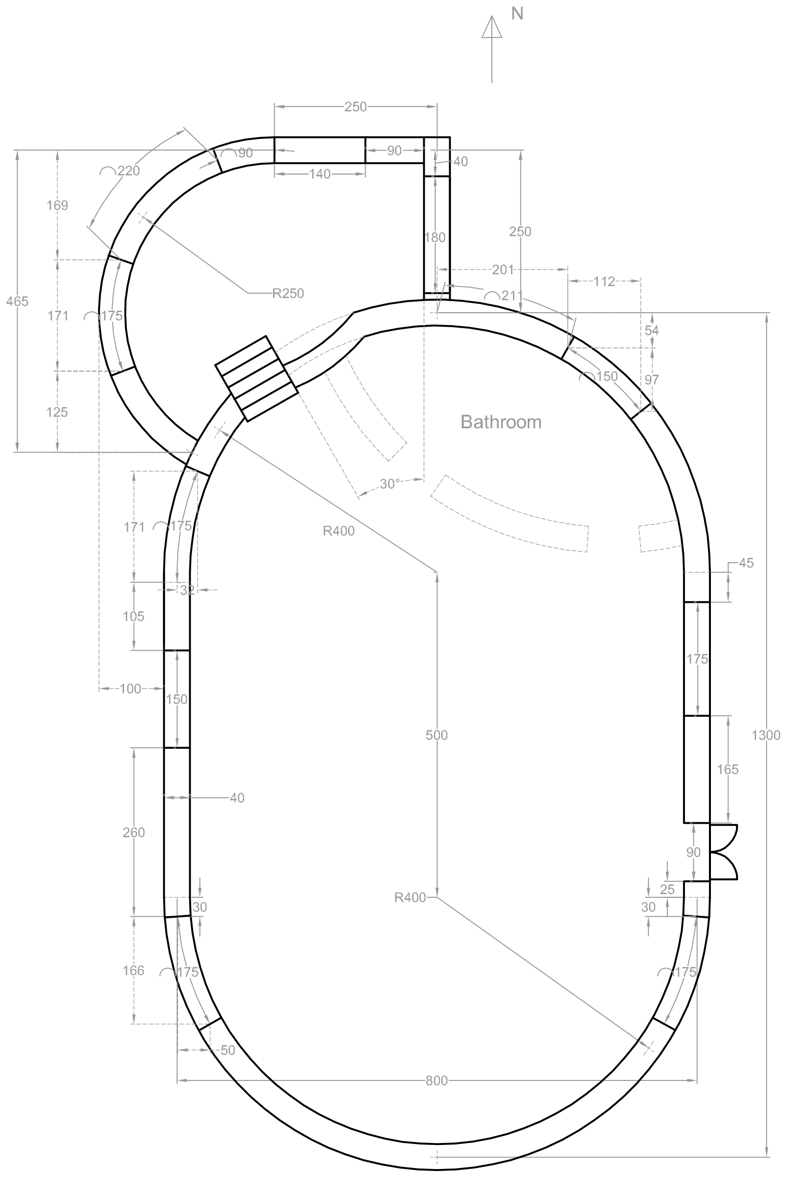


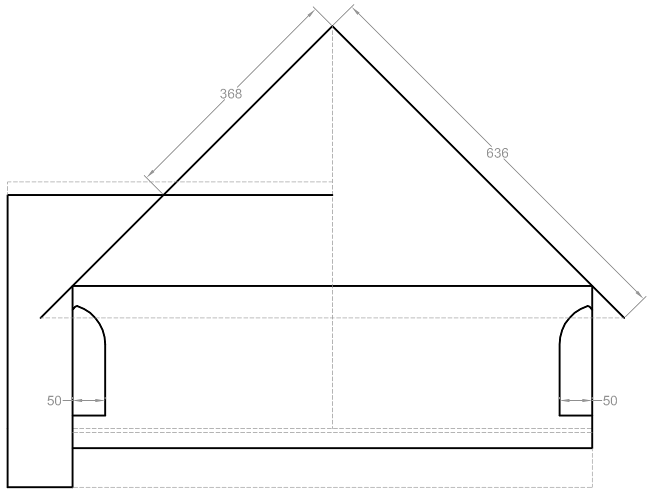
South facade

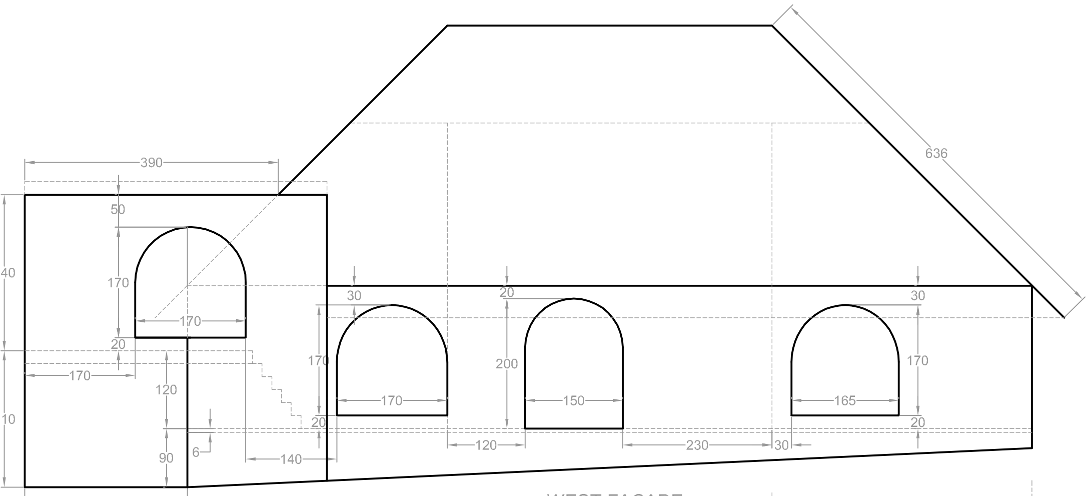


