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EVALUATION OF THE NEW POLICY FOR THERMAL INSULATION STANDARDS IN THE RESIDENTIAL SECTOR IN MEXICO.

- APPLICABILITY OF THE STANDARD NOM-020-ENER-2011 -

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PRESENTS:

ALBERT HEINRICH BEELE

CO-DIRECTOR OF THESIS PMPCA:

DR. CARLOS CONTRERAS SERVÍN

CO-DIRECTOR OF THESIS ITT:

DR. JOHANNES HAMHABER

ASSESSOR:

MDU. FILIBERTO ADRIÁN MORENO MATA

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DR. SALVADOR RODRÍGUEZ KURI

CENTRO DE INVESTIGACIÓN EN ENERGÍA

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Cuernavaca

FIELDWORK SUPERVISOR:

DRA. GUADALUPE HUELSZ LESBROS

DR. JORGE ANTONIO ROJAS MENÉNDEZ

STUDIES SUPPORTED BY:

DEUTSCHER AKADEMISCHER AUSTAUSCH DIENST (DAAD)

CONSEJO NACIONAL DE CIENCIA Y TECNOLOGÍA (CONACYT)

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Erklärung / *Declaración*

Name / *Nombre*: Albert Heinrich Beele

Matri.-Nr. / *N° de matricula*: **11076187 (CUAS), 191542 (UASLP)**

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Abstract

A first-generation energy efficiency standard for residential buildings in Mexico, the NOM-020-ENER-2011, was promulgated in 2011. The purpose of the standard is to "rationalize the energy use in cooling systems", by means of the limitation of the heat gains through the envelope of buildings. Due to its geographical extension the country hosts a broad range of different climates. This diversity has to be contemplated by the standard. It is not possible to use a regulation from European or North American countries as a reference, due to the fact that their bulk for building energy consumption is in winter, and their codes generally only refer to one thermal insulation value for the whole country. An energy efficiency standard for non-residential buildings was promulgated in Mexico in 2001, but up to date it has not been incorporated on large scale into local construction regulations, which is a prerequisite for it, so as to be enforced in praxis. This is a matter of lack of information of the importance of building energy use by local authorities and can also be attributed to the resistance of the construction industry. A deficit of 20 million housing units is projected upon 2030, of which 11.3 million represent additional demand of new dwellings. Depending on the climate zone significant energy savings can be achieved by the integration of thermal insulation, while at the same time having a positive return on investments. The general objective of the thesis is to assess the applicability of the NOM-020-ENER-2011. The investigation contemplates three major considerations. The first will assess in which climatic zones the implementation of a mandatory energy efficiency standard leads to significant energy and economic savings. A second goal is to assess the methodology of the standard. The third line of investigation examines the benefits of the standard to the sustainable housing policies in Mexico. The thesis was elaborated in collaboration with GIZ[1], within the framework of a consultancy service to the Mexican National Commission for the Efficient Use of Energy (CONUEE).

Keywords: Energy efficiency standard, code implementation, thermal envelope, residential buildings

[1] GIZ – *Deutsche Gesellschaft für Internationale Zusammenarbeit* – German Agency for International Cooperation. The GIZ is a federally owned enterprise, supporting the German government in achieving its objectives in the field of international cooperation for sustainable development.

Resumen

Por primera ocasión una norma sobre eficiencia energética en la envolvente térmica para edificaciones de uso residencial en México, la NOM-020-ENER-2011, fue promulgada en 2011. El objeto de la Norma es de “racionalizar el uso de la energía en los sistemas de enfriamiento”, mediante la limitación de la ganancia de calor de los edificios a través de su envolvente. Debido a su extensión geográfica el país alberga una amplia gama de diversos climas particulares, aspecto que considera la norma, por lo que no es posible usar un código europeo o norteamericano como referencia. Una Norma sobre eficiencia energética en la envolvente térmica para edificaciones no-residenciales se promulgó en México en 2001, pero hasta la fecha no ha sido adoptada por ningún reglamento de construcción local, lo cual es un requisito esencial para entrar en vigor en praxis. Esto se debe a la falta de información sobre la importancia del consumo energético de edificios entre autoridades locales y a la resistencia de la industria constructora. Para el 2030 se proyecta un déficit de 11.3 millones de nuevas viviendas. Según la zona climática se logran ahorros energéticos significativos mediante la integración de aislamiento térmico, generalmente con un bajo costo. El objetivo general de la tesis es evaluar la aplicabilidad de la NOM-020-ENER-2011. La investigación contempla tres consideraciones principales: i) Evaluar el impacto de la Norma en relación con las zonas climáticas, ii) Evaluar la metodología de la Norma, iii) Analizar los beneficios de la Norma hacia las políticas de vivienda sustentable en México. La tesis fue elaborada en colaboración con la GIZ[2], dentro del marco de un servicio consultorio a la Comisión Nacional para el Uso Eficiente de Energía (CONUEE).

Palabras clave: Reglamento de construcción sobre eficiencia energética, implementación del código, envolvente térmica, vivienda

[2] GIZ- *Deutsche Gesellschaft für Internationale Zusammenarbeit* – Cooperación Alemana al Desarrollo. La GIZ es una empresa de propiedad federal, que apoya al gobierno alemán en el logro de sus objetivos en el ámbito de la cooperación internacional para el desarrollo sustentable.

Zusammenfassung

In 2011 wurde in Mexiko die erste Norm für Energieeffizienz in der thermischen Gebäudehülle von Wohngebäuden erlassen - die NOM-020-ENER-2011. Das Ziel der Norm ist es, mittels der Begrenzung der Wärmegewinne durch die Hülle von Wohngebäuden „den Energieverbrauch in Kühlsystemen zu rationalisieren". In Folge der geografischen Ausdehnung beherbergt das Land eine große Anzahl verschiedener Klima. Diese Vielfalt muss von der Norm berücksichtigt werden. Aufgrund dieser Tatsache ist es nicht möglich, eine europäische oder nordamerikanische Norm als Referenz zu verwenden. In 2001 wurde eine Norm für Energieeffizienz in der thermischen Gebäudehülle für Nichtwohngebäude erlassen. Bis auf wenige Ausnahmen wurde die Norm nicht in die lokalen Bauvorschriften übernommen, was dazu führte, dass die Norm in der Praxis nicht angewendet wird. Dies ist zum einen auf mangelndes Fachwissen auf Kommunalebene bezüglich des Energieverbrauchs von Gebäuden, sowie zum anderen auf Widerstand seitens der Bauindustrie zurückzuführen. Für das Jahr 2030 wir ein Defizit von 11.3 Millionen neuer Wohneinheiten prognostiziert. Je nach Klimazone können mittels der Integration von Wärmedämmung signifikante Reduzierungen des Energieverbrauchs zu niedrigen Investitionskosten erreicht werden. Das übergeordnete Ziel dieser Masterarbeit ist es, die Anwendbarkeit der Norm NOM-020-ENER-2011 zu beurteilen. Die Investigation gliedert sich in drei hauptsächliche Aspekte: i) Analyse der energetischen und ökonomischen Einsparpotentiale in Abhängigkeit von der Klimazone, ii) Beurteilung der Methodologie der Norm, und iii) Untersuchung des Wechselwirkung zwischen der Norm und der Politik für nachhaltigen Wohnungsbau in Mexiko. Die Masterarbeit wurde in Zusammenarbeit mit der GIZ[3] im Rahmen eines Beratungsservices für das Mexikanische Energie-Effizienz Ministerium (CONUEE) erstellt.

Stichworte: Norm für Energieeffizienz, Implementierung von Normen, thermische Gebäudehülle, Wohnungsbau

[3] GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit. Die Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmBH ist ein Bundesunternehmen, welches die Bundesregierung unterstützt, ihre Ziele in der internationalen Zusammenarbeit für nachhaltige Entwicklung zu erreichen.

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List of Abbreviations

$	Peso mexicano (Mexican peso)
A/V	Surface area to volume ratio
AEAEE	Asociación de Empresas para el Ahorro de Energía en la Edificación
AHM	Asociación Hipotecaria Mexicana (Mexican Mortgage Association)
AMMAC	Asociación de Municipios de México (Mexican Association of Municipalities)
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning
BANJERCITO	Banco Nacional del Ejército Fuerza Aérea y Armada
BANOBRAS	Banco Nacional de Obras y Servicios Públicos S.N.C. (Mexican National Bank for Public Works and Services)
BMU	Bundesministerium für Umwelt, Naturschutz and Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety of Germany)
BMV	Bolsa Mexicana de Valores
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development of Germany)
CAM	Colegio de Arquitectos de México
CDM	Clean Development Mechanism
CEV	Código de Edificación de Vivienda (Residential Building Code)
CFE	Comisión Federal de Electricidad (Federal Electricity Comission)
CFL	Compact fluorescent lamp
CMM	Centro Mario Molina
CMNUCC	Convención Marco sobre el Cambio Climático
CO_2	Carbon dioxide
COFEMER	Comisión Nacional de Mejora Regulatoria
CONAE	Comisión Nacional para el Ahorro de Energía (Energy Efficiency Agency)
CONAFOVI	Comisión Nacional de Fomento a la Vivienda
CONAGO	Conferencia Nacional de Gobernadores (National Governors' Conference)
CONAVI	Comisión Nacional de Vivienda (National Housing Comission)
CONUEE	Comisión Nacional para el Uso Eficience de la Energía (National Comission for the Efficienct Use of Energy)
CoP	Coeficient of performance
COP	Conference of the Parties
CRE	Comisión Reguladora de Energía (Regulatory Energy Comission)
CS	Coeficiente de sombreado (shading coefficient)
DEEVi	Diseño Energéticamente Eficiente de la Vivienda

DIT	Technical Suitability Report
DOF	Diario Oficial de la Federación (Official Journal of the Federation)
DUIS	Desarrollos Urbanos Integrales Sustentables (Sustainable Integrated Urban Developments)
EE	Energy efficiency
EEBC	Energy efficiency building code
EN	European Norm
EPS	Expanded polystyrene
FCAM	Federación de Colegios de Arquitectos de México
FIDE	Fideicomiso para el Ahorro de Energía Eléctrica (Fund for Electricity Savings)
FONHAPO	Fondo Nacional de Habitaciones Populares (National Fund for Popular Housing)
FOVI	Fondo de Operación y Financiamiento Bancario a la Vivienda
FOVIMI	Fondo de la Vivienda Militar
FOVISSSTE	Fondo de la Vivienda del Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado (Housing Fund of the Institute of Social Security and Services for the Government Workers)
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Agency for International Cooperation)
GMT	Greenwich Mean Time
GOPA	GOPA Consultants mbH
GPEDUIS	Grupo de Promoción y Evaluación de Desarrollos Urbanos Integrales Sustentables
HV	Hipoteca Verde
IDB	Inter-American Development Bank
IDG	Índice Desempeño Global
IEA	International Energy Agency
IFC	International Finance Corporation
IMSS	Instituto Mexicano del Seguro Social
INAFED	Instituto Nacional para el Federalismo y Desarrollo Municipal (National Institute for Federalism and Municipal Development)
INEGI	Instituto Nacional de Estadística, Geografía e Informática
INFONAVIT	Instituto del Fondo Nacional de la Vivienda para los Trabajadores (Institute of the National Housing Fund for Workers)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Norm, International Standard Organisation
ISSSTE	Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado

ISV	Índice de Sustentabilidad en la Vivienda
KfW	Kreditanstalt für Wiederaufbau (German government-owned development bank)
LASE	Ley para el Aprovechamiento Sustentable de Energía
LPG	Liquefied petroleum gas
MEEP	Mexican Energy Evaluation Package
Meteonom	Climatological dataset software
MRV	Monitoring, reporting, verification
MXN	Mexican peso
MXN/y	Mexican peso per year
NAFIN	Nacional Financiera, Sociedad Nacional de Crédito (National Development Bank)
NAFTA	North American Free Trade Agreement
NAMA	Nationally Appropriate Mitigation Actions
NMX	Normas Mexicanas (voluntary standards of Mexico))
NOM	Normas Oficiales Mexicanas (official standards of Mexcio)
NOM-020	NOM-020-ENER-2011 Official Mexican Standard for Energy Efficiency in Buildings
NTC	Norma Técnica Compementaria
ONNCCE	Organismo Nacional de Normalización y Certificación de la Construcción y Edificación
PAN	Partido Acción Nacional
PE	Primary Energy
PEC	Procedimiento para la Evaluación de la Conformidad (Procedure for the Evaluation of Conformity)
PECC	Programa Especial de Cambio Climático 2009-2012 (Special Climate Change Program)
PHI	Passive House Institute
PHPP	Passive House Planning Package
PNV	Programa Nacional de Vivienda (National Housing Program)
PoA	Program of Activities
PRI	Partido Revoluciónario Institucional
PRONASE	Programa Nacional para el Aprovechamiento Sustentable de la Energía 2009-2012 (National Program for the Sustainable Use of Energy 2009-2012)
RE	Renewable Energies
RENACE	Red Nacional de Comisiones de Energía (National Network of Energy Commissions)
RUV	Registro Único de Vivienda (Unified Housing Registry)
SAAVi	Simulación del Ahorro de Agua en la Vivienda

SALUD	Secretaría de Salud (Health Secretariat)
SC	Shading Coefficient
SCV	Sistema de Calificación de Vivienda
SEDESOL	Secretaria de Desarrollo Social (Social Development Secretariat)
SEMARNAT	Secretaría de Medio Ambiente y Recursos Naturales (Ministry of Environment and Resources)
SENER	Secreatía de Energia (Ministry of Energy)
SHF	Sociedad Hipotecaria Federal (Federal Mortgage Company)
SiSeViVe	Sistema de Evaluación de Vivienda Verde
SOFOLES	Sociedades Financieras de Objeto Limitado (Limited Purpose Financial Institutions)
SOFOMES	Sociedades Financieras de Objeto Múltiple (Multiple Purpose Financial Institutions)
SOFTEC	Consultoría en Proyectos Inmobiliarios
TFA	Treated Floor Area
UNEP-SBCI	United Nations Environment Program – Sustainable Building Climate Initiative
UNFCCC	United Nations Framework Convention on Climate Change
USD	Dólar Americano (American Dollar)
UV	Unidad Verificadora (Verification Unit)
Valor R	Thermal resistance, $(m^2 \cdot K)/W$
Valor U	Thermal transmittance, $W/(m^2 \cdot K)$
VESAC	Vivienda y Entorno Sustentable
VSMMDF	Minimum monthly salary Federal District
WFA	Window to Floor Area
WMO	World Meteorological Organization
XPS	Extruded Polystyrene
λ (Lambda)	Thermal conductivity, (W/mK)

UNITS

$(m^2 \cdot K)/W$	Square meter Kelvin per Watt
$kg/(m^2a)$	Kilogram per square meter annually
$kg/(m^2y)$	Kilogram per square meter per year
$kgCO_2/kWh$	Kilogram carbon dioxide per kilowatt-hour
$kWh/(m^2y)$	Kilowatt-hours per square meter per year
kWh/d	Kilowatt-hours per day
W	Watt
$W/(m^2 \cdot K)$	Watt per square meter Kelvin
W/(mK)	Watt per meter Kelvin

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1 Introduction

In Mexico there exists a potential of improvement in energy efficiency of the building envelope in the residential sector due to the low energetic standards in practice. A first-generation energy efficiency standard for residential buildings in Mexico, the NOM-020-ENER-2011, was promulgated the 08^{th} of August 2011 in the Official Journal of the Federation (Diario Oficial de la Federación – DOF). The purpose of the standard is to reduce "the heat gain through the building envelope of residential buildings, with the objective of rationalizing the energy use in cooling appliances" [NOM-020].

Due to its geographical extension the country hosts a broad range of different climates. This diversity has to be contemplated by the standard. The countries with Energy Efficiency Building Codes (EEBC) for the building envelope are by majority the European and North American countries. In Europe the geographical extension of the countries is small and the majority of energy consumption is for heating in winter, for that reason the EEBCs generally comprehend minimum average thermal insulation requirements with one "R"-value for the whole country. In relation on the North American continent, thermal insulation serves in both seasons of the year: winter and summer. The Federal Regulatory Improvement Commission (COFEMER) and the Energy Secretariat (SENER) agree that due to the geographic characteristics of other countries it is not possible to use their regulations as a reference for the case of Mexico, given the broad range of climates present in the country [COFEMER 2011]. For this reason a new approach was developed for the standard NOM-020-ENER-2011.

Up to date the Official Mexican Standard NOM-020-ENER-2011 is the only official instrument regulating energy efficiency in the thermal building envelope in the Mexican housing sector. A similar standard for office buildings (non-residential buildings), the NOM-008-ENER-2011 was promulgated in 2001, but had literally no impact, given the fact that it was only adapted by 2 local building regulations, which is a prerequisite for it so as to be enforced in practice. In ten years' time since its promulgation only 17 buildings have been certified, though in practice many new buildings fulfil and even exceed the standard. This is a matter of lack of information of the importance of building energy use by local authorities and can also be attributed to the resistance of the construction industry.

According to the Mexican National Housing Agency CONAVI [2010] a deficit of 20 million housing units is projected upon 2030, of which 11.3 million represent additional demand of new dwellings. Depending on the climate zone significant energy savings can be achieved by the integration of thermal insulation, while at the same time having a positive return on investment.

In accordance with the National Program for the Sustainable Use of Energy 2009-2012 [PRONASE] the National Commission for the Efficient Use of Energy (CONUEE) establishes in its Yearly Work Plan 2011 [CONUEE 2011] under the strategy *5.5 Edificaciones* the improvement of thermal insulation in new construction. The division "Sustainable Energy in Construction" of the German Agency for International Cooperation (GIZ) advises the CONUEE in this area. This Master thesis wants to contribute to the energy efficiency improvement by evaluating the applicability of the standard NOM-020-ENER-2011. The Master thesis investigation was conducted within the framework of the consultancy of GIZ to CONUEE.

A research period at the Energy Research Center of the Autonomous University of Mexico (Centro de Investigación en Energía de la Universidad Autónoma de México – CIE-UNAM) allowed for the interchange with experts in the field of heat transfer and mass of buildings, whilst providing technical assistance in the realization of the dynamic thermal simulations.

1.1 Problem statement

As an Official Mexican Standard (NOM) the NOM-020-ENER-2011 is mandatory in the whole country. The country hosts a broad range of different climates, having different acclimatization needs, ranging from hot dry climates and high temperatures with high humidity, till temperate climates with a lot of rainfall and fog. The benefits of the implementation of the NOM-020-ENER-2011, as well as its potential impact on electricity consumption due to heating and cooling loads varies according to typology, climatic zone, cost and size of the building. It is suspected that these benefits could be insignificant in some of the climatic zones, like the temperate and cold zones for example, for which in those cases the standard would convert into an additional obstacle in the construction process.[4]

The objective of the standard is to reduce energy consumption due to mechanical cooling by enhancing the thermal performance of the building envelope. This is to say the standard was developed regarding buildings with mechanical cooling appliances. In the temperate climate zones it is possible to reach thermal comfort without mechanical cooling. Thermal inertia plays an important role in bioclimatic architecture. It is suspected that thermal insulation as proposed by the standard might have a negative effect in non-air-conditioned buildings when not applied properly.

A precedent report by Heard [2004] on the project of the standard conducted thermal dynamic simulations in localities of arid, tropical and the semi-cold climate of Mexico City, leaving out the temperate climates. The report on a supported National Appropriate Mitigation Action (NAMA) design concept by Wehner [*et al.*] [CONAVI 2010] coincides on the need for further investigation about the potential impact of thermal insulation requirements on the electricity consumption due to air-conditioning.

Recent assessments of the incorporation of Energy Efficiency Standards in the Mexican construction regulation by CONUEE / GIZ [Rodríguez & Sielfeld 2010] and a World Bank Case Study on Mexico [World Bank 2010] reveal a number of country-specific major barriers for the implementation and enforcement of a standard for thermal insulation in the housing sector in Mexico, as listed below:

[4] Due to the additional cost for: planning, applications, materials and compliance of the standard.

- Lack of agreement between the different actors at the federal and state level.
- Lack of information of the importance of building energy use by local authorities and lack of knowledge of EEBCs at the appropriate political level, in combination with local autonomy over construction.
- Lack of institutional capacity to supervise the establishment and implementation of the proposed norms.
- Lack of resources from the local authorities to ensure compliance and review of building codes.
- Resistance from the construction industry. Due to additional cost for compliance and new investments in equipment, training and new supply lines for materials.

The enforcement of the standard is crucial when implementing a first-generation energy-efficiency standard. In Mexico the first essential step for a successful implementation is the adoption of the standard into local building regulations so as to become mandatory. As the World Business Council for Sustainable Development [WBSCD 2008] states the building sector is characterized by fragmentation within sections of the value chain and lifecycle. These characteristics are important in understanding the market mechanisms for how to improve energy efficiency in buildings. Current mechanisms appear to reinforce a tendency towards short-term financial criteria to dominate decision-making.

Up to date no technical manual is available that facilitates the easy application of the standard and explains the compliance process. The consultancy of GIZ to CONUEE foresees the elaboration of such a Manual for the parties involved in the compliance of the standard.

In Mexico Social housing is a robust and competitive business, which is provided on a large scale by big developers. The sector includes a range of key players, including public sector finance, private financial institutions, housing developers and consumers. The system of social housing provision is well established, with the two largest housing funds existing for more than 30 years. The governance institutions provide loans to workers and guarantee the upfront payment to the developers. According to CONAVI [2011] there were approximately ten big housing developers and around 2,000 small developers actively constructing housing units in 2010.

The Mexican mortgage loan institution INFONAVIT currently is discussing the possibility of adopting the NOM-020-ENER-2011 into the Hipoteca Verde[5], but there are certain knowledge gaps regarding the costs and the benefits of the implementation of the standard. It is suspected that the compliance with the standard could be too expensive, thus reducing the flexibility of the *Hipoteca Verde* system[6]. Research on this topic is necessary in order to advise local municipalities about the benefits, and to evaluate if the standard serves its purpose. For this

[5] Hipoteca Verde is a mortgage loan by INFONAVIT that includes an additional subsidy for the acquisition of “Eco-technologies”, which allow for an efficient use of electricity, water and gas. For detailed information see: http://portal.infonavit.org.m

[6] Personal communication with D. Loy, Consultant GIZ, November 2011.

reason the results of this investigation will be of use for decision makers in the above mentioned institutions.

INFONAVIT currently is developing a new Housing Qualification System (*Sistema de Calificación de Vivienda* - SCV) in collaboration with GIZ, the Passive House Institute and Fundación IDEA[7]. The system shall be implemented by November 2012. Being an Official Mexican Standard the NOM-020-ENER-2011 has to be considered by the governmental and mortgage loan institutions. At the 17th Conference of the Parties (CoP17) to the United Nations Framework Convention on Climate Change (UNFCCC) in Durban, the Mexican National Housing Commission (*Comisión Nacional de Vivienda* CONAVI) presented the draft of the world's first Nationally Appropriate Mitigation Action (NAMA) in the housing sector. One prerequisite when receiving international financing is the compliance with the national standards[8]. The NOM-020-ENER-2011 therefore affects both, the SCV and the internationally financed projects. There is a knowledge gap regarding the effect that the standard has on the different respective qualification scales and about the breach between the new insulation requirements set by the standard and the *status quo* of the common construction standards in Mexico.

From the above mentioned the following research needs are identified (table 1-1):

Table 1-1 Research needs

Domain	Research need
Energetic analysis	Identify the potential impact of the implementation of the standard on the Energy Intensity (kWh/m2/year) according to typology, climatic zone, cost and size of the building.
Economic analysis	Identify the cost associated with the compliance of the standard (Return of Investment and net benefit) and the financial impact for the social housing sector according to typology, climatic zone, cost and size of the building.
Financial scheme	Evaluate if the standard could serve as an indicator or evaluation criterion to financing schemes
Certification scheme	Analysis of a possible integration of the standard as a baseline in a building certification scheme

[7] Fundación IDEA describes itself as "a nonprofit, independent and nonpartisan, whose mission is to design and promote innovative public policies to generate equal opportunities for Mexicans through economic development and poverty reduction as well as being a reliable source of independent analysis for government officials and the general public." Source: Fundación IDEA 2012, Mexico City, viewed 01 July 2012, <http://www.fundacionidea.org.mx/>.

The participation of Fundación IDEA in the development of the SCV is financed in the framework of a project by the British Embassy in Mexico. Source: Britisch Embassy Mexico City 2012, Mexico City, viewed 01 July 2012, <http://ukinmexico.fco.gov.uk/es/working-with-mexico/programme-team-es/projects-ongoing-es/fundacion-idea-es>.

[8] Personal communication with G. Kraft, IzN Friedrichsdorf, May 2012.

1.2 Justification/ significance of the subject

Simulations for low-income housing carried out by the AEAEE[9] came to the conclusion, that savings of 25 to 34 percent of total electricity use could be achieved by the use of thermal insulation of roof and walls and resizing of the air-conditioning units [World Bank 2010]. Given the scale of the housing demand in Mexico and the lifecycle of buildings, energy efficiency measures have to be applied in the construction of an additional building stock. Apart from the fact that these measures often will have a positive return on investments, a series of positive economic, social and environmental side effects underline this argument, like for example, less energy demand, less expenses on energy for low-income families and higher life quality for inhabitants due to a healthy interior climate.

The investigation of this master thesis analyses a problem of topicality; and aims at identifying challenges and opportunities in order to derive recommendations for the implementation of strategies that tackle the related issues. The investigation is justified by a need for research derived from praxis.

1.3 Hypothesis

Based on the above problem statement, this thesis postulates the following hypothesis:

> *The standard NOM-020-ENER-2011 fulfills its objective of rationalizing the energy use in cooling appliances by reducing the heat gain through the building envelope of residential buildings. The additional investments for the energy efficiency measures have a positive return on investment. The implementation of the standard supports the sustainable housing policies and sustainable housing programs in Mexico.*

1.4 General objective

The general objective of the thesis is to assess the applicability of the NOM-020-ENER-2011. The investigation contemplates three major considerations. The first will assess in which climatic zones the implementation of the standard leads to significant energy and economic savings. A second goal is to assess the methodology proposed by the standard in comparison to different methodological approaches. The third objective is to discuss the benefits of the standard in relation to sustainable housing policies in Mexico, and the aptitude of the standard to serve as an evaluation criterion to national and international financing schemes.

[9] Asociación de Empresas para el Ahorro de Energía en la Edificación – AEAEE.

1.5 Particular objectives

a) Energetic and economic analysis of the standard in relation to building type, size and climatic zone, in order to assess the benefits of the application of the standard and to provide a basis for decision making at state and municipal level.

I In which of the climatic zones of Mexico does the standard NOM-020-ENER-2011 lead to a significant reduction of the energy and carbon intensity in comparison to currently applied construction practices?

II What are the costs associated to the compliance of the standard and what is the net benefit of the necessary energy efficiency measures?

b) Assessment of the methodology of the standard. Development of a guidebook for the involved parties[10].

I What are the advantages and disadvantages of the methodology proposed by the NOM-020-ENER-2011 in comparison to other methodological approaches?

II Could the standard NOM-020-ENER-2011 be a first step for a thermal regulation in Mexico?

c) Overall discussion of the benefits of the standard NOM-020-ENER-2011 in relation to sustainable housing policies in Mexico. Assessment of the aptitude of the code to serve as an evaluation criterion to national and international financing schemes.

I What is the role of the standard NOM-020-ENER-2011 in relation to housing policies and sustainable housing programs (building certification system INFONAVIT, supported NAMAs, *Hipoteca Verde*, *Ésta es tu casa*)?

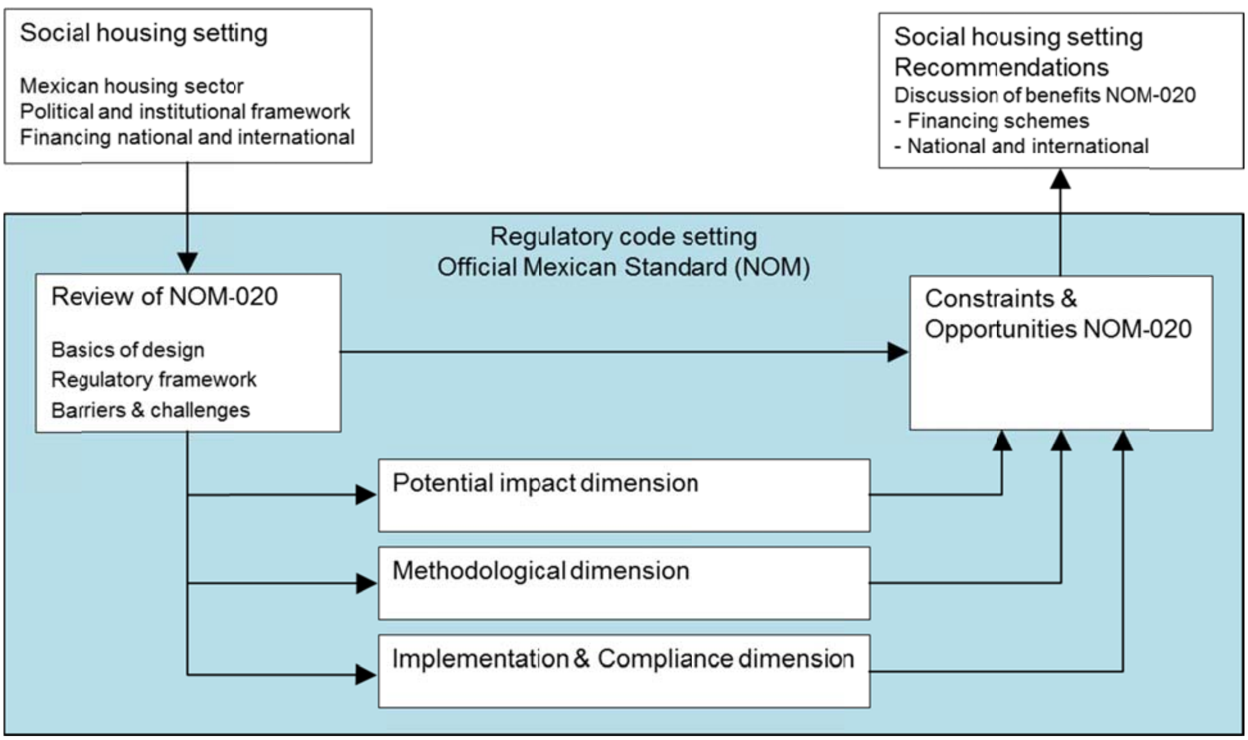
II Does NOM-020 support / stimulate these programs or could it even become a barrier if it is not technically solid, useful or applicable?

[10] Within the framework of the consultancy of GIZ / GOPA to CONUEE the author collaborated in the elaboration of a Manual for the NOM-020-ENER-2011. Further information on the development process and on the contributions of the author within the frame of this Master thesis will be given in paragraph 4.4.3.

1.6 Research model

The master thesis investigation will be organized according to the research model shown below. First the social housing setting will be laid out, so as to show the interrelations of the standard within the political and institutional framework, as well as the national and international financing schemes. The following chapter reviews the historical framework and the fundamentals of the standard, as well as the barriers and challenges. The analysis of the standard will investigate three dimensions related to the standard, examining the dimension related to implementation and compliance, the potential impact of the standard, as well as the methodology proposed by the standard. From the examination of these three dimensions conclusions will be drawn to assess the constraints and opportunities of the NOM-020-ENER-2011. The last chapter discusses the former results, as well as the benefits of the standard in relation to sustainable housing policies and financing schemes in Mexico, so as to give recommendations for the social housing setting.

Figure 1-1 Research model



1.7 Structure of the thesis

This thesis is divided in seven chapters that are briefly described in the following part.

In the beginning of the report an overview about the research topic is given (see chapter **1 Introduction**). The hypothesis, the objectives and the research questions are described. At the end of chapter 1 the research model is laid out as the conceptual framework of the thesis and the basis for the research methodology, followed by this description of the thesis' structure of the thesis. After the introduction the chapter **2 Methodology** describes the methodological approach of this Master thesis and gives a justification for the selection of the proposed methods that were used during this research.

The following chapter **3 Social housing in Mexico** examines the social housing setting. In the first paragraph the historical framework is laid out, so as to subsequently describe the prevalent system of housing provision. The second paragraph describes the institutional framework and the related relevant stakeholders, followed by a description of the political and programmatic framework. Next the current financing schemes and their relevance to energy efficiency implementation are explained. The chapter closes with a discussion of the main findings.

The next chapter provides the relevant information regarding the development, implementation and enforcement of the standard NOM-020-ENER-2011 (chapter **4 Review of the NOM-020-ENER-2011**). The first paragraph describes the historical framework of energy efficiency standards in Mexico and the relevant key players. Subsequently follows a description of the design fundamentals. Next the barriers, challenges and opportunities are explained. The last paragraph examines the fields related to the implementation and compliance dimension, followed by a discussion of the main findings.

The results of the energetic and economic analysis of the standard NOM-020-ENER-2011 are described in chapter **5** (**Potential impact dimension**). First the study design and the methodology era explained in detail. The following paragraph explains the selection of the studied typologies and locations. The next paragraph reports the results of the calculations for each type of housing, whereas the subsequent paragraph presents the results per location, thus allowing for comparability between the performances of the different typologies. The chapter closes with a discussion of the results.

The results of an analysis with three different energetic performance calculation tools are reported in chapter **6 Methodological dimension**. After an introductory paragraph on thermal performance assessment, the study design and the three different methodologies, as well as the respective boundary conditions for the calculations are explained. The next paragraph reports the results of the calculations for each applied tool, followed by a comparison of the values. The chapter closes with a discussion of the reported results.

The last chapter (**7 Conclusions and recommendations**) of this Master thesis summarizes the results of the analysis of the **Potential impact dimension** and the results of the analysis of the **Methodological dimension**, as well as the findings of the chapter 3 (**Social housing in Mexico**) and chapter 4 (**Review of the NOM-020-ENER-2011**) which examine the fields related to the **Implementation and compliance dimension**. Recommendations for a future revision of the standard will be proposed and the constraints and opportunities regarding the standard will be laid out. At the end of chapter 7 the conclusion of the research is presented in order to prove the research hypothesis and to summarize the answers to the research questions; finally future research needs are listed.

2 Methodology

This chapter summarizes the methodological choices. As the proposed investigation contemplates different dimensions and particular objectives it is necessary to apply various data collection and analysis methods. According to the research model the methodological approach for the following settings and dimensions will be described. For the potential impact dimension and the methodological dimension a detailed description of the methodology of the analysis, as well as a justification of the applied methodology will be given at the beginning of the respective chapters.

1. The *social housing setting* is studied by means of literature review and expert interviews. Close contact to key stakeholders and energy experts was given through the possibility to attend internal reunions related to the activities of GIZ / GOPA, as well as by the attendance of different workshops and conferences. Particular aspects were interviewed as face to face meetings or by e-mail communication.

2. The *review of the NOM-020-ENER-2011* is studied by means of literature review, access to internal documents and expert interviews. Close contact to key stakeholders and energy experts was given through the possibility to attend internal reunions related to the activities of GIZ / GOPA, as well as by the attendance of different workshops and conferences. Particular aspects were interviewed as face to face meetings or by e-mail communication.

3. The *potential impact dimension* is studied using six different case studies of real housing developments in Mexico in order to analyze the energetic and economic impact of the implementation of the standard. Six different housing types are studied in four different locations. The projects are analyzed applying the methodology proposed by the standard and using the Passive House Planning Package tool (PHPP). The Passive House Institute currently develops a simplified version of the PHPP as an evaluation tool for the new Housing Qualification System of Infonavit. Furthermore the PHPP was applied to perform the calculations for the Mexican Nationally Appropriate Mitigation Action (NAMA) in the housing sector.

4. The *methodological dimension* is analyzed by applying three different thermal performance evaluation methodologies to one case study in four different locations. The projects are analyzed applying three different methodologies. First the methodology proposed by the standard will be applied, which is a “Reference-methodology” based on steady-state calculation. In a second line the Passive House Planning Package will be applied to calculate the thermal performance; this tool also performs steady-state calculations, but follows a “Whole Building Approach”. The last line of calculations will be performed by means of numerical simulations applying a dynamic building simulation program.

The result of the analysis of these settings and dimensions is a comprehensive image of the aspects related to the implementation of the standard and its context; and leads to recommendations for the implementation and integration of the standard into sustainable housing policies and programs.

The applied instruments for the thermal performance analysis are the following.

1. Methodology proposed by the NOM-020-ENER-2011: A spreadsheet-calculation tool was developed base on the calculation method of the standard in order to automatize the calculations.

2. Passive House Planning Package: This design and verification tool is based in large parts on European and international norms (e.g. EN 382 and ISO 13790). According to Kraft (Source) “the PHPP has been validated with detailed simulations and with monitored results of hundreds of energy efficient buildings. As the theoretical results coincide well with monitored data of built low and very low energy houses, its calculation methodology is reliable.”

3. Dynamic building simulation: The numerical simulations will be undertaken using the calculation engine *Energy Plus V7.0*, in combination with the user surface *Design Builder V3.0*. It is important to clarify that the objective of a dynamic thermal simulation, like those represented in chapter 6, is to reflect the performance of a building as close to reality as possible. However, it is always necessary to apply elements of simplification and assumptions of usage patterns (ventilation, use of illumination and equipment, etc.) that may differ from the conditions and real uses [Campos 2011].

3 Social housing in Mexico

This chapter describes the boundary conditions of the social housing sector in Mexico. First the system of housing provision will be laid out, followed by a description of the political and institutional framework. Subsequently the current energy-efficiency implementation initiatives and the related national and international financing schemes will be laid out.

3.1 Mexican housing sector

In Mexico Social housing is a robust and competitive business, which is provided on a large scale by big developers. The sector includes a range of key players, including public sector finance, private financial institutions, housing developers and consumers. The system of social housing provision is well established, with the two largest housing funds existing for more than 30 years. The governance institutions provide loans to workers and guarantee the upfront payment to the developers. Seven out of 10 housing units in Mexico are financed by Infonavit or Fovissste. Today 22.4 % of the Mexican population lives in a home financed by Infonavit [García 2011], and according to the National Institute for Statistics and Geography 76 % of the people live in their own property [INEGI 2010]. According to CONAVI [2011] there were approximately ten big housing developers and around 2,000 small developers actively constructing housing units in 2010.

3.1.1 Background / history

The history of housing provision and policies is a key factor to understanding the current situation of social housing provision in Mexico.

In Mexico, access to housing is a right for which the Mexican people have fought for many years and it was one of many conflicts that subsequently generated the Mexican Revolution in 1910. One of the outcomes of the Revolution was the integration of the right of workers for access to housing in the Article 123 (Work and Social Welfare) in the Constitution of 1917. This article establishes the obligation of employers to provide a healthy house to their workers, and laid out the foundations for the social housing financing scheme as we know it today

As a result of a constant growth of the urban population due to mass migration from rural communities to the city in the early 1940s the government initiated different strategies to solve the problem of housing shortage. According to Schteingart [1989] the product of these strategies was the first sign of a Construction Industry under government orders, producing dominantly housing for rent. In 1963 FOVI (Fondo de Operación y Financiamiento Bancario a la Vivienda), the first housing fund, was created. It was the institution responsible for coordinating investment and the supply of affordable housing. This program canceled the option of housing for rent production and concentrated on the provision of private property housing. In 1972 the country's economic conditions improved, the government strengthened and under increasing pressure for housing demand created INFONAVIT (Instituto del Fondo Nacional para los Trabajadores) which is the main existing fund in Mexico. In 1973 FOVISSTE

(Fondo de la Vivienda del Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado) in 1973 and FOVIMI (Fondo de la Vivienda Militar) were created. According to García [2010] these actions helped the emergence of the housing market.

INFONAVIT originated as a solidarity fund, workers with more resources would be able to provide funds to the less fortunate ones. The institute captures its resources through 5% of the salary of all employees and provides loans repayable within 10 to 20 years.

The addition of funds, mainly from INFONAVIT was a significant leap in the production of state-supported housing. The institute owned territory reserves for the production of new completed housing, INFONAVIT hired Mexican companies, supervised the construction, promoted and delivered housing to the employee.

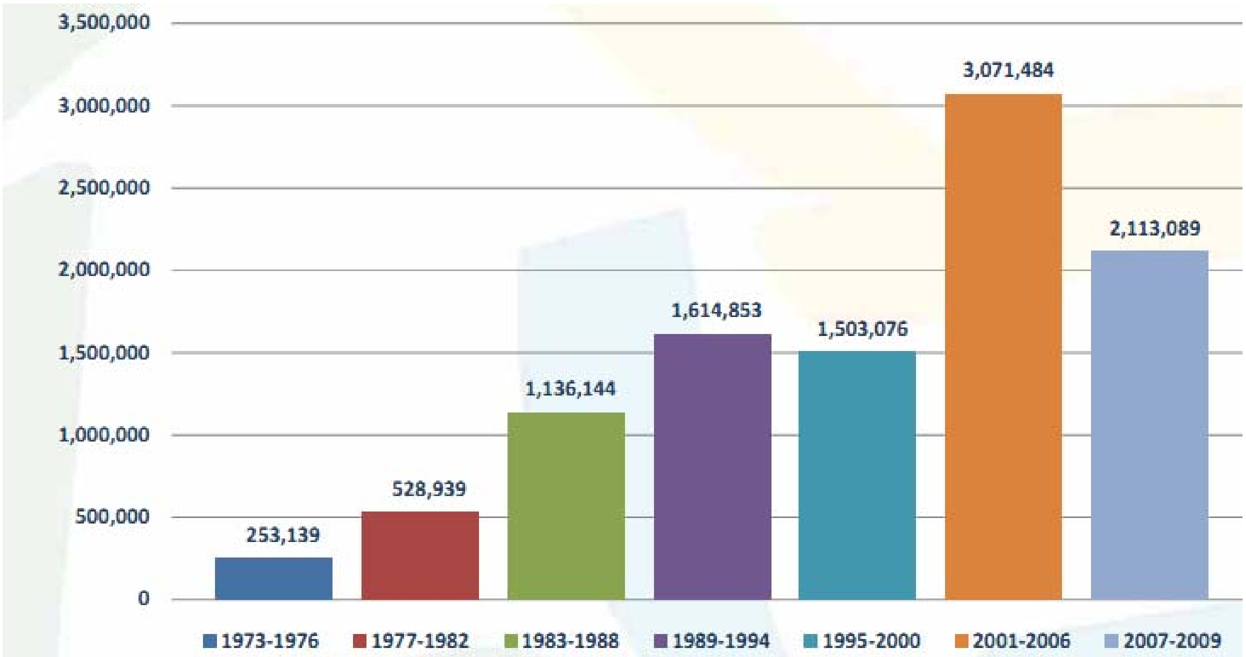
In the 90s after (NAFTA) North American Free Trade Agreement, the Mexican government, under the influence of World Bank, launched a dramatic reform and expansion of housing finance system in Mexico. According to Monkkonen [2009] the reforms included:

- INFONAVIT left its role as promoter, that is, the institution stopped all their different activities and concentrated on the financial system.
- INFONAVIT sold the land reserves to the open market.
- The community land (*Ejidos*) changed its legal status, which provides the possibility of selling the property to the market.
- The regulations changed and dimensions of land portion and square meters of constructions were reduced due to construction costs.
- The government introduced financial incentives to the construction industry for housing developments.
- Private banks opened the option of mortgage loans.
- Private capital entered the market through tenders.

According to Monkkonen [2009] the results of the reforms were the growth and consolidation of large housing development companies and the emergence of large-scale housing complexes. Workers from now on were able to choose their home on the market, whilst the access to the system became difficult for low-income families. Land hoarding and speculation came up and the people from Ejidos began to sell their land, which worsened their situation.

In 2000 the PAN (Partido Acción Nacional) took over the presidential seat after a more than seventy years period, ruled by the PRI (Partido Revoluciónario Institucional). Along with the new government came a series of structural reforms in housing policy to provide housing for workers, particularly those workers with fewer resources. According to the new president Vicente Fox Quesada, *"housing became one of the most important commitments and challenges of the new administration"* [PSV]. Under this premise Fox issued the new housing law regulatory of Article 4 of the Constitution of Mexico, which establishes the right of every family to enjoy a decent and proper house. The new housing law, *Ley de Vivienda* [LViv], organizes the structure and operation of housing policy. As a result of this new law the investment on housing that the government has made increased significantly since 2011 (see chart 3-1).

Chart 3-1 Housing Acquisition



Source: CONAVI 2009, Estadísticas de Vivienda 1973-2009 Housing Acquisition, Housing Equivalent Units.

3.1.2 Projected housing demand / housing deficit

In 2010 77.8% of the Mexican population lived in cities. According to the 2010 Census Mexico has 112.3 million inhabitants, of whom 76.4% of the registered population owns their property [INEGI 2010].

Mexico is facing to increase its building stock significantly in the next 20 years so as to fulfill the growing demand for additional new housing. According to the Mexican National Housing Commission (CONAVI 2010) the current Mexican housing stock is estimated at 26.7 million houses. The same institution forecasts the demand for additional houses to reach 20.2 million from now upon 2030. Of this total, 11.3 million represent the demand for new houses and 8.9 million is the stock of houses in inadequate conditions, which require partial or total refurbishment [CONAVI 2010].

The access to the social housing mortgage programs depends on income and employment situation. According to CONAVI there are three main population groups regarding the housing demand in Mexico (table 3-1). Group one, who is entitled to receive housing credits, is composed by workers formally registered in the social security system. They are members of different social security institutions (INFONAVIT, FOVISSSTE and BANJERCITO). These workers are known as the "beneficiary population" as they are entitled to the social security benefit. Group two is composed of a section of the population, which is not part of the social security system (non-beneficiary), but has a credit history and a banking track record; therefore they are entitled to receive CONAVI's subsidy. The third group is formed by informal workers with very low income and no credit history. Due to their lack of formal affiliations, this share of the population is not reached by any of the housing programs. However, group 3 represents 41% of housing demand. Currently, this group receives some support from institutions affiliated to CONAVI, but it is not covered by the subsidy [CONAVI 2010].

Table 3-1 Access to mortgage loans and subsidies by population group

	Demographic Dividend	Housing Backlog	Total
Beneficiary Population (Group 1)	4.4	0.9	5.3
Non-beneficiary population with payment capability (Group 2)	3.0	3.6	6.6
Non-beneficiary population without payment capability (Group 3)	3.9	4.4	8.3
	11.3	8.9	20.2

Source: CONAVI 2010

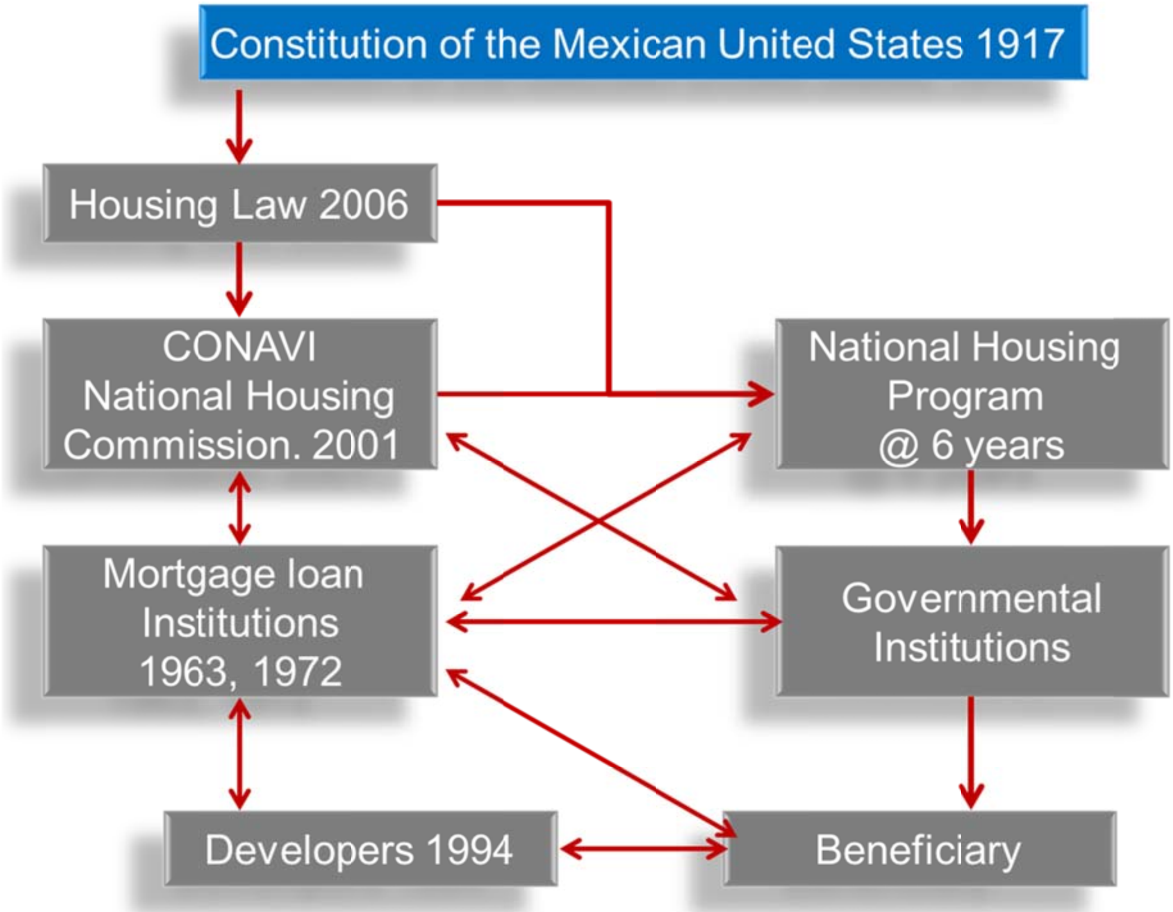
3.1.3 System of housing provision today

The system of housing provision in Mexico is working through different institutions that perform various functions. The lead agency, the National Housing Comission (*Comisión Nacional de Vivienda* - CONAVI), previously CONAFOVI, was created in 2001 with the aim to encourage, coordinate, promote and implement the policy and the National Housing Program of the federal government [CONAVI 2012b]. This institution handles the necessary information on population, territory, housing demand and necessary funds to accomplish its task.

The National Housing Program [PNV] is basically the action plan presented by the President of the Republic every 6 years based on the information CONAVI provides. The main function is to set the targets and clarify the way the resources will be spent. For the present administration 2007-2012, the goal was the construction of 6 million houses in order to cover the existing shortfall and the projected additional housing demand due to population growth. An important feature of the National Housing Program of this administration is a shift towards a sustainability concept integrated into Mexican policies.

Several other government institutions are responsible for providing support to the part of the population that does not have access to a mortgage loan, especially rural and urban poor. This institutions work accordingly to the funds that the government is able to provide and according to the program they are implementing; either self-help when the supply only construction materials or improvement when they are enough resources to deliver skilled labor and material to improve the buildings. Amongst these institutions are SEDESOL (Secretaria de Desarrollo Social), acting via FONHAPO, CONAVI by means of the Program “Esta es tu casa”, as well as NGO’s, federal institutions, private entreprises and others.

Figure 3-1 Relations between the principal actors in Housing provision system



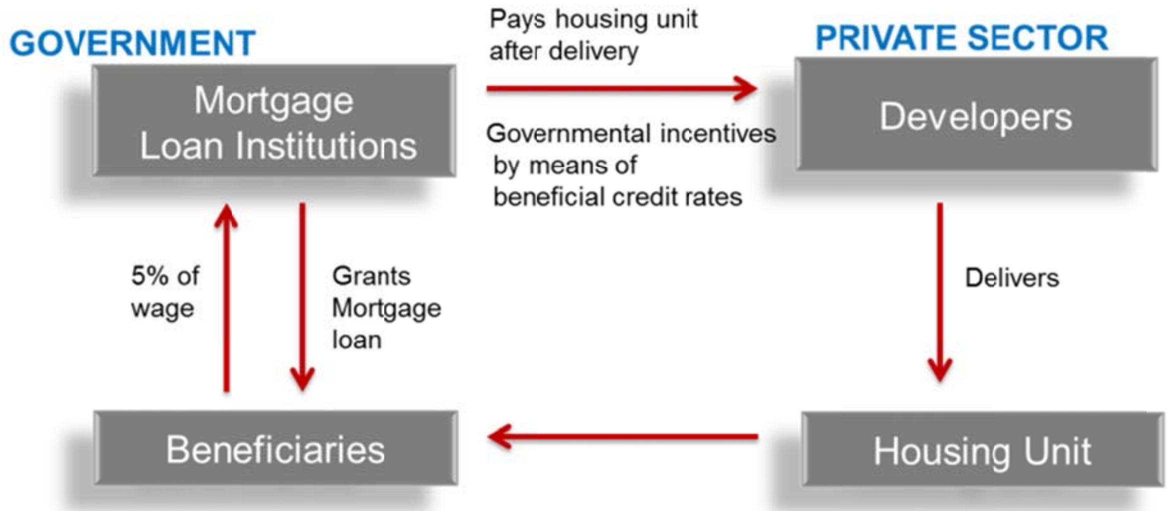
The main mortgage Loan Institutions are INFONAVIT and FOVISSTE. They are responsible for providing funding to meet the housing needs of salaried workers of the private enterprises enrolled in the IMSS (Instituto Mexicano del Seguro Social) and of salaried state workers enrolled in the ISSSTE (Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado). The operating modus of both institutions is similar. The government awards housing funds according to the number of registered workers in each state. In the case of INFONAVIT, employers must register their workers to IMSS in order for them to obtain access to medical services, these records and the payments are linked. 5% of the integrated daily wage of the worker is addressed directly to the Institute's funds for housing financing. INFONAVIT represents the biggest institution regarding the amount of funds, as well as the volume of construction.

The requirements to obtain a credit from Infonavit are [INFONAVIT 2011]:

- To participate in the orientation workshop to know how to decide. The workshop is free of charge and the certificate is valid for one year.
- To submit credit application with the required data.
- To having an effective working relationship of minimum 3 years.
- The employer must have paid the contributions.
- To comply with the required minimum score of 116 points, which are determined based on age, salary, amount of saving in the SSV (Saldo de la Subcuenta de Vivienda) and the number of months of continuous work.

The system of Social Housing provision in Mexico is characterized by a strong top-down approach. Even though a few participatory programs do exist, the bulk of housing provision follows the model described in figure 3-2.

Figure 3-2 Model of social housing provision in Mexico



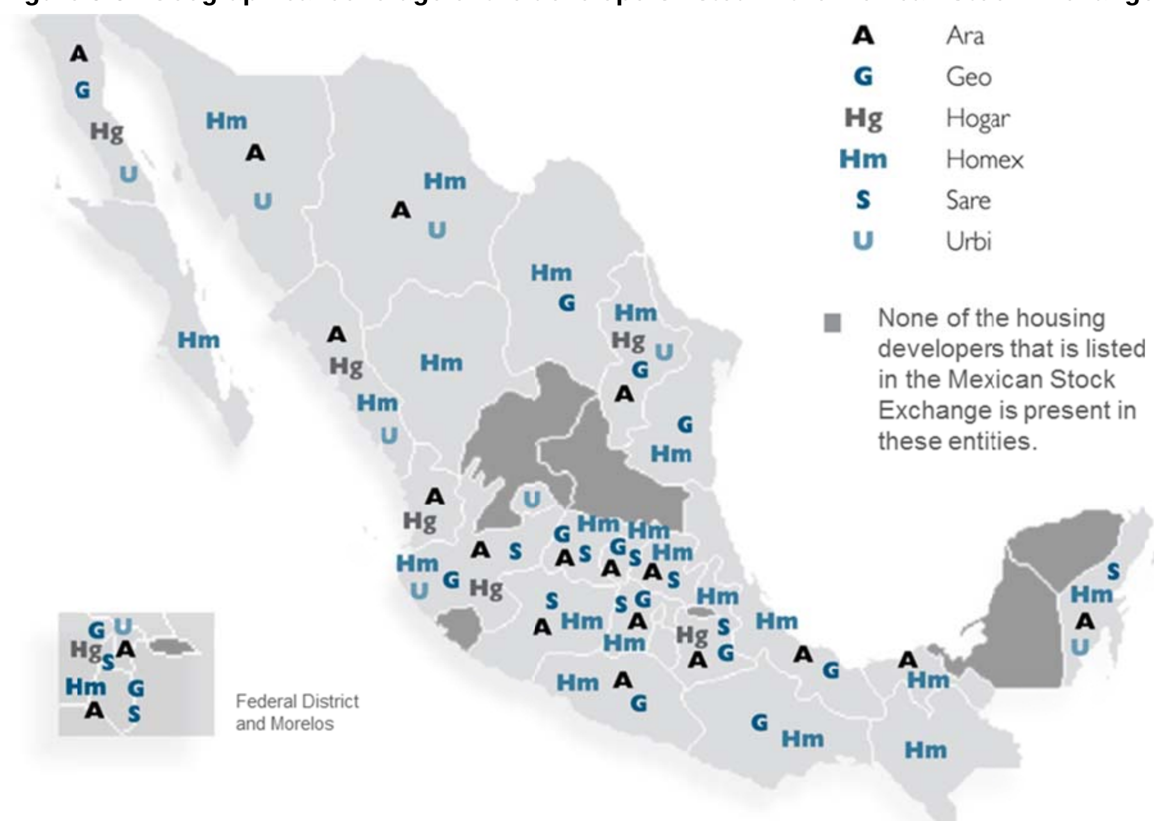
1. Mortgage loan institutions set the requirements for access to credit and the amounts that will be paid.
2. Developers buy land, built infrastructure and housing usually in the periphery and take advantage of government incentives that allows them to make investments.
3. Beneficiaries choose their house and apply for the loan.
4. Mortgage loan institutions evaluate the application and whether the recipient is eligible for the credit. The loan is granted if the beneficiary fits the criteria.
5. Developers deliver the unit to beneficiaries and subsequently receive the payment from the Mortgage Loan Institutions.
6. Beneficiaries receive their homes and pay the loan in monthly rates within the following 10 to 20 years.

3.1.4 Market players

According to Hirata [World Bank 2010a] the ten largest homebuilders nowadays account for 25 to 45 percent of the housing market. The low-income housing developments produced by these developers have 100 to 2,500 houses on average, with larger developments containing more than 15,000 units. Because of the limited urban land availability, homebuilders have urban reserves equivalent to 2 to 5 years and are continuously acquiring more.

Since the end of the severe crisis in the 1990s, several events led to the rise of large developers, leaving behind small and middle companies. Furthermore the housing sector proved to be resistant to fluctuations of the economy and has been growing at an annual rate of 15 percent between 1997 and 2008 [World Bank 2010a]. In 2010, Mexican mortgage institutions programmed the funding of 1,102,843 loans and subsidies, representing a total volume of 251.7 billion MXN [SHF 2010]. Of the six developers that are listed in the Mexican Stock Exchange Market (BMV), the three biggest make up for 86.1 percent of the total of the generated capitalization. Desarrolladora Homex has the major participation with 33.4percent, which is close to 68 billion MXN in July 2009; followed by Urbi with 31.5 percent and Corporación Geo with 21.2 percent [SHF 2009]. Those three companies have in common that they serve the social interest and medium segments, as well as their presence in a large number of the 32 Mexican federal states (figure 3-4).

Figure 3-3 Geographical coverage of the developers listed in the Mexican Stock Exchange



Source: SHF 2009

The pattern of housing provision by large scale developments of big developers allowed on one hand to provide mass housing for a large part of the Mexican population. On the other hand several social, economic and ecologic problems, that are closely linked, can be observed. A strong demand for housing, a housing deficit, failed reforms and the lack of affordable land close to the city centers led to land speculation and the associated high costs of infrastructure. Other consequences are dormitory settlements and high density housing in the peripheries of the cities. Social segregation and the often poor quality of the built houses led to the emergence of abandoned houses. Informal workers, which represent the most vulnerable group of the population, do not have access to credits. In terms of economic problems the current urbanization patterns promote the growth of cities over agricultural land and the horizontal urbanization leads to an increase of traffic-related CO_2 emissions.

3.2 Political and institutional framework

3.2.1 Federal public administration and institutional framework

The territorial organization of Mexico is defined by the Political Constitution of the United Mexican States [CONSTITUCIÓN]. The document defines the country as a federal state, which is governed under the form of a Republic. The territory is divided into 32 federative entities, of which 31 are free and sovereign, having the right to give themselves a proper Constitution and government body. The Federal District is under shared governance of the Mexican federation and the local government organs. The 32 federative entities host 2,438 municipalities. According to the article 115 of the political Constitution, the municipalities have the authority to pass laws and regulations in municipal matters [Rodríguez 2010].

The Mexican republic has a Supreme Power, which according to article 49 of the Constitution is divided into three powers: i) the executive, ii) the legislative, and iii) the judiciary; and the United States of Mexico are represented by the federal government.

The **executive power** is independent from the legislative and is governed by the president, advised by the cabinet of secretariats, which are nominated by the president. The president is elected for six years by direct vote of the citizens. The state secretariats administer the different programs for health, education, justice, energy, taxes, foreign relations, and others. Several autonomous and decentralized organizations, like banks, commissions, councils, trusteeships, funds and institutes collaborate with the federal executive powers.

The **legislative power** is executed by the Congress of the Union, a two-chamber legislative body, composed by the chamber of senators and the chamber of deputies. Every state or federative entity is represented by two senators, which are elected by direct vote and are in office for six years. The representatives are elected directly by the citizens and hold their post for three years.

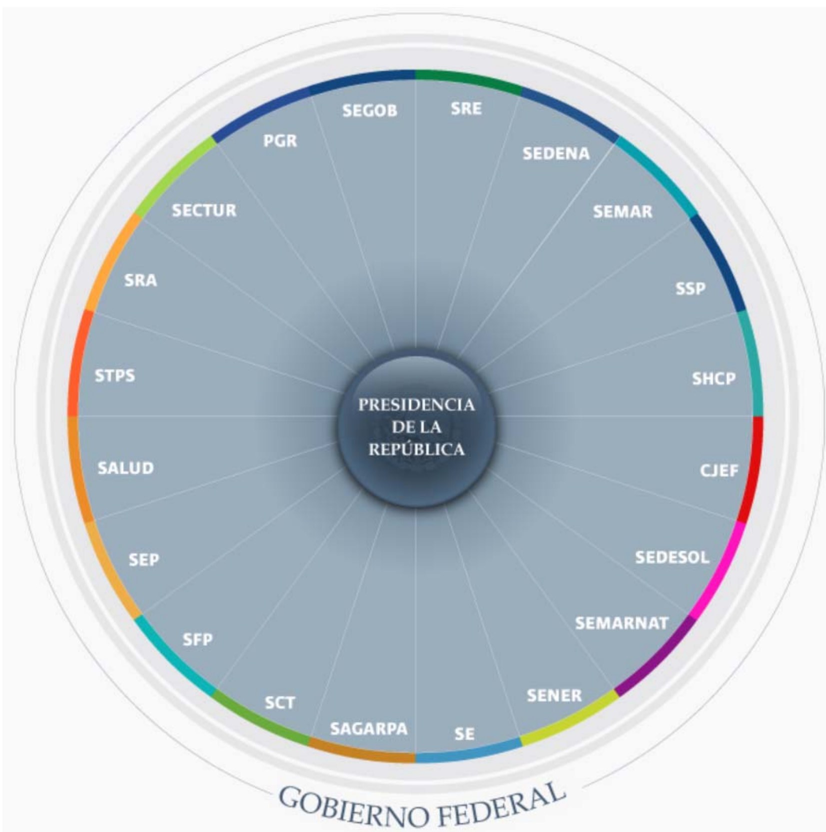
The **judiciary power** is executed by the supreme court of justice of the nation, the federal judiciary council and different courts [Instituto de Investigaciones Jurídicas 2012].

Article 40 of the Constitution establishes that the Mexican government has to fulfill three principal characteristics: i) be democratic, ii) representative, and iii) federal. According to this all the federal states are independent from each other, and autonomous in their internal administration. Every federal state has its own Constitution, its proper civil and penal law, and a judicial office; these proper laws correspond to the particular necessities of each state, but can never oppose themselves to the federal constitution of the whole country [CONEVYT 2012].

The Mexican public administration is composed by three different levels: i) Federal level, ii) State level, and iii) Municipal level; and the Federal system delegates authority in many matters to State and local governments [Piña-Segura, n.d.]. Every state has its own capital and is divided in municipalities governed by the city council. Here the responsible person is the municipal president and the persons that form the town council, all of them elected by the citizens.

At Federal level there are different administrative units of which there are to distinguish the Presidency of the Republic, the State Secretariats, the Department for Legal Matters, the Attorney General's Office of the Republic, decentralized organisms, public enterprises, national credit institutions and public trusteeships.

Figure 3-4 Federal government structure



Source: Presidencia de la República 2012, Presidency of the Republic, Mexico, viewed 01 July 2012, <http://en.presidencia.gob.mx/government/estructura-del-gobierno-federal/>.

At State level there are to distinguish the state governor, the general government secretary, the chief government official of the current government administration, the attorney general, the treasurer, secretariats, administrative departments or unities, decentralized organizations, public enterprises and public trusteeships.

At municipal level there are to distinguish the city council, the mayor, syndicates and city councils, municipal treasury, decentralized organizations, municipal enterprises, public or municipal trusteeships.

Figure 3-4 shows the structure of the federal government, and composition of the cabinet of secretariats, which consists of the 20 different secretariats. Depending on the secretariat there is a set of related decentralized administrative agencies.

Following a brief description of the secretariats related to energy efficiency and social housing will be given.

The Energy Secretariat (*Secretaría de Energía,* SENER) conducts energy policy, exercises the nation´s right over petroleum, natural gas and nuclear energy, and is in charge of the resources for generating, transforming and supplying electricity. Furthermore it directs the public companies which exploit natural oil and gas reserves under the ecological legislation. Directly related to SENER are the public companies *Petróleos Mexicanos* (PEMEX), the Federal Electricity Commission (*Comisión Federal de Electricidad,* CFE), the Regulatory Energy Commission (*Comisión Reguladora de Energía,* CRE), and the National Commission for the Efficient Use of Energy (*Comisión Nacional para el Uso Eficiente de Energía,* CONUEE) [Presidencia 2012]. CONUEE is responsible for the implementation of the measures necessary to enhance energy efficiency and the reduction of energy consumption.

The Social Development Secretariat (*Secretaría de Desarrollo Social,* SEDESOL) "formulates, conducts and evaluates the general policy for effectively combating poverty, by coordinating the actions that affect and foster higher living standards. It promotes social welfare and regional and urban development, by promoting financing, infrastructure and equipment mechanisms as well as ensuring the proper distribution, commercialization and supply of basic consumption products for the population with limited resources." [Presidencia 2012] Several institutions are subordinated to SEDESOL, of which the National Fund for Popular Housing (*Fideicomiso Fondo Nacional de Habitaciones Populares,* FONHAPO) is of interest for this thesis, as it offers housing financing schemes.

The Health Secretariat (*Secretaría de Salud,* SALUD) "conducts national policy regarding social welfare, medical services and general health, and coordinates the health service programs in Federal Public Health. It also administers the assets and funds the Federal Government has assigned for welfare services." [Presidencia 2012] Several different institutes and commissions are subordinated to SALUD, of which the Housing Fund of the Institute of Social Security and Services for the Government Workers (*Fondo de la Vivienda del Instituto de Seguridad y*

Servicios Sociales de los Trabajadores del Estado, FOVISSSTE) is of interest for this thesis, as it offers housing financing schemes.

Apart from the organizations which are related directly to the different secretariats there exist several independent decentralized organisms, public enterprises, national credit institutions and public trusteeships. For the Mexican housing sector and the implementation of energy efficiency policies and standards the following organizations play a crucial role.

The Institute of the National Housing Fund for Workers (*Instituto del Fondo Nacional de la Vivienda para los Trabajadores*, INFONAVIT) is a public sector finance institution, providing home mortgages [Infonavit 2012]. Together with FOVISSSTE it is one of two large public housing providential funds, both over 30 years old. INFONAVIT serves employees in the private sector, and FONHAPO serves the public sector employees. Both collect 5% of employees' salaries, withheld at source by the employer, through individual savings accounts [CONAVI 2011].

The National Housing Agency (*Comisión Nacional de Vivienda*, CONAVI) is a decentralized organization. It establishes housing policies and practices to achieve the objectives and goals of the Federal Government related to housing. It addresses policy strategies to different hierarchic levels, so as to provide for a more holistic approach towards sustainable urban growth. CONAVI, together with FONHAPO, is also one of two organizations that provide public subsidy programs directly to low income home buyers. Furthermore CONAVI has the responsibility to promote the issuing of Official Mexican Standards related to housing; favor the simplification of the administrative process related to housing, and create institutional links for technical assistance and information exchange between national and international organizations [CONAVI 2012b].

The Federal Mortgage Society (*Sociedad Hipotecaria Federal*, SHF) is a government-owned mortgage development bank and acts as a secondary mortgage market facility. SHF promotes the construction and acquisition of housing in the mid-range and social-interest sector [SHF 2012].

3.2.2 Political and programmatic framework

This paragraph lays out the political and programmatic framework related to the implementation of energy efficiency measures and the standard NOM-020-ENER-2011 in Mexico. First the embedding into the international context and the agreements under the Kyoto protocol will be laid out briefly. Following the relevant key strategies of the National Development Plan 2007-2012 (*Plan Nacional de Desarrollo 2007-2012,* PND) and the related programs and laws will be summarized (see table underneath for a list of the documents).

Table 3-2 Programs and laws related to energy efficiency in the Mexican housing sector

Abbreviation	Name of document
LASE	*Ley para el Aprovechamiento Sustentable de la Energía*
PECC	*Programa Especial de Cambio Climático 2009-2012*
PND	*Plan Nacional de Desarrollo 2007-2012*
PNV	*Programa Nacional de Vivienda 2007-2012*
PRONASE	*Programa Nacional para el Aprovechamiento Sustentable de la Energía 2009-2012*

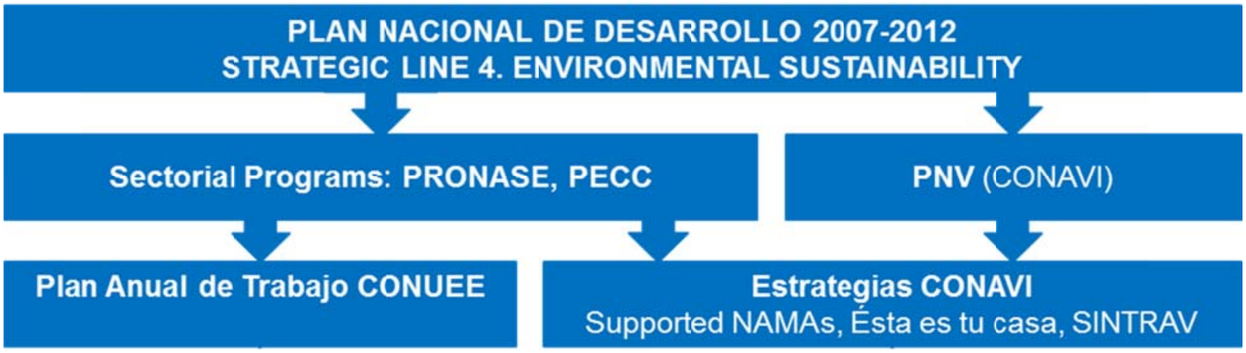
According to Sielfeld [2010] the Kyoto protocol and the related agreements particularly accelerated the incorporation of a series of measures at normative and technological level, leading to the reduction of environmental and negative economic impacts in several countries. The World Disasters Report 2010 [IFRC 2010] relates energy efficiency in the housing sector to the broader context of climate change, high-lighting the “co-benefits” of mitigation: this is to say that “reducing greenhouse gas emissions can meet broader goals of increased energy independence, lower costs and higher quality of life.”

The United Nations Framework Convention on Climate Change (UNFCCC) provides the global legislative framework for reducing global warming and responding to climate change. It convenes the annual meeting for negotiating emissions reductions and adaptation financing known as the Conference of the Parties (COP), e.g. COP17 in Durban, South Africa, held in December 2011. The Intergovernmental Panel on Climate Change (IPCC) is the global scientific body established by the United Nations Environment Program and the World Meteorological Organization (WMO). It produces Assessment Reports that summarize the state of knowledge on climate change and its potential consequences.

Mexico committed itself to climate change by signing the United Nations Framework Convention in 1992 and its ratification was approved in 1993. The Kyoto Protocol was signed by Mexico the 9th of June 1998 and its ratification was approved by the Mexican senate the 29th of April 2000. In November 2009 Mexico reported the Fourth National Communication to the United Nations Framework Convention on Climate Change (*México: Cuarta Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático*) [SEMARNAT 2009b].

The National Development Plan (*Plan Nacional de Desarrollo,* PND) [PND] is the document that contains the basis that establishes the governmental politics of Mexico for the different sectors. This document serves as the basis on which the different dependencies of the public sector define actions and programs to be implemented in economic, politic and social matter (see figure 3-5). The issue of climate change has been included for the first time in the PND under the strategic guideline number 4 which is dedicated to Environmental sustainability [INE 2012]. Objective 10 of the PND proposes to “reduce greenhouse gas emissions (GHG)”, and objective 11 proposes to “impulse measures of adaptation to the effects of climate change”.

Figure 3-5 Diagram of public policies regarding climate change in Mexico



The National Program for the Sustainable Use of Energy 2009-2012 (*Programa Nacional para el Aprovechamiento Sustentable de la Energía 2009-2012,* PRONASE) [PRONASE] establishes the strategies, objectives, actions and goals that allow for a more efficient use of energy, focusing on the reduction of energy end use. This valid legal frame incorporates different aspects of energy efficiency in various sectors, including the housing sector, into a common vision. Regarding the housing sector the program identifies the areas “illumination”, “household and building appliances”, and “construction”; which all fall under the field of activity of the National Commission for the Efficient Use of Energy (*Comisión Nacional para el Uso Eficiente de la* Energía CONUEE). The program identifies the construction sector as part of the medium and long-term cost-efficient opportunity areas. In its strategies 5.1 and 5.2 it highlights the need for improving the thermal insulation in new construction by means of supporting the incorporation of standards in building codes and by means of promoting respective best practices in construction.

In accordance with the PRONASE 2009-2012 CONUEE [2011] establishes in its Yearly Work Plan 2011 under the strategy *5.5 Edificaciones* the improvement of thermal insulation in new construction. To achieve this goal CONUEE establishes the line for support of the incorporation of thermal insulation standards in building regulations and for the support of the compliance of the applicable standards for the expedition of building permits for residential and non-residential buildings in the relevant climatic zones.

The Special Climate Change Program 2009-2012 (*Programa Especial de Cambio Climático 2009-2012,* PECC) [PECC] sets general guidelines to establish an ambitious Mexican GHG emission reduction pathway of -30% with respect to a business-as-usual scenario by 2020. This program sets the objectives and strategic guidelines for Mexico´s contribution, given a multilateral agreement by the UNFCCC and the related necessary provisions for adequate technical and financial support for developing economies [CONAVI 2011]. The National Appropriate Mitigation Action (NAMA) described within the Copenhagen Accord in December 2009 is seen by Mexico as an important tool to achieve the goals laid out in the PECC.

In order to support the governments’ goals in the PND 2007-2012, in 2007 CONAVI initiated the National Housing Program (*Programa Nacional de Vivienda*, PNV 2008-2012) [PNV]. Environmental Sustainability is a clear priority, established under the objective two of the PNV.

The plan promotes the dissemination of green-housing technologies, as well as the development and implementation of norms and regulations standardizing green-housing options in order to move towards high-quality, environmentally sustainable housing.

3.3 Financing and energy efficiency implementation initiatives

This paragraph will give a brief overview of the implementation strategies of sustainable housing policies related to thermal insulation standards in residential buildings. The potential of these strategies to foster the implementation of the standard NOM-020-ENER-2011, as well as the benefits of the standard to support those strategies, will be commented briefly.

Mexico has a strong housing financing program. Over 70 percent of the financing is generated by national agencies; see figure 3-6. This includes subsidies of the federal government for low-income families. About two thirds of the Mexican population falls into the low-income category. The ten largest homebuilders in Mexico account for 25 to 45 percent of the housing market. The low-income housing developments produced by these developers have 100 to 2,500 houses on average, while larger housing developments might contain more than 15,000 units [World Bank 2010a].

Figure 3-6 National Mortgage Financing Program – 2009 Results

Entity	Credits/Subsidies Number	Investment Million Pesos
INFONAVIT	447,481	98,297
FOVISSSTE	100,082	47,421
SHF	45,761	5,573
CONAVI	159,540	4,873
FONHAPO	180,929	2,364
Private Financial Institutions	144,786	66,595
Other Institutions #	50,038	9,051
Total	1,128,617	234,174 US$18,000 million*

Source: Data from <http://www.conavi.gob.mx/vivienda_en_cifra.html>. Cited by: World Bank 2010a

3.3.1 CONAVI

In order to face the challenges of social housing in Mexico, the government seeks to incorporate sustainability initiatives into its public housing policy strategies, so as to provide for sustainable urban growth. CONAVI establishes housing policies and practices to achieve sustainability in housing. It addresses policy strategies to different hierarchic levels, so as to provide for a more holistic approach towards sustainable urban growth. A set of projects was formulated for the levels of regional planning, urban development and housing (figure 3-7). These projects are all embraced by three strategic guidelines [Wolpert 2011]:

Migrate towards an integral vision of public policy for sustainable housing, considering:

- Regional planning, urban development and housing.
- Strengthen the leadership of local governments in the leadership of these areas. (Regional planning, urban development and housing.)
- Stimulate the financing of projects by means of green funds.

Figure 3-7 CONAVI Strategic Projects

STRATEGIC PROJECTS		
Regional Planning	**Urban Development**	**Housing**
▪ regional economic planning	▪ DUIS ▪ Redensification programs ▪ Low Carbon Urban Development LCUD – PNUD ▪ National Appropriate Mitigation Actions URBAN NAMA	▪ Vertical housing ▪ Basic caracterisitics of housing ▪ Clean Development mechanisms CDM ▪ National Appropriate Mitigation Actions for housing RESIDENTIAL NAMA

Source: Wolpert 2011.

Being in charge of establishing the housing policies and practices to achieve the objectives and goals of the Federal Government, CONAVI has several projects that related to the NOM-020-ENER-2011. CONAVI elaborated the *Código de Edificación de Vivienda*, CEV, which shall serve as a reference for construction regulations. Under its sustainability chapter it currently refers to the NMX-C-460-ONNCCE-2009 (a voluntary standard for thermal insulation in the building envelope), but in the next edition will promote the NOM-020-ENER-2011 as the reference for specifications of the thermal envelope.

The subsidy "*Ésta es tu casa*" of CONAVI represents an important effort in implementing sustainability aspects. The Federal Government contributes to the construction of sustainable housing by means of the *Ésta es tu casa* Program, providing subsidies to low-income citizens. When granted a subsidy the homeowner has to proof the fulfillment of sustainability criteria. The fulfillment of these measures leads in a significant way to a reduction of CO_2 emissions. This subsidy is accessible to a wider target group than the *Hipoteca Verde* from Infonavit, as it also includes citizens that are not beneficiaries of the social security. The subsidy is not linked to the acquisition of a new house; it also applies to refurbishment and auto-construction or auto-production of housing[11]

[11] Source: <http://www.conavi.gob.mx/programas-estrategicos/tu-casa>.

In March 2008 CONAVI published the document *Indicadores para Desarrollos Habitacionales Sustentables* [CONAVI 2008], which determine the basic sustainability parameters that have to be fulfilled as a prerequisite to obtain a federal housing subsidy. Currently, under the *Paquete Básico* [CONAVI 2009], regarding thermal insulation the compliance with the minimum "R"-values established by the NMX-C-460-ONNCCE-2009 is defined as mandatory. Including the NOM-020-ENER-2011 into the set of mandatory requirements would have a huge impact on the success of the implementation of the standard.

Another mission of CONAVI is the simplification of the administrative process related to housing, which is addressed by the implementation of the *Sistema Nacional de Trámites para Vivienda*, SINTRAV. SINTRAV is a software-platform that combines all administrative processes during the development of a housing project, from land acquisition till the selling of the home, within one single administrative unit. CONAVI will provide the software tools and technical assistance and training to the participating municipalities, thus addressing the problem of lacking resources of local authorities to ensure compliance and review of the building regulations. A possible future integration of the standard NOM-020-ENER-2011 into the SINTRAV would address the related respective issues. SINTRAV is currently implemented in pilot projects in 13 municipalities.

3.3.2 Sustainable Integrated Urban Developments – DUIS

The Federal Government defined the multidimensional strategy of the DUIS with the participation of several government agencies [Silva 2010]. DUIS result out of the participation/integration of public, private and social actors. A series of environmental, social and economic considerations is taken into account, so as to stimulate a sustainable urban growth. The developments provide for a mix of residential, commercial and industrial uses and maintain the connectivity between residential zones and urban centers, by means of providing street infrastructure and efficient public transport.

DUIS have to fulfill a series of sustainability indicators in order to be selected by an approval committee and in consequence get access to resources and incentives. Eleven Federal States participate in the DUIS-network in 2011. According to CONAVI today there are 4 projects authorized by the DUIS promotion and evaluation group (GPEDUIS), representing 250,000 housing units, 1,150,000 beneficiaries and an estimated investment of 93 billion MXN (considering the creation from zero) [Wolpert 2011].

3.3.3 International financing and Green Funds

The incorporation of energetic certification systems for residential buildings in several countries led to a reduction of the energetic consumption of the sector. In the majority of the cases this was achieved due to the complementary application of a series of measures at normative and technological level; of financial support, information and capacity building. Being voluntary processes in some cases or by means of regulations and obligatory standards in others, these measures incorporated a new dimension to the construction of housing. According to Sielfeld [2011] the expected results, in principal the reduction of environmental and negative economic impacts have been particularly accelerated since the Kyoto Protocol and the related agreements became effective.

December 19th, 2009, at the XV United Nations Climate Change Conference (COP15) by the Copenhagen Agreement; the developed countries compromised themselves to a green fund proposed by Mexico. For the period 2010-2012 it is foreseen to establish a fund of approximately 30 billion USD for supporting immediate actions facing climate change [SHF 2010]. At the 17th Conference of the Parties (COP17) to the United Nations Framework Convention on Climate Change (UNFCCC) in Durban, South Africa[12], the Mexican National Housing Commission (*Comisión Nacional de Vivienda*, CONAVI) presented the draft of the world's first Nationally Appropriate Mitigation Action (NAMA) in the housing sector. Its implementation is a key aspect of the Mexican government's strategy for "improving the energy efficiency of residential buildings, particularly in low- and medium-income markets where robust growth is expected over the coming decade" [CONAVI 2011]. This international carbon financing scheme will provide financing to cover subsidies for the implementation of sustainable practices in the housing sector, as well as for capacity building (see figure 3-8 for a diagram of the financing mechanism). This scheme has the potential to address the barriers of high upfront investment costs for energy efficiency measures and to address the issue of existing technical and administrative knowledge gaps by means of capacity building. In order to quantify the mitigation potential of proposed actions, the influence on the Energy Intensity ($kWh/m^2/year$) and the Carbon Intensity ($kgCO_2e/m^2/year$) needs to be demonstrated. This allows for the incorporation of these programs into the green fund financing scheme which then in return provides further funding for their realization.

The quantification of the mitigation potential can be done by means of different tools. Different studies proved the height of the reduction potential and the resulting CO_2-abatement cost, applying the PHPP or dynamic thermal simulations with *Design Builder*, using the calculation engine *Energy Plus*, or equivalent software. As these studies were performed in 2011 they do not consider the NOM-020-ENER-2011, which at the time of their elaboration was not yet promulgated. According to international standards the minimum legal requirements of the standard NOM-020-ENER-2011 have to be respected when calculating and establishing the qualification scales. It has to be proven, that the financing measures lead to an improvement with reference to the current valid legal requirements[13]. Due to this the standard affects the international financing schemes by defining the baseline reference for the calculation. As the standard was promulgated recently it has not yet been put into practice, and the current standards of building practices in Mexico are likely not to meet the requirements set by the standard. In this way the potential of energy efficiency improvement is less than if the baseline would be based according to the *status quo* of thermal insulation levels in Mexico.

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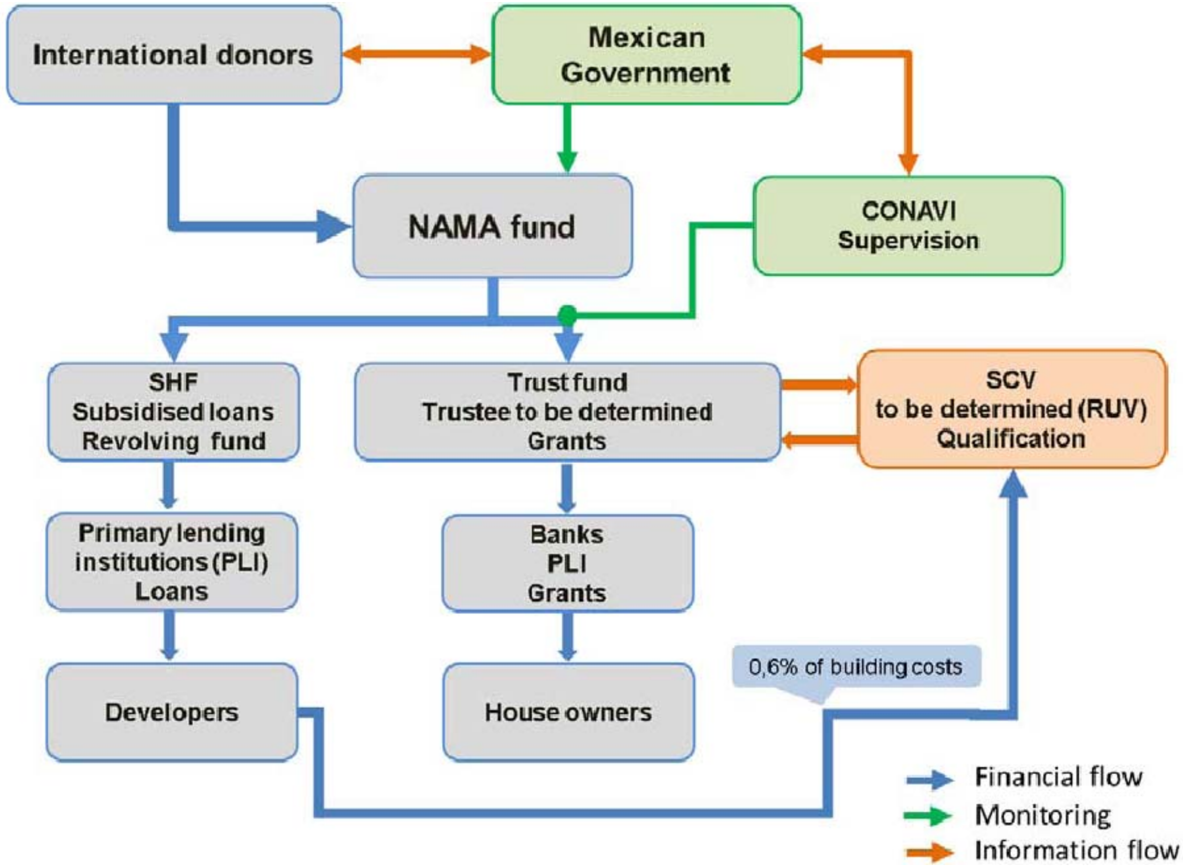
[12] Please refer to the following publication for further reading: *Comisión Nacional de Vivienda 2011, Supported NAMA for Sustainable Housing in Mexico – Mitigation Actions and Financing Packages*. CONAVI, SEMARNAT, Mexico City, viewed 01 July 2012, <www.conavi.gob.mx/viviendasustentable>.

[13] Personal communication with G. Kraft, IzN Friedrichsdorf, May 2012.

Figure 3-8 Financing mechanism of direct mitigation measures



Source: IzN Friedrichsdorf. Cited in: CONAVI 2011.

For a next step of the development of the NAMA schemes the standard NOM-020-ENER-2011 has to be considered for the definition of the baseline case to respect international standards. A possible scheme for the NAMA qualification scale could be established according to the following methodology.

1. The baseline case is established according to the minimum legal requirements. In this case this would be according to the specifications of the reference building, as defined by the NOM-020-ENER-2011.

2. Based on the baseline case calculation, the energy efficiency of the buildings is improved (better insulation, more efficient equipment, etc.) and using the same calculation tool as for the baseline case, improved values for all the relevant indicators are calculated.

3. Calculation of improvement targets:
   The values of the indicators received in step 2 are compared to the values of the indicators in step 1. The targets for the improvement, for example, could be defined as:

   20% of CO_2 savings with respect to the baseline case for the target 1
   40% of CO_2 savings with respect to the baseline case for the target 2

For the proposal for the Mexican NAMA in housing [CONAVI 2011] the PHPP tool was applied to quantify the mitigation potential of proposed actions, the influence on the Energy Intensity (kWh/m^2/year) and the Carbon Intensity (kgCO_2e/m^2/year). The study analyzed the row housing unit (*Adosada*), the isolated housing unit (*Aislada*) and the vertical housing unit (*Vertical*), which are analyzed in chapter 5 of this Master thesis. As this work assesses the impact of the implementation of the NOM-020-ENER-2011, the “Reference Building” case will indicate the Energy intensity and the Carbon Intensity that would form the basis for a definition of the baseline as described in the methodology mentioned above. In order to allow for comparability the boundary conditions for the calculations with the PHPP correspond to those that were assumed for the proposal of the Mexican NAMA. A discussion of how the baseline affects the resulting new qualification scales lies beyond the scope of this work.

The investigation of further typical housing typologies is recommended, so as to determine typical values to define the range for CO_2 emissions. These calculations will be done when the first version of the energy efficient housing design tool (*Diseño Energéticamente Eficiente de la Vivienda* – DEEVi) is available (see chapter 3.3.4). This Master thesis analyzes six selected projects, which cover a representative range of the classified housing types by the homogenized classification of housing according to type and value, and by the classification by number of housing units per lot (see chapter 5.3.1). The results therefore could form the basis for the recommended further research.

3.3.4 INFONAVIT, Sistema de Calificación de Vivienda

The *Hipoteca Verde* of INFONAVIT is an additional credit granted to the beneficiary when acquiring a dwelling, allowing for equipping the house with eco-technologies. These measures allow for diminishing the consumption of electricity, water and gas, thus diminishing the monthly expenses of the homeowner significantly, as well as reducing the related CO_2 emissions. The Program initiated as a pilot project in the State of Mexico in 2007, since then 253,450 credits have been given with *Hipoteca Verde*. In 2009 *Hipoteca Verde* is implemented at national scale [INFONAVIT 2012]. According to the Federal Mortgage Institution (SHF) [SHF 2010] the “Green mortgage” program is internationally recognized as a case of successful implementation of an energy efficiency program. A field study revealed that the consumption of electricity, water and gas diminished by more than 50%.

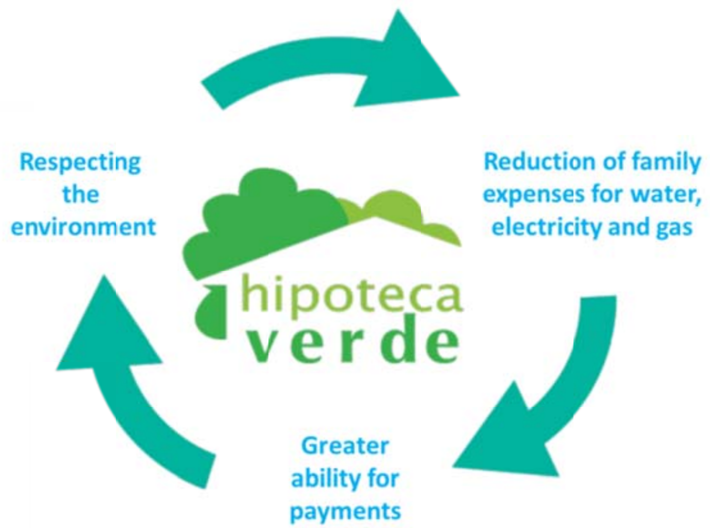
Table 3-3 Range of minimum savings and additional amount of credit *Hipoteca Verde*

Income	Minimum saving (pesos)	Maximum amount of HV	Additional amount of credit up to:
1 up to 6.99 VSM	215	Up to 10 VSM	$18,185.28
7 up to 10.99 VSM	290	Up to 15 VSM	$27,277.92
11 VSM and more	400	Up to 20 VSM	$36,370.56

Source: Camara Mexicana de la Industria de la Construcción 2012, Mexico City, viewed 01 July 2012, <http://www.cmic.org/comisiones/sectoriales/vivienda/2011/infonavit/HV_2011/HV.htm>.

The first generation of *Hipoteca Verde* consisted of fixed packages of different so called eco-technologies for the different climate zones. The second generation of *Hipoteca Verde* was designed as a flexible system. The client could choose the eco-technologies that best suit his needs; each eco-technology has a number of points assigned and the client could put together a set of technologies within a maximum number of points.

Figure 3-9 Virtuous circle of Hipoteca Verde



Source: INFONAVIT 2012

In 2010 GIZ started collaborating with Infonavit on the Development of new Housing Qualification System (*Sistema de Calificación de Vivienda* - SCV) for the Social Housing Sector in Mexico. In collaboration with Fundación IDEA and the Passive House Institute these efforts led to the development of the Green Housing Evaluation System (*Sistema de Evaluación de Vivienda Verde – SiSeViVe*). The objective is to elaborate a certification system that shall establish a minimum efficiency level for housing construction practice in Mexico. In the future the *Hipoteca Verde* shall be replaced by the SiSeViVe. The SiSeViVe system takes a holistic approach to measure the resource consumption of a building. A global performance index (*Índice Desempeño Global* - IDG) measures the overall performance of a building on a scale from 0 to 100. The index is composed by three indicators: i) Energy Demand, ii) Projected Energy Consumption, and iii) Projected Water Consumption.

$$IDG = A \cdot ED + B \cdot EC + C \cdot WC$$

Where:

IDG = *Indicador de Desempeño Global* – Global Performance Indicator
ED = Energetic Demand for cooling and heating in $kWh/(m^2y)$
EC = Projected Energy Consumption (incorporates projected consumption of electricity and fossil fuels, and contributions of renewable energy) in $kWh/(m^2y)$
WC = Projected Water Consumption
A, B, C = Weighting parameters. Values from 0 to 1.

Each indicator (ED, EC, WC) is multiplied by a weighting parameter according to a weighting scheme that weights each component depending on the thermal, energy and water conditions of the different regions. In areas, where water resources are scarce, for example, the water consumption indicator will have a greater weighting. Two planning tools have been developed to reliably estimate the before mentioned indicators, the housing water savings simulator (*Simulación del Ahorro de Agua en la Vivienda* – SAAVi), and the energy efficient housing design tool (*Diseño Energéticamente Eficiente de la Vivienda* – DEEVi).

Figure 3-10 Components SiSeViVe

DEEVi + SAAVi

=

IDG

The SiSeViVe qualification system uses a qualification scale, so as to inform the actors of the housing sector in an easily understandable manner about the environmental and energetic efficiency of each housing project. The qualification scale shall allow for an easy comparison between different housing projects and recognizes the efforts of the housing industry to develop more efficient residential buildings.

Figure 3-11 Qualicication scale of the SISEViVe

Calificación de eficiencia energética y medio ambiental	Aislada	Adosada	Vertical
A+	100 <	100 <	100 <
A	90 ≤ 100	90 ≤ 100	90 ≤ 100
B	75 ≤ 90	75 ≤ 90	75 ≤ 90
C	55 ≤ 75	60 ≤ 75	60 ≤ 75
D	35 ≤ 55	40 ≤ 60	40 ≤60
E	15 ≤ 35	20 ≤ 40	20 ≤ 40
F	0 ≤ 15	0 ≤ 20	0 ≤ 20
G	< 0	< 0	< 0

Source: GIZ / GOPA Consultants.

A Reference Baseline (F) is defined for each combination of climatic zone and the three housing types: i) Isolated housing (*Aislada*), ii) Attached housing (*Adosada*), and iii) Vertical housing (*Vertical*). In terms of energy efficiency the Reference Baseline refers to the Baseline defined for the Mexican NAMA for new housing. Regarding the water consumption the Reference Baseline refers to the permited maximum consumption according to the valid Mexican standards. Buildings that do not meet the demands for the Reference Baseline fall into the qualification level G. The qualification levels A and A+ stand for highly efficient homes (see figure 3-11). A label will inform the user and home owner in an easily understandable way about the efficiency and the benefits of the building (see figure 3-12).

Figure 3-12 Label of SISEViVe qualification system

Source: GIZ / GOPA Consultants.

As mentioned in chapter 3.3.3 the compliance with the valid local standards is a prerequisite when going for international financing of pilot projects. It has to be proven that the pilot projects serve to achieve an improvement with respect to the valid standards. For this reason the NOM-020-ENER-2011 has to be respected. Infonavit will require the fulfillment of the NOM-020-ENER-2011 from January 2013 on. In 2011 Infonavit internally discussed the possibility of adopting the NOM-020-ENER-2011 into the *Hipoteca Verde* package of eco-technology options, but there are certain knowledge gaps regarding the costs and the benefits of the implementation of the standard. It is suspected that the compliance with the standard could be too expensive, thus reducing the flexibility of the *Hipoteca Verde* system[14]. The economic evaluation in chapter 5 shall provide further results to evaluate this issue.

One difficulty is that the standard uses a “reference methodology”. As a consequence the indicators reported by the DEEVi, like (kWh/m^{2}y) vary greatly for the allowed maximum limit of heat gains[15], depending on climate and type of housing (see paragraph 5.6). Hence the standard will be integrated into by DEEVi by means of a data entry mask that serves the two calculation methods, using the same input values. In that manner, whilst evaluating the mitigation potential of a proposed design, at the same time the conformity with the standard will

[14] Personal communication with D. Loy, Consultant GIZ, November 2011.

[15] The standard defines a maximum heat gain for the theoretical model of a reference building. The heat gains of the projected building have to be equal or lower, so as to comply with the standard.

be proofed without additional time and effort. According to Gonzalez[16] the two concepts of the DEEVi and the NOM-020-ENER-2011 do not contradict themselves; it is rather the case that the standard will profit from the DEEVi. The DEEVi provides a calculation tool for the standard and at the same time the DEEVi is a transparent tool that allows estimating the effect of architectural measures of enhancing the building design, like optimized floor plans, orientation and compactness. In this sense the DEEVi could help to overcome the limitations given by the ”reference methodology” of the standard (see chapter 5.6).

The calculations performed with the Passive House Planning Tool in chapter 5 for the row housing type (*Adosada*), the isolated housing unit (*Aislada*) and the vertical housing unit (*Vertical*) furthermore served to study the certification scales. The reference building was modeled in PHPP according to the specifications of the standard. The results were used by Fundación IDEA to evaluate how the NOM-020-ENER-2011 would affect the certification scales, when used as reference for the baseline of certification scale.

Apart from allowing assessing the mitigation potential and the water consumption the two tools DEEVi and SAAVi will offer additional benefits to the developers. If the tools are officially recognized, the developers are able to prove that a development uses less energy or less water. As a consequence the infrastructure of a project can be dimensioned accordingly, thus reducing costs. For example if it can be proved that a new development uses less water, smaller water tanks can be installed, permits for the use of water can be obtained for smaller quantities and less investment is necessary for permits and construction of water wells. The collective electrical installations of a new housing development could be designed for a lower peak load; if it can be proved that energy consumption due to mechanical cooling is reduced significantly by energy efficient buildings. According to Mayagoitia[17] this would lead to important savings for the project. Furthermore the SiSeViVe will act as a tool for competitiveness that will help the developers to sell energy efficient houses. On the other hand, considering the environmental aspect, by means of the DEEVi it can be measured whom to support.

In the first phase of development the SCV will only focus on aspects on an architectural scale. In a second phase consideration of urban sustainability shall be integrated into the SCV. The Centro Mario Molina (CMM) currently develops a qualification system that addresses these issues. The Index of Sustainability in Housing (*Índice de Sustentabilidad de la Vivienda* – ISV) is a composed index, which is formed by indicators that contribute to form three specific indicators for social housing in Mexico: i) the environmental index, ii) the economic index, iii) the social index. The final objective of the index is to identify opportunities for improving the performance of housing development at national level. The results shall serve to orient decision makers and public policy makers in the tasks of incentivizing construction and sustainable practices in the sector[18]. A future incorporation or cross-reference between both qualification systems would provide for a holistic assessment of social housing in Mexico.

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[16] Personal communication with E. Gonzalez, AEAEE, July 2012.

[17] Personal communication with F. Mayagoitia, URBI, executive director VESAC, July 2012.

[18] Vivienda y Entorno Sustentable 2012, Mexico City, viewed 01 July 2012, <http://www.ves.ac/contenidos.aspx#5>.

3.4 Discussion

On one hand today we find a raising awareness about the issues related with mass housing provision. In order to face these challenges public housing policy in Mexico seeks to incorporate sustainability initiatives into their strategies, so as to provide for sustainable urban growth. On the other hand the system of housing provision itself remains untouched. The system of housing provision in Mexico is characterized by a top-down approach, allowing for minimal participation of the individual. Social housing on a large scale is still provided by big developers. The governance institutions provide loans to workers and guarantee the upfront payment to the developers.
By maintaining the same system of housing provision for more than 30 years, and by continuously trying to improve and to compensate failures of housing policy, Mexico could provide private owned social housing to a significant number of the population.

A number of social, ecological and economic problems are attached to the established schemes of housing provision. These current problems are a result of a strong demand for housing, a housing deficit and failed reforms of the system.

Informal workers, which are the most vulnerable group, are excluded from the housing provision scheme. Though in the political speeches each *Sexenio*[19] "the responsibility to meet the needs of those with fewer resources" was repeated continuously, the weakest of the Mexican society today still are excluded from the system of social housing provision, and the system is more beneficial to the big developers than the actual beneficiaries.

There is a raise of awareness about the current problems of the provision of mass housing in Mexico and current policy strategies seek to integrate sustainability considerations in policy guidelines and strategic projects. These issues are addressed at different hierarchic levels in a multi-dimensional approach with the participation of all mayor public, private and social players in the housing sector.

The Mexican Federal system delegates authority in many matters to State and Municipal governments. For the case of the NOM-020-ENER-2011 this implies that, although the standard is mandatory in the whole Republic, each of the 2,438 municipalities has to adopt the standard into its' building regulation, in order to make it a prerequisite for the issuing of a building permit. Due to the short mandate of the municipal administrations (three years), the approbation of reforms to the building codes by the city council is complicated, given the fact that the periods and political conditions interfere strongly in those processes.

The Mexican policy initiatives regarding energy efficiency standards for thermal insulation are embedded in the objectives of the PND, which also reflects the commitments of the Mexican Government to the UNFCCC. Institutions of the Executive power, like SENER, SEDESOL, and

[19] Sexenio – referes to the six year lasting period in which the president of the Mexican Republic and the governors hold their charges, without possibility of re-election.

decentralized organizations like INFONAVIT, CONAVI and SHF are in charge of implementing strategic projects to fulfill the governments' objectives regarding social housing and sustainability. Due to the authority of the State and Municipal governments organizations of the Federal Executive branch like CONAVI cannot force the adoption and implementation of its recommendations at municipal level.

National mortgage and subsidy programs like "*Está es tu casa*" and *Hipoteca Verde* foster the implementation of energy efficiency and sustainability measures in the social housing sector in Mexico. The subsidy program of CONAVI reaches an even greater number of people than the HV, as the subsidy is not limited to entitled members of the social security system. International financing schemes like the Mexican NAMA will have to respect the minimum requirements set by the valid standard NOM-020-ENER-2011, according to international standards. Projects applying for international funding have to prove a reduction of energy intensity and CO_2 emissions with respect to the national valid standards. Infonavit currently is elaborating a Housing Qualification System (SCV) that will also report the compliance with the standard, and provide an embedded calculation tool for the NOM-020-ENER-2011. The next chapter will analyze the regulatory framework and further aspects related to the implementation and compliance dimension. This information is relevant to assess the relation between the sustainable housing policies / housing programs and the standard. An overall discussion of the role of the NOM-020-ENER-2011 in relation to the programs of CONAVI and INFONAVIT will be given after chapter 4.