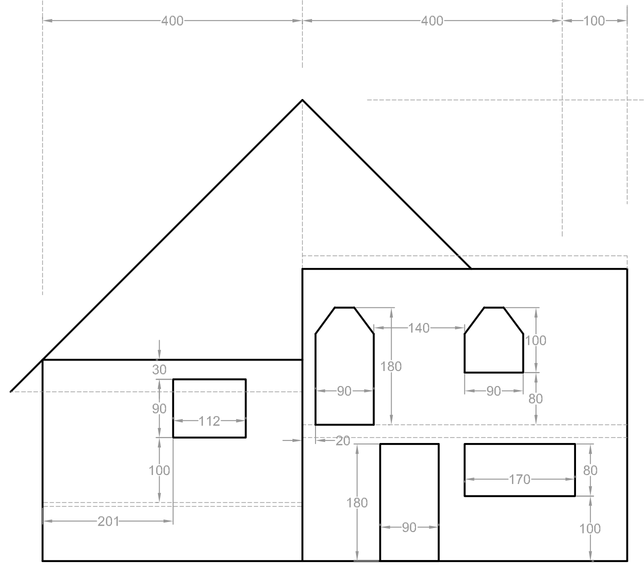
North facade

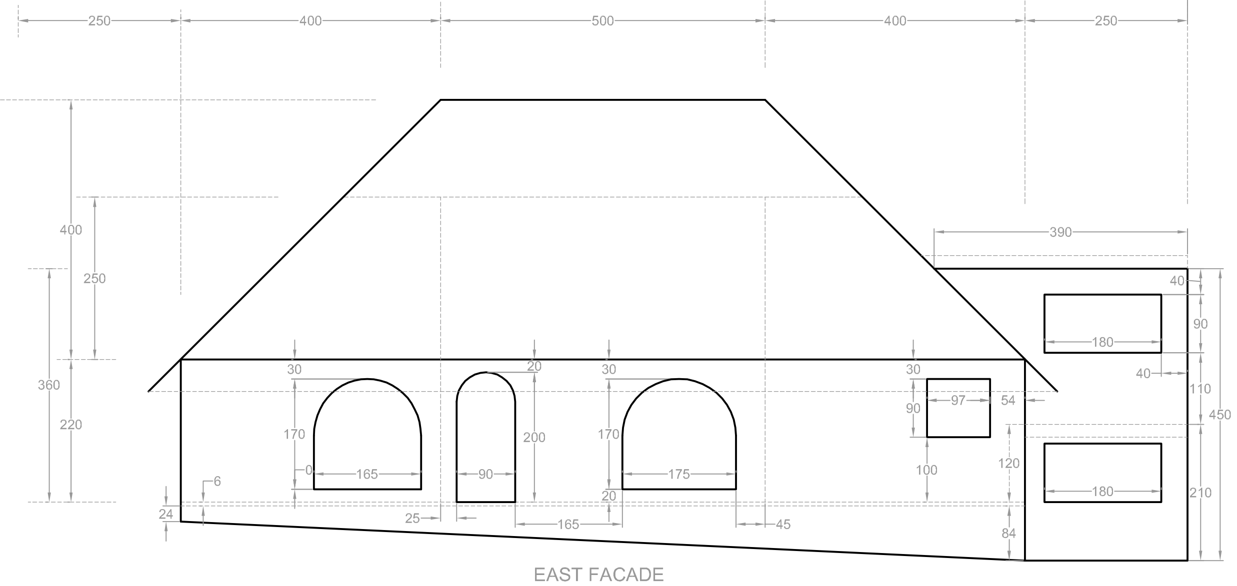
Construction Plan: Casa Brunner Valdés, Finca la Abundancia, Mahahual