4 Review of the NOM-020-ENER-2011

4.1 Historical framework

This paragraph will lay out the history of the process of the development and introduction of standards for energy efficiency in the thermal envelope of buildings in Mexico. To close the historical framework, a subsequent paragraph lays out the role of the private sector, CONAVI and INFONAVIT in the before mentioned process.

4.1.1 History of thermal energy efficiency standards in Mexico

Energy Efficiency Building Codes (EEBCs) virtually did not exist prior to 1973. They were created by governments as one of many policy instruments in response to a worldwide “oil shock” in 1973 from an OPEC[20] oil embargo. Thus, many industrialized countries quite quickly developed and implemented EEBCs as part of a broad range of government and demand side management energy programs, in efforts to reduce their dependence on foreign sources of energy, especially oil [Deringer et al. 2004].

Mexico was one of the first countries in Latin America to implement an EEBC. Initial efforts date back to 1985, when the federal government first addressed the issue of high cooling energy consumption in northwest Mexican housing. Mexico´s federal administration changed in December 1988. This change provided a new opportunity for the enactment of energy efficiency standards. In September 1989, President Salinas de Gortari signed a bill that created the Mexican Energy Efficiency Agency (Comisión Nacional para el Ahorro de Energía – CONAE). One of the first established goals was to develop an Energy Efficiency Building Code (EEBC) for residential buildings in Mexico. In August 1991, the Mexican government proposed the first building energy standard and commissioned a review of the building codes of 23 cities and seven states in northern Mexico. However, this effort failed, primarily due to the fact, that the proposed standard contained no clear identification of the economic benefits of the proposed measures [World Bank 2010a].

In July 1992, the Mexican Congress passed a law requiring all federal government ministries to produce standards for their jurisdictions, participate in national standardization efforts, and organize consulting committees for these purposes. The standards produced under this structure are called Official Mexican Code (Norma Oficial Mexicana – NOM), or Mexican Standard (Norma Mexicana – NMX). The objective of the NOMs is to establish standard specifications for products, processes, and services that would otherwise represent security risks, affect the health of humans, animals, or plants, disrupt the general or labor environment, or affect the preservation of natural resources.

In 1993 CONAE started developing a commercial building envelope standard, with the support from the U.S. Agency for International Development (USAID), and technical assistance from

[20] Organization of the Petroleum Exporting Countries.

the Laurence Berkeley National laboratory (LBNL). The first draft of the mandatory energy efficiency standard for nonresidential / industrial buildings, NOM-008-ENER-1995, was completed in August 1997 [Huang et al. 1998]. After more than seven years of negotiations, the standard was finally promulgated in 2001 as NOM-008-ENER-2001. This standard only becomes effective if it is integrated into local construction regulations. Unfortunately, at the moment of promulgation the officials of CONAE had to struggle for the continuity of this organization. For this reason the promotion of the adoption of the norm was handed over to the *Fideicomiso para el ahorro de energía eléctrica* (FIDE), which did not show much commitment to the task [De Buen 2010]. In fact the standard was only adapted by 2 local building regulations. In ten years' time since its promulgation only 17 buildings have been certified, though in practice many new buildings fulfil and even exceed the standard. This is a matter of lack of information of the importance of building energy use by local authorities. It can also be attributed to the resistance of developers due to the costs of compliance, and the fact that they have already invested in very specific technologies that would become obsolete if new standard would require investments in equipment and training in new processes and in new supply lines for new materials [World Bank 2010a].

For one decade and during the mandate of four directors of the organization the project of an energy efficiency standard for residential buildings was kept within the "limbo" of the standardization committee of the CONAE [De Buen 2010]. The 09th of August 2011 the NOM-020-ENER-2011, Energy Efficiency in Construction – Thermal Envelope of Buildings for Residential Use was finally promulgated in the Official Journal of the Federation (Diario Oficial de la Federación – DOF) [NOM-020].

4.1.2 Role of the private sector, CONAVI and INFONAVIT

In the paper *El sector privado, al frente de la transición energética* De Buen [2010] lays out that despite the new environmentalist discourse of the Mexican Government of Felipe Calderon and the Ministry of Energy (Secretaría de Energía – SENER), the key driving forces behind the energetic transition in Mexico in the last six years have not been the officials of the federal government, but members of the private sector and NGOs.

The efforts of the Mexican National Fund for Workers´ Dwellings (Instituto del Fondo Nacional de la Vivienda para los Trabajadores – INFONAVIT), the *Instituto de Ecología* (INE) and the *Instituto de Ingeniería de la UNAM* (with marginal participation of CONAE and FIDE) for initiating, by means of studies and production of technical manuals, a process that nowadays led to the application of so-called eco-technologies and new residential projects throughout the country have to be recognized.

Housing construction in Mexico is technically regulated at the local (states and municipalities) level. Local rules differ greatly in their scope and requirements and are often inadequate to guarantee safety and quality of construction. In this context the Mexican National Housing Agency (Comisión Nacional de Vivienda – CONAVI) developed a national building regulation (Código de Edificación de Vivienda – CEV), published in 2007, and started promoting the CEV for adoption among local governments in 2008 [De Buen 2010]. The objective of the CEV is to regulate the urban housing construction process to improve public health, safety and welfare. The CEV covers basic requirements for energy efficient design and construction in its sustainability chapter [World Bank 2010a].

CONAVI has also been involved in developing a Clean Development Mechanism (CDM) methodology based on its housing projects. The methodology was approved in 2009. The anticipated carbon credits are expected to provide some incremental cost financing for participating housing projects, as well as to support development of a monitoring, evaluation and capacity building program.

The recent efforts by CONAVI represent an attractive approach to leverage market uptake of more efficient buildings through federal low-income housing subsidies. This could effectively demonstrate to both the supply chain and consumers the real benefits of applying and acquiring energy and water saving technologies. CONAVI is also starting to support several states and municipalities to incorporate CEV requirements into their building regulations and enforce compliance. This could be the beginning of a wider application of energy efficiency requirements in the Mexican building sector [De Buen 2010].

In March 2003 a group of manufacturers of thermal building insulation establishes the *Asociación de Empresas para al Ahorro de Energía en la Edificación* (AEAEE) [De Buen 2010]. On initiative of the AEAEE the Mexican Standard NMX-C-460-ONCCE-2009 “Building Industry – Insulation - “R”-Value for the Housing Envelope by Thermal Zone for Mexican Republic – Specification and Verification” was developed. The standard was enacted in August 2009 and establishes thermal insulation “R”-values for roof and walls of new houses in different locations under three scenarios: a) minimum, b) comfort, and c) energy efficiency [World Bank 2010a]. Since then it is referenced by the CEV as the standard requirement for the “R”-value for the CONAVI mortgage program [CEV 2010, p. 304]. The AEAEE turned into one of the main players pursuing energy efficiency. According to De Buen [2010] the support of the AEAEE was crucial for the regulatory framework of the housing mortgage subsidy-program of CONAVI, in particular when designing, negotiating and establishing the Mexican Standard that determines the levels of insulation that will be required for the subsidized housing program of CONAVI [De Buen 2010].

It has to be mentioned that several authors coincide that the resistance of the developers, due to higher construction costs, for new machinery and training, was one of the major barriers for the adoption of the NOM-008-ENER-2001 into local construction regulations.

According to Gonzalez[21], in the case of the production of social housing, Infonavit achieved to lower the resistance from the construction industry by gradually integrating the use of thermal insulation materials into the system of the *Hipoteca Verde*. In 2008 the HV integrated thermal insulation of the roofs surfaces, without specifying requirements regarding the R-Value. In 2009

[21] Personal communication with E. Gonzalez, AEAEE, July 2012.

the HV expanded the use of thermal insulation to roof surfaces and to the wall where the major thermal gains occurred. In 2010 the specification of a R-Value for the applied thermal insulation in roof and most exposed wall was introduced. By doing so the concept of thermal resistance (R-Value) was “introduced” into the sector.

Another fact supporting the thesis that the barrier of the resistance of the construction industry is about to be overcome is the creation of the association Housing and Sustainable Environment (*Vivienda y Entorno Sustentable* – VESAC[22]). The creation of the association was announced in the Sustainable Housing Forum 2011, with the aim to incentivate the production of sustainable housing projects, by means of measuring the ecological footprint of housing developments in Mexico. The group is formed by Conavi, Infonavit, Fovissste, Sociedad Hipotecaria Federal, Centro Mario Molina and some of the most important housing developpers, Grupo Sadasi, Consorcio ARA, Urbi, Casa Geo and Lean House Consulting. The development of the ISV (see chapter 3.3.4) was initiated by the VESAC.

4.2 Fundamentals NOM-020-ENER-2011

This paragraph first will explain briefly the different climatic zones of Mexico. Then the projection and the saving potential by the implementation of the standard will be laid out, followed by a description of the calculation methodology applied by the standard.

4.2.1 Climatic zones in México

In Mexico there exists a broad range of different climates, ranging from hot dry climates and high temperatures with high humidity, till temperate climates with a lot of rainfall and fog. The countries with EEBC for the building envelope are by majority the European and North American countries. In Europe the geographical extension of the countries is small and the majority of energy consumption is for heating in winter, for that reason the EEBCs generally comprehend minimum average thermal insulation requirements with one “R”-value for the whole country. In relation on the North American continent, thermal insulation serves in both seasons of the year: winter and summer. Mexico has to consider a code that contemplates the diverse range of climates in the country, due to its geographic location. This situation does not coincide with the former mentioned countries. In this respect the *Comisión Federal de Mejora Regulatoria* (COFEMER) agrees with the SENER that, due to the geographic characteristics of other countries it is not possible to use their regulations as a reference for the case of Mexico, given the broad range of climates present in the country [Cofemer 2011a]. The range of different climates in México needs specific design strategies. The CONAFOVI guide “Uso eficiente de la energía en la vivienda” [Conafovi 2006] provides bioclimatic design strategies for the different climates in Mexico.

[22] Source: <www.ves.ac>.

Different maps of the climatic and ecologic zoning have been developed in recent years. In 2006 Conafovi [CONAFOVI 2006] published a map of the ecologic regions of Mexico, which defines 7 different ecologic regions for the country (see annex I, figure 1). In the publication *Criterios e indicadores para desarrollos habitacionales sustentables* [CONAVI 2008] Conavi applies a regionalization that divides the country into four ecologic regions: i) arid zones, ii) tropical dry, iii) temperate zones, and iv) tropical humid (see appendix I, figure 2). Furthermore these four ecologic regions are subdivided into ten climatic regions (see table 4-1).

Table 4-1 Bioclimatic regions and ecologic regions according to CONAVI

Bioclimatic region	Ecologic region	Cities
10. Hot-dry	TROPICAL HUMID	Acapulco, Madero-Tampico, Campeche, Cancún, Cozumel, Chetumal, Manzanillo, Tapachula, Veracruz, Villahermosa
9. Hot semi-humid	TROPICAL DRY	Mérida, Colima, Ciudad Victoria, Mazatlán, Tuxtla-
8. Extremely hot-dry	ARID	Mexicali, Hermosillo, Ciudad Obregón, Chihuahua,
7. Hot-dry		Monterrey, Culiacán, Gómez Palacio, La Paz, Torreón
6. Temperate-humid	TEMPERATE	Tepic y Cuernavaca
5. Temperate		Guadalajara, Guanajuato, Chilpancingo
4. Temperate-dry		Aguascalientes, Durango, León, Oaxaca, Querétaro, Saltillo, San Luís Potosí, Tijuana
3. Semicold-humid		Xalapa
2. Semicold		DF, Toluca, Puebla, Morelia, Tlaxcala, Pachuca
1. Semicold dry		Tulancingo y Zacatecas

Source: CONAVI 2008.

The Köppen-Geiger climate classification is one of the most widely known. In 2007 Peel [*et al.*] published an update world-map of the Köppen-Geiger Classification (see appendix I – figure 3). Köppen separate the world into five main climate categories: i) tropical climate, ii) dry climates, iii) temperate climates, iv) continental climates, and iv) very cold, alpine or polar climates. Three main climate types, according to the Köppen classification, are featured in Mexico: A-tropical in the South and on the Western coast, B-dry in the Central regions inland and C-temperate in the North. Taking into account all the subcategories, Mexico features 12 different climates (see appendix I, table 1).

The voluntary standard NMX-C_460-ONNCCE-2009 for thermal insulation established a thermal zoning of Mexico applying the Degree Days methodology. Currently CONAVI is taking up this approach, developing a Degree Day map of Mexico.

According to Szokolay [2008] "for the purposes of building design a simple system (after Atkinson, 1953), distinguishing only four basic types, is adequate". The four basic climate types and their implication for the human thermal problem according to Szokolay are the following:

- ***Cold*** climates, where the main problem is the lack of heat (underheating), or an excessive heat dissipation for all or most of the year.

- ***Temperate*** (moderate) climates, where there is a seasonal variation between underheating and overheating, but neither is very severe.

- ***Hot-dry*** climates, where the main problem is overheating, but the air is dry, so the evaporative cooling mechanism of the body is not restricted. There is usually a large diurnal (day-night) temperature variation.

- ***Warm-humid*** climates, where the overheating is not as great as in hot-dry areas, but it is aggravated by high humidities, restricting the evaporation potential. The diurnal temperature variation is small.

4.2.2 Projections and savings potential

The energy savings that can be achieved with thermal insulation in low-income housing are substantial. According to simulations for low-income social housing carried out by the AEAEE savings of 25 to 34 percent of total electricity use could be achieved by using thermal insulation of the roof with R-15 and of R-16 for the walls and resizing of the air-conditioning units. Estimated costs for the thermal insulation ranges from US$ 600 to US$ 900, equivalent to about 5 percent of the construction cost of a low-income housing unit [World Bank 2010a].

A recent cost-benefit calculation by the SENER for the code-implied building efficiency measures during the projection period 2012-2026 came to the result that already after the first year of implementation the savings in energy consumption would result in positive benefits [Cofemer 2011a].

4.2.3 Design fundamentals NOM-020-ENER-2011

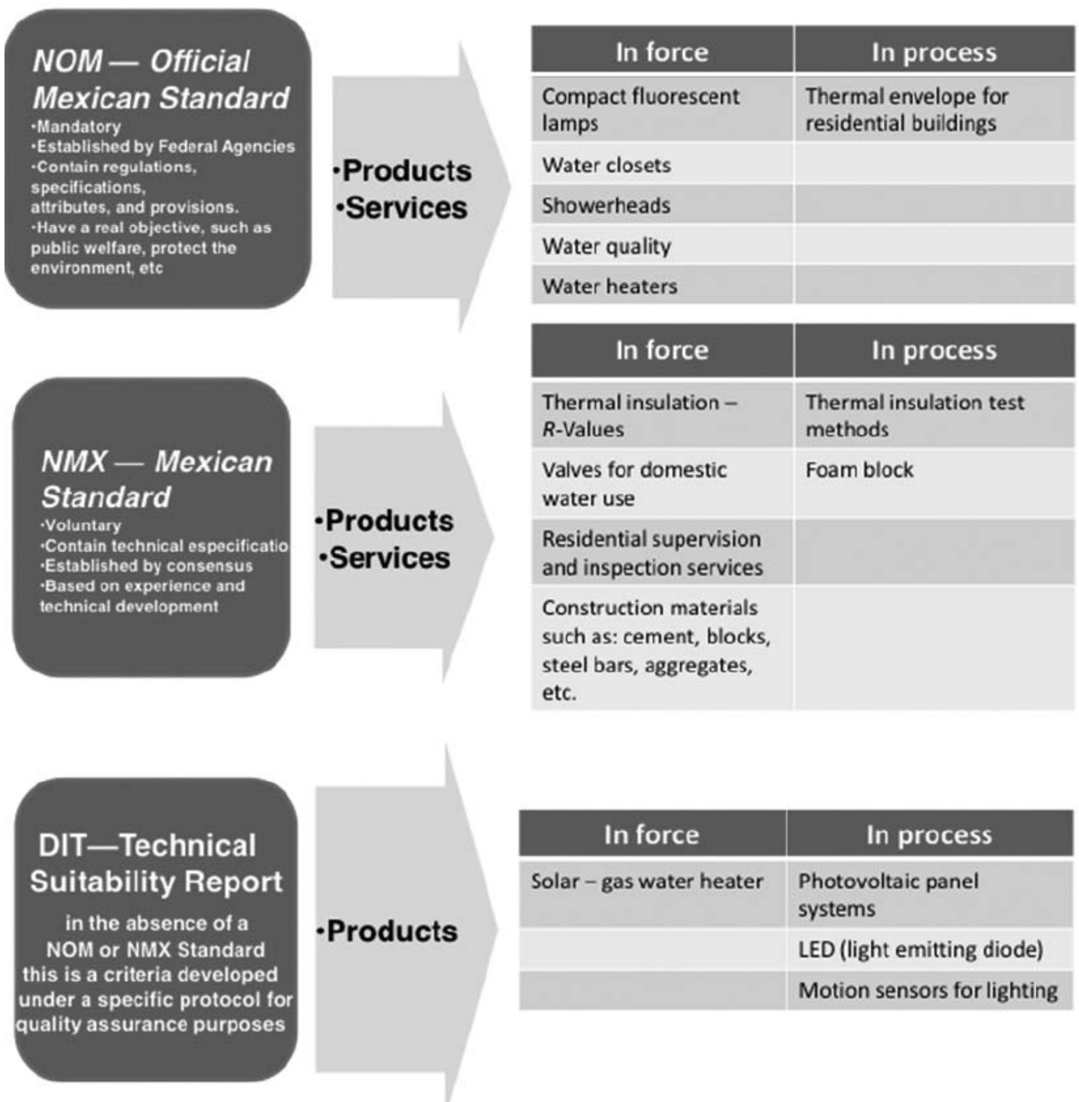
The Official Mexican Code (Norma Oficial Mexicana) NOM-020-ENER-2011 is a mandatory regulatory and control instrument, established by the CONUEE (federal agency). It is a first-generation energy efficiency standard. It´s objective is to optimize the thermal behavior of buildings by limiting heat gains through their envelope and to reduce the use of energy for space cooling.

The code establishes indicators to calculate the heat exchange according to the insulation material used during construction and classifies the buildings according to the energy savings in comparison to a reference value. The code sets minimum requirements for the design and construction of the envelope of new residential buildings and extensions of existing residential buildings. The code is performance based. Prescriptive requirements are used in defining the reference building to which the proposed building must be compared. The “R”-factors for walls and roof of the reference building vary by climate and are specified for 91 major cities. For compliance checks simplified calculation methods can be used. Apart from the thermal characteristics of the construction materials for every climate, locality and the impact or effect of the orientation that the dwelling should have, the code further implicates passive energy saving systems, like shading of windows, as well as specifications of minimum areas for skylights and natural lighting.

In order to comply with the specifications of the code, it is necessary to conduct an energetic estimation (evidence of conformity). The resulting heat gain of the energetic estimation of the thermal envelope of the projected building has to be smaller or equal to the heat gain of the thermal envelope of the reference building [Morillón 2009].

4.2.4 System of Mexican building energy and appliances codes and standards

Figure 4-1 System of Mexican building energy and appliance codes and standards



Source: World Bank 2010a

Based on the Federal Law on Metrology and Standards (*Ley Federal sobre Metrología y Normalización*), the National Standardization Program was established, requiring all federal government ministries to develop mandatory official technical standards (*Normas Oficiales Mexicanas* – NOM) for the areas they regulate [World Bank 2010a]. The mandate to develop appliance standards and building energy efficiency codes was transferred from SENER to CONUEE for the case of energy efficiency codes and standards.

The Mexican system of building energy and appliance codes and standards distinguishes three different types of standards. Official technical standards (*Normas Oficiales Mexicanas* – NOM) are mandatory and are to be established by Federal Agencies. Accredited private standardization organizations can pass voluntary regulations, the Mexican standards (*Normas Mexicanas* – NMX). Lowest in the hierarchy of standards, are the technical suitability reports (DITs) that can be developed to assure the quality of certain products and appliances that are not covered by NOM or NMX standards.

4.3 Barriers, challenges and opportunities

Recent assessment of the incorporation of energy efficiency standards in the Mexican construction regulation by CONUEE / GIZ [Rodríguez & Sielfeld 2010] and a World Bank Case Study on Mexico [World Bank 2010a] reveal a number of country-specific major barriers for the implementation and enforcement of energy efficiency standards in the Mexican context (see Figure 4-2).

- Lack of agreement between the different actors at the federal and state level.
- Lack of information of the importance of building energy use by local authorities and lack of knowledge of EEBCs at the appropriate political level, in combination with local autonomy over construction.
- Resistance from the construction industry. Due to cost of compliance caused by sunk investment in very specific technologies that have costs at a competitive level, and new investment in the equipment and training in the new process and in new supply lines for the new materials.
- Lack of institutional capacity to supervise the establishment and implementation of the proposed norms.
- Lack of resources from the local authorities to ensure compliance and review of building codes.
- Highly subsidized energy tariffs.[23] Elimination of most subsidies and enforcement of energy efficiency standards would substantially diminish peak loads due to air conditioning and eliminate the need for additional peak load capacity.

[23] Consumers living in hot climates where air conditioning is more likely, receive higher subsidies, both through lower tariffs in summer and higher consumption limits. In 2006, electricity subsidies not covered through the utility bill amounted to more than US$ 10 billion, about 1 percent of Mexico´s GDP, included in the budget of the federal government. Source: <http://www.jchs.harvard.edu/publications/international/pickering_w00-2.pdf>.

Figure 4-2 Barriers to EEBC Implementation and Enforcement in Mexico

Barriers for EEBCs in Developing Countries		Barriers to Implementation and Enforcement of an energy efficiency standard for thermal insulation in the Mexican context	
Key Barriers to EEBC Effectiveness.	Barriers to energy efficiency improvements in developing	Assessment of barriers in the Mexican context.	Barriers for EEBCs in Mexico
Source : Deringer, J. et al (2004)	*Source* : Koeppel, S. and D. Ürge-Vorsatz (2007) UNEP-SBCI	*Source* : Rodríguez, S. and R. Sielfeld (2010), GIZ Mexico	*Source* : Liu, F. et al (2010), The World Bank
1.) Strong first cost bias.			Limited borrowing capacity for housing of low-income households limts the investment that can be incorporated by developers in such housing.
2.) Access to building finance.	Lack of financing.		
3.) Lack of consistent international funding.		Lack of resources from the local authorities to ensure compliance and review of building the codes.	
4.) Lack of Governement Championship.			
5.) Availability of energy efficienct materials in the local market.			
6.) Lack of equipment testing / certification.			
7.) Transition in energy expertise.	Lack of knowledge among architects. Lack of qualified personnel.		
8.) Lack of awareness and tools.	Lack of awareness of the importance and the potential of energy efficiency improvements.		Lack of information of the importance by local authorities and lack of information of EEBCs at the appropriate level, combined with local autonomy over construction.
9.) Corruption and potential code official abuses.			Doubts about effectiveness of EEBC compliance enforcement if combined to the building permit process, due to "extreme discretionality of the authorities" in the "verification process".
	Training of institutions required.	Lack of institutional capacity to supervise the establishment and implementation of the proposed norms.	
		Lack of agreement between the different actors at the federal and state level.	Compliance with the commercial EEBC is not part of the official list of requirements for a building permit in any municipality.
		Resistance from the construction industry.	Resistance from the construction industry. Due to sunk investment costs, new investment in equipment/ training, new supply lines for materials.

The enforcement of building codes and incorporation of energy efficiency norms are crucial for the development of an integrated approach towards sustainable housing in Mexico. Sufficient resources on basis of a long-term commitment need to be dedicated so as to allow for implementation, enforcement, regular evaluation and monitoring. If this is provided, and enforcement can be secured, regulatory and control instruments such as codes are amongst the most effective and cost-effective instruments, allowing for high GHG emission reductions [Köppel & Ürge-Vorsatz 2007]. Further success factors mentioned by Koeppel and Ürge-Vorsazt [2007] include a well-planned and phased implementation, allowing for pilot projects and fostering adequate support to the respective institutions, designers and engineers, as well as coordination with similar projects. This conforms to the results of an assessment of the potential of different EEBC implementation activities for overcoming key barriers by Deringer et al. [2004]. The implication is quite strong that more emphasis (and funding) should be placed on combining regulatory approaches with (1) market transformation approaches, and (2) more comprehensive, well-planned EEBC implementation programs, such as those outlined below in Figure 4-3.

Figure 4-3 Potential of Implementation Activities to Overcome Key Barriers

	Potential for Overcoming Barriers (H=High, M=Medium)								
EEBC Implementation Activities	1 Strong first cost bias	2 Access to building financing	3 Lack of long-term donor commitment	4 Lack of Government Champion	5 Availabilty of efficient products	6 Lack of equipment testing & certification	7 Limited local energy expertise	8 Lack of awareness and tools	9 Potential Abuses
1 Promulgation	H		H	H					H
2 Compliance Process			H					H	
3 EEBC Administration and Enforcement Structure	H		H		M	M		H	
4 Training and Capacity Building			H				H	H	
5 Outreach and Public Information Programs			H	H			M	H	H
6 Estimate energy savings and cost effectiveness			H	M	M		M	H	M
7 Market Transformation Programs	H	H	H		H	M	H	H	
8 Program of Multiple Demonstration Buildings	H	M	M	M	H	M	H	H	M

Source: Deringer et al. 2004

The federal funded and subsidized housing programs that require the application of energy efficiency investments have the potential to become successful large-scale demonstration projects for energy-efficient, sustainable construction. Due to the efforts of CONAVI municipalities are becoming more open to the incorporation of energy efficiency requirements into their building regulations and many of them seem to be willing to consider the adoption of the CEV [World Bank 2010a].

A number of further necessary measures proposed by the World Bank Case Study on Mexico include:

- Adoption of regulations under CONAVI and INFONAVIT programs.
- Design and implementation of a nationwide information program directed at municipal authorities to help them understand the importance and potential of energy efficiency in buildings and the relevant instruments and mechanisms in place (national standards and codes).
- Increase and strengthen capacity of UVs.
- Data gathering.
- Identify funding.

4.4 Implementation and compliance

This paragraph exmines the implementation and compliance dimension according to the research model. First the legal framework for the compliance and enforcement of the standard will be laid out. Subsequently the process of compliance and verficiation and the function and nature of the verification units will be explained briefly. Finally the needs and current capacity building activities will be summarized, and the process of the elaboration and conception of the Manual for the NOM-020-ENER-2011 will be described.

4.4.1 Energy efficiency standard development, implementation and enforcement

In Mexico, there is no national law that defines the basic premises for health and safety aspects of construction projects. The local governments of the 2,438 municipalities in Mexico can self-responsibly design and implement building codes and norms for setting standards and rules for urban planning, urban design, and building construction, and building regulations are established et the level of the states and municipalities. In the case of construction the standards and codes have to be adopted by the local building regulations, so as to form part of the requirements for receiving a construction permit. According to Rodríguez and Sielfeld [2010] at least each state of the federal republic disposes of a state building code. For the field of application of building codes some cases refer to the state building code, whereas other municipalities have their proper municipal building code. According to De Buen [2010] the country lacks a unified code and the dispersed nature of activities and the decentralized political configuration in Mexico (see paragraph 3.2.1) lead to a number of different construction regulations. The fact that the enforcement of the energy efficiency standard should be done at the regional level, makes it a difficult process to manage and monitor.

The revision of construction regulations is of municipal character and has to be approved by a commission which members are nominated by the municipal president. The commission has to be assembled by representatives of the Association of Civil Engineers, the Association of

Architects, the Association of Mechanical Engineers, representatives of professional organizations, and other public and private organizations or institutions that are considered appropriate. The town council has to be represented by an equal number of representatives. The approval of the regulations depends on the agreement of key players of the municipal administration like: the Municipal President, the Secretariat of Urban Development, the Public Works Department, the Syndicates and City Councils. Due to the short duration of the municipal administrations (three years), the approbation of reforms to the building codes by the city council is complicated, given the fact that the periods and political conditions interfere strongly in those processes [Rodríguez & Sielfeld 2010]. The construction regulations in Mexico have been modernized little by little. Many of the included revisions date back to the earthquake in 1985 and put emphasis on structural security.

Municipalities have the primary right to issue licenses and permits for construction. The enforcement and compliance of building codes is under their authority. Also, they are in charge of inspecting for compliance with the code. Compliance is demonstrated through a set of documents that have to be presented and signed by accredited third-party, private-sector agents [World Bank 2010a]. The housing units in the social housing sector in Mexico fulfill very basic needs. According to Rodriguez and Sielfeld only 21.6 % of the houses financed by Infonavit in 2009 counted with a useable floor surface of more than $50m^2$. Several building codes in Mexico exclude residential constructions with floor surfaces of less than 50 m^2 (in some cases less than 30 m^2) [Rodríguez & Sielfeld 2010]. This is to say a large percentage of new housing projects do not have to apply local building codes.

In comparison with many other countries, the process of obtaining construction permits is fairly well established and involves relatively little time and costs. The best performers among Mexican cities do better than their counterparts in other OECD countries. Thus, in principle, the system of building code enforcement in Mexican municipalities is fairly well established. The system for verifying compliance with federally mandated codes and standards is already in place. Some observers have, however, identified "extreme discretionality of the authorities" in, among others "the verification process." This raises doubt about the effectiveness of energy efficiency standard compliance enforcement if energy efficiency requirements are added to the permit process [World Bank 2010a].

In 2010 CONAVI published the second edition of the *Código de Edificación de la Vivienda,* CEV, which promotes the application of the relevant valid standards, and includes design and sustainability recommendations for the different bioclimatic zones. At present the CEV only serves as a reference for construction regulations. This is due to the fact that building regulations are established at the level of the states and municipalities. Being a federal agency, CONAVI cannot force the adoption and implementation of its recommendations.

The current mandatory standards related to energy efficiency in housing are listed in the table 4-2. In addition there are some 20 valid energy efficiency standards for household appliances. The voluntary standard NMX-C-460-ONNCCE-2009 establishes specifications for the total thermal resistance ("U"-Value) that applies to the thermal envelope of residential buildings, according to the climatic zone in which the building is located. The elaboration of the standard was initiated by the *Asociación de Empresas para el Ahorro de Energía en la Edificación*, AEAEE, and in contrast to the NOM-020-ENER-2011 applies the degree-days methodology.

Table 4-2 Standards related to energy efficiency in the Mexican housing sector

Standard	Name of document
NOM-018-ENER-2011	*Aislantes Térmicos para Edificaciones. Características y Métodos de Prueba*
NOM-020-ENER-2011	*Eficiencia Energética en Edificaciones. Envolvente de Edificios para Uso Habitacional*
NOM-028-ENER-2010	*Eficiencia Energética de Lámparas para Uso General. Límites y Métodos de Prueba*
NMX-C-460-ONCCE-2009	*"Industria de la Construcción – Aislamiento Térmico – Valor "R" para las Envolventes de Vivienda por Zona Térmica para la República Mexicana – Especificaciones y Verificación"*

In order to face the problem of municipal authority in the adoption of standards to local building regulations Rodríguez and Sielfeld [2010] propose the elaboration of a set of *Normas Técnicas Complementarias*, NTC regarding "Energetic Sustainability" by means of incorporating energy efficiency measures and renewable energies. The NTC are issued by the Department of Public Works of the municipal administrations, and would represent a mechanism of implementing technical standards through building regulations, without having to reform the regulation. Specific NTCs would have to be developed by a technical committee for the 10 bioclimatic regions of the country. The NOM-020-ENER-2011 would then be adopted into the NTCs according to the benefits in the different regions.

According to the Annual Work Plan CONUEE fosters the adoption of the standard NOM-020-ENER-2011 into local building regulations by establishing collaboration with several pilot municipalities so as to promote the adoption into local construction regulations.

4.4.2 Compliance process and Verification Units (UVs)

The compliance with the standard is monitored, verified and certified by designated Verification Units (*Unidades de Verificación* - UVs). There are 185 UVs in the country, but some states do not have any UV. According to CONAVI [2010], due to their low capacity and limited number of UVs and the lack of supervision of their work, the enforcement of building codes and norms in Mexico is very low [CONAVI 2010].

Three different types of legal forms of Verification Units are authorized, allowing for example that a big housing developer has an internal UV, if certain conditions are given. These questions are regulated in the following legal documents (see table 4-3). The Manual of the NOM-020-ENER-2011 features a chapter on the accreditation of Verification Units, the different legal forms and the process of verification and certification. For this reason this chapter treats the topic only briefly.

Table 4-3 Regulations concerning the accreditation of UVs and the compliance process

Name of document
P.E.C. NOM-020-ENER-2011 *Procedimiento para la evaluación de la conformidad de la Norma Oficial Mexicana NOM-020-ENER-2011, eficiencia energética en edificaciones, envolvente de edificios para uso habitacional.*
NMX-EC-17020-IMNC-2000, ISO/IEC 17020: 1998, *Entidad Mexicana de Acreditación, A.C. 2010, Manual de procedimientos aplicación de la Norma NMX-EC-17020-IMNC-2000 para unidades de verificación (organismos de inspección).*
LEY Federal sobre Metrología y Normalización
Reglamiento de la ley federal sobre metrología y normalización

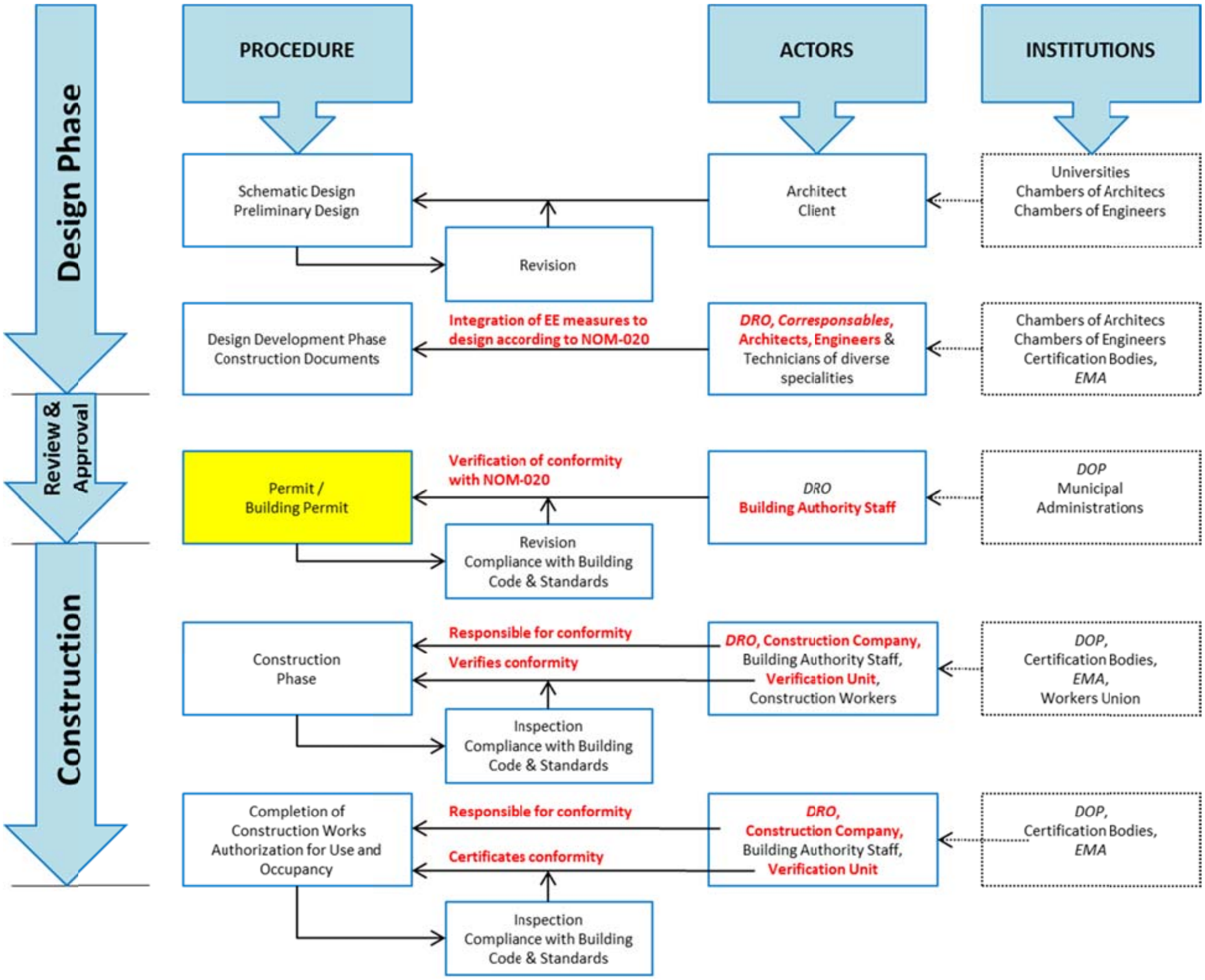
With each standard a document for the Procedure of the Evaluation of Conformity (*Procedimiento para la evaluación de la conformidad de la Norma Oficial* – PEC) has to be established. This PEC defines the procedure of the monitoring, verification and certification of the compliance with the standard.

At the time of concluding this work the PEC was still not published, nevertheless a draft for the document is in the process of internal revision in CONUEE. Figure 4-4 shows a diagram of the different steps and the involved key actors related to the implementation of energy efficiency measures in the construction process. The processes related to the verification and compliance of the NOM-020-ENER-2011 is represented in red font. According to the construction process the author proposes the following process:

1. A previous report (*predictamen*) should be demanded as a prerequisite for the issuing of the building permit, certifying that the design of the building fulfills the minimum requirements of the standard.

2. A final report (*dictamen*) should be demanded as a prerequisite for the issuing of the Authorization of Use and Occupancy, certifying that the execution of the building is compliant with the authorized specifications (*predictamen*), or in the case of design changes posterior to the issuing of the *predictamen*, that the construction fulfills the minimum requirements of the standard.

Figure 4-4 Steps and key actors for the implementation of EE measures in Mexico[24]



Source: Own elaboration, after: *Energía sustentable en la Edificación*, CONUEE / GTZ.

Currently there no UVs accredited for the NOM-020-ENER-2011, as the standard was promulgated recently. In order to foster the process of accreditation, CONUEE will offer the training and the exam for the UVs in the NOM-020-ENER-2011 free of charge. Nevertheless the fees for the accreditation as certifying body by the Mexican Accreditation Entity (*Entidad Mexicana de Acreditación* – EMA) will apply.

4.4.3 Capacity building and Manual NOM-020-ENER-2011

According to the World Bank [2010] the lack of information of the importance of building energy use by local authorities and a lack of knowledge about energy efficiency standards at the appropriate political level, in combination with local autonomy over construction, is one of the

[24] The same figure is provided in the Appendix II (Steps and key actors for the implementation of EE measures) in a larger scale, so as to allow for legibility.

major barriers to the implementation of the standard. A recent assessment of the incorporation of energy efficiency standards in the Mexican construction regulation by CONUEE / GIZ [Rodríguez & Sielfeld 2010] identified the lack of institutional capacity to supervise the establishment and implementation of the proposed norms as another barrier. Several related capacity building initiatives are currently ongoing. In the frame of its Annual Work Plan CONUEE fosters the adoption of the standard NOM-020-ENER-2011 into local building regulations by establishing collaboration with several pilot municipalities so as to promote the adoption into local construction regulations. Furthermore CONUEE addresses technical and administrative knowledge gaps by means of elaborating a Manual for the NOM-020-ENER-2011 in collaboration with GIZ. Next the different ongoing capacity building activities and their importance for the NOM-020-ENER-2011 will be explained, followed by a short description of the development process for the Manual of the NOM-020-ENER-2011 and the contributions of the author within the frame of this Master thesis.

Beginning of 2012, CONUEE carried out workshops directed at local and federal authorities in various municipalities throughout the country, so as to train and inform about the NOM-020-ENER-2011. In parallel the Association of Companies for Energy Saving in Buildings (*Asociación de Empresas para el Ahorro de Energía en la Edificación* – AEAEE) carried out a series of workshops in Mexico directed at professionals in the field of social housing construction. According to Gonzalez[25] more than 1,500 individuals assisted to the training workshops for the NOM-020-ENER-2011 by the AEAEE. Furthermore the same organization developed a spreadsheet calculation tool that simplifies the calculation according to the standard. This tool is available free of charge and was distributed in the frame of the training workshops.

INFONAVIT is planning to implement the Green Housing Evaluation System SiSeViVe (see chapter 3.3.4) in November 2012 at national level, and will demand if for all new dwellings that are financed by the institution. Institutions like CONAVI, Fovissste and SHF are also planning to adapt the tool. For this reason the social housing industry needs to be trained in the application of the qualification system and the use of the tools. In July 2012 the Passive House Institute on behalf of INFONAVIT trained 40 multipliers as instructors for the SiSeViVe and the according calculation tools. From September 2012 these multipliers will train professionals in the field throughout the country. The spreadsheet calculation tool developed by AEAEE was further adapted and integrated into the DEEVi. A special part of the course will explain the calculation methodology of the NOM-020-ENER-2011 and the use of the tool. For this reason the efforts of INFONAVIT will also foster the implementation of the standard on a large scale.

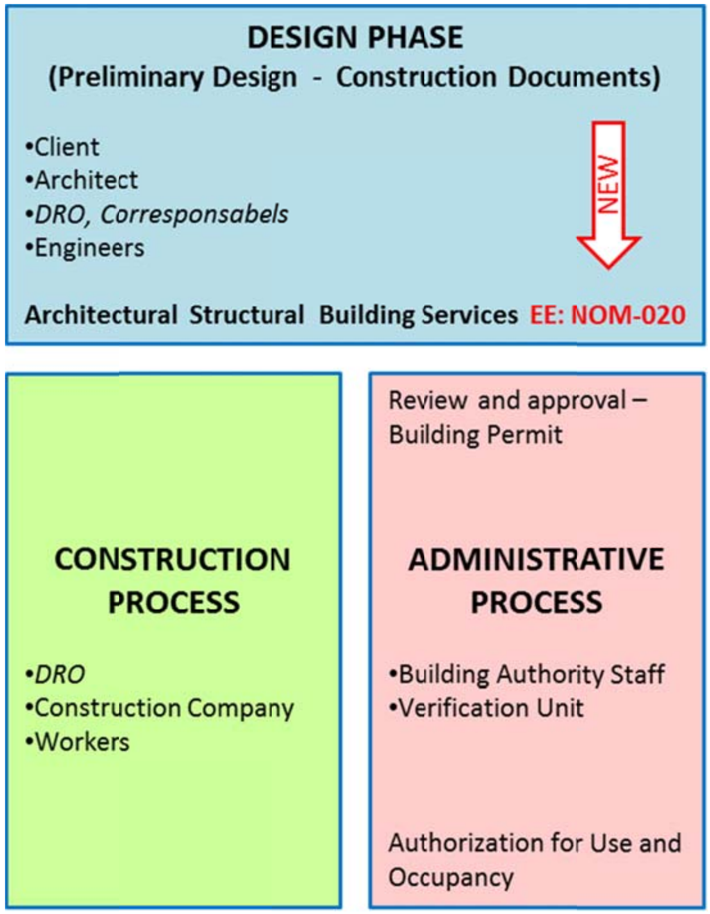
Manual NOM-020-ENER-2011

Within the framework of the consultancy of GIZ / GOPA to CONUEE the author collaborated in the elaboration of a Manual for the NOM-020-ENER-2011. Based on the examination of the construction process in Mexico and the involved key actors, a model for the process of the verification, monitoring and certification of the energy efficiency standard was established (see figure 4-4, paragraph 4.4.2). Based on this model three different processes and phases were

[25] Personal communication with E. Gonzalez, AEAEE, July 2012.

identified, according to the role of the different involved actors: i) design phase, ii) construction process, and ii) administrative process (figure 4-5).

Figure 4-5 Focus groups and construction process



These three groups of involved actors form the focus groups at which the Manual is directed. Based on the analysis of the construction process and the focus groups, a table of contents of the Manual was established, discussed and agreed upon with CONUEE. This table of content formed the basis for the contracting of an external consultant for the elaboration of the Manual and the compilation of the content. This Master thesis delivered a series of contributions to the content of the Manual. The experiences from the application of the standard, calculating different housing types, helped to identify questions and doubts regarding the correct interpretation of the standard. These doubts were clarified in several sessions with the area of Standardization (*Normatividad*) of CONUEE. Furthermore the calculations of the housing types row housing unit, middle segment (*Medio*), isolated housing unit, residential segment (*Residencial*), and vertical housing unit (*Vertical*) were selected as examples to be shown in the Manual. These examples allow illustrating a wide range of possible frequently asked questions.

The publication of the Manual is foreseen for September 2012. This would allow for a distribution within the frame of the SiSeViVe training workshops, thus allowing to reach a large number of professionals.

4.5 Discussion

One of the key points for a successful implementation is the adoption by local construction regulations. The strategies and programs of the federal institutions like PRONASE and the PNV target the adoption of the standard into local construction regulations. In general three different approaches can be distinguished: i) Adoption of the standard as a prerequisite for existing housing subsidies (financial incentives and market-transformation approach), ii) Integration of the standard as a baseline for a certification system related to supported NAMA-schemes (financial incentives and market-transformation approach), iii) Adoption of the standard into construction regulations in form of a set of “Sustainability” NTCs, specifically adapted to the ten different bioclimatic regions (mandatory approach).

The adoption of the standard as a prerequisite by the *Hipoteca Verde* and *Ésta es tu* casa program is likely to favor the large-scale implementation of the standard, allowing for market transformation, considering that the financing institutions INFONAVIT and FOVISSTE make up around two thirds of the mortgage market [CONAVI 2011]. But this implies that the administrative infrastructure for the compliance with the standard has to be established.

The integration of the standard as a baseline for a certification system under a supported NAMA-scheme would have the co-benefit that the NAMA financing scheme would provide funding for the implementation of administrative infrastructure, technical assistance and capacity building. The administrative infrastructure also would allow for the implementation and compliance with a mandatory minimum insulation standard.

The adoption of the standard in form of a set of “sustainability” NTCs seems to be a strategy to collaborate more efficiently, first at state level, updating the state building regulation which then serves as a reference regulation for the different municipalities. Nevertheless experiences from negotiating the adoption of a standard for solar thermal collectors at municipal level reported that it is already “a good achievement if two lines of the building regulation are adapted”[26], confirming the statement of Rodríguez, that the approbation of reforms to the building codes by the city council is a complicated process.

In comparison to the time of promulgation of the NOM-008-ENER-2001 today we have a more beneficial context, due to the efforts made by the private sector and the mortgage programs of CONAVI and INFONAVIT. The strategies and programs of the federal executive institutions have the potential to tackle different barriers to the implementation of the standard NOM-020-ENER-2011, like for example, the resistance due to high-upfront investment costs, or the lack of institutional capacity to supervise the establishment and implementation of the standard. Although the NOM-020-ENER-2011 was not embedded into a policy-package, the present-day context, with the existence of a voluntary energy-label (NMX-C-460-ONCCE-2009), the *Código de Edificación de Vivienda* (CEV), as well as several showcase-developments throughout the country, includes various components considered necessary to allow for a market

[26] Personal communication with E. Villaseñor, Executive Director of ICLEI México, July 2011.

transformation. The adoption of the standard into the SiSeViVe Housing scheme of INFONAVIT will foster the implementation of the standard and provide for training of professionals in the field, as the standard is embedded in the calculation tools.

The development of a Manual for the standard will tackle the issue of a lack of information amongst professionals in the field of social housing construction, personal of local and federal authorities and provide the necessary information to the possible future verification units. By doing so the Manual shall facilitate the compliance with the standard and allow for an understanding of the importance and potential of energy efficiency in buildings and the relevant instruments and mechanisms.

The enforcement of the code is crucial when implementing a first-generation energy efficiency standard. For this reason, in parallel to the promulgation of the NOM-020-ENER-2011 assistance needs to be provided for implementation and enforcement. This could be initiated by collaborating with a small number of selected municipalities and fostering them assistance in the implementation and compliance process, so as to detect possible obstacles and to provide for more comprehensiveness of the energy efficiency standard implementation program.[27] By working with municipalities that already host showcase developments of CONAVI or INFONAVIT, a functioning program could be developed, for subsequent adoption in other municipalities. The federal mortgage program therefore is a good strategic ally in achieving adoption of the code in local construction regulations. The Clean Development Mechanism financing, established in collaboration with CONAVI in 2009 is a potential source of funding for the respective monitoring, evaluation, and capacity building.

Concluding, it can be remarked that the NOM-020-ENER-2011, as the only official standard for thermal insulation in the building envelope of residential buildings, is the legally binding reference for the federal mortgage and subsidy programs and housing policies. According to international standards the minimum legal requirements of NOM-020-ENER-2011 are the reference for a baseline when measuring the abatement potential in relation to international financing of energy efficiency implementation. In this sense, the standard reduces the mitigation potential, given the fact, that the levels of thermal insulation, that are current standard in social housing construction in Mexico, are likely not to meet the minimum requirements of the standard in the majority of the cases. The research question “Does NOM-020 support / stimulate these programs or could it even become a barrier if it is not technically solid, useful or applicable?” can best be answered the other way around: It can be observed that the sustainable housing policies and housing programs, as well as the efforts of organizations like INFONAVIT and CONAVI in implementing these programs, support and stimulate the implementation of the standard NOM-020-ENER-2011.

[27] Personal communication with S. Rodríguez, GIZ México, September 2011.

5 Potential impact dimension

This chapter analyzes the potential impact dimension of the research model. An energetic analysis shall identify the potential impact of the implementation of the standard on the energy consumption (kWh/m^{2}y) according to typology, climate zone, cost and size of the building. The economic analysis shall identify the cost associated with the compliance of the standard (investment payback time and net benefit) and the financial impact for the housing sector according to typology, climate zone, cost and size of the building.

In the first section of this chapter the design of the study and the methodology are laid out. Subsequently the six housing types under study and the four locations and their according climate are described. The main section is subdivided into paragraphs corresponding to the six different types of housing, of which each is analyzed in the before mentioned four different climates. Each paragraph consists of:

a) Architectural description.
b) Results of the energetic evaluation according to the NOM-020-ENER-2011.
c) Results of the energetic evaluation with the Passive House Planning Package.
d) Results of the economic evaluation.

A final section summarizes the results, thus allowing for a comparison of the performance of the six different typologies in the same location and climate, followed by a discussion of the results.

5.1 Study design

The following definitions for the different cases will be used throughout the study:

Reference Building	Corresponds to the concept of the Reference Building defined by the standard NOM-020-ENER-2011.
BASELINE	Corresponds to the specifications of the architectural project according to the plans and information provided by the developers to GOPA.
LINE NOM-020	Is based on the BASELINE case, but Energy Efficiency measures have been applied, so as to comply with the standard.

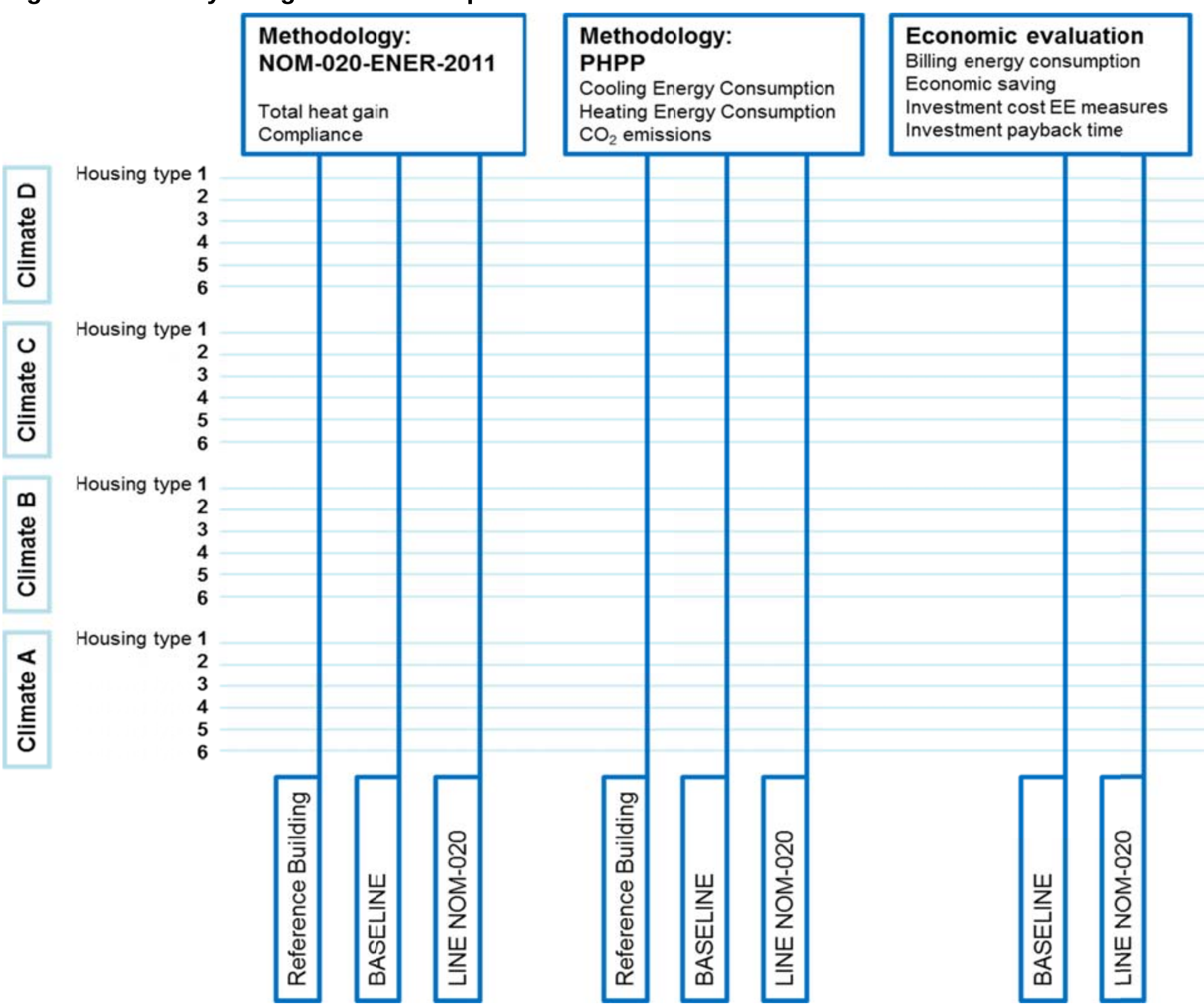
Six different housing types, of different cost, size, number of storeys and housing units per lot are analyzed in four different locations, with different climates: i) extremely hot dry, ii) extremely hot humid, iii) temperate, iv) temperate cold. The different cases will be analyzed with two different steady-state building energy simulation tools.

A first line of investigation is the validation of compliance with the standard NOM-020-ENER-2011 according to the methodology established by the code. The Reference Building and the BASELINE case (Projected Building) are calculated. In case the project does not comply with the standard energy efficiency measures are applied to the Projected Building so as to fulfill the requirements of the standard, representing the LINE NOM-020 scenario.

In a second line of investigation the three different cases Reference Building, BASELINE and LINE NOM-020 are calculated with the Passive House Planning Package tool (PHPP). The use of this tool allows on one hand to estimate the cooling and the heating load for each month of the year and thus provides for a more detailed analysis than the calculation method established by the standard. On the other hand the resulting data will be of use for the integration of the NOM-020 into the Housing Rating System of Infonavit and into the Mexican NAMA (see chapter 3.3.3 and 3.3.4). The reported cooling and heating loads build the basis for the calculation of the CO_2 emissions and their respective reduction.

A third line of investigation estimates the monthly billing for energy consumption on basis of the cooling and heating loads calculated with the PHPP. The economic saving achieved by the implementation of the NOM-020-ENER-2011 are estimated, and together with the reported investment cost for the energy efficiency measures a simple calculation of the investment payback time is undertaken. The investment payback time is calculated considering the domestic tariffs of CFE, and is also being reported on basis of the accounting cost of electricity production, not considering the subsidy on electricity.

Figure 5-1 Study design Potential Impact Dimension



5.2 Methodology

Following the different steps of the investigation in this chapter are laid out. The data sources and the applied methodology are described. An explanation of the energy balance calculation according to the methodology established by the NOM-020-ENER-2011 is given subsequently. Afterwards the Passive House Planning Tool (PHPP) is described, as well as the relevant boundary conditions for the calculation and the assumptions for thermal comfort criteria and internal heat loads.

5.2.1 Description of the architectural design and the building envelope

The projects analyzed in this study correspond to recently built developments from the Mexican housing market, provided by 5 different developers to Gopa Consultants. The BASELINE case is calculated accordingly to the information contained in the plans and descriptions provided by the developers. The approach is to evaluate the current state of the art regarding energy efficiency.

In this chapter the relevant features of the architectural design are described briefly: i) Surface, ii) Number of habitations, iii) Adjacency and iv) Orientation. In the case of attached housing the number of housing units that form the housing complex for the evaluation of the energy balance is reported (see paragraph 5.2.8. for an explanation of the calculation of attached housing). A description of the thermal building envelope[28] of the BASELINE case is given, as well as of eventual thermal insulation elements or shading devices that affect the energy balance. The reported U-Values consider the entire composition of the building component according to the specifications delivered in the architectural projects. However only the key elements are reported in the “Materials and Energy Efficiency” tables so as to allow for legibility. A detailed description of the different components of the building envelope and the material properties is given in annex I.

Table 5-1 Denomination thermal transmittance and thermal resistance

ISO Standards	NOM-020-ENER-2011 y NOM-008-SCFI-2002	Magnitude	Unit	Symbols of the unit
Valor U	Valor K	Termal transmittance	Watt per square meter kelvin	$W/(m^2 \cdot K)$
Valor R	Valor M	Termal resistance	Square meter kelvin per watt	$(m^2 \cdot K)/W$
SC	CS	Shading coefficient		

The NOM-020-ENER-2011 refers to the standard NOM-008-SCFI-2002, General system of measurement units, for the denomination of values and coefficients. The use of the international ISO-standards is more common, thus in this study the values for thermal resistance (R-Value), thermal transmittance (U-Value) and the shading coefficient (SC) will

[28] “Refers to roof, walls, openings, doors, florrs and lower surfaces, that delimitate the interior space of a building for residential use.” Official Mexican Standard NOM-020-ENER-2011, Energy efficiency in buildings. – Thermal envelope of buildings for residential use.

refer to the ISO-standards, so as to allow for easy comparison of material properties and results (see table 5-1).

5.2.2 Energy balance according to the NOM-020-ENER-2011

The thermal performance of the different housing typologies was analyzed according to the methodology established by the NOM-020-ENER-2011. The results of the energy balance[29] are reported; the values of the total heat gain for the Reference Building and the Projected Building (BASELINE), as well as the specific values for the below-mentioned building components are represented.

- Glazing R - Radiation heat gains of the transparent parts of the building envelope
- Glazing C - Conduction heat gains of the transparent parts of the building envelope
- Walls - Conduction heat gains of the walls
- Roof - Conduction heat gains of the roof

The itemized reporting of the heat gains allows for a more detailed identification of the effects on the energy balance of eventual thermal insulation elements or shading devices. Furthermore it facilitates the definition of energy efficiency strategies for the LINE NOM-020 cases. For all BASELINE cases the thermal characteristics of the building materials correspond to the description in the architectural projects provided by Gopa Consultants. Values for thermal resistance and thermal conductivity correspond to the annex D of the Standard [NOM-020], or to the certifications provided by the developers for non-generic products and insulation materials. For hollow concrete blocks the annex D does not provide a thermal resistance for a thickness of 12cm, therefore the value of 0.159 m^2K/W reported by Pérez et al. [2008] was taken into account.

5.2.3 Energy efficiency strategies of the LINE NOM-020 and their impact

If the total heat gains of the Projected Building (BASELINE) exceed the total heat gains of the Reference Building a LINE NOM-020 scenario is proposed, which complies with the standard. Energy efficiency strategies where applied to the Projected Building of the LINE NOM-020 scenario, which allow for reducing the total heat gains until they are equal or lower than those of Reference Building. Based on the itemized analysis of the BASELINE a measure was chosen that enhanced the thermal performance of windows, walls, roof or a combination of these. The objective of the proposed strategy is to modify those elements that show an excess on heat gains in comparison to the equivalent element of the Reference Building, until the requirements of the standard are fulfilled.

[29] Refers to the comparation of the heat gains through the envelope between the projected building for residential use and the reference building." Official Mexican Standard NOM-020-ENER-2011, Energy efficiency in buildings. – Thermal envelope of buildings for residential use.

The values of the total heat gain for the Projected Building and the Reference Building (LINE NOM-020), as well as the specific values for the below-mentioned building components are represented.

- Glazing R - Radiation heat gains of the transparent parts of the building envelope
- Glazing C - Conduction heat gains of the transparent parts of the building envelope
- Walls - Conduction heat gains of the walls
- Roof - Conduction heat gains of the roof

The impact of the implementation of the energy efficiency measures, which allow for complying with the standard, is reported as reduction of the total heat gain. The reduction of total heat gain represents the abatement of the total heat gain of the Projected Building of (BASELINE) in relation to the total heat gain of the Projected Building (LINE NOM-020).

$$RHG = \left(1 - \left(\frac{HG_{LINE\ NOM-020}}{HG_{BASELINE}}\right)\right) * 100\%$$

Where,

RHG = Reduction of total heat gain

$HG_{LINE\ NOM-020}$ = Total heat gain projected building LINE NOM-020

$HG_{BASELINE}$ = Total heat gain projected building BASELINE

The applied thermal insulation materials in the enhanced scenarios are certified according to the NOM-018-ENER-2011 (Thermal Insulation for Buildings. Characteristics, limits and test methods.), and count with either a certificate by the Mexican Fund for Electricity Savings (FIDE) or by the National Agency for Standardization and Certification in Construction and Building (ONNCCE). According to the standard NOM-020-ENER-2011 structural material like blocks or bricks for example do not have to fulfill a standard. Generic values or values provided by manufacturers can be applied in the calculation of the energy balance. Nevertheless all structural materials applied in the LINE NOM-020 scenario count with a certification according to the NMX-C-460-ONNCCE-2009, or are certified by ONNCCE. The selection of the materials was limited to those certified by FIDE or ONNCCE and is based on the criterion of the performance of the thermal resistance. This selection does not represent a recommendation of certain products.

5.2.4 Costs of energy efficiency measures

The costs of the Energy Efficiency strategies are reported. In all cases the reported amounts in this study represent the additional investment necessary for their implementation with respect to the BASELINE case. If an improvement of the thermal performance was achieved by replacing a product, like for example a hollow concrete block with a hollow thermal concrete block, only the price difference of the two products is reported, yet as costs for labour and freight are considered the same. In the case of a product, that is applied additionally like for example an additional layer of expanded polystyrene, the additional cost considers also mounting accessories, coating and labour.

For particular products that are only produced by a single manufacturer a specific cost estimate including the shipment was requested for each of the study locations. The cost estimations were obtained between March and June 2012. Table 5-2 reports the cost for the additional investment of the energy efficiency measures per square meter for the concepts of product replacement by products having a better thermal performance. Table 5-3 shows the cost for the additional investment for work concepts that include the cost for additional mounting material, labour, etc. The reported prices include value added tax of 16 percent on materials, plus an additional 28% to cover the indirect cost of the construction company. Cost estimations were requested for a reference development of fifty housing units of forty square meters treated floor area each, summing up to 2,000 square meter of treated floor area.

Table 5-2 Price difference Energy Efficiency measures_Products

Scenario	Product	Freight to	λ	R-Value	U-Value	Price (incl. IVA)	U.P. incl. 28% Ind.	Difference
			[W/mK]	*[m^2K/W]*	*[W/m^2K]*	*[MXN/m^2]*	*[MXN/m^2]*	*[MXN/m^2]*
GLAZING								
BASELINE	Single glazing, clear 3mm	---			**5.319**	87.00	111.36	
LINE NOM-020	Double glazing 3+9+3 mm, LowE, SC 0.46	---			**1.874**	551.00	705.28	**593.92**
ROOF								
BASELINE	Hollow concrete block, 12x20x40cm	---		**0.159***		94.25	120.64	
LINE NOM-020	Hollow thermal block (certified), 12x20x40cm	---	0.433	**0.292**		108.75	139.20	**18.56**
LINE NOM-020	Industrialized brick (certified), 11.5x12x25cm	Cancún	0.110	**1.060**		162.77	208.35	**87.71**
LINE NOM-020	Industrialized brick (certified), 11.5x12x25cm	Hermosillo	0.110	**1.060**		170.89	218.74	**98.10**
LINE NOM-020	Industrialized brick (certified), 11.5x12x25cm	Guadalaj.	0.110	**1.060**		122.95	157.37	**36.73**
LINE NOM-020	Industrialized brick (certified), 11.5x12x25cm	Puebla	0.110	**1.060**		92.02	117.78	**-2.86**

* Source: Pérez et. al. 2010. Estudio Numérico de la Resistencia Térmica en Muros de Bloques de Concreto Hueco con Aislamiento Térmico. Hermosillo, México.

Table 5-3 Price difference Energy Efficiency measures_Work concepts

Scenario	Work concept	λ [W/mK]	R-Value [m^2 K/W]	Materials (incl. IVA) [MXN/m^2]	Manpower [MXN/m^2]	Direct Cost [MXN/m^2]	U.P. incl. 28% Ind. [MXN/m^2]	Difference [MXN/m^2]
ROOF								
BASELINE	Suministro y colocación entortado en azotea, 3cm de espesor con mortero cal.hidra-arena 1:4	0.872	**0.034**	21.32	42.29	65.57	83.93	
LINE NOM-020	Suministro y colocación relleno de mezcla **Perlita Mineral** en azotea, 6cm de espesor promedio	0.075	**0.800**	105.98	54.98	162.92	208.53	**124.60**
LINE NOM-020	Suministro y colocación **EPS 2.0"**, con malla gallinera y entortado de 3cm en azotea	0.035	**1.451**	120.39	62.29	184.64	236.34	**152.41**
WALLS								
BASELINE	Repellado en muros a plomo y regla con mortero cal hidra-arena 1:6 espesor promedio = 2cm	0.872	**0.023**	13.55	50.47	66.42	85.01	
LINE NOM-020	Suministro y colocación **EPS 1.5"**, con fijación, malla de fibra de vidrio y empastado en muro	0.035	**1.089**	135.02	40.00	177.42	227.10	**142.09**
LINE NOM-020	Suministro y colocación **EPS 2.0"**, con fijación, malla de fibra de vidrio y empastado en muro	0.035	**1.451**	153.08	40.00	195.48	250.21	**165.20**

5.2.5 Energetic evaluation with Passive House Planning Package

In order to analyze cooling and heating load for each month of the year a second line of calculations was undertaken with the Passive House Planning Package (PHPP) tool. For each of the six housing typologies in each of the four climates a Reference Building and a BASELINE case was calculated. The BASELINE case was calculated with the same specifications of the architectural project used in the previous calculation applying the methodology established by the NOM-020-ENER-2011. The Reference Building was calculated according to the definition of this virtual model established in the NOM-020-ENER-2011. The geometrical dimensions are identical to the architectural project and the characteristics of the building envelope correspond to the definitions established in the paragraph 6.1 and the table 1 of the standard (see section 5.2.8. for further explanation). As the NOM-020 does not consider window frames, windows have been calculated with a glazing fraction per window of 100 %. If the project did not comply with the NOM-020-ENER-2011 in the previous verification, a third scenario, LINE NOM-020, was calculated, using the same specifications as the LINE NOM-020 scenario in the previous calculation according to the NOM-020.

The Passive House Planning Package (PHPP) follows the whole house approach; this is to say analyzes more aspects than the NOM-020-ENER-2011, like internal heat loads for example. All boundary conditions and variables contemplated in the PHPP, and that are not considered in the methodology of the NOM-020-ENER-2011 correspond to the assumptions that were made for the calculations of the Baseline case of the Housing Rating System (SCV) of Infonavit (see section 5.2.9. for further details). This allows for comparability and the integration of the NOM-020-ENER-2011 into the scale of the SCV. Furhtermore these assumptions also correspond to those, made for the calculations undertaken by the Passive House Institute for the Mexican National Apprpriate Mitigation Action (NAMA) for Housing [CONAVI 2011].

The data for the monthly useful cooling and heating demand was exported from the “Monthly Method” and “Cooling” sheet to a separate spreadsheet for further calculations. The “Monthly Method” worksheet uses a semi-dynamic method in accordance with the European standard EN 13790, and the resulting useful heating demand represents the amount of heat that must be inserted into the building in order to obtain a comfortable indoor temperature. This means that energy contributions required for heating system losses are not yet included. The “Cooling” worksheet, similar to the “Monthly Method” worksheet uses a calculation algorithm based on the European standard EN 13790. The reported useful cooling demand represents the amount of heat that must be extracted from the building in order to obtain a comfortable indoor climate, and represents only the sensible portion of the cooling energy. Similar to the useful heating demand, energy contributions required for cooling system losses are not yet included [PHI 2007]. The latent useful cooling demand, which represent energy contributions that may be required for dehumidification are not considered in this study.

5.2.6 Determination of emission and primary energy factors

The estimated equivalent annual CO_2 emissions u_{CO2}, due to the energy consumption for heating and cooling are reported in kg/(m^{2}a) for the Reference Building, the BASELINE and the LINE NOM-020. The methodology for the determination of the primary energy consumption is based on the information provided in the manual for the Passive House Planning Package [PHI 2007], however some denominations have been adapted to fit the study design.

In order to determine the CO_2 emissions the useful cooling demand Q_C and the useful heating demand Q_H have to be converted by various factors. First, the final energy demand Q_{Final} has to be determined. The final energy demand depends on the coefficient of performance (CoP) of the acclimatization appliances. A CoP of 2.5, corresponding to a less efficient apparatus, was assumed for the cooling appliance, and a CoP of 0.75 for the heating appliance.

For space cooling the final energy demand is calculated as followed:

$$Q_{Final} = e_c * Q_C$$

where

Q_{Final}	*[kWh/a]*	= Final energy demand
e_c		= Efficiency (CoP) of the heat extraction
Q_C	*[kWh/a]*	= Useful cooling demand

For space heating the final energy demand is calculated as followed:

$$Q_{Final} = e_h * Q_H$$

where

Q_{Final}	*[kWh/a]*	= Final energy demand
e_h		= Efficiency (CoP) of the heat generation
Q_H	*[kWh/a]*	= Useful heating demand

Next the final energy demand has to be converted into the primary energy demand, which allows a comparison between buildings independent of their energy source, taking into account the non-renewable primary energy factor of the energy carrier:

$$Q_P = p * Q_{Final}$$

where

Q_P	*[kWh/a]*	= Primary energy demand
p	*[kWh/kWh]*	= Primary energy factor
Q_{Final}	*[kWh/a]*	= Final energy demand

The specific demand for primary energy allows for comparison amongst projects independent, by reporting the energy demand per square meter:

$$q_p = \frac{Q_p}{A_{TFA}}$$

where

q_p	*[kWh/(m²a)]*	= Specific primary energy demand
Q_P	*[kWh/a]*	= Primary energy demand
A_{TFA}	*[m²]*	= Treated floor area

The equivalent carbón dioxide emissions can be calculated from the primary energy demand, by integrating the CO_2-equivalent emissions factor:

$$U_{CO2} = x_{CO2} * Q_P$$

where

U_{CO2}	*[kg/a]*	= Annual CO_2 emissions equivalent
x_{CO2}	*[g/kWh]*	= CO_2-emissions factor equivalent per kWh of final energy
Q_P	*[kWh/a]*	= Primary energy demand

To allow for comparison between different buildings, the specific anual CO_2-emissions equivalent reports the emissions per square meter:

$$u_{CO2} = \frac{U_{CO2}}{A_{TFA}}$$

where

u_{CO2}	*[kg/(m²a)]*	= Specific Annual CO_2-emissions equivalent
U_{CO2}	[kg/a]	= Annual CO_2 emissions equivalent
A_{TFA}	[m²]	= Treated floor area

In Mexico currently no federal entity is reporting official conversion factors for the reporting of CO_2 emissions. According to Graichen [2012] different factors are used by different projects and institutions, as well as different methods of calculating the conversion factors (built margin, combined margin or operating margin). The calculations took into account a combined emission factor for the entire interconnected national electricity system of 0.487 $kgCO_2$/kWh, estimated according to the methodology of the UNFCCC (United Nations Framework Convention on Climate Change), published in a report on emission reduction potential in Mexico by the Mexican Ministry of Environment and Resources [SEMARNAT 2009].

For this study it was assumed that the heating load would be served by gas heaters. According to the Ministry of Energy the use of liquefied petroleum gases (LPG) is most common, being used in five out of seven household [SENER 2010]. The conversion factor for liquefied petroleum gases depends on the chemical properties of the fuel, and contrary to grid electricity does not depend on national variables like the composition of the energy generating plants. Therefore the CO_2 emissions were calculated using a default emission factor for stationary combustion in the residential category of 0.227 $kgCO_2$/kWh for liquefied petroleum gases, published by the Intergovernmental Panel on Climate Change [IPCC 2006, chapter 2, table 2.5].

For the conversion of consumed energy to primary energy, country-specific primary energy factors of 2.7 for the electricity mix of Mexico, and of 1.1 for liquefied petroleum gas have been used in accordance with the assumptions for the calculations of the Baseline case of the Housing Rating System (SCV) of Infonavit.

Table 5-4 CoP, Primary Energy & CO_2 emission conversion factor

	Cooling	Heating
CoP (Coefficient of Performance)	2.5	0.75
PE (non-regenerative) [kWhPrim/kWhFinal]	2.7	1.1
CO_2 emission conversion factor [$kgCO_2$/kWh]	0.487	0.227

5.2.7 Economic evaluation and investment payback time

For the energy efficiency optimization scenario LINE NOM-020 a simple calculation of the investment payback time was undertaken. The estimated economic savings due to the reduction of the consumption for cooling and heating, as a result of the implemented energy efficiency measures, were taken into account.

$$IPT = \frac{C}{S}$$

where

IPT	= Investment Payback Time
C	= Additional cost for energy efficiency measures
S	= Estimated economic saving by reduced billing for cooling and heating

The economic savings due to reduced billing were estimated on basis of the monthly cooling load and the monthly heating load calculated with the Passive House Planning Package. In the case of electricity consumption a basic consumption of 75 kWh/month per household was assumed and added to the cooling load. These 75 kWh/month correspond to the basic range in the electricity tariffs for the residential sector and according to the Ministry of Energy [SENER 2008] 75kWh/month correspond to the "basic equipment that a low-income household could have". Table 3 in the appendix IV shows the composition of this basic energy consumption by different household appliances. Furthermore this value corresponds to the lowest average monthly sales per customer reported by the Ministry of Energy [SENER 2008], with Oaxaca (74.4 kWh/month, summer 2007) and Frontera (72.2 kWh/month, summer 2007) at the lower end of the scale of the reported localities (see table 2, annex IV). On the upper end of the scale there are Hermosillo (531.0 kWh/month, summer 2007) and Méxicali, (750.3 kWh/month, summer 2007).

The estimation of the electricity bill was elaborated on basis of an average value for 2011 (january 2011- december 2011) of the valid CFE tariffs, according to the applicable tariff for each location [CFE 2012]. According to the Ministry of Energy [SENER 2010] the residential tariffs in Mexico are subsidized by 58 percent. This subsidy varies depending on the average temperature of each location, period of the year (summer, or out of summer), as well as the level of consumption. In order to exclude the effect of this subsidy on the calculation of the investment payback time an alternative calculation was included, taking as a reference the accounting cost for electricity production of 2.3 $/kWh, reported by the Mexican Ministry of Energy [SENER 2010]. The decision whether an investment is recommended or not is based on the investment payback time, calculated on basis of the accounting cost for electricity production. This is due to the fact, that a building has a lifecycle of at least 30 years. The policies on electricity subsidy might well change within this timespan.

For liquefied petroleum gas (LPG) a máximum price for the end consumer is fixed in Mexico and published in the Oficial Journal of the Federation. In 2005 an agreement of 145 regiones has been signed. The estimation of the billing for gas is based upon the average value for the last twelve month (July 2011 – June 2012) of the fixed maximum price for each location [SENER 2012]; Cancún (0.88 $/kWh), Hermosillo (0.81 $/kWh), Guadalajara (0.85 $/kWh), Puebla (0.84 $/kWh).

5.2.8 Methodology of calculation NOM-020-ENER-2011

The methodology established by the NOM-020-ENER-2011 is a so called "reference methodology". A virtual model of a reference building, which has the same geometric dimensions (and orientation) as the projected building, includes basic thermal requirements according to specifications defined in the standard. The standard limits the total thermal gains in Watt (W) for this virtual reference building, considering conduction heat gains (opaque and transparent parts), solar radiation heat gains (transparent parts), as well as deductions for solar radiation heat gains by shading elements. The total thermal gains for the projected building have to be equal or lower than the total thermal gains of the Reference Building.

The standard defines the following characteristics for the reference building:

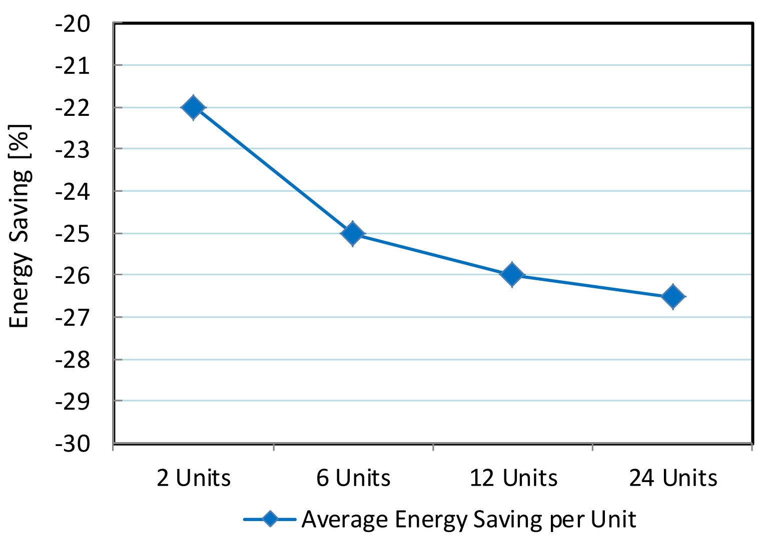
- Roof: 100% opaque.
- Walls: 90% opaque, 10% transparent.
- Thermal transmittance value for Roof and Walls according to location specific values for 95 cities (table 1 of NOM-020-ENER-2011).
- Thermal value for Windows: 5.319 W/m^2K, shading coefficient 1.0, no shading devices.

At the time of undertaking the first calculations no calculation-tool was available for the methodology proposed by the standard. The author developed a spreadsheet calculation tool based on the format for reporting the energy balance in the appendix C of the standard, so as to automatize the process. During the calculations of the different types of housing several situations arose where the standard needs to be interpreted. The different doubts and questions were discussed and clarified with the respective area of CONUEE in several sessions. Furthermore these doubts were listed and served as input for the Manual for the easy application of the standard (see chapter 4.4.3).

The calculation of attached housing is not defined by the standard itself. This point will be defined in the Procedure for the Evaluation of Conformity (*Procedimiento para la Evaluación de la Conformidad – P.E.C.*) which was not published at the time of writing of this thesis. The draft of this document establishes that buildings of „identic design (dimension, materials, elevation and plan)…, with or without shared walls" have to be evaluated as a group if they have shared walls [CONUEE 2012]. This is to say attached housing is treated similar like a vertical multy-family housing unit. A vertical multy-family housing unit contains several departments but is treated as one single building with one thermal envelope. Boundary walls to adjacent departments do not have to be considered in the calculation, given the fact that in an ideal case the temperature in the adjacent room would be equal and therefore no heat transfer will occur.

In the case of attached housing an end unit has a different thermal performance than an intermediate unit with two adjacent units, given the fact that it possesses more exterior wall surface and that sun exposure is different. A study of the row housing unit (*Aislada*) measured the effect, which the number of housing units in a complex is having on the value for energy saving in percent, which is an indicator for the compliance with the standard. Chart 5.1 shows the average energy saving per unit, according to the number of housing units in a housing complex. A negative value represents that the total heat gain of the projected building is higher than the total heat gain of the reference building, thus the project does not fulfill the standard. As seen in chart 5.1 the energy saving for a complex consisting of 2 units is -22.0 percent, for a complex of six units -25.0 percent, for 12 units -26.0 percent and -26.5 percent for a complex consisting of 24 units. This represents a strong decrease of -3.0 percent between 2 and 6 units, and a decrease of -1.5 percent between 6 and 24 units. Calculating with a complex composed of 6 housing units absorbes to a large part the effect that the increased surface of exterior walls and the different sun exposure of the end units have on the overall result.

Chart 5-1 Energy Saving in relation to the numer of calculated units



5.2.9 Methodology Passive House Planning Package Tool

The Passive House Plannig Tool[30] follows the “whole building approach”, regarding the house as an energy system with interdependent parts. The approach of the NOM-020 regards building components in an isolated way, efficiency gains in the considered components could be offset by losses in other components that are not considered. The NOM-020 does not include any appliances and does not calculate the primary energy need and the CO_2 emissions. Contrary the “whole building approach” delivers results for target values in terms of

[30] The Passive House Planning Package (PHPP) is a software developed by the Passive House Institute to support the design of energy efficient housing More information about the tool is available at: <http://www.passiv.de/en/index.html>

the specific energy need per year and square meter of a building. These results can be clearly defined, monitored and validated.

At the moment of writing of this thesis a calculation tool, which includes a whole building approach including primary energy, CO_2 emissions and the requirements of the NOM-020, was not yet available. Therefore the additional calculation of the three scenarios, calculated previously according to the methodology established by the NOM-020, with the PHPP allows on one hand for assessing the thermal performance of the status quo of housing construction in Mexcio (BASELINE case). The yearly cooling demand and the yearly heating demand are evaluated on a more detailed level. On the other hand the results indicate the thermal performance, primary energy consumption and CO_2 emissions of a possible reference case, based on the specifications of the reference building, as established by the NOM-020 (Reference Building scenario). Furthermore the calculation of the LINE NOM-020 scenario allows for estimating the reduction of the CO_2 emissions, achieved by the implementation of the standard, in relation to the status quo of housing construction (BASELINE scenario) in Mexico.

To be able to calculate the target values for the primary energy the building under study should be a fully equipped residential unit (lighting, household appliances, hot water generation, etc.), considering all the internal heat gains (occupancy, household appliances, etc.). The additional variables that are not considered by the NOM-020 correspond to the assumptions made for the calculations of the Housing Rating System (SCV) of Infonavit. Table 5-5 shows the different components considered for the calculation of the total internal heat gains of 5.25 W/m^2. The occupancy rate was considered over a lifecycle of 30 years with 2 persons per 40 m^2 unit.

Table 5-5 Summary of internal heat sources (IHS) parameters and examples

Parameters to consider for IHS	
Percentage pf CFLs	100 %
Washing machine	1.12 kWh/Use
Refrigerator (combinde with freezer)	2.68 kWh/d
Consumer electronics and small appliances	150 W
Microwave oven	1200 W
Cooking	With gas
Hot water demand	25 lts/person/day
Occupation	2 persons for a 40 m2 housing unit (30 years lifecycle)
Total internal heat loads	**5.25 W/m^2**

Source: Passive House Institue. Cited by: CONAVI 2011

Further boundary conditions have been defined as shown in table 5-6. The comfort range, defined by the overheating limit of 25°C and the minimum interior temperature of 20°C, dorresponds as well to the assumptions made for the SCV. According to CONAVI [2011] this temperature range is based on the ISO 7730 standard and establishes the ideal range for human comfort. Regarding the absorptivity of exterior wall surfaces a value of 0.5 was chosen.

For roofs a value of 0.3, corresponding to a bright colored, but aged roofing surface was chosen for hot climates; for temperate climates a value of 0.7, corresponding to a teracotta colour, was considered appropriate.

Table 5-6 Boundary conditions comfort range and absorptivity

Location Climate	**Cancún** extremely hot humid	**Hermosillo** extremely hot dry	**Guadalajara** temperate	**Puebla** temperate cold
Absorptivity Roof	0.3	0.3	0.7	0.7
Absorptivity Walls	0.5	0.5	0.5	0.5
Upper Comfort Temperature	25°C	25°C	25°C	25°C
Lower Comfort Temperature	20°C	20°C	20°C	20°C

Calculation of the Reference Building

The Reference Building was calculated according to the definition of the virtual model established in the NOM-020-ENER-2011. The geometrical dimensions are identical to the architectural project and the characteristics of the building envelope correspond to the definitions established in the paragraph 6.1 and the table 1 of the standard (see section 5.2.8. for further explanation). As the NOM-020 does not consider window frames, windows have been calculated with a glazing fraction per window of 100 %.

Calculation of the BASELINE case

The BASELINE scenario corresponds to the specifications of the architectural project given by the developer and is identical to the previous calculation by the NOM-020.

Calculation of the LINE NOM-020 case

If the project did not comply with the NOM-020-ENER-2011 in the previous verification, a third scenario, LINE NOM-020, was calculated, using the same specifications as the LINE NOM-020 scenario in the previous calculation according to the standard.

The calculation of the Reference Building, the BASELINE and the LINE NOM-020 reveals the following indicators:

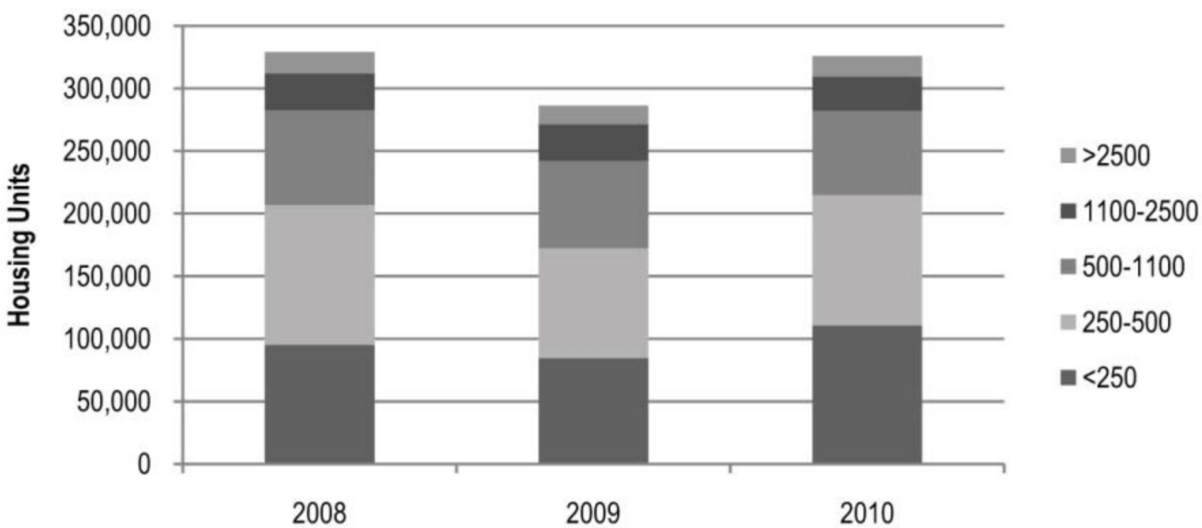
- The yearly end use energy for cooling and heating in kWh/m^2y
- The value for thermal transmittance of the building components, U-Value, in W/m^2K
- The yearly primary energy need of the building for cooling and heating in kWh/m^2y
- The yearly CO_2 emissions in kg/m^2y

5.3 Typologies and localities

5.3.1 Housing typologies

The construction of social housing at large scale is predicted in México for the upcoming years. According to the Mexican National Housing Commission the existing Mexican housing is estimated at 26.7 million houses. The same institution foresees an additional demand of 20.2 housing units upon 2030, of which 11.3 million represent the demand for new housing. The majority of the houses currently built belong to the low-cost sector, meeting the demand of low-income families. In 2010, as shown in chart 5-2, 38 percent of the new housing was built for less than $250,000 and 32 percent for a cost of $250,001 up to $500,000 [CONAVI 2010]. These houses fulfill very basic needs. According to Rodriguez and Sielfeld only 21.6 % of the houses financed by Infonavit in 2009 counted with a useable floor surface of more than $50m^2$. Several building codes in Mexico exclude residential constructions with floor surfaces of less than 50 m^2 (in some cases less than 30 m^2) [Rodríguez & Sielfeld 2010]. This is to say a large percentage of new housing projects do not have to apply local building codes.

Chart 5-2 Annual housing inventory by home value (in MXN 1,000)



Source: CONAVI 2010

The Mexican housing market is classified into different segments according to housing type and value. The value is calculated in multiples of the monthly minimum wage in the Federal District.[31] In order to allow for comparability in April 2010 Infonavit, SHF, CONAVI, financial

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[31] Monthly minimum wage for the Federal District (VSMMDF) valid from 1st of January 2012: MXN 1,894.83. The VSMMDF represents the daily minimum wage for the Federal District of MXN 62.33, multiplied by 30.4 days (average duration of a month). For example 118 VSMMDF is equivalent to MXN 223,589.94. The amount of the mortgage loan is establishen in VSMMDF. Sources: Comisión Nacional de los Salarios Mínimos 2012, CONASAMI, viewed 01 July 2012, <http://www.conasami.gob.mx/t_sal_mini_prof.html>; INFONAVIT 2012, viewed 01 July 2012, <http://portal.infonavit.org.mx/wps/portal/Glosario/>.

institutions (SOFOLES and SOFOMES[32]), FOVISSSTE, SOFTEC and AHM agreed on a new homogenized classification. The objective was to provide a single nomenclature that shall be used and recognized on a national and international level for the generation of comparable information, statistics and private and public analysis and studies [SHF 2010]. The classification includes six different types of housing. Three of them, the economic, the popular and the traditional, fall into a first general category denominated social interest. The other three categories are Medium, Residential and Residential Plus (see table 5-7).

Table 5-7 Homogenized classification of housing according to type and value

Type of Housing	**VSMMDF** *Minimum wage Federal District*	**Range of cost** *MXN*	**Average built surface** m^2
Social interest			
Economic	Up to 118	206,100	30.0
Popular	118.1 - 200	349,350	42.5
Traditional	200.1 - 350	611,350	62.5
Medium	350.1 - 750	1,310,100	97.5
Residential	750.1 – 1,500	2,620,200	145.0
Residential Plus	More than 1,500	More than 2,620,000	225.0

Source: SHF 2010

A part from this homogenized classification according to type and value, the housing types can be categorized by the number of stoerys and housing units per lot. In its Housing Building Code (Código de Edificación de Vivienda - CEV) CONAVI [2010b] proposes a classification of housing units per lot. A first classification is given by the separation whether it is a single-family or multy-family (condomino) housing unit per lot. The second classification is given by the number of storeys (table 5-8).

[32] “Limited Purpose Financial Institutions (Sociedades Financieras de Objeto Limitado, SOFOLES) and Multiple Purpose Financial Institutions (Sociedades Financieras de Objeto Múltiple, SOFOMES) are private non-bank lending institutions licensed to lend to particular sectors. SOFOLES and SOFOMES play a large role in lending to consumers who are not covered by INFONAVIT and FOVISSSTE or who seek to finance a mortgage with a higher value than the maximum amount offered by the public institutions.“ [CONAVI 2010]

Table 5-8 Classification by number of housing units per lot

Single-family housing unit	
A)	One story
B)	Two storys
Multy-family housing unit	
C)	Duplex
D)	One storey
E)	Two storeys
F)	Five storeys
G)	More than 5 storeys

Source: CONAVI 2010b

The data of the six projects analyzed in this study was provided by five Mexican housing developers to GIZ/Gopa Consultants. All provided architectural projects are recently constructed developments in different locations in Mexico. The six selected projects cover a representative range of the classified housing types by the two before-mentioned classification-schemes. No information was provided about the cost of the projects. By the criteria of built surface the six selected projects represent the economic, popular, medium and residential type of the homogenized classification according to type and value (table 5-7). By the criteria of number of owners and storeys per lot, the six selected projects represent the categories A, B, C, D, E and F (although the actual project has 6 storeys, it fits into this category).

Table 5-9 Typologies

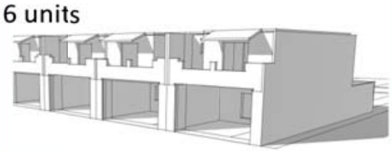
Typologie	Surface	Developer	Prototype	Location
Adosada	45.0 m^2	Consorcio ARA	Almendros conjunto Vista Real	Ejido Isla Mujeres, Q. Roo.
Dúplex	40.0 m^2	SADASI	Conjunto Prado Norte	Cancún, Q. Roo.
Aislada	44.7 m^2	Consorcio Hogar	Sierra, desarrollo Valle Floresta	Munic. de Pesquera, N. L.
Medio	101.8 m^2	VINTE	Playa	Playa del Carmen, Q. Roo.
Residential	167.5 m^2	VINTE	Tekamac	Queretaro, Qro.
Vertical	50.0 m^2	AISA	Torres 475	Puebla, Pue.

Compactness

One criterion to compare different typology related to thermal comfort is the compactness of the building geometry. The heat gains or losses depend on the rate between the house envelope surface area (A) and the house conditioned volume (V). This relation can be expressed as an area to volume ratio (A/V). More thermally efficient buildings have lower ratios. The envelope surface area considers all elements of the thermal envelope the divide the conditioned volume of the house from the exterior; this is to say walls, doors, windows, roofs and floor slabs. Figure 5-2 shows indicative A/V ratios for different housing typologies. According to the Passive House Institute[33] an A/V ratio of ≤ 0.7 m^2/m^3 can be considered as a reasonably good value. The compactness of the six studied housing types ranges from 0.69 m^2/m^3 (row housing unit, middle segment) to 1.49 m^2/m^3 (isolated housing unit), as shown in table 5-10).

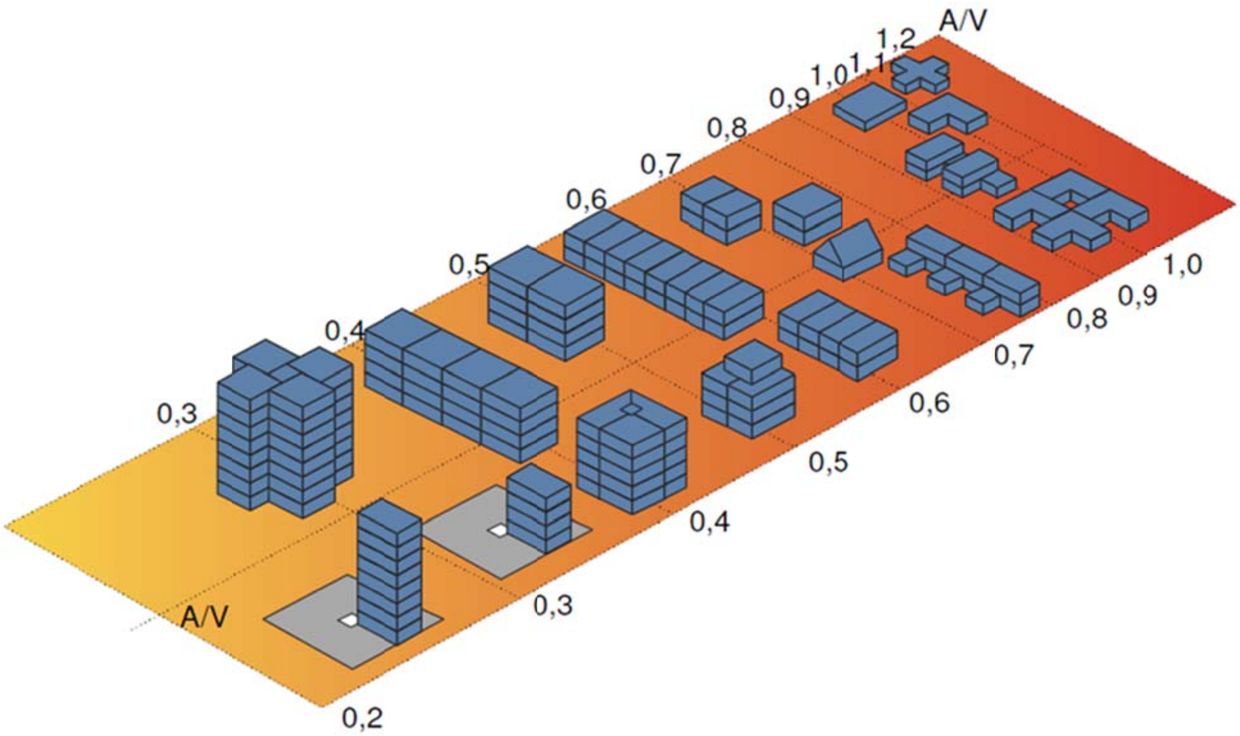
[33] Passive House Institute, lecture during the training course DEEVi train the trainer, July 2012, Mexico City.

Table 5-10 Comparison of compactness and window to floor area of typologies

Building Typology	Treated Floor Area per Unit	Building Envelope Surface Area	Building Accondition. Volume	Surface Area to Volume (A/V) Ratio	Window to Floor Area (WFA) RB
Row housing unit, 6 units 	40.7 m^2	836.5 m^2	796.7 m^3	1.05 m^{-1}	12.3 %
Duplex housing uni, 12 units 	36.3 m^2	991.3 m^2	1371.4 m^3	0.72 m^{-1}	16.9 %
Isolated housing unit 	38.2 m^2	172.6 m^2	116.1 m^3	1.49 m^{-1}	22.4 %
Row housing unit, middle segment, 6 units 	84.2 m^2	1290.4 m^2	1858.8 m^3	0.69 m^{-1}	11.4 %
Isolated housing unit, residential segment 	141.2 m^2	408.9 m^2	500.1 m^3	0.82 m^{-1}	29.0 %
Vertical housing unit, 24 units 	40.9 m^2	2054.3 m^2	2807.2 m^3	0.73 m^{-1}	17.2 %

The relation of window area to habitable floor area is an indicator for the available natural lighting. Many construction regulations determine a minimum of window area per habitable surface, e.g. a minimum window area of 10% of the habitable surface must be provided, which would equal a window of 1.2 m^2 for a room of 12 m^2. For the calculation of the Reference Building the NOM-020-ENER-2011 defines a portion of transparent parts of 10% of the wall area. This is to say 10% of the wall area is defined as window surfaces that do not have to meet only minimum requirements regarding the U-Value and the shading coefficient, and do not have to be protected by shading devices. Contrarily to the window area to floor area ratio used in construction regulations the standard NOM-020-ENER-2011 relates the portion of the window area directly to the projected wall surface. This results in a particular Window to Floor Area (WFA) for each architectural project. As a result compact typologies, having a small area to volume ratio (A/V), are designated less “unprotected” window area, as they present less wall surface per treated floor area. The relation of the WFA, as defined by the Reference Building according to the description in the standard, is represented in table 5-10.

Figure 5-2 A/V ratio in reltaion to housing typology

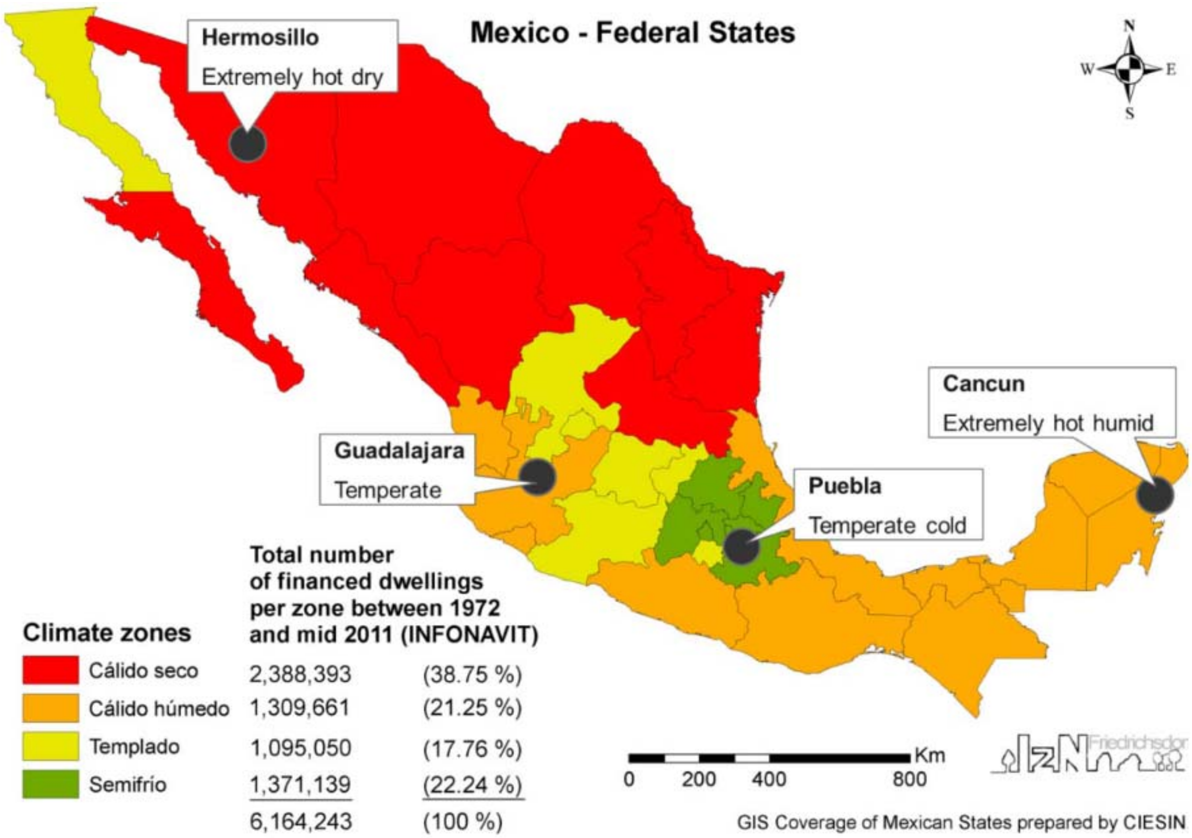


Source: Goretzki. Cited by Passive House Institute, course material training course *DEEVi train the trainer*, July 2012, Mexico City.

5.3.2 Study locations and climates

This paragraph lays out the descriptions of the clima and the most relevant respective data for the four locations analyzed in this study: Cancún, Hermosillo, Guadalajara and Puebla. The choice of the locations, illustrated in figure 5-3 corresponds to the previous studies undertaken by the Passive House Institute PHI for the Mexican NAMA [CONAVI 2011] and to the locations studied for the Housing Rating System (SCV) by Infonavit. Following the medium annual temperatures will be reported and the climate zones will be described briefly. The classification of the climate according to Köppen is reported according to García [1973].

Figure 5-3 Mexico's climate zones and the locations used for the NAMA calculations



Source: IZN Friedrichsdorf. Cited in: CONAVI 2011

CANCUN

Cancún forms part of the **extremely hot and humid climate** zone, being classified as climate type tropical wet and dry or savanna climate (Aw) by the Köppen classification, with maximum temperatures in summer of 35°C and minimum temperatures in winter of 15°C. The daily oscilation of the temperature is between 10°C and 14°C. The climate has a pronounced dry season, with the driest month having precipitation lass than 60 mm and also less than (100 – (mean annual precipitation/25)). According to Campos [2011] the climatic conditions imply a building design adapted to warm conditions practically all year round.

HERMOSILLO

Hermosillo forms part of the **extremely hot dry climate** zone, being classified as climate type arid desertical hot climate (BWh) by the Köppen classification, with maximum temperatures in summer between 40°C and 45°C and minimum temperatures in winter between 5°C and 7°C. The daily oscilation of the temperature is between 10°C and 14°C. According to Campos [2011] the climatic conditions imply a building design adapted to warm conditions (May till Ocobter), as well as to cold conditions (from December till February).

GUADALAJARA

Guadalajara forms part of the **temperate climate** zone, being classified as climate type temperate with dry winters and hot summers (Cwa) by the Köppen classification, with maximum temperatures in summer of 35°C and minimum temperatures in winter of 1°C. The daily oscilation of the temperature is between 8°C and 16°C. Although the climatic conditions present unbearably hot dry periods in summer, “passive cooling is possible” [Meteonom 2011].

PUEBLA

Puebla forms part of the **temperate climate** zone, being classified as climate type temperate with dry winters and warm summers (Cwb) by the Köppen classification, with maximum temperatures in summer of 30°C and minimum temperatures in winter of 3°C to 5°C. The daily oscilation of the temperature is between 10°C and 20°C. According to Campos [2011] the climatic conditions imply a building design principally adapted to cold conditions. Care has to be taken that the design strategies used to prevent underheating in winter will not lead to overheating in summer.