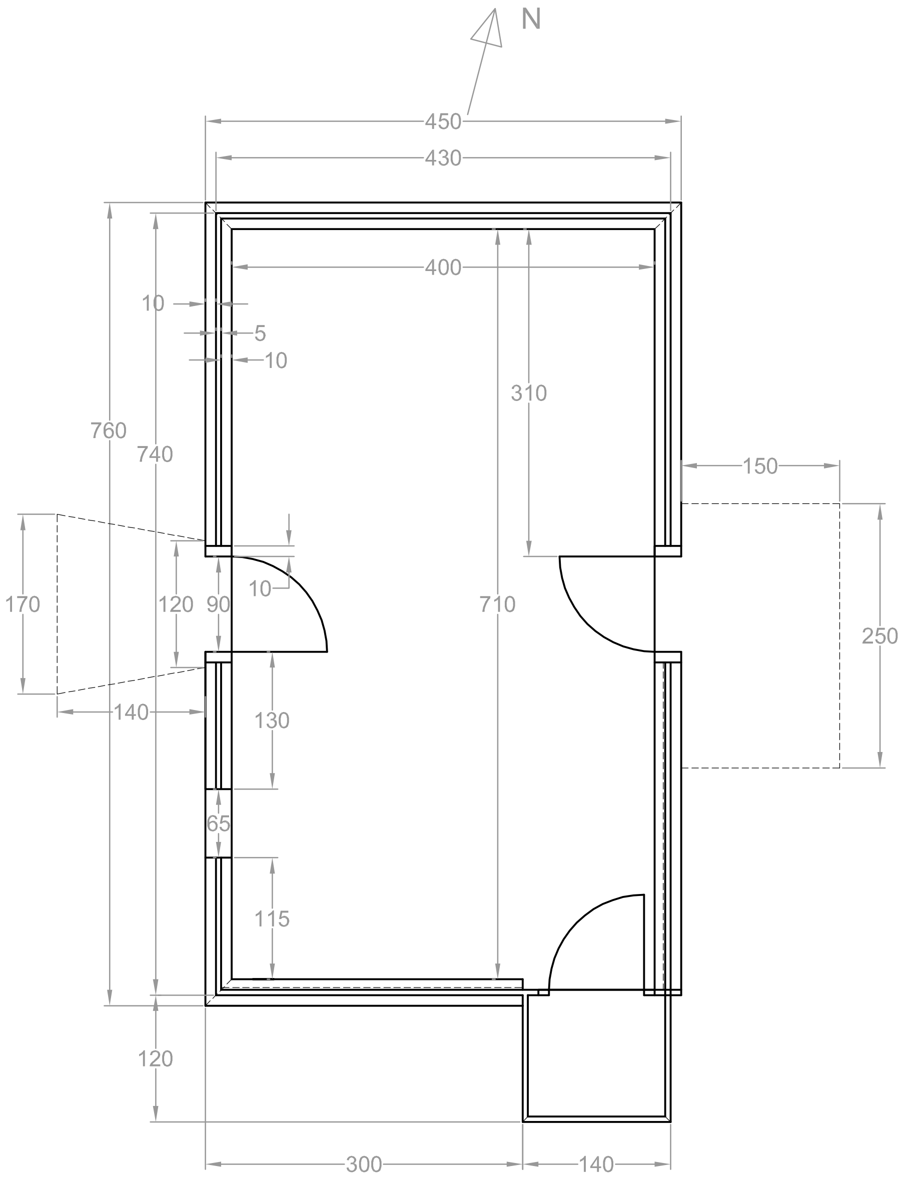

SOUTH FACADE

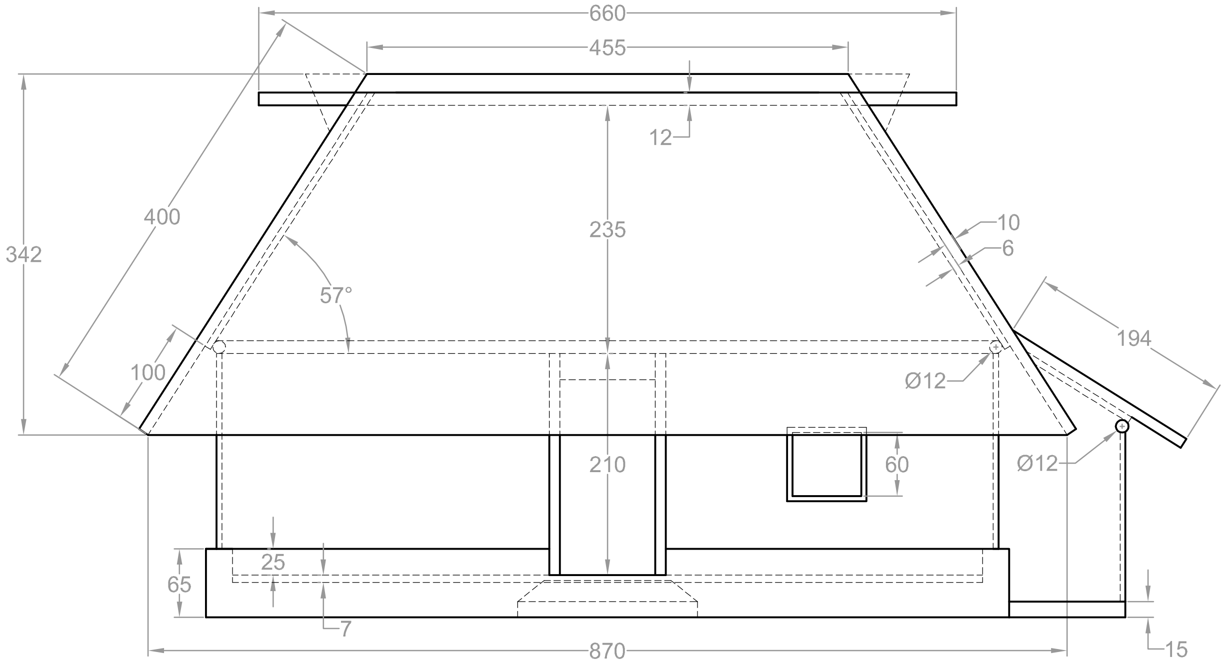

WEST FACADE


NORTH FACADE