Figure 5-4 Mean monthly temperature in °C (Period 1970-2000)

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Average 6 month*
Cancún, Q. Roo	24.3	24.7	25.7	27.4	28.6	29.1	29.3	29.2	28.7	27.4	26.2	24.7	27.1	**28.7**
Hermosillo, Son.	16.6	18.1	20.2	23.4	26.9	31.5	32.3	31.6	30.7	26.5	20.5	16.8	24.6	**29.9**
Guadalajara, Jal.	15.3	16.7	18.6	20.8	22.9	23.4	21.8	21.7	21.3	19.9	17.6	15.9	19.7	**22.0**
Puebla, Pue.	13.8	14.8	17.0	18.7	19.8	19.4	18.4	18.3	18.1	17.1	15.8	14.4	17.1	**18.8**

* Average value of the six hottest consecutive month of the year.

Source: Servicio Meteorológico Nacional. <http://smn.cna.gob.mx/climatologia/normales/t-med.html>

Table 5-11 Climate

Cancún, Quintana Roo
Climate zone: Extremely hot humid
Classification Köppen: Aw
(Tropical, savannah)
Latitude: N 21° 1'
Longitude: W 86° 51'
Elevation: 5m above sea level
Time zone: GMT -6:00 hours
Tariff CFE: 1C

Hermosillo, Sonora
Climate zone: Extremely hot dry
Classification Köppen: BWh
(Arid, desert, hot)
Latitude: N 29° 3'
Longitude: W 110° 57'
Elevation: 211m above sea level
Time zone: GMT -7:00 hours
Tariff CFE: 1F

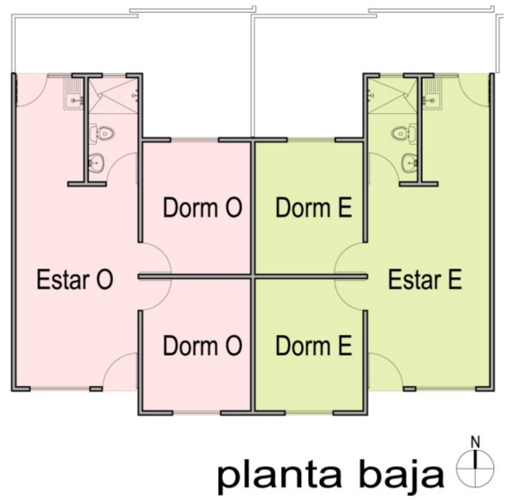
Guadalajara, Jalisco
Climate zone: Temperate
Classification Köppen: Cwa
(Temperate, dry winter, hot summer)
Latitude: N 20° 40'
Longitude: W 103° 19'
Elevation: 1491m above sea level
Time zone: GMT -6:00 hours
Tariff CFE: 1

Puebla, Puebla
Climate zone: Temperate cold
Classification Köppen: Cwb
(Temperate, dry winter, warm summer)
Latitude: N 19° 1'
Longitude: W 98° 11'
Elevation: 2166m above sea level
Time zone: GMT -6:00 hours
Tariff CFE: 1

Sources: Images: Google Earth, software available for download at: <http://www.google.com/earth/index.html>; Climate Zone: IzN Friedrichsdorf. Cited in CONAVI 2011; Classification Köppen: Meteonom-files (Weather-data-files), available for download at <http://tech.groups.yahoo.com/group/EnergyPlus_Support/>.

5.4 Performance by typology and climatic zone

5.4.1 Row housing unit (*Adosada*)



Housing type	Adosada
Gross floor area	44.71 m^2
Treated floor area	40.74 m^2

Description of the architectural design and the building envelope

The row housing unit (*Adosada*) is classified by the number of housing units per lot as category D) multy-family housing unit, one storey. Each unit has a treated floor area of 40.74 m^2, corresponding to the popular segment of the social interest category of the homogenized classification of housing according to type and value. Each unit consists of a living room with connected kitchen, bathroom and two bedrooms. The attached housing units share a separation wall of 19.5 m^2 between the bedrooms and a separation wall of 22.3 m^2 between the living rooms. The main facades (living room) of the calculated building are oriented towards the south; the rear façade is oriented towards the north. The east and west facades of the end-units contemplate the windows foreseen in the architectural plans.

A complex formed by six housing units forms the basis for the calculation. This complex has a ratio of the building envelope surface to the conditioned building volume (A/V) of 1.05 m^2/m^3. The theoretical window to floor area (WFA) given by the characteristics of the Reference Building is 12.3 % for the whole complex. The WFA for the BASELINE case and for the LINE NOM-020 case is 20.8 % for the whole complex.

The characteristics of the BASELINE case of this housing type correspond to the information provided by Consorcio ARA, based on the prototype “Almendros del conjunto Vista Real II”, projected in the municipality Ejido Isla Mujeres, in the state Quintana Roo.

The design of the BASELINE case disposes of a roof with thermal insulation, composed of a reinforced concrete slab of 13 cm thickness in combination with EPS insulation slab panels of 9 cm, as well as an additional layer of EPS of 1.5 ” on the exterior side. The walls are foreseen as reinforced concrete of 10 cm thickness and the windows with single glazing of 3 mm without shading devices (table 5-13).

Table 5-12 Adosada_Energetic evaluation according to NOM-020-ENER-2011

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
REFERENCE BUILDING, Total heat gain	*[W]*	1,354	1,420	970	814
PROJECTED BUILDING, Total heat gain	*[W]*	2,600	2,974	1,214	782
COMPLIANCE		**NO**	**NO**	**NO**	**YES**

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
PROJECTED BUILDING, Total heat gain	*[W]*	1,076	1,173	771	---
Reduction of Total Heat Gain	*[%]*	59%	61%	36%	---

Energy balance according to the NOM-020-ENER-2011

In the locations of Cancún and Hermosillo the total heat gains of the BASELINE case exceed the permitted limit for the total heat gain by the Reference Building by 92 % and by 110 %. In both locations the project exceeds the reference radiation gains for the transparent parts of the building envelope, as well as the reference conduction gains for the walls (chart 5-3). According to the analysis additional insulation of the walls and the application of shading devices or solar protection for the transparent building parts would be an appropriate energy efficiency strategies to fulfill the standard.

In the location of Guadalajara the total heat gains of the BASELINE case exceed the permitted limit of the total heat gain by the Reference Building by 25 %. The project exceeds the reference radiation gains for the transparent parts of the building envelope (chart 5-3). The application of shading devices or solar protection for the transparent building parts is recommended as energy efficiency strategy to fulfill the standard.

In the case of Puebla an Energy Saving (Ahorro de Energía) of 4 % is reported, this is to say the total heat gain of the BASELINE case is 4 % below the permitted limit of the total heat gain by the Reference Building; therefore the Adosada type fulfills the requirements of the standard in Puebla. The analysis of the energy balance reports elevated radiation gains for the transparent parts of the building, which are compensated on one hand by the thermal insulation of the roof. On the other hand the analysis reports "negative" heat gains or heat loss for the conduction gains of walls and glazing. This phenomenon is due to the fact, that the respective interior reference temperature of 24°C is higher than the equivalent temperatures for massive walls (north 21°C, east and south 23°C, west 22°C). The conduction heat gains are calculated using the following equation:

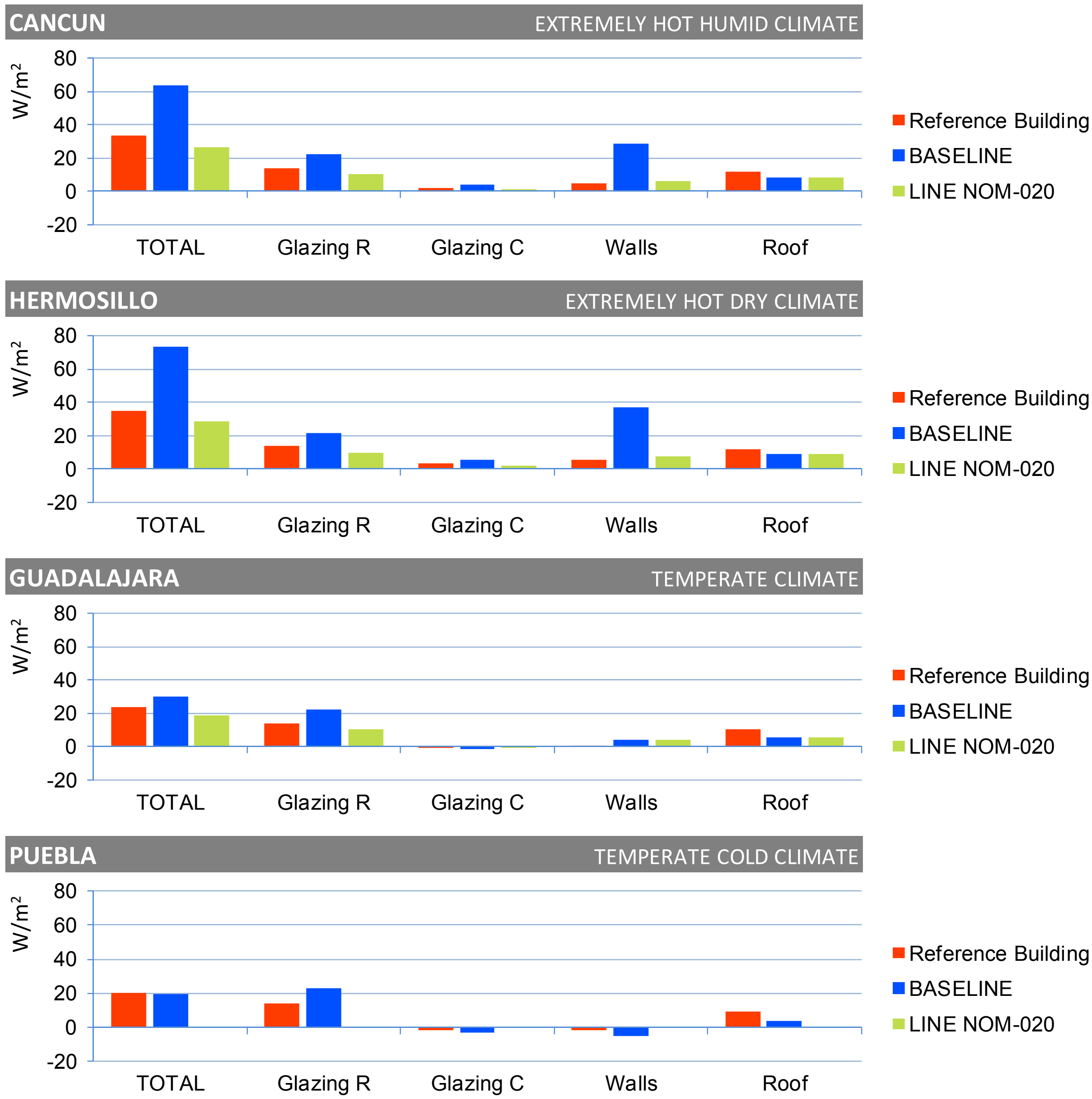
$$\phi \text{ pci} = \sum_{j=1}^{n} \left[K_j * A_{ij} * (t_e - t_i) \right]$$

Where

K_j	*[kWh/a]*	= Thermal transmittance (U-Value)
A_{ij}	*[m²]*	= Area of the building part
t_e	*[°C]*	= Equivalent temperature
t_i	*[°C]*	= Interior temperature

If, like in the case of Puebla the interior temperature is higher than the equivalent temperature, the result turns into a negative value, thus reducing the total heat gain. The higher the U-Value (the less insulated the building part), the bigger is the reduction on the total of the heat gains.

Chart 5-3 Adosada_Energetic evaluation NOM-020-ENER-2011



This phenomenon occurs only for the walls and transparent parts of the building envelope, as the equivalent temperatures for the roof and for lightweight walls are significantly higher.

In Puebla (or similar climates), according to the analysis of the heat gains (see chart 5-3), a possible strategy to reduce the total heat gain to the maximum level defined by the standard could take advantage of this phenomenon. On one hand the highest available U-Value would have to be chosen for the walls (a reinforced concrete wall of 10 cm for example), thus leading to a major “negative” heat gain. On the other hand an important reduction of the total heat gain could be achieved by reducing the radiation gains for the transparent parts of the building envelope. This could be done by applying a 3 mm single glazing with a LowE coating or film, having a shading coefficient of 0.50 or lower. From an economic point of view this would represent a very cost-effective solution to comply with the standard. From an energetic point of view this solution could be contra productive. The results of the evaluation with the PHPP (see table 5-14) show that there is an important projected heating energy consumption for the location of Puebla, so as to maintain the defined comfort temperatures. According to common knowledge in architectural practice it can be expected that the harvesting of solar gains by the windows of major solar exposure and the integration of thermal insulation into the walls of minor solar exposure will reduce the heating demand.

Energy efficiency strategies of the LINE NOM-020, their impact and cost

For the LINE NOM-020 case in the locations of Cancún and Hermosillo an additional layer of EPS of 2.0 inches was applied to all exterior walls. The clear single glazing of 3 mm of all windows was replaced by a low-emissive double glazing with a shading coefficient of 0.46. In both locations these measures lead to a significant reduction of the conduction heat gains of the walls and of radiation heat gains of the windows, as well as the conduction heat gains of the windows. The total heat gains of the projected building of the BASELINE case were reduced by 59 % for the LINE NOM-020 case in Cancún and by 61 % in Hermosillo. The applied energy efficiency measures in both locations represent an additional investment cost of $9,168.

Table 5-13 Adosada_Materials and Energy Efficiency measures

BASELINE - **PROJECTED BUILDING**		
Roof EPS 1.5" exterior side. Reinforced concrete slab, 13cm, with EPS insulation slab panels, 9cm. U-Value = 0.37 W/m^2K	**Walls** Reinforced concrete, 10cm. U-Value = 3.54 W/m^2K	**Windows** Single glazing, clear, 3mm. Shading Coefficient 1.00. U-Value = 5.32 W/m^2K

LINE NOM-020 - **CANCÚN**		
Roof EPS 1.5" exterior side. Reinforced concrete slab, 13cm, with EPS insulation slab panels, 9cm. U-Value = 0.37 W/m^2K	**Walls** EPS 2.0" exterior side. Reinforced concrete, 10cm. U-Value = 0.58 W/m^2K	**Windows** Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m^2K
Investment Cost Energy Efficiency Measures		**$9,168**

LINE NOM-020 - **HERMOSILLO**		
Roof EPS 1.5" exterior side. Reinforced concrete slab, 13cm, with EPS insulation slab panels, 9cm. U-Value = 0.37 W/m^2K	**Walls** EPS 2.0" exterior side. Reinforced concrete, 10cm. U-Value = 0.58 W/m^2K	**Windows** Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m^2K
Investment Cost Energy Efficiency Measures		**$9,168**

LINE NOM-020 - **GUADALAJARA**		
Roof EPS 1.5" exterior side. Reinforced concrete slab, 13cm, with EPS insulation slab panels, 9cm. U-Value = 0.37 W/m^2K	**Walls** Reinforced concrete, 10cm. U-Value = 3.54 W/m^2K	**Windows** Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m^2K
Investment Cost Energy Efficiency Measures		**$3,793**

For the LINE NOM-020 case in Guadalajara the clear single glazing of 3 mm of all windows was replaced by a low-emissive doble glazing with a shading coefficient of 0.46. The total heat gains of the projected building of the BASELINE case were reduced by 36 %. The cost of the energy efficiency measures is estimated at $3.793.

Energetic evaluation with Passive House Planning Package and CO_2 emissions

For the BASELINE case in Cancún according to the evaluation with the PHPP the annual cooling energy consumption accounts for 77 kWh/m^2y, whereas there is no consumption for heating. The total of both values would represent an equivalent of 101 kg/m^2y of CO_2 emissions. The LINE NOM-020 case reduces the cooling energy consumption by 48 %, leading to a reduction of CO_2 emissions of 48 kg/m^2y.

In Hermosillo for the BASELINE case the energy consumption is composed by 59 kWh/m^{2}y for cooling, and by 21 kWh/m^{2}y for heating, which represents a total equivalent of 83 kg/m^{2}y of CO_2 emissions. The applied energy efficiency measures in the LINE NOM-020 scenario reduce the cooling energy consumption by 65 % and achieve to eliminate the need for heating in the cold season. This leads to a reduction of the equivalent CO_2 emissions of 46 kg/m^{2}y.

For the BASELINE case in Guadalajara a theoretical cooling energy consumption of 6 kWh/m^{2}y and a theoretical heating energy consumption of 2 kWh/m^{2}y is reported, which equal an equivalent of 8 kg/m^{2}y of CO_2 emissions. The proposed energy efficiency strategy, derived from the results of the analysis of the NOM-020, would lead to a reduction of the cooling energy consumption of 1.1 kWh/m^{2}y, and would slightly increase the heating energy consumption by 0.1 KWh/m^{2}y. The total equivalent CO_2 emissions would be reduced by 1.5 kg/m^{2}y.

In Puebla the BASELINE case accounts for a theoretical cooling energy consumption of 2 kWh/m^{2}y, and a heating energy consumption of 78 kWh/m^{2}y, summing up to an equivalent CO_2 emission of 23 kg/m^{2}y.

Economic evaluation and investment payback time

In Cancún the implementation of the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling of $2,236, considering the CFE tariff 1C, which would lead to an investment payback time of 4.3 years. The investment payback time, when calculating with the accounting cost of 2.3 $/kWh would be 2.6 years. The investment of an additional $9,086 to fulfill the standard is recommended.

In Hermosillo the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling of $975, and would eliminate the need for heating which accounts for $214 annually. Considering the CFE tariff 1F the investment payback time would be 8.7 years. Considering the accounting cost of 2.3 $/kWh, the investment payback time would be 2.9 years. The investment of $9,086 to fulfill the standard is recommended.

For the case of Guadalajara the expected total economic saving by the implementation of the energy efficiency strategy to fulfill the standard woul lead to an estimated $40 annually. The investment payback time would exceed a lifecycle of 30 years for both the scenario considering the CFE tariff 1, as well as the scenario considering the accounting cost. From en economical point of view the investment of $3.793 is not recommended.

Table 5-14 Adosada_Energetic evaluation with PHPP & Economic evaluation

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m² y]*	77	59	6	2
Heating Energy Consumption	*[kWh/m² y]*	0	21	2	78
CO_2 Emissions	*[kg/m² y]*	101	83	8	23
Billing Heating	*[MXN/y]*	0	214	26	799
Billing Cooling, Tariff CFE	*[MXN/y]*	4,329	2,020	859	734
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	9,258	7,594	2,623	2,293

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m² y]*	40	28	5	---
Heating Energy Consumption	*[kWh/m² y]*	0	0	3	---
CO_2 Emissions	*[kg/m² y]*	53	37	7	---
Reduction of CO_2 Emissions	*[kg/m² y]*	48	46	1	---
Billing Heating	*[MXN/y]*	0	0	26	---
Billing Cooling, Tariff CFE	*[MXN/y]*	2,236	1,189	819	---
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	5,820	4,705	2,516	---
Economic Saving	*[MXN/y]*	2,093	1,045	40	---
Investment Cost of EE Measures	*[MXN]*	9,168	9,168	3,793	---
Investment Payback Time, Tariff CFE	*[y]*	4.4	8.8	95.9	---
Investment Payback Time, 2.3 MXN/kWh[1]	*[y]*	2.7	3.0	36.0	---

[1] Accounting cost

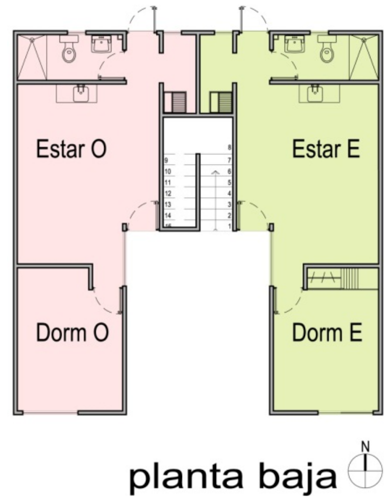
Key findings and conclusion

The analysis showed that the principal energy efficiency strategies to fulfill the standard are the following for the row housing unit Adosada:

- Cancún and Hermosillo:
  – Reduce conduction heat gains in walls
  – Reduce radiation heat gains by shading devices or solar protection
- Guadalajara:
  – Reduce radiation heat gains by shading devices or solar protection

The investment of $9,168 is recommended in Cancún and Hermosillo. There is no heating energy demand in Cancún and the heating energy demand would be eliminated in Hermosillo by the implementation of the energy efficiency measures. Economically the investment is not recommended in Guadalajara, as the results show no significant reduction of energy consumption. In the case of Puebla the Adosada type fulfills the standard, and therefore the NOM-020 label would suggest an energy efficient building. The results show nevertheless that the building has a significant heating energy demand to allow for thermal comfort, which is not contemplated by the standard. It has been detected that the standard provides misleading results, as the interior temperature is higher than the equivalent temperatures for massive walls and transparent parts of the building envelope. A revision of this particular point of the standard is recommended.

5.4.2 Duplex housing unit (*Dúplex*)



Housing type	Dúplex, adosada
Gross floor area	39.71 m^2
Treated floor area	36.33 m^2

Description of the architectural design and the building envelope

The duplex housing unit (*Dúplex*) is classified by the number of housing units per lot as category C) multy-family housing unit, duplex. Each unit has a treated floor area of 36.33 m^2, corresponding to the popular segment of the social interest category of the homogenized classification of housing according to type and value. Each unit consists of a living room with integrated kitchen area, bathroom, one bedroom and one utility room. The attached housing units share a separation wall of 29.3 m^2 between the living room and bedroom, and a separation wall of 6.6 m^2 between the utility rooms. The main facades (bedroom and living room) of the calculated building are oriented towards the south; the rear facades (bathroom) are oriented towards the north. The east and west facades of the end-units do not foresee additional windows.

A complex formed by twelve (six units per floor) housing units forms the basis for the calculation. This complex has a ratio of the building envelope surface to the conditioned building volume (A/V) of 0.72 m^2/m^3. The theoretical window to floor area (WFA) given by the characteristics of the Reference Building is 16.9 % for the whole complex. The WFA for the BASELINE case and for the LINE NOM-020 case is 14.0 % for the whole complex.

The characteristics of the BASELINE case of this housing type correspond to the information provided by housing developer SADASI, based on the prototype “Conjunto Prada Norte”, projected in the municipality of Cancún, in the state of Quintana Roo.

The design of the BASELINE case does not include thermal insulation measures that are contemplated by the NOM-020. The roof and the walls of the end units are projected with an acrylic elastomeric coating. This so-called cool surface material has a high emissivity value, thus reflecting the solar radiation. Nevertheless this effect is not contemplated by the code. According to Heard [2012] this is due to the fact, that the developers of the code considered the color of a house as a temporary, and not as a permanent element. The insulating effect of the material is considered in the calculations, however it is negligible.

The roof of the building is projected as a reinforced concrete slab of 10 cm thickness. The walls as well are projected with reinforced concrete of 10 cm thickness, and the windows with single glazing of 3mm (table 5-16). An exterior shading correction factor[34] of 0.85 for the bedroom windows and of 0.24 for the windows next to the main entrance was determined according to the NOM-020.

Table 5-15 Dúplex_Energetic evaluation according to NOM-020-ENER-2011

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
REFERENCE BUILDING, Total heat gain	*[W]*	1,353	1,478	940	765
PROJECTED BUILDING, Total heat gain	*[W]*	3,304	3,862	1,420	758
COMPLIANCE		**NO**	**NO**	**NO**	**YES**

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
PROJECTED BUILDING, Total heat gain	*[W]*	1,238	1,406	918	---
Reduction of Total Heat Gain	*[%]*	63%	64%	35%	---

Energy balance according to the NOM-020-ENER-2011

In the locations of Cancún and Hermosillo the total heat gains of the BASELINE case exceed the permitted limit for the total heat gain by the Reference Building by 144% and by 161%. In both locations the project exceeds the reference conduction gains for the roof and the walls (chart 5-4). The radiation heat gains for the windows are within the limit radiation heat gains of the Reference Building, which is due to the fact, that the WFA of the BASELINE case of 14.0 % is lower than the theoretical WFA of the Reference Building with 16.9 %. According to the analysis additional insulation of the roof and of the walls would be an appropriate energy efficiency strategy to fulfill the standard.

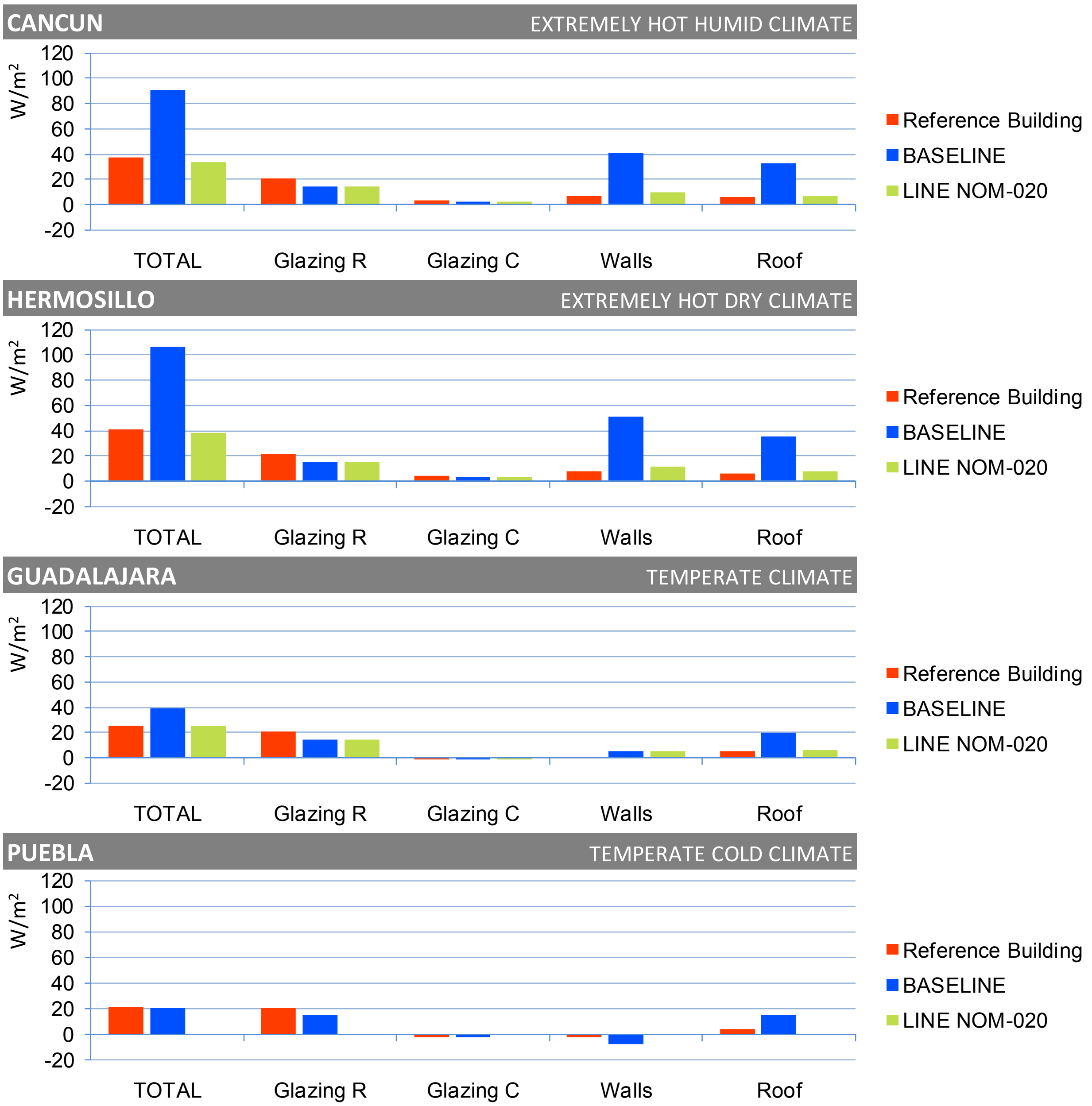
In Guadalajara the total heat gains of the BASELINE exceed the permitted limit of the total heat gain by the Reference Building by 51 %. The project exceeds the reference conduction heat gains for the roof, and a slightly higher value for conduction heat gains of the walls is compensated by lower radiation heat gains for glazing (chart 5-4). The application of additional thermal insulation on the roof is recommended as energy efficiency strategy to fulfill the standard.

For the location of Puebla an energy saving (ahorro de energía) of 1 % is reported, therefore the Duplex type fulfills the standard in Puebla. The analysis of the energy balance reports elevated radiation heat gains for the roof, which are on one hand compensated by the lower radiation heat gains of the glazing, due to smaller portion of window opening than in the

[34] “Is a dimensionless value between zero and one, determined by the shadow that is projected on the translucent part.” [NOM-020]. 0 represents 100 % shading and 1 represents no shading.

reference building. On the other hand they are compensated by the reported “negative” conduction heat gains for the walls, due to the fact, that the interior temperature is higher than the equivalent temperatures (see 5.4.1; Energy balance according to the NOM-020-ENER-2011).

Chart 5-4 Dúplex_Energetic evaluation NOM-020-ENER-2011



Energy efficiency strategies of the LINE NOM-020, their impact and cost

For the LINE NOM-020 case in the locations of Cancún and Hermosillo an additional layer of EPS of 2.0 inches was applied to the roof surface and to the exterior walls. In both locations these measures lead to a significant reduction of the conduction heat gains through roof and walls. The total heat gains of the BASELINE case were reduced by 63 % for the LINE NOM-

020 case in Cancún and by 64 % in Hermosillo. The applied energy efficiency measures in both locations represent an additional investment cost of $11,710.

For the LINE NOM-020 case in Guadalajara the roof screed was replaced by a mineral perlite aggregate of 6 cm thickness, thus enhancing the thermal insulation. The total heat gains of the projected building of the BASELINE case were reduced by 35 %. The cost of the energy efficiency measures is estimated at $2,572.

Table 5-16 Dúplex_Materials and Energy Efficiency measures

Roof	Walls	Windows
BASELINE - PROJECTED BUILDING		
Reinforced concrete slab, 10cm.	Reinforced concrete, 10cm.	Single glazing, clear, 3mm. Shading Coefficient 1.00.
U-Value = 2.85 W/m^{2}K	U-Value = 3.17 W/m^{2}K	U-Value = 5.32 W/m^{2}K
LINE NOM-020 - CANCÚN		
EPS 2.0" exterior side. Reinforced concrete slab, 10cm.	EPS 2.0" exterior side. Reinforced concrete, 10cm.	Single glazing, clear, 3mm. Shading Coefficient 1.00.
U-Value = 0.62 W/m^{2}K	U-Value = 0.64 W/m^{2}K	U-Value = 5.32 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$11,710**
LINE NOM-020 - HERMOSILLO		
EPS 2.0" exterior side. Reinforced concrete slab, 10cm.	EPS 2.0" exterior side. Reinforced concrete, 10cm.	Single glazing, clear, 3mm. Shading Coefficient 1.00.
U-Value = 0.62 W/m^{2}K	U-Value = 0.64 W/m^{2}K	U-Value = 5.32 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$11,710**
LINE NOM-020 - GUADALAJARA		
Mineral perlite aggregate, 6cm. Reinforced concrete slab, 10cm.	Reinforced concrete, 10cm.	Single glazing, clear, 3mm. Shading Coefficient 1.00.
U-Value = 0.90 W/m^{2}K	U-Value = 3.17 W/m^{2}K	U-Value = 5.32 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$2,573**

Energetic evaluation with Passive House Planning Package and CO_2 emissions

For the BASELINE case in Cancún according to the evaluation with the PHPP the annual cooling energy consumption accounts for 111 kWh/m^{2}y, whereas there is no consumption for heating. The total of both values represents an equivalent of 147 kg/m^{2}y of CO_2 emissions. The

LINE NOM-020 case reduces the cooling energy consumption by 34 %, leading to a reduction of CO_2 emissions of 50 kg/m^{2}y.

In Hermosillo for the BASELINE case the energy consumption is composed by 85 kWh/m^{2}y for cooling, and by 76 kWh/m^{2}y for heating, which represents a total equivalent of 130 kg/m^{2}y of CO_2 emissions. The applied energy efficiency measures in the LINE NOM-020 scenario reduce the cooling energy consumption by 39 % and de facto eliminate the need for heating in the cold season, by reducing the cooling energy consumption to 1.1 kg/m^{2}y. This leads to a reduction of the equivalent CO_2 emissions of 62 kg/m^{2}y.

Table 5-17 Dúplex_Energetic evaluation with PHPP & Economic evaluation

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m^2 y]*	111	85	12	5
Heating Energy Consumption	*[kWh/m^2 y]*	0	76	37	177
CO_2 Emissions	*[kg/m^2 y]*	147	130	25	51
Billing Heating	*[MXN/y]*	0	2,240	1,149	5,412
Billing Cooling, Tariff CFE	*[MXN/y]*	6,817	2,480	1,085	812
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	11,380	9,138	3,039	2,497

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m^2 y]*	73	52	14	---
Heating Energy Consumption	*[kWh/m^2 y]*	0	1	17	---
CO_2 Emissions	*[kg/m^2 y]*	96	68	23	---
Reduction of CO_2 Emissions	*[kg/m^2 y]*	50	62	1	---
Billing Heating	*[MXN/y]*	0	34	533	---
Billing Cooling, Tariff CFE	*[MXN/y]*	4,234	1,681	1,256	---
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	8,201	6,404	3,268	---
Economic Saving	*[MXN/y]*	2,583	3,005	444	---
Investment Cost of EE Measures	*[MXN]*	11,710	11,710	2,573	---
Investment Payback Time, Tariff CFE	*[y]*	4.5	3.9	5.8	---
Investment Payback Time, 2.3 MXN/kWh[1]	*[y]*	3.7	2.4	6.6	---

[1] Accounting cost

For the BASELINE case in Guadalajara a cooling energy consumption of 12 kWh/m^{2}y and a heating energy consumption of 37 kWh/m^{2}y is reported, which equal an equivalent of 25 kg/m^{2}y of CO_2 emissions. The proposed energy efficiency strategy, derived from the results of the analysis of the NOM-020, would lead to an augmentation of the cooling energy consumption of 2.7 kWh/m^{2}y, but would reduce the heating energy consumption by 20 kWh/m^{2}y. The total equivalent CO_2 emissions would be reduced by 1.4 kg/m^{2}y.

In Puebla the BASELINE case accounts for a theoretical cooling energy consumption of 5 kWh/m^2y, and a heating energy consumption of 177 kWh/m^2y, summing up to an equivalent CO_2 emission of 51 kg/m^2y.

Economic evaluation and investment payback time

In Cancún the implementation of the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling of $2,583, considering the CFE tariff 1C, which would lead to an investment payback time of 4.5 years. The investment payback time, when calculating with the accounting cost of 2.3 $/kWh would be 3.7 years. The investment of an additional $11,710 to fulfill the standard is recommended.

In Hermosillo the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling and heating of $3,005, and would de facto eliminate the need for heating. Considering the CFE tariff 1F the investment payback time would be 3.9 years. Considering the accounting cost of 2.3 $/kWh, the investment payback time would be 2.4 years. The investment of $11,710 to fulfill the standard is recommended.

For the case of Guadalajara the theoretical billing for cooling would increase, whereas the billing for heating would decrease, leading to an estimated annual economic saving of $444. The investment payback considering the CFE tariff 1 would be 5.8 years. Considering the accounting cost of 2.3 $/kWh, the investment payback time would be 6.6 years. The investment of an additional $2,573 to fulfill the standard is recommended.

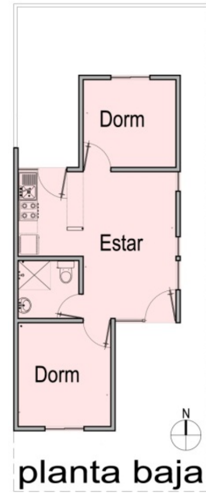
Key findings and conclusion

The analysis showed that the principal energy efficiency strategies to fulfill the standard are the following for the duplex housing unit Duplex:

Cancún and Hermosillo:	– Reduce conduction heat gains through the roof
	– Reduce conduction heat gains through the walls
Guadalajara:	– Reduce conduction heat gains through the roof

The investment of $11,710 is recommended in Cancún and Hermosillo. There is no heating energy demand in Cancún and the heating energy demand would de facto be eliminated in Hermosillo by the implementation of the energy efficiency measures. From an economic point of view the investment of $2,573 is recommended in Guadalajara. Although the cooling energy demand slightly increases, the heating energy demand is reduced by 54 %. In the case of Puebla the *Dúplex* type fulfills the standard, and therefore the NOM-020 label would suggest an energy efficient building. The results show nevertheless that the building has a significant heating energy demand of 177 kWh/m^2y, so as to allow for thermal comfort, which is not contemplated by the standard. As in the case of the *Adosada* type the fact that the interior temperature is higher than the equivalent temperature provides misleading results. A revision of this particular point of the standard is recommended.

5.4.3 Isolated housing unit (*Aislada*)



Housing type	Aislada
Gross floor area	43.50 m^2
Treated floor area	38.17 m^2

Description of the architectural design and the building envelope

The isolate housing unit (*Aislada*) is classified by the number of housing units per lot as category A) single-family housing unit, one storey. It has a treated floor area of 38.17 m^2, corresponding to the popular segment of the social interest category of the homogenized classification of housing according to type and value. Each unit consists of a living room with connected kitchen, bathroom and two bedrooms. The façade of the main entrance of the calculated building is oriented towards the south; the façade of the living room is oriented towards the east. The façade oriented to the west does not contain any window openings.

This housing type has a ratio of the building envelope surface to the conditioned building volume (A/V) of 1.49 m^2/m^3. This represents the highest ratio of all six studied housing types, with a range from 0.69 m^2/m^3 up to 1.49 m^2/m^3. The theoretical window to floor area (WFA) given by the characteristics of the Reference Building is 22.4 %. The WFA for the BASELINE case and for the LINE NOM-020 case is 24.3 %.

The characteristics of the BASELINE case of this housing type correspond to the information provided by Consorcio Hogar, based on the development “Sierra, Valle Floresta”, projected in the municipality of Pesquera, in the state of Nuevo León.

The design of the BASELINE case does not include thermal insulation measures that are contemplated by the NOM-020. The walls that due to their orientation have mayor sun exposure and the roof are projected with an acrylic elastomeric coating. This so-called cool surface material has a high emissivity value, thus reflecting the solar radiation. As mentioned in the paragraph 5.4.2 (Description of the architectural design and the building envelope), this effect is not contemplated by the code. The insulating effect of the material is considered in the calculations, however it is negligible.

The roof of the building is projected as a reinforced concrete slab of 10 cm thickness. The walls as well are projected with hollow concrete block of 10 cm thickness, and the windows with single glazing of 3mm (table 5-19). An exterior shading correction factor[35] of 0.73 for the bedroom window facing south and of 0.14 for the window next to the main entrance door was determined according to the NOM-020.

The appendix D (Values for thermal conductivity and thermal resistance of diverse materials) of the NOM-020 only lists one value for thermal resistance for a hollow concrete block of 20 cm thickness, a measure not common in the construction of social housing. Therefore a value of 0.159 m^2K/W, reported by Pérez et al. [2011] was considered for the calculations. It is recommended that the list of appendix D is complemented respectively, so as to provide the values for the most common materials used in the social housing sector. The inclusion of reference values for still air spaces[36] would as well allow for the calculation of hollow blocks.

Table 5-18 Aislada_Energetic evaluation according to NOM-020-ENER-2011

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
REFERENCE BUILDING, Total heat gain	*[W]*	2,166	2,379	1,546	1,267
PROJECTED BUILDING, Total heat gain	*[W]*	5,474	6,243	2,675	1,730
COMPLIANCE		**NO**	**NO**	**NO**	**NO**

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
PROJECTED BUILDING, Total heat gain	*[W]*	2,071	2,298	1,371	872
Reduction of Total Heat Gain	*[%]*	62%	63%	49%	50%

Energy balance according to the NOM-020-ENER-2011

In the locations of Cancún and Hermosillo the total heat gains of the BASELINE case exceed the permitted limit for the total heat gain by the Reference Building by 153% and by 162 %. In both locations the radiation gains for the transparent parts of the building envelope do not exceed the radiation heat gains of the Reference Building. The WFA of the BASELINE case is slightly higher than the WFA of the Reference Building, but this is compensated by the reduction factor for exterior shading of the south-oriented windows. The conduction heat gains for the roof and the walls exceed the reference conduction heat gains in Cancún and Hermosillo. According to the analysis additional insulation of the roof and the exterior walls would be an appropriate energy efficiency strategy to fulfill the standard.

In the case of Guadalajara and Puebla the total heat gains of the BASELINE case exceed the permitted limit of the total heat gain by the Reference Building by 73 % and by 37%. Both projects do not exceed the radiation gains for the transparent parts of the building envelope, but exceed the conduction heat gains for the roof. In the location of Puebla, as in the two

[35] "Is a dimensionless value between zero and one, determined by the shadow that is projected on the translucent part." [NOM-020]. The value 0 represents 100 % shading and 1 represents no shading.

[36] The European standard EN ISO 6946 [ISO 6946] provides values for the thermal resistance of still air spaces and could serve as a reference.

previous housing types, the analysis reports “negative” heat gains for conduction of walls and glazing. According to the analysis insulation the roof surfaces would be an appropriate energy efficiency strategy to fulfill the standard.

Chart 5-5 Aislada_Energetic evaluation NOM-020-ENER-2011

Energy efficiency strategies of the LINE NOM-020, their impact and cost

For the LINE NOM-020 case in the locations of Cancún and Hermosillo an additional layer of EPS of 2.0 inches was applied to the roof surface and to the exterior walls. In both locations these measures lead to a significant reduction of the conduction heat gains through roof and walls. The total heat gains of the BASELINE case were reduced by 62 % for the LINE NOM-020 case in Cancún and by 63 % in Hermosillo. The applied energy efficiency measures in both locations represent an additional investment cost of $19,149.

Table 5-19 Aislada_Materials and Energy Efficiency measures

BASELINE - PROJECTED BUILDING		
Roof Reinforced concrete slab, 10cm. U-Value = 2.87 W/m^{2}K	**Walls** Hollow concrete block, 12cm. U-Value = 2.61 W/m^{2}K	**Windows** Single glazing, clear, 3mm. U-Value = 5.32 W/m^{2}K
LINE NOM-020 - CANCÚN		
Roof EPS 2.0" exterior side. Reinforced concrete slab, 10cm. U-Value = 0.56 W/m^{2}K	**Walls** EPS 2.0" exterior side. Hollow concrete block, 10cm. U-Value = 0.55 W/m^{2}K	**Windows** Single glazing, clear, 3mm. Shading Coefficient 1.00. U-Value = 5.32 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$19,149**
LINE NOM-020 - HERMOSILLO		
Roof EPS 2.0" exterior side. Reinforced concrete slab, 10cm. U-Value = 0.56 W/m^{2}K	**Walls** EPS 2.0" exterior side. Hollow concrete block, 10cm. U-Value = 0.55 W/m^{2}K	**Windows** Single glazing, clear, 3mm. Shading Coefficient 1.00. U-Value = 5.32 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$19,149**
LINE NOM-020 - GUADALAJARA		
Roof Mineral perlite aggregate, 6cm. Reinforced concrete slab, 10cm. U-Value = 0.90 W/m^{2}K	**Walls** Hollow concrete block, 10cm. U-Value = 2.60 W/m^{2}K	**Windows** Single glazing, clear, 3mm. Shading Coefficient 1.00. U-Value = 5.32 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$5,655**
LINE NOM-020 - PUEBLA		
Roof EPS 2.0" exterior side. Reinforced concrete slab, 10cm. U-Value = 0.56 W/m^{2}K	**Walls** Hollow concrete block, 10cm. U-Value = 2.60 W/m^{2}K	**Windows** Single glazing, clear, 3mm. Shading Coefficient 1.00. U-Value = 5.32 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$6,947**

For the LINE NOM-020 case in Guadalajara the roof screed was replaced by a mineral perlite aggregate of 6 cm thickness, thus enhancing the thermal insulation. The total heat gains of the projected building of the BASELINE case were reduced by 49 %. The cost of the energy efficiency measures is estimated at $5,655.

In Puebla the LINE NOM-020 case received an additional layer of EPS of 2.0 inches on the exterior side of the roof surface. The total heat gains of the projected building of the BASELINE case were reduced by 50 %. The cost of the energy efficiency measures is estimated at $6.947.

Energetic evaluation with Passive House Planning Package and CO_2 emissions

For the BASELINE case in Cancún according to the evaluation with the PHPP the annual cooling energy consumption accounts for 116 kWh/m^{2}y, whereas there is no consumption for heating. The total of both values would represent an equivalent of 153 kg/m^{2}y of CO_2 emissions. The LINE NOM-020 case reduces the cooling energy consumption by 31 %, leading to a reduction of CO_2 emissions of 47 kg/m^{2}y.

In Hermosillo for the BASELINE case the energy consumption is composed by 93 kWh/m^{2}y for cooling, and by 121 kWh/m^{2}y for heating, which represents a total equivalent of 152 kg/m^{2}y of CO_2 emissions. The applied energy efficiency measures in the LINE NOM-020 scenario reduce the cooling and heating energy consumption by 69 %, while nearly eliminating the need for heating in the cold season. This leads to a reduction of the equivalent CO_2 emissions of 70 kg/m^{2}y.

For the BASELINE case in Guadalajara a cooling energy consumption of 9 kWh/m^{2}y and a heating energy consumption of 50 kWh/m^{2}y is reported, which equal an equivalent of 24 kg/m^{2}y of CO_2 emissions. The proposed energy efficiency strategy, derived from the results of the analysis of the NOM-020, would lead to an augmentation of the cooling energy consumption of 4.5 kWh/m^{2}y, but would reduce the heating energy consumption by 43 kWh/m^{2}y. The total equivalent CO_2 emissions would be reduced by 4.9 kg/m^{2}y.

In Puebla for the BASELINE case the energy consumption is composed by 4 kWh/m^{2}y for cooling, and by 251 kWh/m^{2}y for heating, which represents a total equivalent of 68 kg/m^{2}y of CO_2 emissions. The proposed energy efficiency strategy, derived from the results of the analysis of the NOM-020, would lead to an augmentation of the cooling energy consumption of 1.3 kWh/m^{2}y, but would reduce the heating energy consumption by 129 kWh/m^{2}y. The total equivalent CO_2 emissions would be reduced by 30 kg/m^{2}y.

Economic evaluation and investment payback time

In Cancún the implementation of the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling of $3.167, considering the CFE tariff 1C, which would lead to an investment payback time of 5.9 years. The investment payback time, when calculating with the accounting cost of 2.3 $/kWh would be identical, with 5.9 years. The investment of an additional $18,646 to fulfill the standard is recommended.

In Hermosillo the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling and heating of $1,926, reducing the demand for space heating significantly. Considering the CFE tariff 1F the investment payback time would be 9.7 years. Considering the accounting cost of 2.3 $/kWh, the investment payback time would be 4.8 years. The investment of $18,646 to fulfill the standard is recommended.

For the case of Guadalajara the expected total economic saving by the implementation of the energy efficiency strategy to fulfill the standard would lead to an estimated $125 annually. The investment payback time would exceed a lifecycle of 30 years for both the scenario considering the CFE tariff 1, as well as the scenario considering the accounting cost. From en economical point of view the investment of $5,420 is not recommended.

In Puebla the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling and heating of $1,196. It has to be mentioned that the billing for cooling increases slightly, and that the economic saving is due to the reduction of the heating energy consumption, which is reduced significantly. Considering the CFE tariff 1 the investment payback time would be 5.8 years. Considering the accounting cost of 2.3 $/kWh, the investment payback time would be 6.2 years. The investment of $6,947 to fulfill the standard is recommended.

Table 5-20 Aislada_Energetic evaluation with PHPP & Economic evaluation

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m² y]*	116	93	9	4
Heating Energy Consumption	*[kWh/m² y]*	0	121	50	251
CO_2 Emissions	*[kg/m² y]*	153	152	24	68
Billing Heating	*[MXN/y]*	0	1,168	485	2,418
Billing Cooling, Tariff CFE	*[MXN/y]*	7,792	2,789	947	794
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	12,260	10,202	2,853	2,451

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m² y]*	80	61	13	5.6
Heating Energy Consumption	*[kWh/m² y]*	0	5	7	122.3
CO_2 Emissions	*[kg/m² y]*	105	82	19	38
Reduction of CO_2 Emissions	*[kg/m² y]*	47	70	5	30
Billing Heating	*[MXN/y]*	0	44	66	1,178
Billing Cooling, Tariff CFE	*[MXN/y]*	4,625	1,986	1,240	837
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	9,106	7,468	3,250	2,565
Economic Saving	*[MXN/y]*	3,167	1,926	125	1,196
Investment Cost of EE Measures	*[MXN]*	18,646	18,646	5,420	6,947
Investment Payback Time, Tariff CFE	*[y]*	5.9	9.7	43.3	5.8
Investment Payback Time, 2.3 MXN/kWh[1]	*[y]*	5.9	4.8	247.8	6.2

[1] Accounting cost

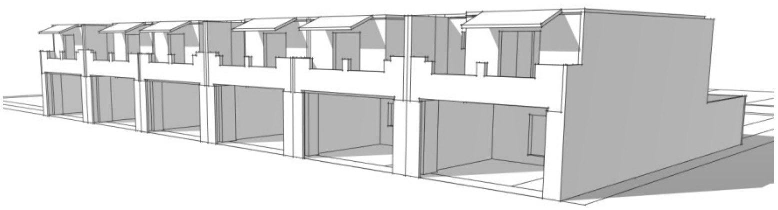
Key findings and conclusion

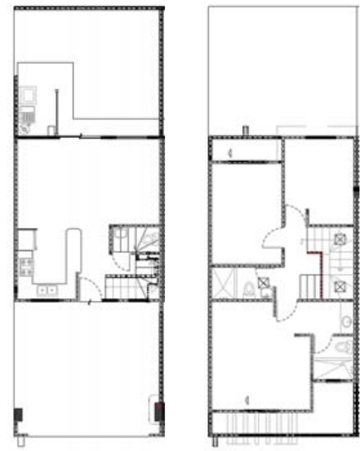
The itemized analysis of the results of the calculation according to the NOM-020 (see chart 5-5) showed that the reported heat gains for roof and walls exceed the maximum values defined by the Reference Building for the locations of Cancún and Hermosillo. For the location of Guadalajara and Puebla the reported heat gains for the roof exceed the defined maximum values. Based on this analysis the principal energy efficiency strategies to fulfill the standard are the following for the isolated housing unit *Aislada*:

- Cancún and Hermosillo:
  - Reduce conduction heat gains through the roof
  - Reduce conduction heat gains through the walls
- Guadalajara and Puebla:
  - Reduce conduction heat gains through the roof

The investment of $18,646 is recommended in Cancún and Hermosillo. There is no heating energy demand in Cancún and the heating energy demand would be nearly eliminated in Hermosillo by the implementation of the energy efficiency measures. Economically the investment is not recommended in Guadalajara, as the investment payback time exceeds the lifecycle of 30 years for both scenarios, considering the CFE tariffs and the accounting cost for electricity generation. In the case of Puebla the Aislada type does not fulfill the standard. The implementation of the LINE NOM-020 scenario would lead to an important annual economic saving and the investment of $6.947 to fulfill the standard is recommended. However it has to be mentioned that the economic saving is due to a reduction of the heating energy consumption, which is not contemplated by the standard. In the case of the isolated housing unit *Aislada*, the reported results affirm that the above mentioned energy efficiency strategies for the compliance with the NOM-020 lead to an improvement of the thermal performance of the building, reducing the heating energy consumption significantly.

5.4.4 Row housing unit, middle segment (*Medio*)





planta baja planta alta

Housing type	Vertical
Gross floor area	101.81 m^2
Treated floor area	84.23 m^2

Description of the architectural design and the building envelope

The row housing unit, middle segment (*Medio*) is classified by the number of housing units per lot as category B) multy-family housing unit, two storeys. Each unit has a treated floor area of 84.23m^2, corresponding to the medium category of the homogenized classification of housing according to type and value. Each unit consists of a ground floor with a living room, kitchen and toilet, and of an upper floor with three bedrooms, two bathrooms and two balconies. The attached housing units share a separation wall of 50.2 m^2 between the stairwells, and a separation wall of 51.4 m^2 on the opposite side. The façade of the main entrance is oriented to the south; the rear façade which opens to the backyard is oriented to the north. The east and west facades of the end-units do not foresee additional windows.

A complex formed by six housing units forms the basis for the calculation. This complex has a ratio of the building envelope surface to the conditioned building volume (A/V) of 0.69 m^2/m^3. This represents the lowest ratio of all six studied housing types, with a range from 0.69 m^2/m^3 up to 1.49 m^2/m^3. The theoretical window to floor area (WFA) given by the characteristics of the Reference Building is 11.4 % for the whole complex. The WFA for the BASELINE case and for the LINE NOM-020 case is 19.8 % for the whole complex.

The characteristics of the BASELINE case of this housing type correspond to the information provided by housing developer VINTE, based on the prototype “Playa”, projected in the municipality Playa del Carmen, in the state of Quintana Roo.

The design of the BASELINE case disposes of a roof with thermal insulation, composed of a reinforced concrete slab of 15 cm thickness in combination with EPS insulation slab panels of 10 cm, as well as an additional layer of EPS of 5 cm on the interior side of the slab. The elevated floor slabs (inferior surfaces[37]) are projected with the same construction system. The

[37] “A typical example is a building for residential use, whose parking occupies the first floors.” [NOM-020]

walls are foreseen with hollow concrete blocks of 12 cm thickness and the windows with single glazing of 3 mm (table 5-22).

An exterior shading correction factor[38] of 0.37 for the south-facing windows on the ground floor next to the main entrance, of 0.71 for the south-facing bedroom window on the upper floors, and of 0.9 for one north-facing bedroom window on the upper floor have been determined according to the NOM-020.

Table 5-21 Medio_Economic evaluation according to NOM-020-ENER-2011

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
REFERENCE BUILDING, Total heat gain	*[W]*	2,228	2,353	1,516	1,314
PROJECTED BUILDING, Total heat gain	*[W]*	3,976	4,442	1,714	1,157
COMPLIANCE		**NO**	**NO**	**NO**	**YES**

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
PROJECTED BUILDING, Total heat gain	*[W]*	2,046	2,278	1,091	---
Reduction of Total Heat Gain	*[%]*	49%	49%	36%	---

Energy balance according to the NOM-020-ENER-2011

In the locations of Cancún and Hermosillo the total heat gains of the BASELINE case exceed the permitted limit for the total heat gain by the Reference Building by 79 % and by 89 %. In both locations the project exceeds the reference conduction gains for the walls, as well as the reference radiation gains for the transparent parts of the building envelope (Chart 5-6). Although the project provides solar protection on all important south-facing windows and does not have windows on the western or eastern facades it exceeds the reference radiation gains. This has to be attributed to the theoretical WFA of the Reference Building of 11.4% which is the lowest ratio within a range of 11.4 % up to 29.0 %. This value is exceeded by the WFA of the BASELINE and LINE NOM-020 case of 19.8 %. According to the analysis additional insulation of the walls and the application of additional shading devices or solar protection for the transparent building parts would be an appropriate energy efficiency strategy to fulfill the standard.

In the location of Guadalajara the total heat gains of the BASELINE case exceed the permitted limit of the total heat gain by the Reference Building by 13 %. The project exceeds the reference radiation gains for the transparent parts of the building envelope (Chart 5-6). The application of shading devices or solar protection for the transparent building parts is recommended as energy efficiency strategy to fulfill the standard.

In the case of Puebla an energy saving (ahorro de energía) of 12 % is reported, this is to say the total heat gain of the BASELINE case is 12 % below the permitted limit of the total heat

[38] "Is a dimensionless value between zero and one, determined by the shadow that is projected on the translucent part." [NOM-020]. 0 represents 100 % shading and 1 represents no shading.

gain by the Reference Building; therefore the *Medio* type fulfills the requirements of the standard in Puebla. The building exceeds the radiation heat gains of the Reference Building. This excess is compensated on one hand by the good thermal insulation of the roof, as well as by the reported “negative” gains of the walls and the glazing.

Chart 5-6 Medio_Energetic evaluation NOM-020-ENER-2011

Energy efficiency strategies of the LINE NOM-020, their impact and cost

For the LINE NOM-020 case in the locations of Cancún and Hermosillo the hollow concrete block of the walls was exchanged by a certified industrialized brick of the same thickness. The clear single glazing of 3 mm of all windows was replaced by a low-emissive double glazing with a shading coefficient of 0.46. In both locations these measures lead to a significant reduction of the conduction heat gains of the walls and of the radiation heat gains of the windows, as well as the conduction heat gains of the windows. The total heat gains of the projected building of the BASELINE case were reduced by 49 % for the LINE NOM-020 case in Cancún and by 49 % in Hermosillo. The applied energy efficiency measures represent an additional investment cost of $16,319 in Cancún and of $17,111 in Hermosillo.

Table 5-22 Medio_Materials and Energy Efficiency measures

Roof	Walls	Windows
BASELINE - PROJECTED BUILDING		
Reinforced concrete slab, 15cm, with EPS insulation slab panels, 10cm. EPS 2.0" interior side.	Hollow concrete block, 12cm.	Single glazing, clear, 3mm. Shading Coefficient 1.00.
U-Value = 0.29 W/m^{2}K	U-Value = 2.60 W/m^{2}K	U-Value = 5.32 W/m^{2}K
LINE NOM-020 - CANCÚN		
Reinforced concrete slab, 15cm, with EPS insulation slab panels, 10cm. EPS 2.0" interior side.	Industrialized brick (certified), 12cm.	Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46.
U-Value = 0.29 W/m^{2}K	U-Value = 0.79 W/m^{2}K	U-Value = 1.87 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$16,319**
LINE NOM-020 - HERMOSILLO		
Reinforced concrete slab, 15cm, with EPS insulation slab panels, 10cm. EPS 2.0" interior side.	Industrialized brick (certified), 12cm.	Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46.
U-Value = 0.29 W/m^{2}K	U-Value = 0.79 W/m^{2}K	U-Value = 1.87 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$17,111**
LINE NOM-020 - GUADALAJARA		
Reinforced concrete slab, 15cm, with EPS insulation slab panels, 10cm. EPS 2.0" interior side.	Hollow concrete block, 12cm.	Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46.
U-Value = 0.29 W/m^{2}K	U-Value = 2.60 W/m^{2}K	U-Value = 1.87 W/m^{2}K
Investment Cost Energy Efficiency Measures		**$9,626**

For the LINE NOM-020 case in Guadalajara the clear single glazing of 3 mm of all windows was replaced by a low-emissive double glazing with a shading coefficient of 0.46. The total heat gains of the projected building of the BASELINE case were reduced by 36 %. The cost of the energy efficiency measures is estimated at $9,626.

Energetic evaluation with Passive House Planning Package and CO_2 emissions

For the BASELINE case in Cancún according to the evaluation with the PHPP the annual cooling energy consumption accounts for 75 kWh/m^{2}y, whereas there is no consumption for heating. The total of both values would represent an equivalent of 99 kg/m^{2}y of CO_2 emissions. The LINE NOM-020 case reduces the cooling energy consumption by 35 %, leading to a reduction of CO_2 emissions of 35 kg/m^{2}y.

In Hermosillo for the BASELINE case the energy consumption is composed by 54 kWh/m^{2}y for cooling, and by 14 kWh/m^{2}y for heating, which represents a total equivalent of 74 kg/m^{2}y of CO_2 emissions. The applied energy efficiency measures in the LINE NOM-020 scenario reduce the cooling energy consumption by 47 % and achieve to nearly eliminate the need for heating in the cold season. This leads to a reduction of the equivalent CO_2 emissions of 30 kg/m^{2}y.

For the BASELINE case in Guadalajara a theoretical cooling energy consumption of 8 kWh/m^{2}y and a theoretical heating energy consumption of 4 kWh/m^{2}y is reported, which equal an equivalent of 12 kg/m^{2}y of CO_2 emissions. The proposed energy efficiency strategy, derived from the results of the analysis of the NOM-020, would lead to a reduction of the cooling energy consumption of 4 kWh/m^{2}y. The total equivalent CO_2 emissions would be reduced by 6 kg/m^{2}y.

In Puebla the BASELINE case accounts for a theoretical cooling energy consumption of 3 kWh/m^{2}y, and a heating energy consumption of 53 kWh/m^{2}y, summing up to an equivalent CO_2 emission of 17 kg/m^{2}y.

Economic evaluation and investment payback time

In Cancún the implementation of the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling of $5,685, considering the CFE tariff 1C, which would lead to an investment payback time of 2.9 years. The investment payback time, when calculating with the accounting cost of 2.3 $/kWh would be 3.2 years. The investment of an additional $16.319 to fulfill the standard is recommended.

In Hermosillo the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling and heating of $1,949, and would de facto eliminate the need for heating. Considering the CFE tariff 1F the investment payback time would be 8.8 years. Considering the accounting cost of 2.3 $/kWh, the investment payback time would be 3.6 years. The investment of $17,111 to fulfill the standard is recommended.

For the case of Guadalajara the expected total economic saving by the implementation of the energy efficiency strategy to fulfill the standard would lead to an estimated $797 annually. Considering the CFE tariff 1 the investment payback time would be 12.1 years. Considering the accounting cost of 2.3 $/kWh, the investment payback time would be 11.6 years. The proposed solution led to an energy saving (ahorro de energía) of 28%. The investment cost of $9,626 could be cut down by only applying low-E double-glazing partially for the most critical rooms, whilst still complying with the standard.

Table 5-23 Medio_Energetic evaluation with PHPP & Economic evaluation

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m² y]*	75	54	8	3
Heating Energy Consumption	*[kWh/m² y]*	0	14	4	53
CO_2 Emissions	*[kg/m² y]*	99	74	12	17
Billing Heating	*[MXN/y]*	0	940	271	3,777
Billing Cooling, Tariff CFE	*[MXN/y]*	12,675	3,438	1,721	858
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	16,666	12,442	3,665	2,620

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m² y]*	49	33	4	---
Heating Energy Consumption	*[kWh/m² y]*	0	3	3	---
CO_2 Emissions	*[kg/m² y]*	64	44	6	---
Reduction of CO_2 Emissions	*[kg/m² y]*	35	30	6	---
Billing Heating	*[MXN/y]*	0	186	246	---
Billing Cooling, Tariff CFE	*[MXN/y]*	6,990	2,242	949	---
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	11,538	8,395	2,858	---
Economic Saving	*[MXN/y]*	5,685	1,949	797	---
Investment Cost of EE Measures	*[MXN]*	14,166	14,959	9,626	---
Investment Payback Time, Tariff CFE	*[y]*	2.5	7.7	12.1	---
Investment Payback Time, 2.3 MXN/kWh[1]	*[y]*	2.8	3.1	11.6	---

[1] Accounting cost

Key findings and conclusion

The analysis showed that the principal energy efficiency strategies to fulfill the standard are the following for the row housing unit, middle segment Medio:

- Cancún and Hermosillo:
  – Reduce conduction heat gains in walls
  – Reduce radiation heat gains by shading devices or solar protection
- Guadalajara:
  – Reduce radiation heat gains by shading devices or solar protection

The investment of $16,319 and of $17,111 is recommended in Cancún and in Hermosillo. There is no heating demand in Cancún and the implemented energy efficiency measures would nearly eliminate the heating demand in Hermosillo. The investment of $9,626 in Guadalajara would lead to an investment payback time of 12.1 years, considering the CFE tariff 1, or 11.6 years, considering the accounting cost for electricity production. The investment cost could be cut down be only applying low-E double-glazing to the most critical windows. The *Medio* type fulfills the standard in Puebla, and therefore the NOM-020 label would suggest an energy efficient building. The results show nevertheless that, in order to allow for thermal comfort, the building has a significant heating energy consumption of 53 kWh/m^{2}y, which is not contemplated by the standard. The phenomenon of “negative” heat gains occurs in Puebla. A revision of this particular point of the standard is recommended.

5.4.5 Isolated housing unit, residential segment (*Residencial*)

Housing type	Vertical
Gross floor area	167.47 m^2
Treated floor area	141.17 m^2

Description of the architectural design and the building envelope

The isolated housing unit, residential segment (*Residencial*) is classified by the number of housing units per lot as category B) single-family housing unit, two storeys. It has a treated floor area of 141.17 m^2, corresponding to the residential category of the homogenized classification of housing according to type and value. It consists of a ground floor with a living room, dining room, study, kitchen, utility room and toilet; and of an upper floor with three bedrooms, three bathrooms and one living area. The façade of the main entrance is oriented to the south; the façade opening to the garden is oriented to the west.

This housing type has a ratio of the building envelope surface to the conditioned building volume (A/V) of 0.82 m^2/m^3. The theoretical window to floor area (WFA) given by the characteristics of the Reference Building is 29.0 %, which represents the highest value for all of the six studied housing types with a range from 11.4 % up to 29.0 %. The WFA for the BASELINE case and for the LINE NOM-020 case is 12.3 %.

The characteristics of the BASELINE case of this housing type correspond to the information provided by housing developer VINTE, based on the prototype “Tekamac”, projected in the municipality of Queretaro, in the state of Queretaro.

The design of the BASELINE case disposes of a roof with thermal insulation, composed of a reinforced concrete slab of 15 cm thickness in combination with EPS insulation slab panels of 10 cm, as well as an additional layer of EPS of 5 cm on the interior side of the slab. The elevated floor slabs (inferior surfaces[39]) are projected with the same construction system. The walls are foreseen with hollow concrete blocks of 12 cm thickness and the windows with single glazing of 3 mm (table 5-25).

[39] “A typical example is a building for residential use, whose parking occupies the first floors.” [NOM-020]

The windows of the north-oriented rear façade do not present any shading devices. The south-oriented windows have shading correction factors[40], ranging from 0.94 up to 0.74. The windows on the façade oriented towards the west have shading correction factors of 0.96 up to 0.95, with two windows having a shading correction factor of 0.24, due to nearby walls, acting as shading elements (partesol).

Table 5-24 Residencial_Energetic evaluation according to NOM-020-ENER-2011

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
REFERENCE BUILDING, Total heat gain	[W]	5,194	5,664	3,597	3,015
PROJECTED BUILDING, Total heat gain	[W]	7,457	9,123	2,661	1,023
COMPLIANCE		**NO**	**NO**	**YES**	**YES**

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
PROJECTED BUILDING, Total heat gain	[W]	5,085	5,648	---	---
Reduction of Total Heat Gain	[%]	32%	38%	---	---

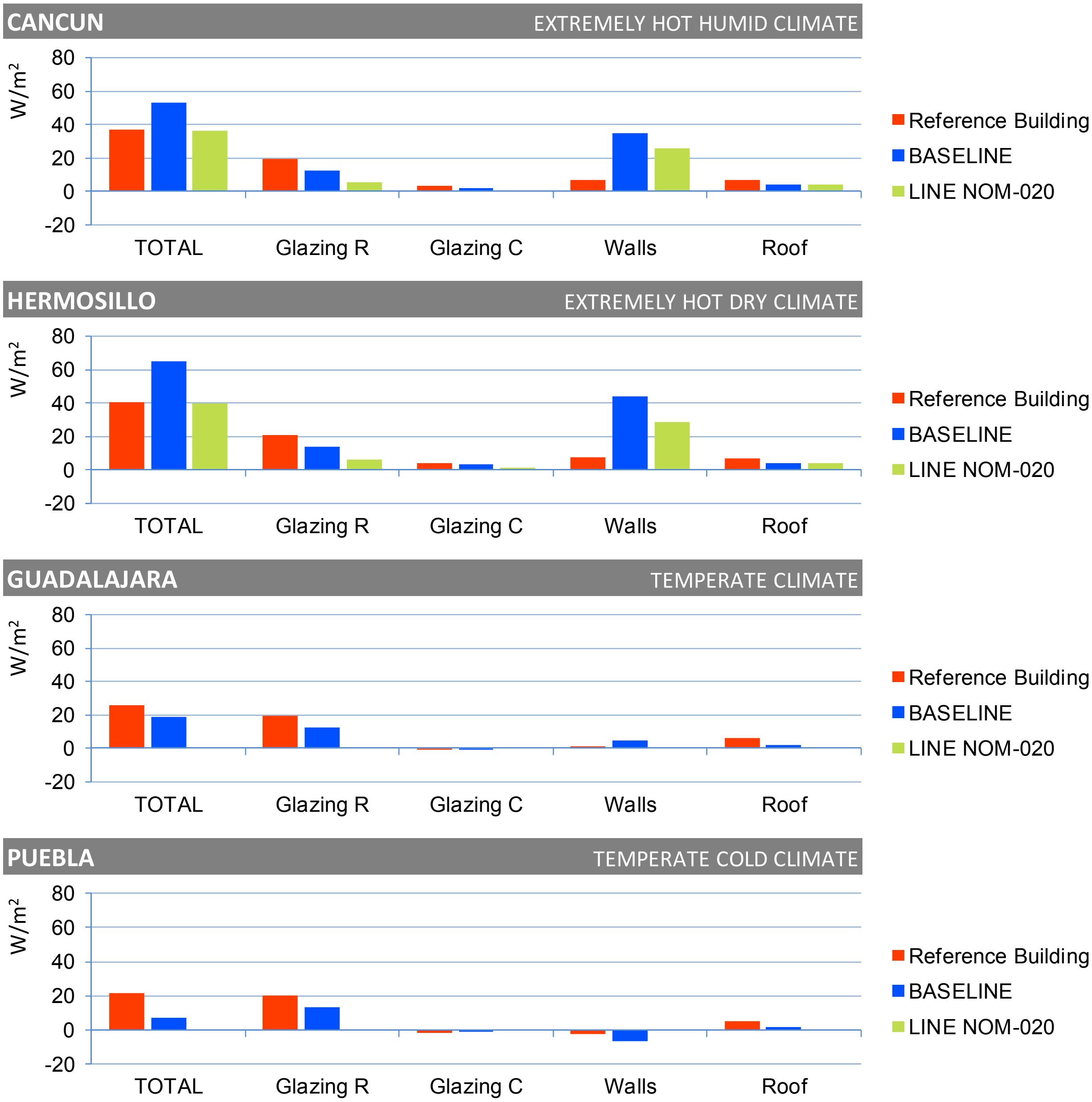
Energy balance according to the NOM-020-ENER-2011

In the locations of Cancún and Hermosillo the total heat gains of the BASELINE case exceed the permitted limit for the total heat gain by the Reference Building by 44 % and by 61 %. In both locations the project exceeds the reference conduction heat gains of the walls. The radiation gains of transparent parts of the building envelope are below those of the Reference Building, this is due to the high value for the WFA of the Reference Building of 29 %, in relation to a WFA of the BASELINE case of 12.3 % (chart 5-7). According to the analysis the application of additional thermal insulation on the exterior walls would be an appropriate energy efficiency strategy to fulfill the standard.

For the location of Guadalajara and Puebla an energy saving (ahorro de energía) of 26 % and of 66 % is reported. The Residencial type fulfills the requirements of the standard in Guadalajara and Puebla. In both locations the radiation heat gains of the transparent parts of the building envelope of the BASELINE case are below those of the Reference Building, which is due to the high ratio for the WFA of the Reference Building of 29 %, in relation to a WFA of the BASELINE case of 12.3 %. The conduction heat gains of the roof are lower than those registered for the reference building, given the good thermal insulation of the constructive system. A slight increase of the conduction heat gains of the walls for Guadalajara is compensated by low values for the radiation heat gains of the glazing. The phenomenon of “negative” conduction heat gains for massive walls and transparent elements is observed in Puebla (chart 5-7).

[40] “Is a dimensionless value between zero and one, determined by the shadow that is projected on the translucent part.” [NOM-020]. 0 represents 100 % shading and 1 represents no shading.

Chart 5-7 Residencial_Energetic evaluation NOM-020-ENER-2011



Energy efficiency strategies of the LINE NOM-020, their impact and cost

For the LINE NOM-020 case in the locations of Cancún and Hermosillo the hollow concrete block of the walls was exchanged by a thermal hollow concrete block of the same dimensions. The clear single glazing of 3 mm of all windows was replaced by a low-emissive double glazing with a shading coefficient of 0.46. Although the energy efficiency strategy according to the analysis of the results of the NOM-020 evaluation would be to only add additional insulation to the exterior walls, the chosen measures resulted in a lower additional investment cost. The replacement of the hollow concrete block by a thermal hollow concrete block is a very economic measure. The price difference to other measures like replacement by certified industrialzed brick or adding a layer of EPS covers the investment cost for a low-E double-glazing of all windows in this particular case (see table 5-2 Price difference Energy Efficiency measures_Products, and table 5-3 Price difference Energy Efficiency measures_Work concepts).

In both locations these measures lead to a significant reduction of the conduction heat gains of the walls and of the radiation heat gains of the windows, as well as the conduction heat gains of the windows. The total heat gains of the projected building of the BASELINE case were reduced by 26 % for the LINE NOM-020 case in Cancún and by 33 % in Hermosillo. The applied energy efficiency measures represent an additional investment cost of $13,279 for both locations.

Table 5-25 Residencial_Materials and Energy Efficiency measures

Roof	Walls	Windows
BASELINE - PROJECTED BUILDING		
Roof Reinforced concrete slab, 15cm, with EPS insulation slab panels, 10cm. EPS 2.0" interior side. U-Value = 0.29 W/m^2K	**Walls** Hollow concrete block, 12cm. U-Value = 2.60 W/m^2K	**Windows** Single glazing, clear, 3mm. Shading Coefficient 1.00. U-Value = 5.32 W/m^2K
LINE NOM-020 - CANCÚN		
Roof Reinforced concrete slab, 15cm, with EPS insulation slab panels, 10cm. EPS 2.0" interior side. U-Value = 0.29 W/m^2K	**Walls** Hollow thermal concrete block (certified), 12cm. U-Value = 1.68 W/m^2K	**Windows** Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m^2K
Investment Cost Energy Efficiency Measures		**$13,279**
LINE NOM-020 - HERMOSILLO		
Roof Reinforced concrete slab, 15cm, with EPS insulation slab panels, 10cm. EPS 2.0" interior side. U-Value = 0.29 W/m^2K	**Walls** Hollow thermal concrete block (certified), 12cm. U-Value = 1.68 W/m^2K	**Windows** Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m^2K
Investment Cost Energy Efficiency Measures		**$13,279**

Energetic evaluation with Passive House Planning Package and CO_2 emissions

For the BASELINE case in Cancún according to the evaluation with the PHPP the annual cooling energy consumption accounts for 83 kWh/m^2y, whereas there is no consumption for heating. The total of both values would represent an equivalent of 110 kg/m^2y of CO_2 emissions. The LINE NOM-020 case reduces the cooling energy consumption by 26 %, leading to a reduction of CO_2 emissions of 29 kg/m^2y.

In Hermosillo for the BASELINE case the energy consumption is composed by 64 kWh/m^2y for cooling, and by 13 kWh/m^2y for heating, which represents a total equivalent of 88 kg/m^2y of

CO_2 emissions. The applied energy efficiency measures in the LINE NOM-020 scenario would reduce the cooling and heating energy consumption by 33 %, whilst reducing the need for heating energy consumption significantly. This leads to a reduction of the equivalent CO_2 emissions of 26 kg/m^{2}y.

The BASELINE case in Guadalajara accounts for a cooling energy consumption of 14 kWh/m^{2}y, and a heating energy consumption of 2 kWh/m^{2}y, summing up to an equivalent CO_2 emission of 19 kg/m^{2}y.

In Puebla the BASELINE case accounts for a theoretical cooling energy consumption of 5 kWh/m^{2}y, and a heating energy consumption of 46 kWh/m^{2}y, summing up to an equivalent CO_2 emission of 19 kg/m^{2}y.

Table 5-26 Residencial_Energetic evaluation with PHPP & Economic evaluation

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m^2 y]*	83	64	14	5
Heating Energy Consumption	*[kWh/m^2 y]*	0	13	2	46
CO_2 Emissions	*[kg/m^2 y]*	110	88	19	19
Billing Heating	*[MXN/y]*	0	1,467	217	5,521
Billing Cooling, Tariff CFE	*[MXN/y]*	26,499	10,208	4,955	1,790
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	29,139	22,966	6,713	3,821

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m^2 y]*	61	46	---	---
Heating Energy Consumption	*[kWh/m^2 y]*	0	6	---	---
CO_2 Emissions	*[kg/m^2 y]*	81	62	---	---
Reduction of CO_2 Emissions	*[kg/m^2 y]*	29	26	---	---
Billing Heating	*[MXN/y]*	0	644	---	---
Billing Cooling, Tariff CFE	*[MXN/y]*	18,575	6,325	---	---
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	21,989	17,066	---	---
Economic Saving	*[MXN/y]*	7,924	4,705	---	---
Investment Cost of EE Measures	*[MXN]*	13,279	13,279	---	---
Investment Payback Time, Tariff CFE	*[y]*	1.7	2.8	---	---
Investment Payback Time, 2.3 MXN/kWh[1]	*[y]*	1.9	2.0	---	---

[1] Accounting cost

Economic evaluation and investment payback time

In Cancún the implementation of the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling of $7,924, considering the CFE tariff 1C, which would lead to an investment payback time of 1.7 years. The investment payback time, when calculating with the accounting cost of 2.3 $/kWh would be 1.9 years. The investment of an additional $13,279 to fulfill the standard is recommended.

In Hermosillo the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling and heating of $4,705. Considering the CFE tariff 1F the investment payback time would be 2.8 years. Considering the accounting cost of 2.3 $/kWh, the investment payback time would be 2.0 years. The investment of $13,279 to fulfill the standard is recommended.

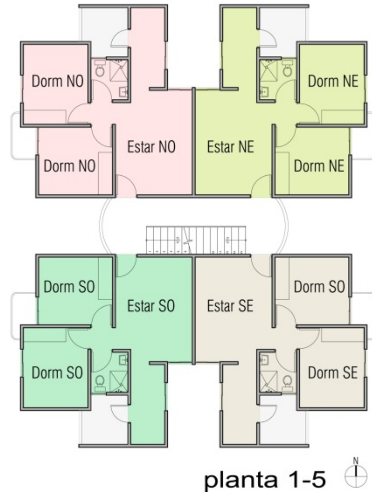
Key findings and conclusion

The analysis showed that the principal energy efficiency strategies to fulfill the standard are the following for the isolated housing unit, residential segment Residencial:

- Cancún and Hermosillo: – Reduce conduction heat gains in walls

The investment of $13,279 is recommended in Cancún and Hermosillo. There is no heating demand in Cancún and the implemented energy efficiency measures reduce the heating energy consumption significantly in Hermosillo. The Residencial type fulfills the standard in Guadalajara and in Puebla. The definition of the Reference Building by the standard, describing 10% of transparent surface for the walls favors this housing type of the residential category (average built surface 145 m^2), providing a theoretical window to floor area (WFA) of 29.0 %. This ratio presents the highest value for all of the six studied housing types within a range from 11.4 % up to 29.0 %. As the BASELINE case presents a WFA of 12.3 %, the resulting low value for the radiation heat gains allow for the project to fulfill the standard in Guadalajara. As for Puebla the project fulfills the standard, but presents an annual 46 kWh/m^2y of heating energy consumption that is not contemplated by the standard. The phenomenon of “negative” heat gains occurs in Puebla. A revision of this particular point of the standard is recommended.

5.4.6 Vertical housing unit (*Vertical*)



Housing type	Vertical
Gross floor area	46.08 m^2
Treated floor area	40.88 m^2

Description of the architectural design and the building envelope

The vertical housing unit (*Vertical*) is classified by the number of housing units per lot as category F) multy-family housing unit, five storeys[41]. Each level consists of four identical departments whose floor plan was mirrored across tow axes. Each unit has a treated floor area of 40.88 m^2, corresponding to the popular segment of the social interest category of the homogenized classification of housing according to type and value. Each unit consists of a living room, kitchen, bathroom, two bedrooms and an exterior utility room. A separation wall of 11.72 m^2, divides the adjacent departments. The façades of the bedrooms, having a bigger proportion of window area, are oriented to the east and to the west.

The calculations are based on the vertical building complex, formed by 24 units (four units per floor). This complex has a ratio of the building envelope surface to the conditioned building volume (A/V) of 0.73 m^2/m^3. The theoretical window to floor area (WFA) given by the characteristics of the Reference Building is 17.2 % for the whole complex. The WFA for the BASELINE case and for the LINE NOM-020 case is 19.3 % for the whole complex.

The characteristics of the BASELINE case of this housing type correspond to the information provided by housing developer AISA, based on the prototype “Torres 475”, projected in the municipality of Puebla, in the state of Puebla.

The design of the BASELINE case disposes of a roof with thermal insulation, composed of a reinforced concrete slab of 20 cm thickness in combination with EPS insulation slab panels of 16 cm, as well as a volcanic rock filling of 6 cm thickness in average on the exterior side. The

[41] The project actually consists of six storeys. In most building regulations in Mexico five storeys in general represent the maximum number of storeys that can be built without providing an elevator. In this sense category F) stands for the maximum number of storeys that can be built without elevator. The next category would then be high rise buildings with elevator above five storeys. The example is projected in Puebla and the local construction code seems to allow for 6 storeys without elevator.

walls are projected as hollow concrete blocks of 12 cm thickness and the windows with single glazing of 3mm without shading devices (table 5-28).

The following exterior shading correction factors[42] have been determined according to the NOM-020. For the living room windows a factor of 0.09 for the north façade and of 0.14 for the south façade is given by the walls adjacent to the windows. For the glazed door, giving access from the bedroom to the balcony, an exterior shading correction factor of 0.75 applies for the eastern and western façades.

Table 5-27 Vertical_Energetic evaluation according to NOM-020-ENER-2011

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
REFERENCE BUILDING, Total heat gain	*[W]*	1,392	1,504	914	715
PROJECTED BUILDING, Total heat gain	*[W]*	2,322	2,854	880	375
COMPLIANCE		**NO**	**NO**	**YES**	**YES**

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
PROJECTED BUILDING, Total heat gain	*[W]*	1,099	1,335	---	---
Reduction of Total Heat Gain	*[%]*	53%	53%	---	---

Energy balance according to the NOM-020-ENER-2011

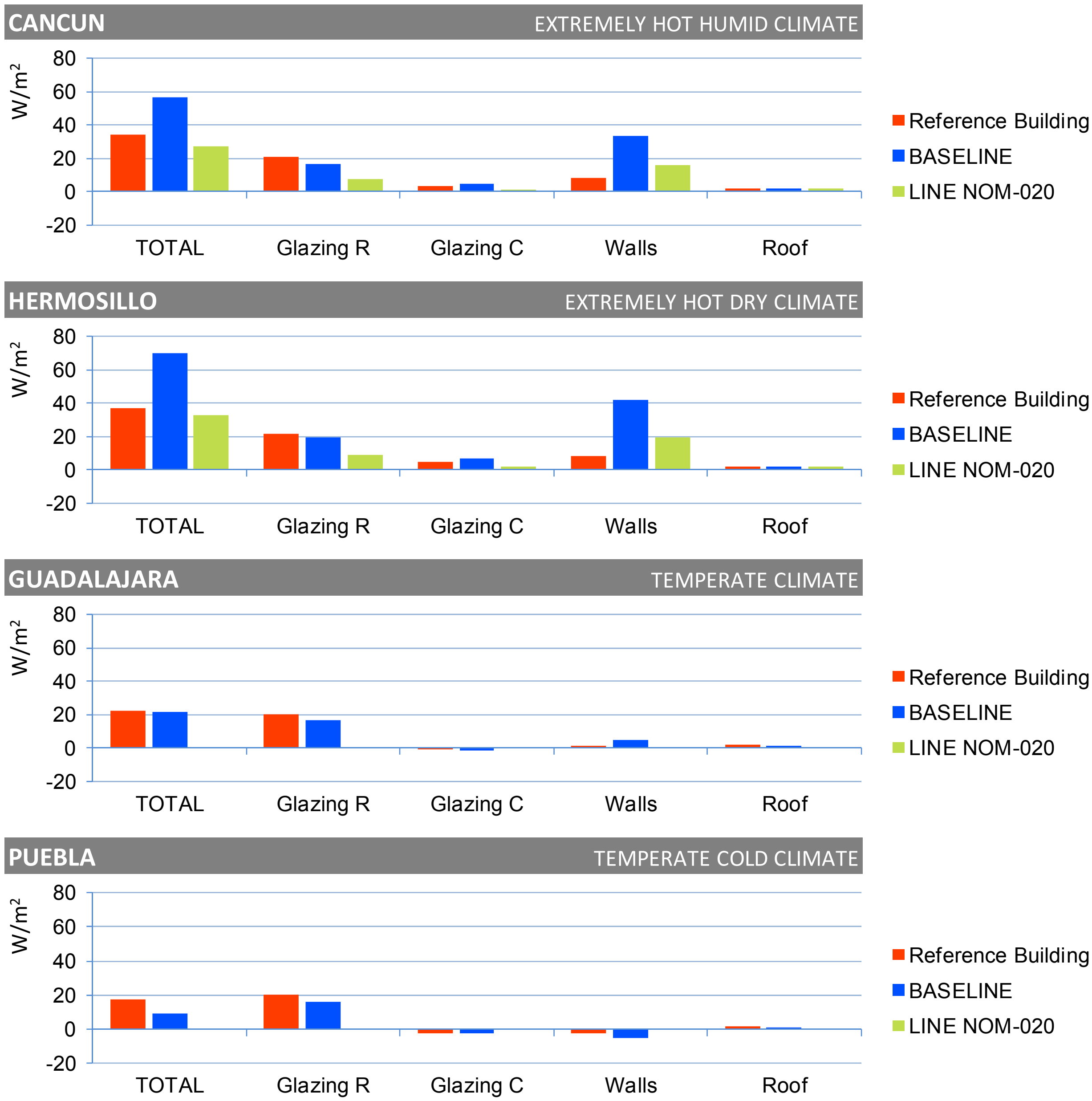
In the locations of Cancún and Hermosillo the total heat gains of the BASELINE case exceed the permitted limit for the total heat gain by the Reference Building by 67 % and by 90 %. In both locations the project exceeds the reference conduction gains for the walls. The conduction heat gains of the roof are lower than those registered for the reference building, given the good thermal insulation of the constructive system. The radiation heat gains for the transparent parts of the building envelope are lower than the value of the Reference Building (chart 5-8). The TWA of 19.3 % of the BASELINE case is lightly higher than the theoretical TWA of 17.2 % of the Reference Building, but the exterior shading of approximately half of the windows lowers the radiation heat gains below the value reported by the Reference Building. According to the analysis the application of additional thermal insulation on the exterior walls would be an appropriate energy efficiency strategy to fulfill the standard.

For the location of Guadalajara and Puebla an energy saving (ahorro de energía) of 4 % and of 48 % is reported. The Residencial type fulfills the requirements of the standard in Guadalajara and Puebla. In both locations the radiation heat gains of the transparent parts of the BASELINE case of the building envelope are below those of the Reference Building, due to the same geometric conditions as mentioned in the case of Cancún and Hermosillo. The conduction heat gains of the roof are lower than those registered for the reference building, given the good thermal insulation of the constructive system. A slight increase of the conduction heat gains of the walls for Guadalajara is compensated by a lower value for the radiation heat gains of the

[42] "Is a dimensionless value between zero and one, determined by the shadow that is projected on the translucent part." [NOM-020]. 0 represents 100 % shading and 1 represents no shading.

glazing. The phenomenon of “negative” conduction heat gains for massive walls and transparent elements is observed in Puebla, contributing to the reported energy saving (ahorro de energía) of 48 % (chart 5-8).

Chart 5-8 Vertical_Energetic evaluation NOM-020-ENER-2011



Energy efficiency strategies of the LINE NOM-020, their impact and cost

For the LINE NOM-020 case in the locations of Cancún and Hermosillo the hollow concrete block of the walls was exchanged by a certified industrialized brick of the same thickness. The clear single glazing of 3 mm of all windows was replaced by a low-emissive double glazing with a shading coefficient of 0.46. In both locations these measures lead to a significant reduction of the conduction heat gains of the walls and of the radiation heat gains of the windows, as well as the conduction heat gains of the windows. The total heat gains of the projected building of the BASELINE case were reduced by 40 % for the LINE NOM-020 case in Cancún and by 51 % in Hermosillo. The applied energy efficiency measures represent an additional investment cost of $10,681 in Cancún and of $11,311 in Hermosillo.

Table 5-28 Vertical_Materials and Energy Efficiency measures

BASELINE - **PROJECTED BUILDING**		
Roof Volcanic rock filling (cacahuatillo), 6cm Reinforced concrete slab, 20cm, with EPS insulation slab panels, 16cm. U-Value = 0.49 W/m²K	**Walls** Hollow concrete block, 12cm. U-Value = 2.60 W/m²K	**Windows** Single glazing, clear, 3mm. Shading Coefficient 1.00. U-Value = 5.32 W/m²K
LINE NOM-020 - **CANCÚN**		
Roof Volcanic rock filling (cacahuatillo), 6cm Reinforced concrete slab, 20cm, with EPS insulation slab panels, 16cm. U-Value = 0.49 W/m²K	**Walls** Industrialized brick (certified), 12cm. U-Value = 0.79 W/m²K	**Windows** Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m²K
Investment Cost Energy Efficiency Measures		**$10,681**
LINE NOM-020 - **HERMOSILLO**		
Roof Volcanic rock filling (cacahuatillo), 6cm Reinforced concrete slab, 20cm, with EPS insulation slab panels, 16cm. U-Value = 0.49 W/m²K	**Walls** Industrialized brick (certified), 12cm. U-Value = 0.79 W/m²K	**Windows** Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m²K
Investment Cost Energy Efficiency Measures		**$11,311**

Energetic evaluation with Passive House Planning Package and CO_2 emissions

For the BASELINE case in Cancún according to the evaluation with the PHPP the annual cooling energy consumption accounts for 92 kWh/m^{2}y, whereas there is no consumption for heating. The total of both values would represent an equivalent of 121 kg/m^{2}y of CO_2 emissions. The LINE NOM-020 case reduces the cooling energy consumption by 40 %, leading to a reduction of CO_2 emissions of 48 kg/m^{2}y.

In Hermosillo for the BASELINE case the energy consumption is composed by 72 kWh/m^{2}y for cooling, and by 40 kWh/m^{2}y for heating, which represents a total equivalent of 104 kg/m^{2}y of CO_2 emissions. The applied energy efficiency measures in the LINE NOM-020 scenario reduce the cooling energy consumption by 51 % and achieve to nearly eliminate the need for heating in the cold season. This leads to a reduction of the equivalent CO_2 emissions of 48 kg/m^{2}y.

The BASELINE case in Guadalajara accounts for a cooling energy consumption of 13 kWh/m^{2}y, and a heating energy consumption of 16 kWh/m^{2}y, summing up to an equivalent CO_2 emission of 21 kg/m^{2}y.

In Puebla the BASELINE case accounts for a theoretical cooling energy consumption of 4 kWh/m^{2}y, and a heating energy consumption of 90 kWh/m^{2}y, summing up to an equivalent CO_2 emission of 28 kg/m^{2}y.

Table 5-29 Vertical_Energetic evaluation with PHPP & Economic evaluation

BASELINE		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m^2 y]*	92	72	13	4
Heating Energy Consumption	*[kWh/m^2 y]*	0	40	16	90
CO_2 Emissions	*[kg/m^2 y]*	121	104	21	28
Billing Heating	*[MXN/y]*	0	409	166	929
Billing Cooling, Tariff CFE	*[MXN/y]*	6,065	2,382	1,367	799
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	10,701	8,795	3,307	2,465

LINE NOM-020		CANCÚN	HERMOSILLO	GUADALAJARA	PUEBLA
Cooling Energy Consumption	*[kWh/m^2 y]*	55	40	---	---
Heating Energy Consumption	*[kWh/m^2 y]*	0	14	---	---
CO_2 Emissions	*[kg/m^2 y]*	72	56	---	---
Reduction of CO_2 Emissions	*[kg/m^2 y]*	48	48	---	---
Billing Heating	*[MXN/y]*	0	146	---	---
Billing Cooling, Tariff CFE	*[MXN/y]*	3,223	1,505	---	---
Billing Cooling, 2.3 MXN/kWh[1]	*[MXN/y]*	7,238	5,843	---	---
Economic Saving	*[MXN/y]*	2,842	1,140	---	---
Investment Cost of EE Measures	*[MXN]*	10,681	11,311	---	---
Investment Payback Time, Tariff CFE	*[y]*	3.8	9.9	---	---
Investment Payback Time, 2.3 MXN/kWh[1]	*[y]*	3.1	3.5	---	---

[1] Accounting cost

Economic evaluation and investment payback time

In Cancún the implementation of the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling of $2,842, considering the CFE tariff 1C, which would lead to an investment payback time of 3.8 years. The investment payback time, when calculating with the accounting cost of 2.3 $/kWh would be 3.1 years. The investment of an additional $10,681 to fulfill the standard is recommended.

In Hermosillo the LINE NOM-020 scenario would lead to an annual economic saving on the billing for cooling and heating of $1,140. Considering the CFE tariff 1F the investment payback time would be 9.9 years. Considering the accounting cost of 2.3 $/kWh, the investment payback time would be 3.5 years. The investment of $11,311 to fulfill the standard is recommended.

Key findings and conclusion

The analysis showed that the principal energy efficiency strategies to fulfill the standard are the following for the vertical housing unit *Vertical*:

- Cancún and Hermosillo: – Reduce conduction heat gains in walls

The investment of $10,681 and of $11,311 is recommended in Cancún and in Hermosillo. There is no heating demand in Cancún and the implemented energy efficiency measures would reduce the heating energy consumption significantly in Hermosillo. The *Vertical* type complies with the standard in Guadalajara and Puebla leading to an energy saving (ahorro de energía) of 4 % and 48 %. In Puebla the label of the NOM-020 would therefore suggest an energy efficient building with an energy saving of 48%. The results show nevertheless that, in order to allow for thermal comfort, the building has a significant heating energy consumption of 90 kWh/m^2y, which is not contemplated by the standard. Here the standard would send a misleading signal. The phenomenon of “negative” heat gains occurs in Puebla. A revision of this particular point of the standard is recommended.

5.5 Results per location

Here a synthesis of the results for the six housing types will be presented for each study location. The compliance with the standard, the impact on the heating and cooling energy consumption, the additional cost of the energy efficiency measures, the investment payback time and the reduction of CO_2 emissions will be reported. Finally the results will be discussed.

CANCÚN

None of the six housing types fulfills the standard in Cancún. The total heat gain of the BASELINE case is reduced between 32 % and 63 % by the implementation of the selected energy efficiency strategies (table 5-30). The cooling energy consumption necessary to maintain the defined temperature comfort zone for the BASELINE is within a range from 75 kWh/m^2y up to 116 kWh/m^2y. The *Dúplex* and *Aislada* types, which don´t have any thermal insulation in the BASELINE case, show the highest consumption. No cooling energy consumption is reported for any of the six housing types. With additional investments between $9,086 and $18,646, the LINE NOM-020 case reduces the cooling energy consumption between 26 % and 48 %, limiting the consumption to a range between 40 kWh/m^2y and 80 kWh/m^2y. Within the LINE NOM-020 the attached housing types *Adosada* and *Medio* have the lowest Energy consumption per square meter, followed by the *Vertical* type. The *Aislada* type shows the highest consumption, followed by the *Duplex* type (table 5-31).

The compliance with the NOM-020 in Cancún leads to CO_2 emission reductions between 29 kg/m^2y and 50 kg/m^2y. Of the LINE NOM-020 cases the *Aislada* type presents the highest CO_2 emissions with 105 kg/m^2y, followed by the *Dúplex* type. The attached housing types *Adosada* and *Medio* present the lowest emissions with 53 kg/m^2y and 64 kg/m^2y (table 5-31).

The reported theoretical economic savings on the billing for electricity range from $2,093 up to $7,924 annually; this span also reflects the different housing sizes (TFA). The reported investment payback time, considering the CFE tariff 1C ranges from 1.7 to 5.9 years. The investment payback time based on the accounting cost for electricity production ranges from 1.9 to 5.9 years (table 5-32). The investment is recommended for all housing types.[43]

HERMOSILLO

In Hermosillo none of the six housing types fulfills the standard. The total heat gain of the BASELINE case is reduced between 38 % and 64 % by the implementation of the proposed energy efficiency measures (table 5-30). In Hermosillo the energy consumption is composed by heating energy consumption in the period from November to February and by cooling energy consumption with a peak in the period from April to October. The cooling energy consumption for the BASELINE case ranges from 13 kWh/m^2y up to 121 kWh/m^2y, with the *Aislada* type having the highest consumption, followed by the *Duplex* type (both examples don´t have any

[43] The decision whether an investment is recommended or not is based on the investment payback time, calculated on basis of the accounting cost for electricity production. This is due to the fact, that a building has a lifecycle of at least 30 years. The policies on electricity subsidy might well change within this timespan.

thermal insulation in the BASELINE case). The implementation of the LINE NOM-020 case lowers the heating energy consumption significantly to a range of 0 kWh/m^{2}y up to 6 kWh/m^{2}y, with exception of the *Vertical* type, accounting for 14 kWh/m^{2}y. It is suspected that the implementation of the standard, when planning carefully, in general eliminates the need for space heating in Hermosillo. The cooling energy consumption necessary to maintain the defined temperature comfort zone for the BASELINE is within a range from 54 kWh/m^{2}y up to 93 kWh/m^{2}y. The implementation of the LINE NOM-020 case lowers this range to 28 kWh/m^{2}y up to 61 kWh/m^{2}y. With additional investments between $9,086 and $18,646, the LINE NOM-020 case reduces the cooling and heating energy consumption between 33 % and 69 %, limiting the energy consumption to a range between 28 kWh/m^{2}y and 66 kWh/m^{2}y. Within the LINE NOM-020 the attached housing types *Adosada* and *Medio* have the lowest energy consumption per square meter. The *Dúplex*, *Residencial* and *Vertical* type have an energy consumption of 52±1 kWh/m^{2}y, and the *Aislada* type shows the highest consumption (table 5-31).

The compliance with the NOM-020 in Hermosillo leads to CO_2 emission reductions between 26 kg/m^{2}y and 70 kg/m^{2}y. Of the LINE NOM-020 cases the *Aislada* type presents the highest CO_2 emissions with 82 kg/m^{2}y, followed by the *Dúplex* type. The attached housing types *Adosada* and *Medio* present the lowest emissions with 37 kg/m^{2}y and 44 kg/m^{2}y (table 5-31).

The theoretical economic savings on the billing for electricity range from $1,045 up to $4,705 annually; this span also reflects the different housing sizes (TFA). The reported investment payback time, considering the CFE tariff 1F ranges from 2.8 to 9.7 years. The investment payback time based on the accounting cost for electricity production ranges from 2.0 to 4.8 years (table 5-32). The investment is recommended for all housing types.

GUADALAJARA

The *Adosada*, *Dúplex*, *Aislada* and *Medio* type do not fulfill the standard in Guadalajara. The total heat gain of the BASELINE is reduced between 35 % and 49 % by the implementation of the LINE NOM-020 (table 5-30). The cooling energy consumption necessary to maintain the defined temperature comfort zone for the BASELINE is within a range from 6 kWh/m^{2}y up to 14 kWh/m^{2}y. The heating energy consumption ranges from 2 kWh/m^{2}y up to 50 kWh/m^{2}y, with the *Dúplex* and *Aislada* types, which don´t have any thermal insulation in the BASELINE case, showing the highest consumption with 37 kWh/m^{2}y and 50 kWh/m^{2}y respectively. The implementation of energy efficiency strategies according to the analysis of the NOM-020 in the LINE NOM-020 scenario incremented the cooling energy consumption in the case of the *Dúplex* and *Aislada* types, while at the same time reducing the heating energy consumption significantly. With an additional investment of between $2,573 and $9,626, the LINE NOM-020 case reduces the energy consumption for cooling and heating between 1.1 kWh/m^{2}y and 38.9 kWh/m^{2}y (table 5-31).

The compliance with the NOM-020 in Guadalajara leads to CO_2 emission reductions between 1 kg/m^{2}y and 6 kg/m^{2}y. Of the LINE NOM-020 cases, and the BASELINE cases that fulfill the standard, the *Dúplex* type presents the highest CO_2 emissions with 32 kg/m2y, followed by the

Vertical type. The attached housing types *Adosada* and *Medio* present the lowest emissions with 7 kg/m^{2}y and 8 kg/m^{2}y (table 5-31).

The investment payback time for the additional investment cost of $3,793 for the *Adosada* and of $5,420 for the *Aislada* exceeds a lifecycle of 30 years for the CFE tariff, as well as for the accounting cost. The investment is not recommended. In case of the *Dúplex* and the *Medio* type the economic saving due to the respective additional investment of $2, 573 and of $9,626 would lead to an investment payback time of 5.8 and 12.1 years, considering the CFE tariff 1. Considering the accounting cost the investment payback time would be 6.6 and 11.6 years (table 5-32). Under the assumption, that the building will be conditioned by heating and cooling appliances to a comfort zone of 20°C to 25°C, the investment is recommended.

PUEBLA

The *Aisldada* type is the only building that does not comply with the standard in Puebla. The total heat gain of the BASELINE case is reduced by 50% by the implementation of the energy efficiency measures (table 5-30). In fact the cooling energy consumption increased by 1.3 kWh/m^{2}y. The heating energy consumption was reduced from 251 kWh/m^{2}y to 122 kWh/m^{2}y. For all building types the cooling energy consumption is within a range from 2kWh/m^{2}y to 5 kWh/m^{2}y. The heating energy consumption is within a range from 251 kWh/m^{2}y to 46 kWh/m^{2}y (table 5-31). Although there is an important heating energy consumption, the NOM-020 would label the buildings as energy-efficient, with energy savings (ahorro de energía) ranging from 1 % to 66 %. For example the *Vertical* type, accounting for a heating energy consumption of 90 kWh/m^{2}y, would receive the label “energy saving (ahorro de energía) 48%”.

For the climate of Puebla the phenomenon of “negative” heat gains or heat loss occurs (explained in detail in paragraph 5.4.1). The respective interior reference temperature of 24°C is higher than the equivalent temperatures for massive walls (north 21°C, east and south 23°C, west 22°C) and transparent parts of the building envelope. In consequence thermal heat gains become negative values, and thus are subtracted from the total heat gains. The higher the U-Value (the less insulated the building part); the bigger is the reduction on the total of the heat gains. It is recommended to revise this particular issue of the standard.

In case of the *Aislada* type the compliance with the NOM-020 in Puebla leads to CO_2 emission reduction of 30 kg/m^{2}y. Of the LINE NOM-020 case of the *Aislada*, and the BASELINE cases that fulfill the standard, the *Dúplex* type presents the highest CO_2 emissions with 51 kg/m^{2}y, followed by the *Aislada* type with 38 kg/m^{2}y. The attached housing types *Adosada* and *Medio*, as well as the *Residencial* type present the lowest emissions between 17 kg/m^{2}y and 23 kg/m^{2}y (table 5-31).

The investment cost of $6,947 in case of the *Aislada* type would lead to an annual economic saving of $1,196, due to the reduction of the heating energy demand by 50 %. The investment payback time would be 5.8 years considering the CFE tariff 1, and 6.2 years considering the accounting cost of 2.3 $/kWh (table 5-32).