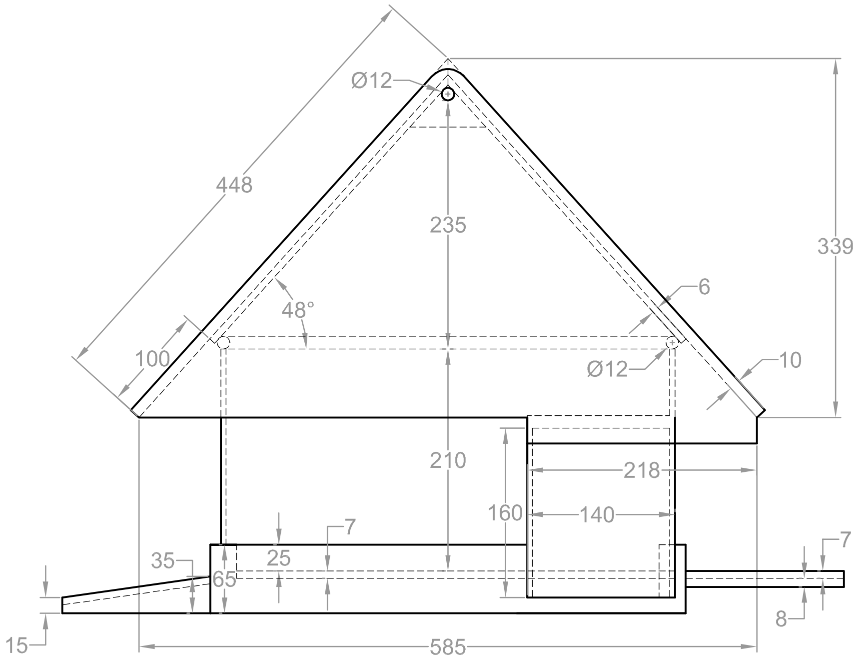

EAST FACADE

Construction plan: Casa Poot Balam, San Román





West Facade



South Facade