Table 5-30 Comparison_Energetic evaluation according to NOM-020-ENER-2011

			ENERGETIC EVALUATION NOM-020				
			Projected Building BASELINE			Projected Building LINE NOM-020	
			Reference Building Total heat gain *[W]*	Projected Building BASELINE Total heat gain *[W]*	Compliance	Projected Building LINE NOM-020 Total heat gain *[W]*	Reduction of Total heat gain *[%]*
CANCÚN	ADOSADA	*[Row housing unit]*	1,354	2,600	**NO**	1,076	59%
CANCÚN	DUPLEX	*[Duplex housing unit]*	1,353	3,304	**NO**	1,238	63%
CANCÚN	AISLADA	*[Isolated housing unit]*	2,166	5,474	**NO**	2,071	62%
CANCÚN	MEDIO	*[Middle segment]*	2,228	3,976	**NO**	2,046	49%
CANCÚN	RESIDENCIAL	*[Residential segment]*	5,194	7,457	**NO**	5,085	32%
CANCÚN	VERTICAL	*[Vertical housing unit]*	1,392	2,322	**NO**	1,099	53%
HERMOSILLO	ADOSADA	*[Row housing unit]*	1,420	2,974	**NO**	1,173	61%
HERMOSILLO	DUPLEX	*[Duplex housing unit]*	1,478	3,862	**NO**	1,406	64%
HERMOSILLO	AISLADA	*[Isolated housing unit]*	2,379	6,243	**NO**	2,298	63%
HERMOSILLO	MEDIO	*[Middle segment]*	2,353	4,442	**NO**	2,278	49%
HERMOSILLO	RESIDENCIAL	*[Residential segment]*	5,664	9,123	**NO**	5,648	38%
HERMOSILLO	VERTICAL	*[Vertical housing unit]*	1,504	2,854	**NO**	1,335	53%
GUADALAJARA	ADOSADA	*[Row housing unit]*	970	1,214	**NO**	771	36%
GUADALAJARA	DUPLEX	*[Duplex housing unit]*	940	1,420	**NO**	918	35%
GUADALAJARA	AISLADA	*[Isolated housing unit]*	1,546	2,675	**NO**	1,371	49%
GUADALAJARA	MEDIO	*[Middle segment]*	1,516	1,714	**NO**	1,091	36%
GUADALAJARA	RESIDENCIAL	*[Residential segment]*	3,597	2,661	**YES**	---	---
GUADALAJARA	VERTICAL	*[Vertical housing unit]*	914	880	**YES**	---	---
PUEBLA	ADOSADA	*[Row housing unit]*	814	782	**YES**	---	---
PUEBLA	DUPLEX	*[Duplex housing unit]*	765	758	**YES**	---	---
PUEBLA	AISLADA	*[Isolated housing unit]*	1,267	1,730	**NO**	872	50%
PUEBLA	MEDIO	*[Middle segment]*	1,314	1,157	**YES**	---	---
PUEBLA	RESIDENCIAL	*[Residential segment]*	3,015	1,023	**YES**	---	---
PUEBLA	VERTICAL	*[Vertical housing unit]*	715	375	**YES**	---	---

Table 5-31 Comparison_Energetic Evaluation with Passive House Planning Package

			ENERGETIC EVALUTATION PHPP				
			Projected Building BASELINE		Projected Building LINE NOM-020		
			Heating & Cooling Energy Consumption *[kWh/m^2 y]*	CO_2 Emissions *[kg/m^{2}y]*	Heating & Cooling Energy Consumption *[kWh/m^{2}y]*	CO_2 Emissions *[kg/m^{2}y]*	Reduction of CO^2 Emissions *[kg/m^{2}y]*
CANCÚN	ADOSADA	*[Row housing unit]*	77	101	40	53	48
	DUPLEX	*[Duplex housing unit]*	111	147	73	96	50
	AISLADA	*[Isolated housing unit]*	116	153	80	105	47
	MEDIO	*[Middle segment]*	75	99	49	64	35
	RESIDENCIAL	*[Residential segment]*	83	110	61	81	29
	VERTICAL	*[Vertical housing unit]*	92	121	55	72	48
HERMOSILLO	ADOSADA	*[Row housing unit]*	80	83	28	37	46
	DUPLEX	*[Duplex housing unit]*	161	130	53	68	62
	AISLADA	*[Isolated housing unit]*	214	152	66	82	70
	MEDIO	*[Middle segment]*	67	74	35	44	30
	RESIDENCIAL	*[Residential segment]*	77	88	52	62	26
	VERTICAL	*[Vertical housing unit]*	111	104	54	56	48
GUADALAJARA	ADOSADA	*[Row housing unit]*	8	8	7	7	1
	DUPLEX	*[Duplex housing unit]*	49	25	32	23	1
	AISLADA	*[Isolated housing unit]*	59	24	20	19	5
	MEDIO	*[Middle segment]*	12	12	8	6	6
	RESIDENCIAL	*[Residential segment]*	16	19	---	---	---
	VERTICAL	*[Vertical housing unit]*	29	21	---	---	---
PUEBLA	ADOSADA	*[Row housing unit]*	80	23	---	---	---
	DUPLEX	*[Duplex housing unit]*	182	51	---	---	---
	AISLADA	*[Isolated housing unit]*	255	68	128	38	30
	MEDIO	*[Middle segment]*	56	17	---	---	---
	RESIDENCIAL	*[Residential segment]*	52	19	---	---	---
	VERTICAL	*[Vertical housing unit]*	94	28	---	---	---

Table 5-32 Comparison_Economic Evaluation

City	Segment		ECONOMIC EVALUATION: Economic Savings Billing – Billing BASELINE *[MXN/y]*	Billing LINE NOM-020 *[MXN/y]*	Economic Saving *[MXN/y]*	Investment Payback Time – Investment Cost of EE Measures *[MXN]*	Investment Payback Time Tariff CFE *[Years]*	Investment Payback Time Accounting Cost[1] *[years]*
CANCÚN	ADOSADA	*[Row housing unit]*	4,329	2,236	2,093	9,086	4.3	2.6
	DUPLEX	*[Duplex housing unit]*	6,817	4,234	2,583	11,710	4.5	3.7
	AISLADA	*[Isolated housing unit]*	7,792	4,625	3,167	18,646	5.9	5.9
	MEDIO	*[Middle segment]*	12,675	6,990	5,685	16,319	2.9	3.2
	RESIDENCIAL	*[Residential segment]*	26,499	18,575	7,924	13,279	1.7	1.9
	VERTICAL	*[Vertical housing unit]*	6,065	3,223	2,842	10,681	3.8	3.1
HERMOSILLO	ADOSADA	*[Row housing unit]*	2,234	1,189	1,045	9,086	8.7	2.9
	DUPLEX	*[Duplex housing unit]*	4,720	1,715	3,005	11,710	3.9	2.4
	AISLADA	*[Isolated housing unit]*	3,957	2,030	1,926	18,646	9.7	4.8
	MEDIO	*[Middle segment]*	4,378	2,429	1,949	17,111	8.8	3.6
	RESIDENCIAL	*[Residential segment]*	11,675	6,970	4,705	13,279	2.8	2.0
	VERTICAL	*[Vertical housing unit]*	2,791	1,651	1,140	11,311	9.9	3.5
GUADALAJARA	ADOSADA	*[Row housing unit]*	885	845	40	3,793	95.9	36.0
	DUPLEX	*[Duplex housing unit]*	2,234	1,789	444	2,573	5.8	6.6
	AISLADA	*[Isolated housing unit]*	1,431	1,306	125	5,420	---	---
	MEDIO	*[Middle segment]*	1,991	1,195	797	9,626	12.1	11.6
	RESIDENCIAL	*[Residential segment]*	5,172	---	---	---	---	---
	VERTICAL	*[Vertical housing unit]*	1,533	---	---	---	---	---
PUEBLA	ADOSADA	*[Row housing unit]*	1,533	---	---	---	---	---
	DUPLEX	*[Duplex housing unit]*	6,223	---	---	---	---	---
	AISLADA	*[Isolated housing unit]*	3,212	2,016	1,196	6,947	5.8	6.2
	MEDIO	*[Middle segment]*	4,635	---	---	---	---	---
	RESIDENCIAL	*[Residential segment]*	7,311	---	---	---	---	---
	VERTICAL	*[Vertical housing unit]*	1,729	---	---	---	---	---

[1] 2.3 MXN/kWh

5.6 Discussion

None of the six housing types fulfills the standard in Cancún and in Hermosillo. The following energy efficiency strategies have been defined according to the analysis of the energy balance by the NOM-020. In case of the *Medio* type and the *Adosada* type the conduction heat gains through the walls had to be reduced, as well as the radiation heat gains by the transparent parts of the building envelope. Both types dispose of thermal insulation in the construction elements for the roof. For the *Residencial* and the *Vertical* type it was sufficient to enhance the thermal performance of the walls. The *Dúplex* and the *Aislada* type do not dispose of any thermal insulation in the BASELINE. The conduction gains through the roof and the walls had to be reduced by adding thermal insulation.

The reported results indicate that the energy efficiency measures, allowing for the compliance with the standard in Cancún, would lower the cooling energy consumption between 26 % and 48 %, leading to CO_2 emission reductions between 29 kg/m^{2}y and 50 kg/m^{2}y. Taking a cost per housing unit of $349,350 (table 5-7) as a reference, the investment cost for the energy efficiency measures would represent between 2.6 % and 5.3 % of the value of the building for the *Adosada*, the *Dúplex*, the *Aislada* and the *Vertical* type. For the *Medio* type with a reference of $1,310,100, the cost would represent 1.2 %, and 0.5 % for the *Residencial* type, with a reference value of $2,620,200. In the location of Cancún of extremely hot humid climate, the compliance with the standard reduces the cooling energy consumption and the related CO_2 emissions significantly in comparison to the performance of the studied reference projects. No cooling energy consumption is reported for Cancún.

In Hermosillo the implementation of the proposed energy efficiency strategies, allowing fulfilling the standard, would lower the cooling energy consumption between 38 % and 64 %, leading to CO_2 emission reductions between 26 kg/m^{2}y and 82 kg/m^{2}y. Furthermore the level of insulation, that is required to comply with the standard, reduced the heating energy consumption significantly to a range of 0 kWh/m^{2}y up to 6 kWh/m^{2}y, with exception of the *Vertical* type, accounting for 14 kWh/m^{2}y.This would increases the comfort significantly during the cold month (from December till February). The percentages of the investment cost on the value of the housing units are identical to the reported figures for Cancún. In the locations of extremely hot dry climate, the compliance with the standard reduces the cooling energy consumption significantly. The heating energy consumption as well is reduced significantly, which increases the comfort during the cold month. The investment payback time would be less than five years for all six housing types, considering the accounting cost of electricity production.

The *Residencial* and the *Vertical* type fulfill the standard in Guadalajara. The following energy efficiency strategies have been defined according to the analysis of the energy balance by the NOM-020. In case of the *Medio* type and the *Adosada* type the radiation heat gains through the transparent parts of the building envelope have been reduced by replacing the windows with a low-E double-glazing. The *Dúplex* and the *Aislada* type do not dispose of any thermal insulation in the BASELINE. The conduction gains through the roof had to be reduced by adding thermal insulation.

The energy efficiency measures, allowing for the compliance with the standard in Guadalajara would lead to a reduction of CO_2 emissions between 1 kg/m^{2}y and 6 kg/m^{2}y. The *Residencial* and the *Vertical* type fulfill the standard. The results show, that the two buildings that don´t dispose of any thermal insulation account for a heating energy consumption of 37 kWh/m^{2}y (*Dúplex*) and 50 kWh/m^{2}y (*Aislada*), which would be reduced to 17 kWh/m^{2}y and 7 kWh/m^{2}y respectively by the proposed energy efficiency strategies. Taking a cost per housing unit of $349,350 (table 5-7) as a reference, the investment cost for the energy efficiency measures would represent between 0.7 % and 1.6 % of the value of the building for the *Adosada*, the *Dúplex*, and the *Aislada* type. For the *Medio* type with a reference of $1,310,100, the cost would represent 0.7 %.

According to information in the Metenom weather files [Meteonom 2011] “passive cooling is possible” in the temperate climate of Guadalajara, despite “unbearably hot dry periods in summer”. The Passive House Institute [CONAVI 2011] coincides, stating that the temperate climate of Guadalajara “is a perfect example of a so called ‘Happy Climate’, meaning that the Passive House Standard can be achieved with relatively little effort.” The average electricity sales per customer reported by CFE (appendix IV – table2) report an average monthly sale per customer of 112.9 kWh/month for the summer period and of 110.5 kWh/month for the off-summer period. The fact, that both values are nearly identical indicates that there is no increase of electricity consumption during the summer month due to the use of air-conditioning. A precedent report by Heard [2004] regarding the modification and actualization of the standard considers “that it is only cost effective to apply thermal insulation at sites whose average temperature of the six warmest consecutive months of the year is above 21.3°C”. In Guadalajara the average temperature of the six warmest consecutive months of the year is 22.0°C (figure 5-4). The reported values for the economic savings in Guadalajara have to be seen as theoretical values, for it is most probably that the houses are not conditioned. If this were the case the standard would also not fulfill its objective to reduce the electricity consumption due to the use of cooling equipment. The reported results show that two of the six typologies already fulfill the standard, and that the additional investment represents only 1.0 ± 0.5 % of the value of the buildings. The theoretical heating energy consumption for houses without any thermal insulation was reduced significantly by the proposed energy efficiency measures. Nevertheless the theoretical cooling energy consumption increased slightly by the proposed measures.

Concluding in Guadalajara there is the doubt, if the implementation of the standard would leave to a significant reduction of the energy consumption. Nevertheless the results report that the requirement of the standard are met by current standards of the housing sector, and can be met with very little investment, which enhances the comfort. The implementation of the standard in Guadalajara would assure an easily achievable minimum thermal standard that enhances the interior comfort.

The *Aisldada* type is the only building that does not comply with the standard in Puebla. Although there is an important heating energy consumption in Puebla, the NOM-020 would label the buildings as energy-efficient, with energy savings (ahorro de energía) ranging from 1 % to 66 %. For example the *Vertical* type, accounting for a heating energy consumption of 90 kWh/m^{2}y, would receive the label “energy saving (ahorro de energía) 48%”. Here the standard would give a misleading signal.

“REFERENCE METHODOLOGY” VERSUS “WHOLE BUILDING APPROACH”

Table 5-33 summarizes the consumption per m^2, the respective CO_2 emissions and the reported energy saving (*Ahorro de Energía*) for all cases that comply with the standard, either LINE NOM-020-ENER-2011, or BASELINE in the case that the standard is already fulfilled.

In all four study location the attached housing types *Adosada* and *Medio* present the lowest CO_2 emissions. In the extremely hot dry and extremely hot humid study locations the *Aislada* type presents the highest CO_2 emissions, followed by the *Dúplex* type.In the temperate and temperate cold study locations the *Dúplex* type presents the hightest CO_2 emissions.

The comparison of the reported CO_2 emissions per m^2 and year and the reported Energy Savings reveals that there is no lineal relationship between both indicators. For example in Cancún the *Dúplex* and the *Medio* type have a reported energy saving of 8%, wheres the CO_2 emissions are 96 kg/m^{2}y and 64 kg/m^{2}y respectively. The same situation occurs in Hermosillo, where 3% of energy savings are reported for the *Aislada* and the *Medio* type. The reported CO_2 emissions for the *Aislada* type of 82 kg/m^{2}y represent nearly twice the amount of the 44 kg/m^{2}y of the *Medio* type. Comparing the range of energy savings from 0% to 5% for all four locations, the reported CO_2 emissions range from 21 kg/m^{2}y up to 105 kg/m^{2}y.

The before mentioned results are of particular importance when discussing the ability of the standard to serve as an evaluation criterion for national or international financing schemes. Two aspects are of particular importance: i) the comparability of the results, and ii) the determination of the benchmark.

It is common knowledge in architectural practice that buildings with maximized useable space, good orientation in terms of solar loads and a good A/V ratio require less effort to make them energy efficient compared to buildings, where these principles were not considered during the design phase. A free standing home (*Aislada*) with more exterior surface requires more energy than an attached housing unit (*Adosada*) with less exterior surface. For example the reported CO_2 emissions 105 kg/m^{2}y for the *Aislada* type, having a A/V ratio of 1.49, represent twice the amount of those of the *Adosada* type (53 kg/m^{2}y) having a A/V ratio of 1.05 (see table 5-33).

A methodology or tool that follows the “whole building approach” reflects the building´s energy efficient design, as it takes into account the architectural means to achieve energy efficiency, as e.g. adequate orientation and compactness. Furthermore it provides indicators that are easily comparable between different housing types. The “reference methodology” of the NOM-020-ENER-2011 in contrast assumes the same geometric dimensions of the architectural project for the reference building and therefore evaluates the projected building with the given particular boundary conditions. These boundary conditions in most cases can be influenced and optimized by the design of the architectural project. The “reference methodology” takes the given boundary conditions, which could be unfavorably, for granted. This results in allowing a higher energy demand, as shown by the following example.

The housing types of the *Adosada* and the *Vertical* project provide the same use and an identical habitable area, with the *Adosada* having a TFA of 40.7m^2, and the *Vertical* having a TFA of 40.9 m^2. The “reference methodology” of the NOM-020-ENER-2011 reports an energy saving of 21% for both designs in the location of Cancún (see table 5-33). The results reported by the PHPP, following the “whole building approach”, however show, that the *Adosada* housing type with 53 kg/m^2y only accounts for three quarters of the emissions of the *Vertical* housing type, with 72 kg/m^2y. In this example, the design of the *Vertical* housing type, which is the more critical from an energy point of view, receives a primary energy bonus. These results confirm the observations of Kraft [2012], that the “reference methodology” excludes architectonic means to achieve primary energy reduction, and in “consequence, a significantly lower primary energy reduction is achieved as would be possible against the background of economic feasibility of given technical possibilities” [Kah 2008[44], cited by Kraft 2012].

SUBSIDIES

In Cancún the influence that the subsidies on electricity have on the investment payback time shortens the period for large consumers (inefficient or large surface) and extends the period for small consumers (efficient and small surfaces). This is due to the fact that the surplus tariff of 2.55 $/kWh is higher than the accounting cost of 2.3 $/kWh. This tariff applies in summer for a monthly consumption exceeding 450 kWh/month, and in the off-summer season for a monthly consumption exceeding 125 kWh/month for the CFE tariff 1C. If the energy efficiency measures lower the energy consumption form a level that exceeds the before mentioned limits to a level below those limits, the investment payback time considering the CFE tariff will be even shorter, than if considering the accounting cost.

In Hermosillo the subsidies on electricity extend the investment period for all six housing types. For the CFE tariff 1F the surplus tariff of 2.55 $/kWh applies in summer for a monthly consumption exceeding 2500 kWh/month, and in the off-summer season for a monthly consumption exceeding 200 kWh/month. The increase of the investment payback time, comparing the tariff 1F to the accounting cost based calculation, ranges from 43 % up to 197 %, increasing the period for four of the six building types between two or three times. A reduction of the subsidy or a lowering of the consumption for the application of the surplus tariff would reduce the investment payback time. Whilst incentivizing energy efficiency, instead of energy consumption, this measure would save the state the current expenses on energy subsidy. According the SENER [2010] electricity for the domestic sector was subsidized by 58 % in México in average for the period 2004-2009. In 2006 the electricity subsidies not covered

[44] Feist, Kah 2008, BBR Studie, Passive House Intitute, Darmstadt, Germany. Cited by Kraft 2012.

throught the utility bill amounted to more than US$ 10 billino, which is the equivalent of 1 percent of Mexico's gross domestic product[45].

In the case of Guadalajara and Hermosillo the influence, which the subsidies on electricity have on the investment payback time, varies form an increase of 5 % to a decrease of 13 %. It has to be mentioned that the cooling energy consumption, which is subject to the effect of the subsidies on electricity, only shows small variations between the BASELINE and the LINE NOM-020 case. The important variations for the heating energy consumption depend on the price of LPG, which is considered the same in both scenarios (CFE tariff and accounting cost).

Table 5-33 Consumption per m² and energy saving according to NOM-020-ENER-2011

		Heating Energy Consumption *[kWh/m² y]*	Cooling Energy Consumption *[kWh/m² y]*	Total Energy Consumption *[kWh/m² y]*	CO_2 Emissions *[kg/m² y]*	Energy savings[1] *[%]*
CANCÚN	ADOSADA	0	40	40	53	21
	DUPLEX	0	73	73	96	8
	AISLADA	0	80	80	105	4
	MEDIO	0	49	49	64	8
	RESIDENCIAL	0	61	61	81	2
	VERTICAL	0	55	55	72	21
HERMOSILLO	ADOSADA	0	28	28	37	17
	DUPLEX	1	52	53	68	5
	AISLADA	5	61	66	82	3
	MEDIO	3	33	35	44	3
	RESIDENCIAL	6	46	52	62	0
	VERTICAL	14	40	54	56	11
GUADALAJARA	ADOSADA	3	5	7	7	21
	DUPLEX	17	14	32	23	2
	AISLADA	7	13	20	19	11
	MEDIO	3	4	8	6	28
	RESIDENCIAL	2	14	16	19	26
	VERTICAL	16	13	29	21	4
PUEBLA	ADOSADA	78	2	80	23	4
	DUPLEX	177	5	182	51	1
	AISLADA	122	6	128	38	31
	MEDIO	53	3	56	17	12
	RESIDENCIAL	46	5	52	19	66
	VERTICAL	90	4	94	28	48

1 Corresponds to the indication of the energy savings (ahorro de energía) reported on the label of the NOM-020, as defined in paragraph 11.3.15. of the standard.

[45] Source: <http://www.jchs.harvard.edu/publications/international/pickering_w00-2.pdf>.

6 Methodological dimension

This chapter analyses the methodological impact dimension of the research model. Four different lines of analysis will be performed, applying three different thermal performance analysis tools.

In the first section of this chapter a short introduction to thermal performance assessment is given. Next the study design is laid out. Subsequently for each applied calculation tool a separate paragraph firstly gives a brief description of the applied method, followed by a description of the relevant boundary conditions that have been determined for each methodology. Next the results of the calculations are reported, followed by a comparative table, allowing for comparison between the reported tendencies.

6.1 Thermal Performance Assessment

According to the Australian association of Building Sustainability Assessors, thermal performance assessment can be defined as the process of predicting the occupancy comfort level or the energy consumption that would be necessary to reach defined comfort levels, by means applying the known principles of thermodynamics to the known thermal properties of building design and materials [46]. This paragraph will introduce shortly to the different methodologies and available tools.

According to Szokolay [2008] a building can be considered as a thermal system with a series of heat inputs and heat outputs, described by the following equation:

$$Qi + Qc + Qs + Qv + Qe = \Delta S$$

Where,
ΔS = Change in heat stored in the building
Qi = Internal heat gain
Qc = Conduction heat gain or loss
Qs = Solar heat gain
Qv = Ventilation heat gain or loss
Qe = Evaporative heat loss

Thermal balance exists when the sum of all heat flows (ΔS) is zero. If the sum is greater than zero, the temperature inside the building increases. If the sum is less than zero, the building is cooling down.

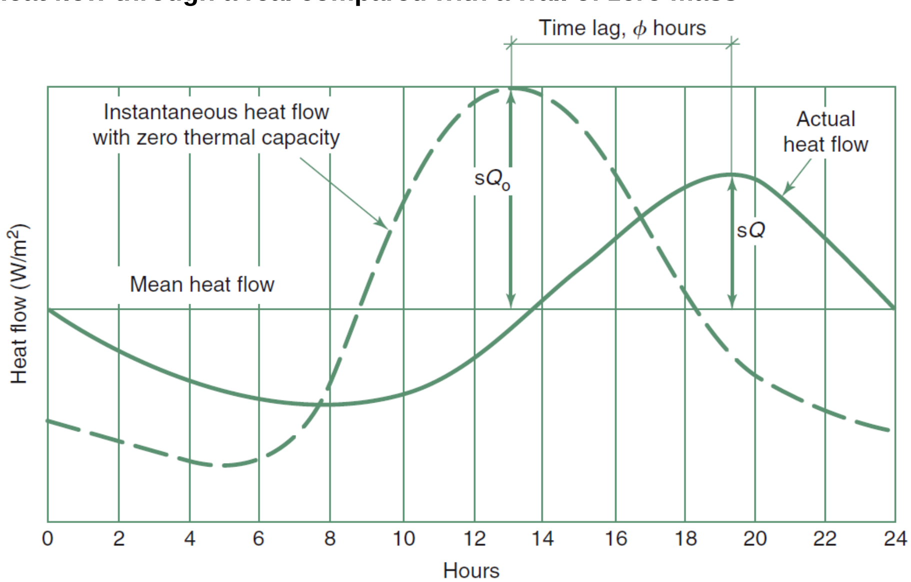
[46] "Thermal performance assessment is the process of using known principles of thermodynamics and the known thermal properties of building design and materials to predict the heating and cooling loads that will be experienced by a building. This may include determining either occupancy comfort levels or the energy that would be required to maintain suitable comfort levels." Association of Building Sustainability Assessors. 2005. Residential Building Thermal Performance Assessment. Sydney

Different methods exist for determining the thermal performance of buildings. The thermal performance assessment of the before mentioned system can be done assuming *steady-state* conditions, this is to say that the indoor end the exterior conditions are steady and do not change. This form of analysis does not consider the building´s dynamic response. This method “may be valid when the diurnal changes are small compared with the indoor-outdoor temperature difference or as the basis of finding the required heating or cooling capacity” [Szokolay 2008].

In contrast thermal response simulations or dynamic building simulations predict the dynamic response and performance of buildings, considering the effect of thermal mass, as well as conduction and convection between different zones within the building. Using detailed real climatic data for the building locations, this detailed analysis not only allows the calculation of the peak loads of the building, but also at what time of the day they will occur. Furthermore dynamic building simulation allows analyzing the thermal comfort of occupants in a building.

According to Szokolay [2008] thermal response simulations allow analyzing the thermal capacity of materials and their delaying action on the heat flow. Reflective and resistive insulation respond to temperature changes instantaneously. As soon as there is heat input at one face, a heat output on the other side will appear, albeit at a controlled rate. In contrast capacitive insulation, this is to say material layers of a high thermal capacity (massive construction) affect not only the magnitude of heat flow, but also its timing.

Figure 6-1 Heat flow through a real compared with a wall of zero mass



Source: Szokolay [2008]

Figure 6-1 illustrates the periodic heat flow over a 24 hour period, and illustrates the difference between thermal response simulation and the steady-state method. The solid line shows the heat flow through an actual masonry wall, taking into account the thermal capacity of the material and its delaying action on the heat flow. The dashed line shows the heat flow through a wall of the same U-value with zero thermal mass. This corresponds to what would be the result if the heat-flow was calculated by a steady-state method for each hour and connected the points.

According to Szokolay [2008] in the case of multilayer elements, the dynamic properties depend not only on the material and thickness of layers, but also on the sequence of layers with respect to the direction of the heat flow. This is to say a construction system composed by, for example, one layer of reinforced concrete and one layer of XPS will behave differently if the insulation is mounted on the interior side, than if the insulation would be mounted on the exterior side. This effect can be analyzed by means of thermal response simulation.

There are numerous programs which trace the heat flow hour-by-hour through all components of the building, using an annual hourly climatic data base. These can predict hourly indoor temperatures or the heating and cooling load if set indoor conditions are to be maintained. Some go further and simulate the mechanical (heating, ventilation or air conditioning) systems, thus predicting the energy consumption for the hour, the day, the month or the year [Szokolay 2008]. The most widely used one is the *Energy Plus*[47] software by the United States Department of Energy, which is available as freeware. *Energy Plus* is the successor of the DOE2.0 software, which was used to determine the reference values of the standard NOM-020-ENER-2011. *Energy Plus* is a calculation engine, with several private sector user interfaces available like *Ecotect*[48] or *Design Builder*[49]. The National Renewable Energy Laboratory (NREL) of the United States Department of Energy further developed the *OpenStudio* plugin, using Energy Plus as calculation engine, for Google´s freeware 3D-modelling program *SketchUp*.

The standard NOM-020-ENER-2011 establishes minimum values for thermal insulation of the building envelope. The development of the standard and the determination of the established values were based on a series a calculations using the thermal performance assessment software DOE2.0, developed by the NREL. At the time of starting the research on this Master thesis, no calculation tool was available for the methodology established by the standard NOM-020-ENER-2011. For this reason the author elaborated a spreadsheet to simplify the calculation process, which was used for the assessment of the thermal performance according to the methodology established by the standard.

As in chapter five the study cases will be calculated with the Passive House Planning Package (PHPP), developed by the Passive House Institute. The PHPP performs calculations that assume *steady-state* conditions. However, the PHPP and the DEEVi also consider the effect of thermal mass by means of a utilization factor. According to the Passive House Institute[50] this factor describes which fraction of the heat losses is useful for reducing the cooling demand.

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[47] Available for download at: <http://apps1.eere.energy.gov/buildings/energyplus/>.

[48] Developed by Autodesk. <http://usa.autodesk.com/>.

[49] <http://www.designbuilder.co.uk/content/view/10/41/>.

[50] Personal communication with J. Steiger, Passive House Institute, August 2012.

Extensive series of dynamic simulations have shown that the utilization factor primarily depends on:

a) the ratio of heat losses and heat gains

b) the time constant of the building, i.e. heat capacity (kWh/K) divided by the overall thermal conductance (W/K)

The according principle, which is also described in the European Standard EN 13790, is to first calculate heat losses and heat gains under steady-state conditions, then to determine the time constant and subsequently the utilization factor. This principle is followed in the PHPP and DEEVi tools, which consider a rough average of the thermal mass of the building by input of the specific capacity, according to the quantity of massive surfaces to be expected for the rooms. According to the PHI the comparison of the results with dynamic simulations of this storage behavior have shown that the calculations with the DEEVi and the PHPP are quite accurate.

The precedent thesis of Huerta [2002], as well as the report from Heard [2004] conducted dynamic thermal simulation using the DOE2.0 software. The recently published report on energy efficiency in the Mexican housing sector by Campos [2011] was undertaken with the *Energy Plus* calculation engine, using the user interface *Design Builder*.

To validate the results of the calculation according to the standard, a dynamic thermal simulation of the same samples with an identical configuration will be performed. This allows assessing the Energy Intensity (kWh/m^{2}y) of the buildings, an important indicator which cannot be determined by the methodology of the standard. As all previous related studies applied the *Energy Plus* (DOE2.0-based) calculation engine, the master thesis will utilize the same software, in order to assure the comparability of the results. *Design Builder* will be used as a graphical interface, given the fact that it offers convenient tools for the graphical representation of the results of the analysis[51].

[51] Personal communication with R. Sielfeld, Consultant GIZ, August 2011.

6.2 Study Design

The three cases that are analyzed in this chapter do not correspond to those in the previous chapter. Different assumptions have been taken regarding the materiality. Whereas in chapter five the focus was on analyzing the thermal performance of current standards in social housing construction, in this chapter the impact of the levels of thermal insulation proposed by the standard shall be examined. For this reason the materials of the thermal envelope of the BASELINE case do not correspond to the specifications made in the architectural project. For the BASELINE case a construction without thermal insulation was assumed. Table 6-1 shows the definition and assumptions regarding the materials of the three cases studied in this chapter: i) Reference Building, ii) BASELINE, iii) LINE NOM-020.

Table 6-1 Definition of the study cases

Reference Building	Corresponds to the concept of the Reference Building defined by the standard NOM-020-ENER-2011. *Defined as 10cm reinforced concrete for roof and walls, plus one layer of XPS on the **exterior side**, with the necessary thickness to deliver the U-Value defined in table 1 of the standard.*
BASELINE	No thermal insulation is considered. *Walls and roof surfaces are assumed as 10cm reinforced concrete.*
LINE NOM-020	Is based on the BASELINE case, but Energy Efficiency measures have been applied, so as to comply with the standard. *Defined as 10cm reinforced concrete for roof and walls; according to the analysis with the NOM-020 (see table 6.9), the following energy efficiency measures have been applied:* *- EPS of either 1.5” or 2.0”, mounted on the **interior side** of walls or roof.* *- Double glazing, LowE, 3+9+3 mm, shading coefficient 0.46*

The material properties used in all four applied methodologies correspond to the values provided in the material library of Design Builder, ENER Habitat or to the standard DIN 10456.

Table 6-2 Material properties Methodological dimension

Materials Methodological Dimension	Thermal Conductivity (W/m·K)	Density kg/m^3	Specific Heat J/(kg·K)	Source
Waterproofing	0.050	70	1,500	2
XPS Extruded Polystyrene, HFC Blowing	0.030	35	1,400	1
Concrete, reinforced (with 1% steel)	2.300	2,300	1,000	1, 3
Cement/plaster/mortar – limestone mortar	0.700	1,600	840	1
Cement/plaster/mortar – gypsum plaster	0.510	1,120	960	1
External rendering	0.500	1,300	1,000	1

Sources: 1. Design Builder Library, 2. ENER Habitat, 3. DIN 10456

The row housing unit (Adosada) was selected for this study, as it is one of the most common typologies in the social housing sector. A complex composed of two housing units was analyzed: i) the west-oriented end-unit, which has the major exposure to solar radiation, and ii) a middle-unit, attached to neighboring units on each side (figure 6-1 and 6-2). The adjacent unit to the east was considered as conditioned habitable floor space. The row housing unit complex is analyzed in four different locations, with different climates: i) extremely hot dry, ii) extremely hot humid, iii) temperate, iv) temperate cold. The different cases will be analyzed with two different steady-state building energy simulation tools, and two analyses will be performed by means of numerical simulation, using the same dynamic thermal simulation software.

Figure 6-2 Perspective working model Design Builder row housing unit *Adosada*

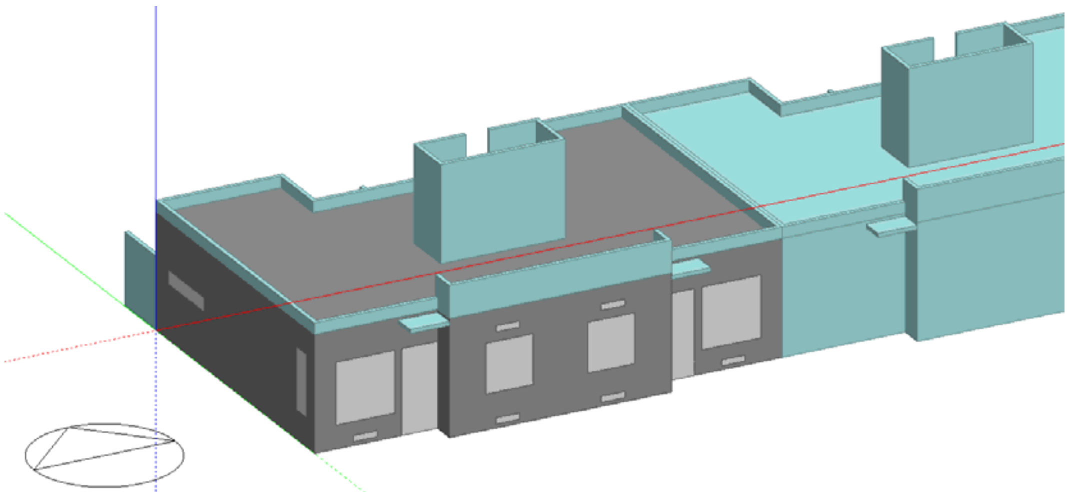


Figure 6-3 Floor plan row housing unit *Adosada*

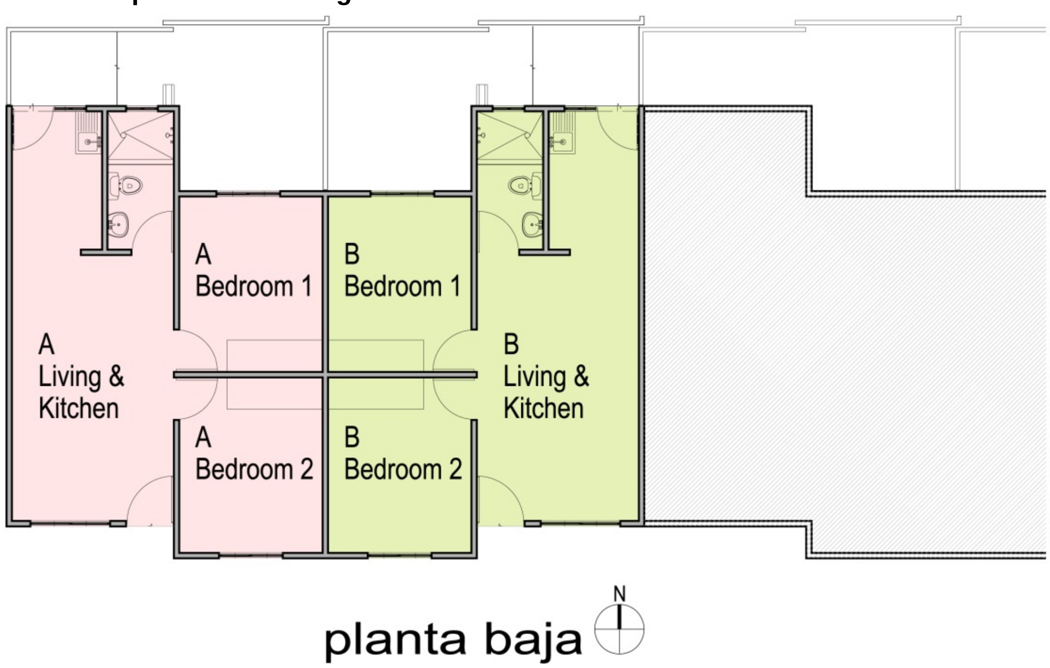


Figure 6-4 Study design Methodological Dimension

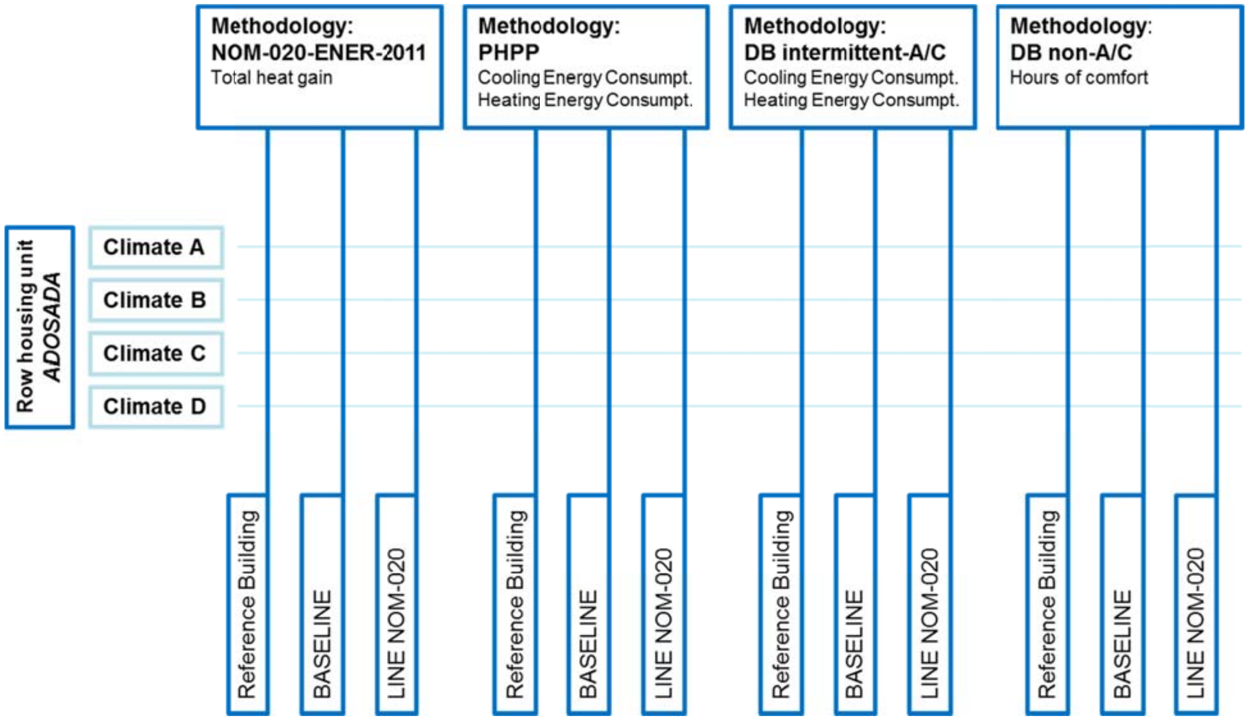


Figure 6-4 shows a diagram of the study design for the methodological dimension. A first line of investigation (paragraph 6.4.1) is the validation of compliance with the standard NOM-020-ENER-2011 according to the methodology established by the code. The Reference Building and the BASELINE case (Projected Building) are calculated. In case the project does not comply with the standard thermal insulation in form of XPS on the interior side is applied to the Projected Building so as to fulfill the requirements of the standard, representing the LINE NOM-020 scenario.

In a second line of investigation (paragraph 6.4.2) the three different cases Reference Building, BASELINE and LINE NOM-020 are calculated with the Passive House Planning Package tool (PHPP). The use of this tool allows on one hand to estimate the cooling and the heating load for each month of the year and thus provides for a more detailed analysis than the calculation method established by the standard. The reported cooling and heating loads build the basis for the calculation of the CO_2 emissions.

A third line of investigation estimates the cooling energy consumption and the heating energy consumption of the three different cases by means of a dynamic thermal simulation with *Design Builder*. According to Barrios et al. [2012] the intermittent control of the space heating and cooling appliances comes closest to the reality in Mexico. The assumption of a constant indoor air temperature is adequate in climates where the daytime outdoor temperature does not cross the thermal comfort zone. The intermittent control of space heating or cooling appliances assumes the heating appliance is turned on when the indoor temperature is below the lower comfort limit and turned off when the indoor temperature is within or above the comfort zone. Accordingly the cooling appliance is turned on when the indoor temperature is above the upper comfort limit and turned off when the indoor temperature is within or below the comfort zone. For the purpose of this study the intermittent control of the heating and cooling appliances was chosen, therefore this line of investigation is dominated **intermittent**-A/C.

In Mexico the temperate climates are also described as “happy climates”, given the fact, that thermal comfort can be achieved without mechanical cooling or heating throughout the year. Thermal inertia and thermal mass play an important role in these climates. The article of Huelsz et al. [2009] on the thermal behavior of different building materials showed that a high U-Value in Mexico does not necessarily lead to a good thermal performance. Szokolay [2008] laid out that “the dynamic properties (time lag, decrement factor and admittance) of multilayer elements depend not only on the material and thickness of layers, but also on the sequence of these layers with respect to the direction of the heat flow.” Barrios et al. [2010] analyzed the thermal behavior of wall/roof in non air-conditioned rooms considering the indoor temperature only as a function of the heat transfer through it. The results showed that a monolayered wall of thermal insulation, having a good performance in an air-conditioned room, has a poor thermal performance in non air-conditioned rooms. Furthermore it was found that thermal insulation mounted on the exterior side has a better thermal performance than if mounted on the interior side. The standard NOM-020-ENER-2011 was designed to reduce the energy consumption due to mechanical cooling, and is mandatory in the whole country. However not all buildings are equipped with an air-conditioning unit. According to the climatic conditions the use of air-conditioning units may or may not be necessary. The above mentioned articles lead to the suspicion, that the levels of thermal insulation, imposed by the standard, might have a negative effect for non air-conditioned rooms. This suspicion led to a fourth line of investigation, which examines the thermal performance of a non air-conditioned room, denominated **non-A/C**. The resulting indoor temperatures are reported as hours in- and outside of the thermal comfort zone.

6.3 Methodology

6.3.1 Calculation according to NOM-020-ENER-2011

The calculation according to the NOM-020-ENER-2011 follows the same principles as described in paragraph 5.2.8 (Methodology of calculation NOM-020-ENER-2011). The calculations differ from those undertaken in chapter 5 only in the assumptions for the materials applied in the three different cases (see table 6-1 and table 6-9). Table 6-3 shows the boundary conditions according to the NOM-020-ENER-2011 for the reference U-Value and the equivalent average temperature t_e.

Table 6-3 Reference U-Value and equivalent interior temperature according to NOM-020

State	City	Reference U-Value (W/m^2K)			Equivalent average temperature t_e (ºC)
		Up to 3 storeys	More the 3 storeys		T interior
		Roof/Wall	Roof	Wall	
Quintana Roo	Cancún	0.526	0.526	0.625	25
Sonora	Hermosillo	0.476	0.476	0.526	25
Jalisco	Guadalajara	0.714	0.714	0.909	25
Puebla	Puebla	0.833	0.833	0.909	24

Source: NOM-020.

6.3.2 Passive House Planning Package

The calculation with the Passive House Planning Package follows the same principles as described in paragraph 5.2.9 (Methodology Passive House Planning Tool). The calculations differ from those undertaken in chapter 5 only in the assumptions for the materials applied in the three different cases (see table 6-1 and table 6-9). Table 6-4 shows the boundary conditions which were assumed for the calculation and which correspond to the assumption taken for the calculations of the Baseline case for the Mexican NAMA for new housing (see paragraph 3.3.3). The defined comfort zone has an upper comfort limit of 25°C and a lower comfort limit of 20°C. Table 6.5 shows the assumptions for the absorptivity of the exterior surfaces. The thermal properties for the applied materials correspond to those in table 6-2.

Table 6-4 Absorptivity of roof and wall surfaces

Absorptivity		
Location	Roof	Wall
Hermosillo	0.3	0.5
Cancún	0.3	0.5
Guadalajara	0.7	0.5
Puebla	0.7	0.5

Table 6-5 Boundary conditions and internal heat loads

Specifications for Reference Building, BASELINE and LINE NOM-020	
Type of lighting	Compact fluorescent light 20W
Electrical appliances	Refrigerator (2.68 kWh/d), TV (0.19 kWh/d), A/C (2.5 COP), ventilator (100 W), washing machine (0.32 kWh/d), microwave oven (0.17 kWh/d) (Information about domestic appliances based on: [Infonavit 2011a], [Infonavit 2011b] [Luz y fuerza n.d.] [SENER 2011]
Heat generator for water	Tank less LP Gas water heater (e.g. CINSA CDP 06)
Cooking	LP Gas Stove
Number of m2 per person	20 m2 per person (considering 30 year lifecycle)
Internal heat gains	5.3 W/m2 (calculated with PHPP)
Airtightness	5 h-1
Temperature limit summer	25°C
Temperature limit winter	20°C
Primary energy factors	Electricity mix: 2,7 kWhPrim/kWhFinal LP Gas: 1.1 kWhPrim/kWhFinal (Sources: Enerdata et al. 2011 and PHPP 2007)

Source: CONAVI 2010, technical Annex (unpublished).

6.3.3 Dynamic thermal simulation with Design Builder & Energy Plus

The thermal dynamic simulations were realized with the calculation engine *Energy Plus V7.0*; using the user interface *Design Builder V3.0.0.104*. The weather data in form of Metenorm Weather Files has been obtained from the Energy Plus Support Group[52]. According to the recommendations in the *Design Builder* Manual the ground temperature has been assumed as: Average Hourly Statistics Dry Bulb temperature in °C minus 2°C. Two simulations have been carried out for each case: i) intermittent-A/C and ii) non-A/C. The settings for each of the two simulations are the following:

Intermittent air-conditioning
Heating: fuel = natural gas; CoP of heating unit: 0.75; Design marge: 1.2;
Temperature of the heating setpoint: 18.0 °C.
Cooling: fuel = grid electricity; CoP of cooling unit: 2.50; Design marge: 1.3;
Temperature of the cooling setpoint: 25.0 °C.

Non air-conditioning
Temperature of the ventilation setpoint (natural ventilation): 23.0 °C.

The assumptions for the thermal properties of the materials correspond to those reported in table 6-2. Table 6.5 shows the assumptions for the absorptivity of the exterior surfaces.

[52] <http://tech.groups.yahoo.com/group/EnergyPlus_Support/>.

6.4 Results reported by calculation methodology

6.4.1 NOM-020-ENER-2011

Table 6-6 Adosada_Energetic evaluation NOM-020-ENER-2011_Power per housing unit

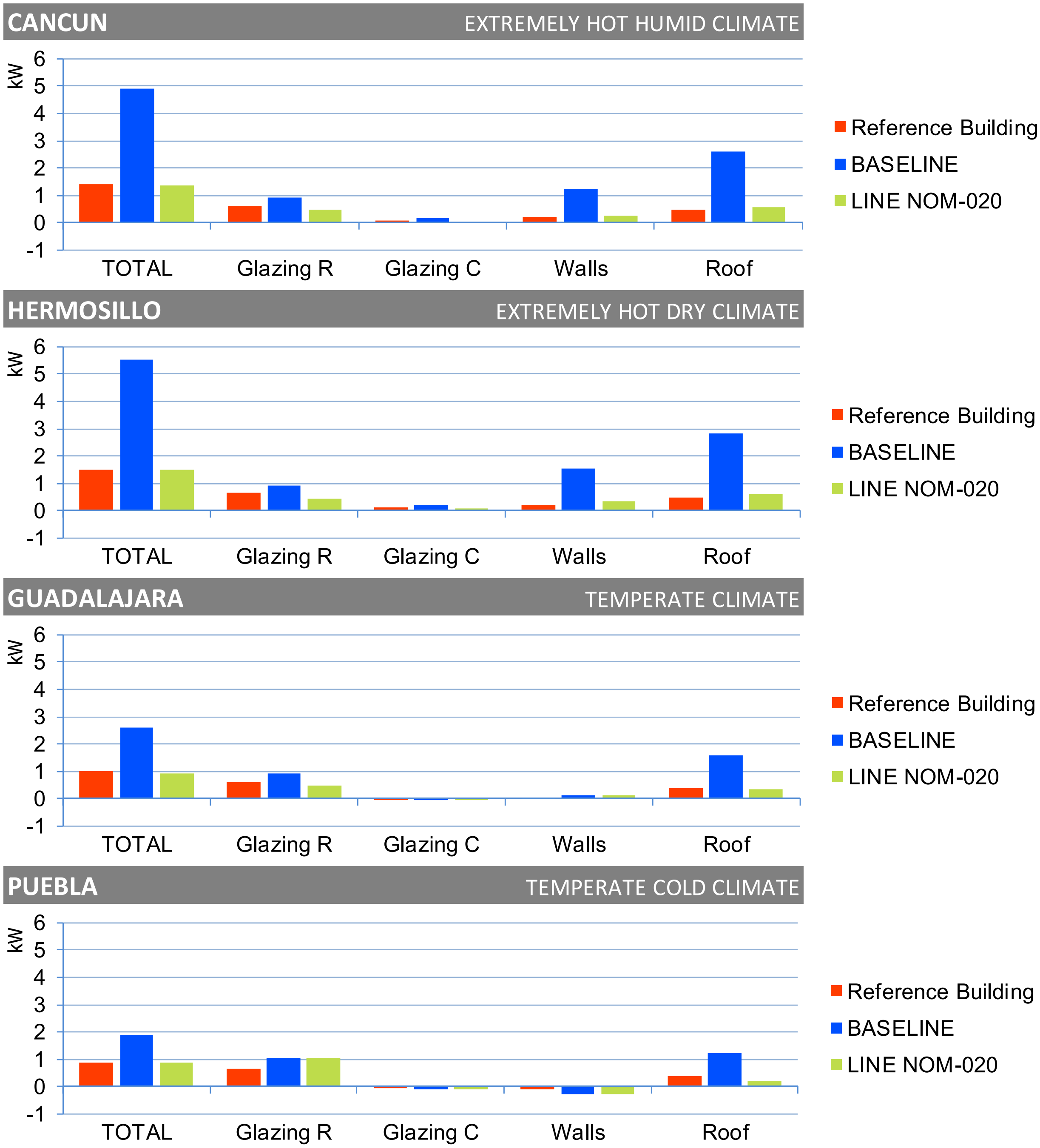
CANCÚN		Reference Building	BASELINE	LINE NOM-020
Conduction Heat gains	Roof	494 W	2,589 W	578 W
	Walls	202 W	1,226 W	270 W
	Glazing **C**	103 W	163 W	58 W
Radiation Heat Gains	Glazing **R**	617 W	947 W	474 W
	TOTAL	**1,416 W**	**4,926 W**	**1,379 W**
Energy Saving *[Ahorro de Energía]*			**-248 %**	**3 %**

HERMOSILLO		Reference Building	BASELINE	LINE NOM-020
Conduction Heat gains	Roof	489 W	2,836 W	633 W
	Walls	229 W	1,533 W	333 W
	Glazing **C**	148 W	234 W	83 W
Radiation Heat Gains	Glazing **R**	640 W	913 W	456 W
	TOTAL	**1,506 W**	**5,516 W**	**1,505 W**
Energy Saving *[Ahorro de Energía]*			**-266 %**	**0 %**

GUADALAJARA		Reference Building	BASELINE	LINE NOM-020
Conduction Heat gains	Roof	415 W	1,603 W	358 W
	Walls	25 W	135 W	145 W
	Glazing **C**	-38 W	-68 W	-24 W
Radiation Heat Gains	Glazing **R**	621 W	936 W	468 W
	TOTAL	**1,024 W**	**2,605 W**	**946 W**
Energy Saving *[Ahorro de Energía]*			**-155 %**	**8 %**

PUEBLA		Reference Building	BASELINE	LINE NOM-020
Conduction Heat gains	Roof	372 W	1,233 W	200 W
	Walls	-77 W	-263 W	-283 W
	Glazing **C**	-66 W	-114 W	-81 W
Radiation Heat Gains	Glazing **R**	665 W	1,058 W	1,058 W
	TOTAL	**894 W**	**1,914 W**	**894 W**
Energy Saving *[Ahorro de Energía]*			**-114 %**	**0 %**

Chart 6-1 Adosada_Energetic evaluation NOM-020-ENER-2011_Power per housing unit



Energy balance according to the NOM-020-ENER-2011

In the locations of Cancún and Hermosillo the total heat gains of the BASELINE case exceed the permitted limit for the total heat gain by the Reference Building by 248 % and by 266 %. In both locations the project exceeds the reference conduction gains for roof and walls, as well as the reference radiation gains for the transparent parts of the building envelope (chart 6-1). According to the analysis additional insulation of the walls and the application of shading devices or solar protection for the transparent building parts would be an appropriate energy efficiency strategies to fulfill the standard.

In the location of Guadalajara the total heat gains of the BASELINE case exceed the permitted limit of the total heat gain by the Reference Building by 155 %. The project exceeds the reference conduction gains for the roof, as well as the reference radiation gains for the transparent parts of the building envelope (chart 6-1). An energy efficiency strategy to fulfill the standard would be to add thermal insulation to the roof and to apply shading devices or solar protection for the transparent building parts.

In the case of Puebla the total heat gains of the BASELINE case exceed the permitted limit of the total heat gain by the Reference Building by 114 %. The project exceeds the reference conduction gains for the roof, as well as the reference radiation gains for the transparent parts of the building envelope (chart 6-1). The analysis reports “negative” heat gains or heat loss for the conduction gains of walls and glazing (see chapter 5.4.1 for further explanation). This phenomenon is due to the fact, that the respective interior reference temperature of 24°C is higher than the equivalent temperatures for massive walls (north 21°C, east and south 23°C, west 22°C). An energy efficiency strategy to fulfill the standard would be to add thermal insulation to the roof and to apply shading devices or solar protection for the transparent building parts.

Energy efficiency strategies of the LINE NOM-020 and their impact

For the LINE NOM-020 case in the locations of Cancún and Hermosillo an additional layer of XPS of 1.5 inches, mounted on the interior side, was applied to the roof and to all exterior walls (see table 6-7). The clear single glazing of 3 mm of all windows was replaced by a low-emissive double glazing with a shading coefficient of 0.46. In both locations these measures lead to a significant reduction of the conduction heat gains of the walls and of radiation heat gains of the windows, as well as of the conduction heat gains of the windows. The total heat gains of the projected building of the BASELINE case were reduced by 72 % for the LINE NOM-020 case in Cancún and by 73 % in Hermosillo.

In the case of the LINE NOM-020 in Guadalajara, an additional layer of XPS of 1.5 inches, mounted on the interior side, was applied to the roof. The clear single glazing of 3 mm of all windows was replaced by a low-emissive double glazing with a shading coefficient of 0.46. The total heat gains of the projected building of the BASELINE case were reduced by 64 %.

For the LINE NOM-020 case in Guadalajara an additional layer of XPS of 2.0 inches, mounted on the interior side, was applied to the roof. The total heat gains of the projected building of the BASELINE case were reduced by 53 %.

Table 6-7 Adosada_Materials and Energy Efficiency measures

BASELINE - PROJECTED BUILDING

Roof	Walls	Windows
Waterproofing Imper NRG Reinforced concrete slab, 10cm. U-Value = 2.82 W/m^2K	Reinforced concrete, 10cm. U-Value = 3.79 W/m^2K	Single glazing, clear, 3mm. U-Value = 5.32 W/m^2K

LINE NOM-020 - CANCÚN

Roof	Walls	Windows
Waterproofing Imper NRG XPS 1.5" exterior side. Reinforced concrete slab, 10cm. U-Value = 0.62 W/m^2K	XPS 1.5" exterior side. Reinforced concrete, 10cm. U-Value = 0.65 W/m^2K	Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m^2K

LINE NOM-020 - HERMOSILLO

Roof	Walls	Windows
Waterproofing Imper NRG XPS 1.5" exterior side. Reinforced concrete slab, 10cm. U-Value = 0.62 W/m^2K	XPS 1.5" exterior side. Reinforced concrete, 10cm. U-Value = 0.65 W/m^2K	Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m^2K

LINE NOM-020 - GUADALAJARA

Roof	Walls	Windows
Waterproofing Imper NRG XPS 1.5" exterior side. Reinforced concrete slab, 10cm. U-Value = 0.62 W/m^2K	Reinforced concrete, 10cm. U-Value = 3.79 W/m^2K	Double glazing, LowE, 3+9+3mm, Shading Coefficient 0.46. U-Value = 1.87 W/m^2K

LINE NOM-020 - PUEBLA

Roof	Walls	Windows
Waterproofing Imper NRG XPS 2.0" exterior side. Reinforced concrete slab, 10cm. U-Value = 0.49 W/m^2K	Reinforced concrete, 10cm. U-Value = 3.79 W/m^2K	Single glazing, clear, 3mm. U-Value = 5.32 W/m^2K

6.4.2 Passive House Planning Package

Chart 6-2 Adosada_Energetic evaluation PHPP

Energetic evaluation with Passive House Planning Package

For the BASELINE case in Cancún according to the evaluation with the PHPP the annual cooling load accounts for 289 kWh/m^{2}y, whereas there is no heating load. The LINE NOM-020 case reduces the cooling load by 49 % (see also table 6-21).

In Hermosillo for the BASELINE case the final energy demand is composed by 223 kWh/m^{2}y cooling load, and by 63 kWh/m^{2}y heating load. The applied energy efficiency measures in the LINE NOM-020 scenario reduce the cooling load by 51 % and achieve to eliminate the need for heating in the cold season.

For the BASELINE case in Guadalajara a cooling load of 26 kWh/m^{2}y and a heating load of 24 kWh/m^{2}y is reported. The proposed energy efficiency strategy, derived from the results of the analysis of the NOM-020, would lead to a reduction of the cooling load of 11%, and would reduce the heating load by 91% (see also table 6-20).

In Puebla for the BASELINE case a cooling load of 13 kWh/m^{2}y, and a heating load of 149 kWh/m^{2}y is reported. The proposed energy efficiency strategy, derived from the results of the analysis of the NOM-020, would increase of the cooling energy consumption by 42 % to 18 kWh/m^{2}y, whereas the heating load would be reduced by 91 kWh/m^{2}y (61%).

6.4.3 Dynamic thermal simulation / Design Builder_Cancún

Table 6-8 Cancún non-A/C_Hours below 18°C and above 25°C

HOURS BELOW 18°C				
Zone		Reference Building	PB_BASELINE	PB_LINE NOM-020
B_Living & Kitchen	[hours/year]	0	8	0
B_Bedroom 1	[hours/year]	0	1	0
B_Bedroom 2	[hours/year]	0	5	0
A_Living & Kitchen	[hours/year]	0	6	0
A_Bedroom 1	[hours/year]	0	1	0
A_Bedroom 2	[hours/year]	0	4	0
PROMEDIO	[hours/year]	0	4	0
Yearly Portion	[%]	0.0%	0.0%	0.0%

HOURS ABOVE 25°C				
Zone		Reference Building	PB_BASELINE	PB_LINE NOM-020
B_Living & Kitchen	[hours/year]	4,206	5,676	4,264
B_Bedroom 1	[hours/year]	4,172	5,789	4,137
B_Bedroom 2	[hours/year]	3,974	4,846	3,886
A_Living & Kitchen	[hours/year]	4,675	5,650	4,419
A_Bedroom 1	[hours/year]	4,243	5,796	4,166
A_Bedroom 2	[hours/year]	4,077	4,863	3,916
PROMEDIO	[hours/year]	4,225	5,437	4,131
Yearly Portion	[%]	48.2%	62.1%	47.2%

Table 6-9 Cancún non-A/C_Annual Temperature Distribution. Frecuency in hours

Reference Building non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	0	0	0	0	0	1	81	257	771	1319	1227	898	1492	1905	801	8	0	0	0
B_Bedroom 1	0	0	0	0	0	0	49	214	669	1291	1420	945	1669	1939	564	0	0	0	0
B_Bedroom 2	0	0	0	0	0	10	140	408	1082	1233	1058	855	1663	1787	524	0	0	0	0
A_Living & Kitchen	0	0	0	0	0	0	48	183	512	1049	1234	1059	1206	1680	1388	390	11	0	0
A_Bedroom 1	0	0	0	0	0	0	43	195	618	1243	1427	991	1558	1985	698	2	0	0	0
A_Bedroom 2	0	0	0	0	0	5	128	363	1032	1251	1061	843	1589	1833	655	0	0	0	0

Projected Building BASELINE non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	0	0	1	7	27	63	139	261	368	531	735	952	1150	1227	1069	881	653	458	238
B_Bedroom 1	0	0	0	1	8	40	87	195	344	522	748	1026	1337	1443	1274	920	578	218	19
B_Bedroom 2	0	0	0	5	28	68	170	345	543	716	936	1103	1206	1284	1063	731	417	141	4
A_Living & Kitchen	0	0	0	6	33	62	135	291	367	548	723	945	1138	1209	1059	802	601	428	413
A_Bedroom 1	0	0	0	1	7	39	86	189	354	516	738	1034	1301	1464	1283	907	588	228	25
A_Bedroom 2	0	0	0	4	25	71	166	337	539	711	936	1108	1185	1284	1081	766	431	116	0

Projected Building LINE NOM-020 non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	0	0	0	0	2	30	114	350	650	961	1128	1261	1527	1500	943	290	4	0	0
B_Bedroom 1	0	0	0	0	0	9	76	242	665	1052	1309	1270	1604	1733	760	40	0	0	0
B_Bedroom 2	0	0	0	0	0	26	147	442	934	1236	1070	1019	1545	1638	679	24	0	0	0
A_Living & Kitchen	0	0	0	0	2	27	112	326	633	902	1098	1241	1540	1457	968	405	49	0	0
A_Bedroom 1	0	0	0	0	0	7	72	238	644	1052	1295	1286	1593	1737	785	51	0	0	0
A_Bedroom 2	0	0	0	0	0	24	146	432	916	1244	1073	1009	1517	1680	702	17	0	0	0

CANCÚN NON-A/C

For the BASELINE case in Cancún according to the non-A/C evaluation the yearly portion of hours above 25°C is 62%, which would be reduced to 47% by the applied energy efficiency strategy in the LINE NOM-020 scenario (see table 6-8). The yearly portion of hours above 28°C would be reduced to 2%, assuming that the use of a ceiling fan can reduce the interior temperature by 2.5°C, the energy efficiency measures necessary to comply with the standard would achieve to eliminate the need for air-conditioning.

The yearly portion of hours below 18°C is zero. The temperatures do not fall below the lower limit of the comfort zone.

Chart 6-3 Cancún non-A/C_Comfort hours

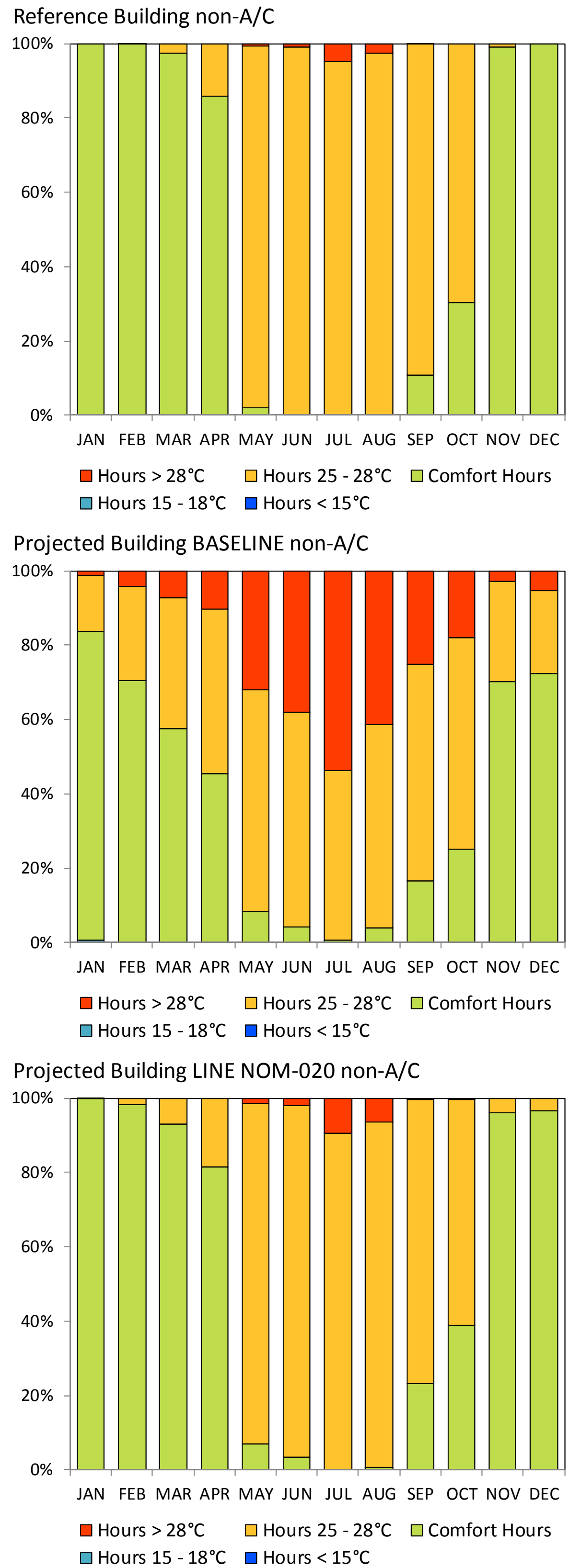


Table 6-10 Cancún intermittent-A/C_Energy consumption and CO2 emissions

CAPACITY COOLING AND HEATING		Reference Building	PB_BASELINE	PB_LINE NOM-020
Total Capacity Heating Design	[kW]	4.0	14.4	4.1
Total Capacity Cooling Design	[kW]	2.1	4.0	2.0

ENERGETIC CONSUMPTION		Reference Building	PB_BASELINE	PB_LINE NOM-020
Heating Load	[kWh/m^2 year]	0.0	0.0	0.0
Cooling Load	[kWh/m^2 year]	28.3	68.9	25.8
Energy Demand	[kWh/m^2 year]	28.3	68.9	25.8
Reduction of Energy Demand	[kWh/m^2 year]		-40.6	2.5

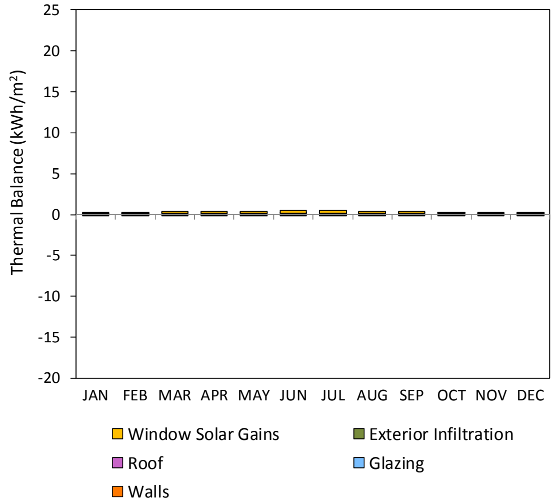
CO^2 EMISSIONS		Reference Building	PB_BASELINE	PB_LINE NOM-020
Heating Energy Consumption	[kWh/m^2 year]	0.0	0.1	0.0
Cooling Energy Consumption	[kWh/m^2 year]	30.6	74.4	27.8
Yearly Emissions CO^2	[kg/m^2]	20.8	50.6	18.9
Reduction of Yearly Emissions CO^2	[kg/m^2]		-29.8	1.9

CANCÚN INTERMITTENT-A/C

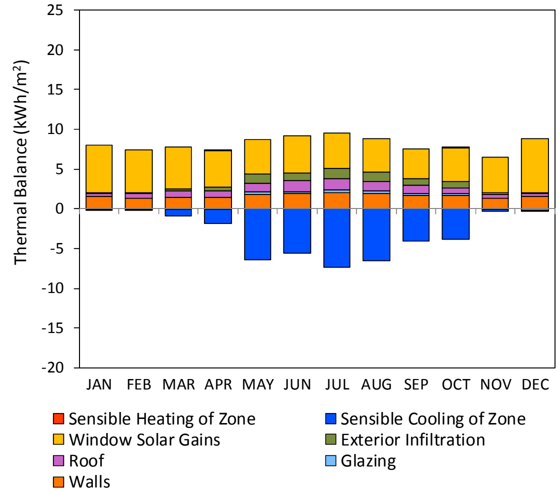
For the BASELINE case in Cancún according to the intermittent-A/C evaluation with *Design Builder* the annual cooling load accounts for 69 kWh/m^{2}y, whereas the heating load is zero. The total of the heating and cooling energy consumption would represent an equivalent of 51 kg/m^{2}y of CO_2 emissions. The LINE NOM-020 case reduces the cooling load by 63 %, leading to a reduction of CO_2 emissions of 32 kg/m^{2}y.

Chart 6-4 Cancún non-A/C & intermittent-A/C_Thermal Balance

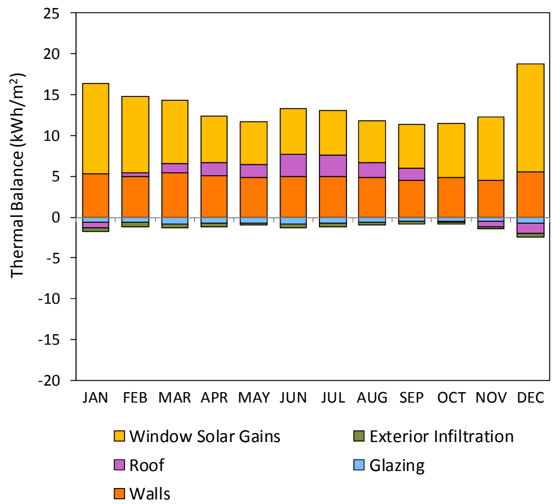
Reference Building non-A/C



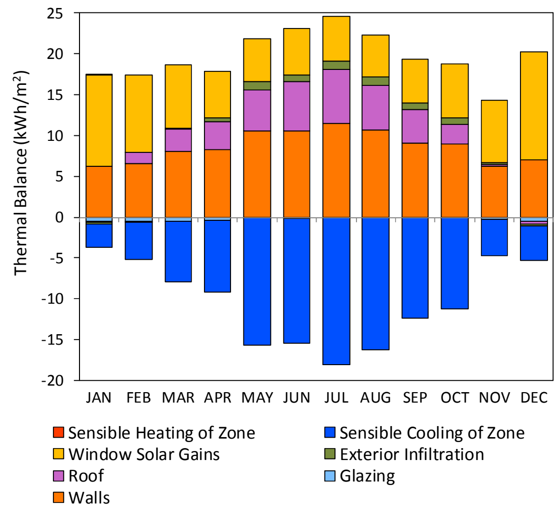
Reference Building intermittent-A/C



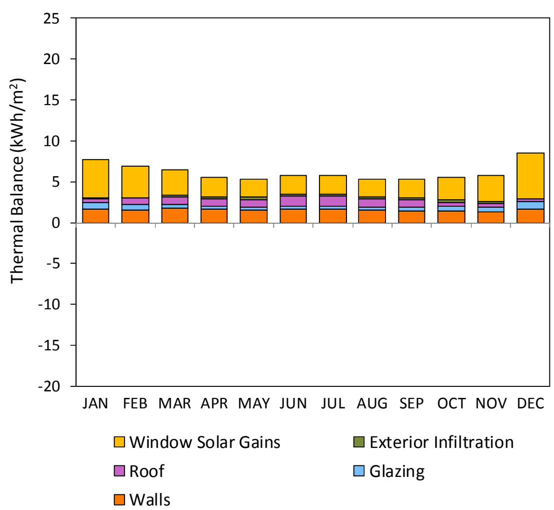
Projected Building BASELINE non-A/C



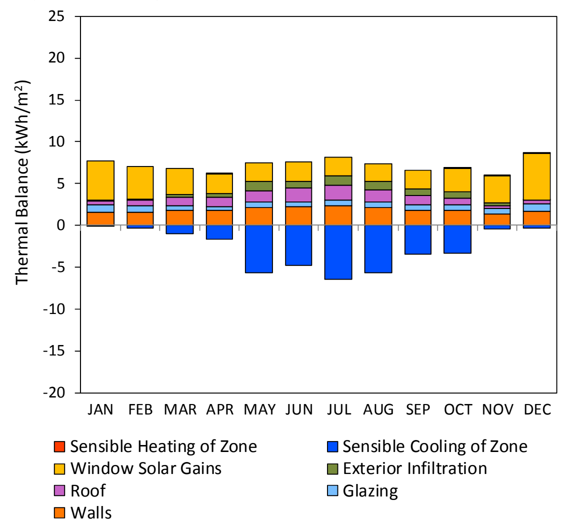
Projected Building BASELINE intermittent-A/C



Projected Building LINE NOM-020 non-A/C



Projected Building LINE NOM-020 intermittent-A/C



6.4.4 Dynamic thermal simulation / Design Builder_Hermosillo

Table 6-11 Hermosillo non-A/C_Hours below 18°C and above 25°C

HOURS BELOW 18°C				
Zone		Reference Building	PB_BASELINE	PB_LINE NOM-020
B_Living & Kitchen	[hours/year]	1,741	1,402	1,534
B_Bedroom 1	[hours/year]	1,613	1,226	1,468
B_Bedroom 2	[hours/year]	1,952	1,819	1,897
A_Living & Kitchen	[hours/year]	1,500	1,432	1,492
A_Bedroom 1	[hours/year]	1,555	1,222	1,447
A_Bedroom 2	[hours/year]	1,930	1,807	1,891
PROMEDIO	[hours/year]	1,715	1,485	1,622
Yearly Portion	[%]	19.6%	16.9%	18.5%

HOURS ABOVE 25°C				
Zone		Reference Building	PB_BASELINE	PB_LINE NOM-020
B_Living & Kitchen	[hours/year]	4,172	4,441	4,176
B_Bedroom 1	[hours/year]	4,177	4,381	4,172
B_Bedroom 2	[hours/year]	4,116	4,137	4,081
A_Living & Kitchen	[hours/year]	4,273	4,430	4,199
A_Bedroom 1	[hours/year]	4,197	4,385	4,179
A_Bedroom 2	[hours/year]	4,129	4,143	4,086
PROMEDIO	[hours/year]	4,177	4,320	4,149
Yearly Portion	[%]	47.7%	49.3%	47.4%

Table 6-12 Hermosillo non-A/C_Annual Temperature Distribution. Frecuency in hours

Reference Building non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	143	355	631	612	427	440	455	383	359	280	291	212	265	386	332	376	655	875	1283
B_Bedroom 1	94	296	565	658	458	462	459	412	391	294	268	226	267	385	355	402	655	966	1147
B_Bedroom 2	236	460	705	551	355	453	441	374	299	280	289	201	305	363	317	444	683	916	1088
A_Living & Kitchen	109	290	509	592	494	466	419	392	355	294	329	238	248	334	312	342	528	754	1755
A_Bedroom 1	85	277	549	644	479	467	450	418	396	297	271	230	259	382	342	384	639	939	1252
A_Bedroom 2	218	436	708	568	345	456	435	380	314	264	301	206	283	371	313	412	673	888	1189

Projected Building BASELINE non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	472	252	313	365	385	392	420	379	384	353	308	296	304	335	374	410	461	452	2105
B_Bedroom 1	317	233	297	379	416	410	432	430	407	366	356	336	288	318	406	470	490	556	1853
B_Bedroom 2	532	346	420	521	447	399	406	337	301	308	309	297	246	276	417	481	510	572	1635
A_Living & Kitchen	495	274	303	360	380	383	392	392	367	338	330	316	303	334	417	411	448	472	2045
A_Bedroom 1	311	235	302	374	406	413	429	432	416	357	356	344	291	318	404	476	488	559	1849
A_Bedroom 2	522	349	416	520	457	401	401	336	304	304	302	305	249	273	415	471	507	584	1644

Projected Building LINE NOM-020 non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	282	335	413	504	507	481	426	395	326	335	308	272	297	289	335	491	607	766	1391
B_Bedroom 1	176	304	442	546	534	488	440	420	352	361	269	256	286	322	332	495	643	891	1203
B_Bedroom 2	302	439	612	544	456	405	437	355	303	290	267	269	279	337	310	478	689	875	1113
A_Living & Kitchen	284	327	407	474	510	478	427	393	348	320	303	290	296	288	326	484	595	749	1461
A_Bedroom 1	175	295	438	539	539	500	436	420	358	348	281	252	287	320	335	488	637	885	1227
A_Bedroom 2	295	432	619	545	452	412	432	350	310	292	269	266	276	330	316	466	689	878	1131

HERMOSILLO NON-A/C

For the BASELINE case in Hermosillo according to the non-A/C evaluation the yearly portion of hours above 25°C is 49%, which would be reduced to 47% by the applied energy efficiency strategy in the LINE NOM-020 scenario (see table 6-11). The analysis of table 6-12 reports a yearly portion of hours above 28°C of 38%, which would be reduced to 37%. The yearly portion of hours above 31°C would be reduced from 21% to 14%. The energy efficiency measures applied to comply with the standard therefore reduced the extreme temperatures above 31%. Mechanical cooling would be necessary to stay below the defined upper limit of the comfort zone of 25°C.

The yearly portion of hours below 18°C incremented from 17% to 19% by the applied energy efficiency measures for the non-A/C scenario.

Chart 6-5 Hermosillo non-A/C_Comfort hours

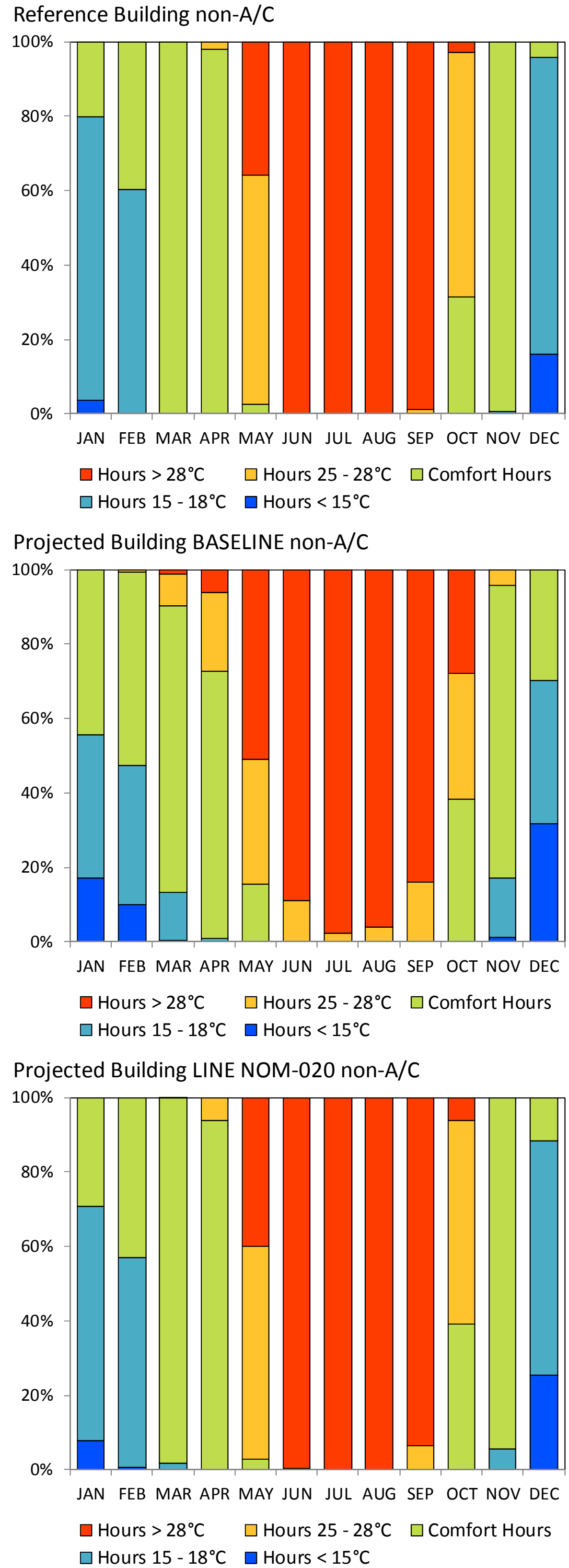


Table 6-13 Hermosillo intermittent-A/C_Energy consumption and CO2 emissions

CAPACITY COOLING AND HEATING				
		Reference Building	PB_BASELINE	PB_LINE NOM-020
Total Capacity Heating Design	[kW]	5.5	15.6	5.8
Total Capacity Cooling Design	[kW]	5.1	7.0	5.0

ENERGETIC CONSUMPTION				
		Reference Building	PB_BASELINE	PB_LINE NOM-020
Heating Load	[kWh/m^2 year]	18.1	40.2	20.5
Cooling Load	[kWh/m^2 year]	60.7	94.5	59.6
Energy Demand	[kWh/m^2 year]	78.8	134.8	80.2
Reduction of Energy Demand	[kWh/m^2 year]		-56.0	-1.4

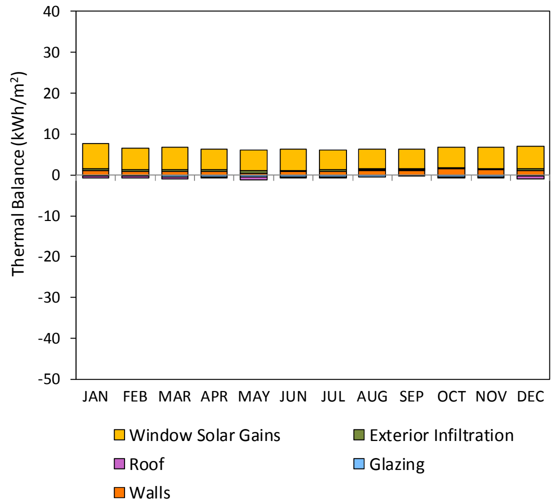
CO^2 EMISSIONS				
		Reference Building	PB_BASELINE	PB_LINE NOM-020
Heating Energy Consumption	[kWh/m^2 year]	26.6	59.0	30.1
Cooling Energy Consumption	[kWh/m^2 year]	65.5	102.1	64.4
Yearly Emissions CO^2	[kg/m^2]	48.0	77.1	47.7
Reduction of Yearly Emissions CO^2	[kg/m^2]		-29.1	0.3

HERMOSILLO INTERMITTENT-A/C

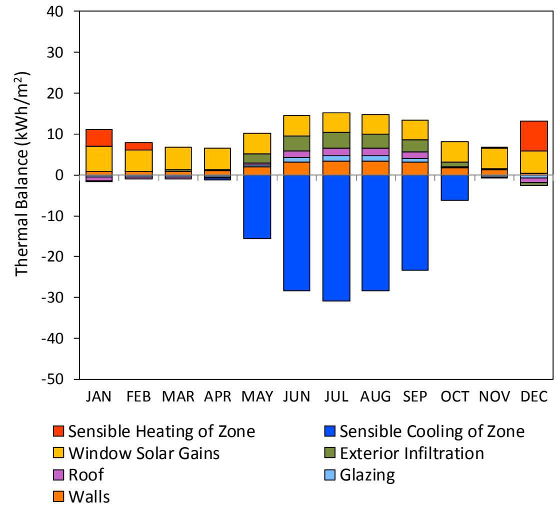
For the BASELINE case in Hermosillo according to the intermittent-A/C evaluation with *Design Builder* the annual cooling load accounts for 95 kWh/m^2y, and the annual heating load accounts for 40 kWh/m^2y. The LINE NOM-020 case reduces the annual energy demand by 41 %, leading to a reduction of CO_2 emissions of 29 kg/m^2y.

Chart 6-6 Hermosillo non-A/C & intermittent-A/C_Thermal Balance

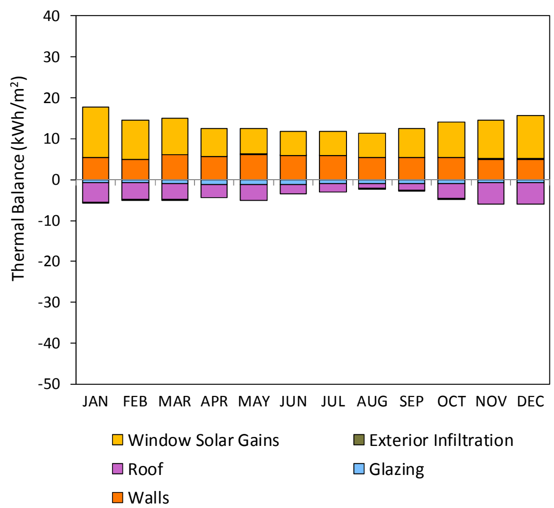
Reference Building non-A/C



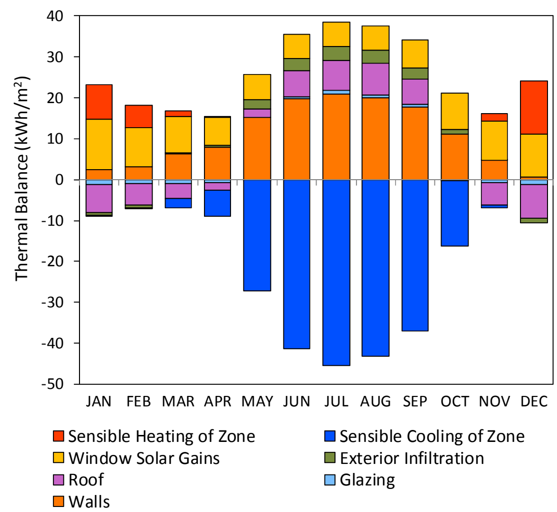
Reference Building intermittent-A/C



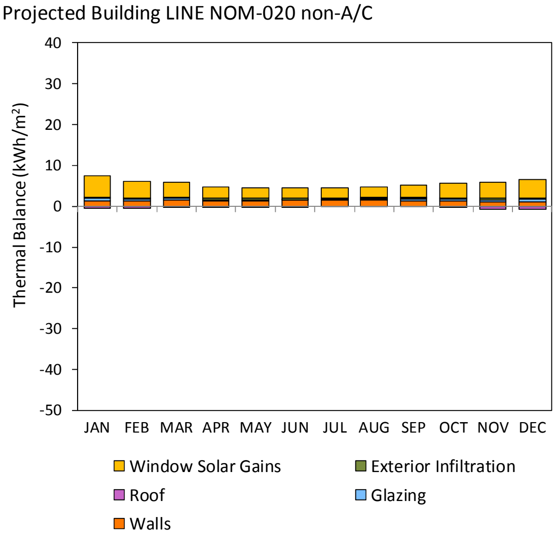
Projected Building BASELINE non-A/C



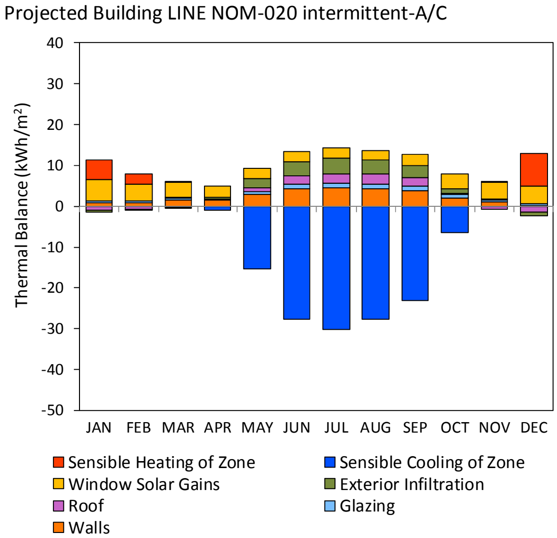
Projected Building BASELINE intermittent-A/C



Projected Building LINE NOM-020 non-A/C



Projected Building LINE NOM-020 intermittent-A/C



6.4.5 Dynamic thermal simulation / Design Builder_Guadalajara

Table 6-14 Guadalajara non-A/C_Hours below 18°C and above 25°C

HOURS BELOW 18°C				
Zone		Reference Building	PB_BASELINE	PB_LINE NOM-020
B_Living & Kitchen	[hours/year]	3,507	2,596	2,957
B_Bedroom 1	[hours/year]	3,480	2,429	2,831
B_Bedroom 2	[hours/year]	3,655	2,964	3,470
A_Living & Kitchen	[hours/year]	3,234	2,687	3,030
A_Bedroom 1	[hours/year]	3,424	2,421	2,843
A_Bedroom 2	[hours/year]	3,606	2,956	3,448
PROMEDIO	[hours/year]	3,484	2,676	3,097
Yearly Portion	[%]	39.8%	30.5%	35.3%

HOURS ABOVE 25°C				
Zone		Reference Building	PB_BASELINE	PB_LINE NOM-020
B_Living & Kitchen	[hours/year]	0	792	223
B_Bedroom 1	[hours/year]	0	442	6
B_Bedroom 2	[hours/year]	0	372	5
A_Living & Kitchen	[hours/year]	4	928	406
A_Bedroom 1	[hours/year]	0	469	7
A_Bedroom 2	[hours/year]	0	359	0
PROMEDIO	[hours/year]	1	560	108
Yearly Portion	[%]	0.0%	6.4%	1.2%

Table 6-15 Guadalajara non-A/C_Annual Temperature Distribution. Frecuency in hours

Reference Building non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	1785	638	472	612	908	1356	1330	798	543	277	41	0	0	0	0	0	0	0	0
B_Bedroom 1	1687	630	519	644	934	1499	1356	738	512	241	0	0	0	0	0	0	0	0	0
B_Bedroom 2	2032	576	462	585	997	1402	1242	724	504	236	0	0	0	0	0	0	0	0	0
A_Living & Kitchen	1542	610	533	549	800	1116	1229	1034	676	386	218	63	4	0	0	0	0	0	0
A_Bedroom 1	1643	622	535	624	903	1452	1405	761	530	274	11	0	0	0	0	0	0	0	0
A_Bedroom 2	1987	586	465	568	958	1368	1277	750	526	269	6	0	0	0	0	0	0	0	0

Projected Building BASELINE non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	1276	380	431	509	753	862	765	741	683	599	514	455	364	213	128	61	24	2	0
B_Bedroom 1	1070	402	448	509	681	939	921	864	821	677	552	434	258	124	52	8	0	0	0
B_Bedroom 2	1350	513	536	565	657	851	898	858	732	641	433	354	201	111	47	13	0	0	0
A_Living & Kitchen	1315	402	445	525	715	874	782	703	657	567	463	384	303	252	171	99	60	34	9
A_Bedroom 1	1073	400	447	501	700	922	916	858	823	671	546	434	283	117	59	10	0	0	0
A_Bedroom 2	1343	510	538	565	642	835	919	848	747	662	443	349	199	108	43	9	0	0	0

Projected Building LINE NOM-020 non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	1379	446	506	626	871	928	850	829	741	649	459	253	152	62	9	0	0	0	0
B_Bedroom 1	1211	483	522	615	939	1140	1163	1098	812	421	258	92	6	0	0	0	0	0	0
B_Bedroom 2	1737	607	577	549	886	1129	1127	964	548	342	216	73	5	0	0	0	0	0	0
A_Living & Kitchen	1445	465	498	622	884	961	858	800	648	503	384	286	193	124	56	28	5	0	0
A_Bedroom 1	1208	477	533	625	928	1134	1168	1079	799	439	257	106	7	0	0	0	0	0	0
A_Bedroom 2	1730	605	577	536	875	1133	1151	989	531	359	205	69	0	0	0	0	0	0	0

GUADALAJARA NON-A/C

For the BASELINE case in Guadalajara according to the non-A/C evaluation the yearly portion of hours above 25°C is 6%, which would be reduced to 1% by the applied energy efficiency strategy in the LINE NOM-020 scenario (see table 6-14). There is no need for air-conditioning for the BASELINE case, however the applied energy efficiency measures to comply with the standard would achieve that the temperatures stay by 99% below the defined upper limit of the thermal comfort zone of 25%.

The yearly portion of hours below 18°C would increase from 31% for the BASELINE case to 35% for the LINE NOM-020, and to 40% for the Reference Building. The applied energy efficiency measures to comply with the standard have a negative effect on the hours below the defined lower comfort limit of 18°C for the non-A/C scenario, as the measures block solar gains through roof and window (see chart 6-8). Nevertheless the yearly portion of hours of 31 % for the BASELINE case below the lower comfort level of 18°C is significant. The analysis of table 6-15 reports a yearly portion of hours below 15°C of 14% for the BASELINE case.

Chart 6-7 Guadalajara non-A/C_Comfort hours

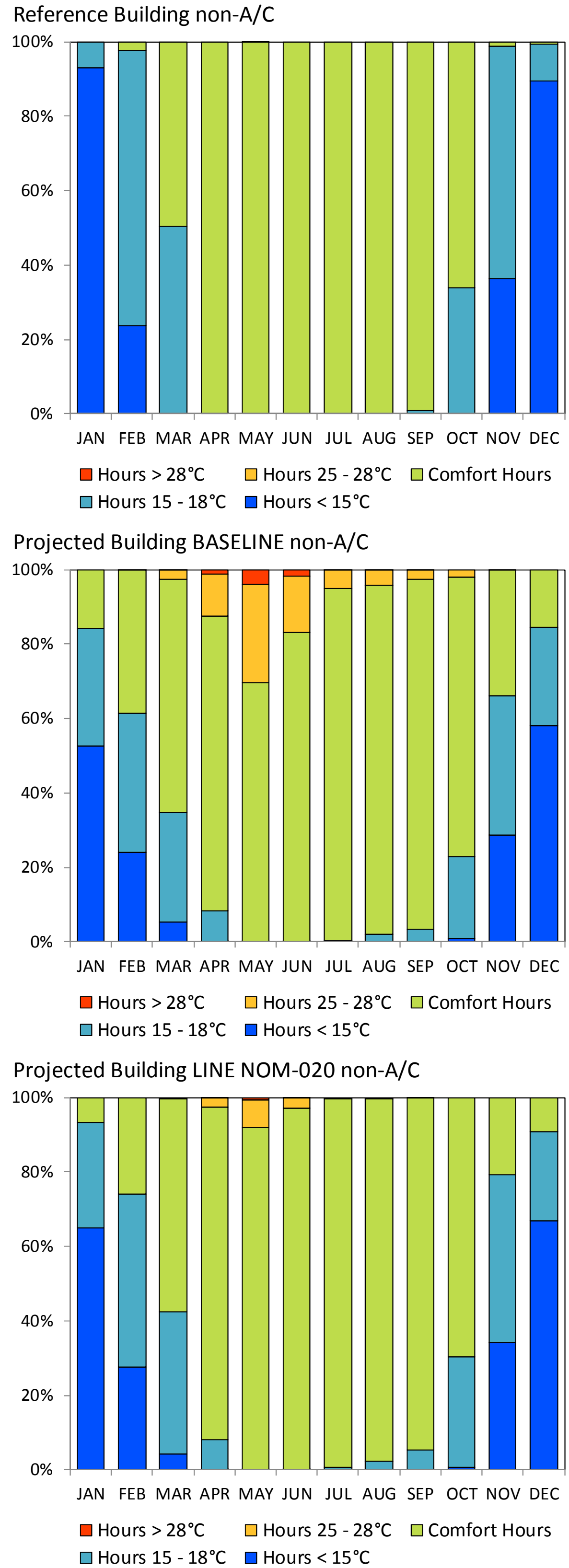


Table 6-16 Guadalajara intermittent-A/C_Energy consumption and CO2 emissions

CAPACITY COOLING AND HEATING		Reference Building	PB_BASELINE	PB_LINE NOM-020
Total Capacity Heating Design	[kW]	7.7	16.5	12.7
Total Capacity Cooling Design	[kW]	0.0	4.3	1.6

ENERGETIC CONSUMPTION		Reference Building	PB_BASELINE	PB_LINE NOM-020
Heating Load	[kWh/m^2 year]	72.4	98.9	95.0
Cooling Load	[kWh/m^2 year]	0.0	7.2	1.2
Energy Demand	[kWh/m^2 year]	72.4	106.1	96.2
Reduction of Energy Demand	[kWh/m^2 year]		-33.7	-23.9

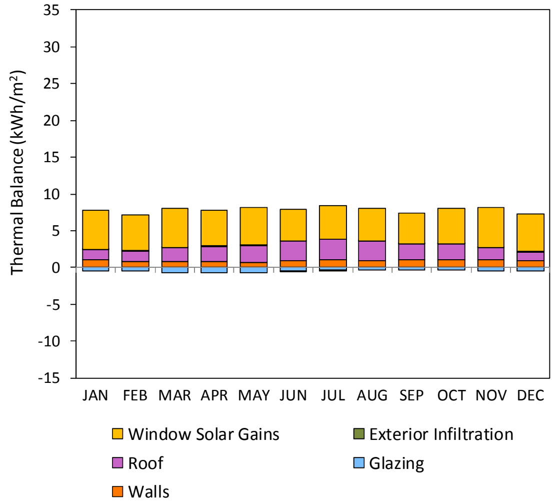
CO^2 EMISSIONS		Reference Building	PB_BASELINE	PB_LINE NOM-020
Heating Energy Consumption	[kWh/m^2 year]	106.1	145.1	139.3
Cooling Energy Consumption	[kWh/m^2 year]	0.0	7.8	1.3
Yearly Emissions CO^2	[kg/m^2]	13.8	24.1	19.0
Reduction of Yearly Emissions CO^2	[kg/m^2]		-10.3	-5.2

GUADALAJARA INTERMITTENT-A/C

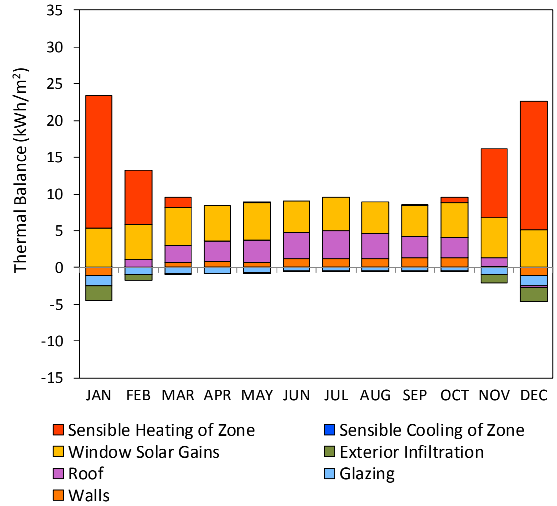
For the BASELINE case in Guadalajara according to the intermittent-A/C evaluation with *Design Builder* the theoretical annual cooling load accounts 7 kWh/m^{2}y, and the annual heating load accounts for 99 kWh/m^{2}y for the BASELINE case. The LINE NOM-020 case reduces the annual energy demand by 9%, leading to a theoretical reduction of CO_2 emissions of 5 kg/m^{2}y. The Reference Building case would reduce the annual energy demand by 32%, leading to a theoretical reduction of CO_2 emissions of 10 kg/m^{2}y.

Chart 6-8 Guadalajara non-A/C & intermittent-A/C_Thermal Balance

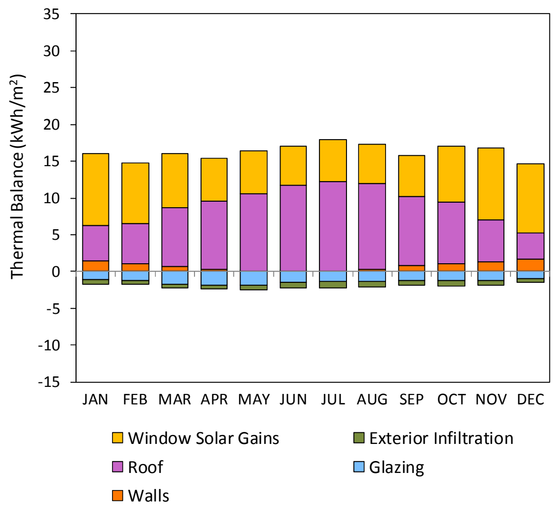
Reference Building non-A/C



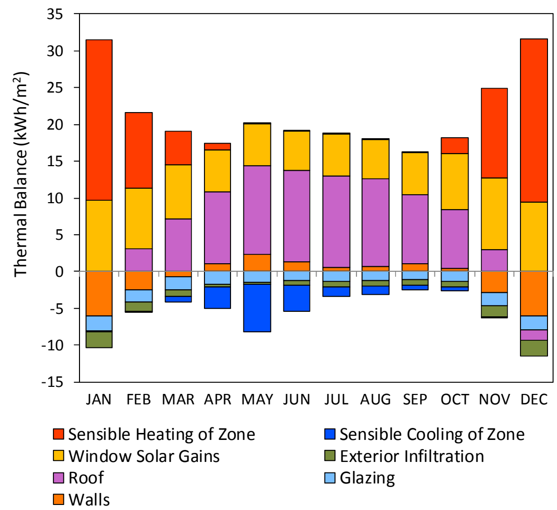
Reference Building intermittent-A/C



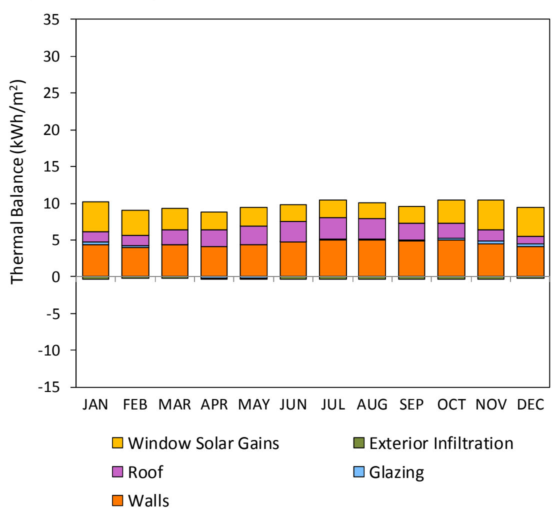
Projected Building BASELINE non-A/C



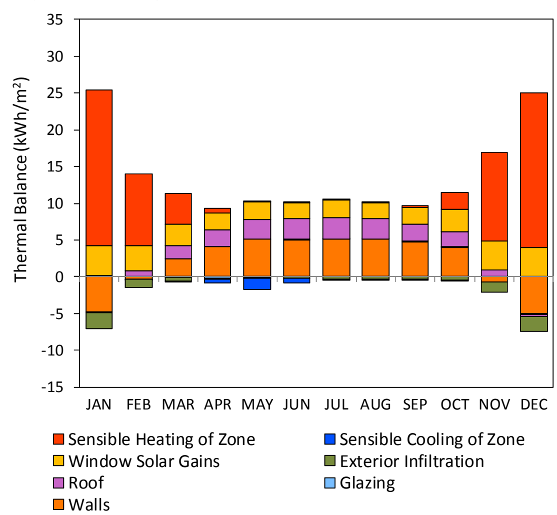
Projected Building BASELINE intermittent-A/C



Projected Building LINE NOM-020 non-A/C



Projected Building LINE NOM-020 intermittent-A/C



6.4.6 Dynamic thermal simulation / Design Builder_Puebla

Table 6-17 Puebla non-A/C_Hours below 18°C and above 25°C

HOURS BELOW 18°C				
Zone		Reference Building	PB_BASELINE	PB_LINE NOM-020
B_Living & Kitchen	[hours/year]	5,968	4,152	4,766
B_Bedroom 1	[hours/year]	6,252	4,019	4,999
B_Bedroom 2	[hours/year]	6,401	4,674	6,004
A_Living & Kitchen	[hours/year]	5,283	4,254	4,897
A_Bedroom 1	[hours/year]	6,104	4,028	4,987
A_Bedroom 2	[hours/year]	6,278	4,641	5,949
PROMEDIO	[hours/year]	6,048	4,295	5,267
Yearly Portion	[%]	69.0%	49.0%	60.1%

HOURS ABOVE 25°C				
Zone		Reference Building	PB_BASELINE	PB_LINE NOM-020
B_Living & Kitchen	[hours/year]	0	80	0
B_Bedroom 1	[hours/year]	0	1	0
B_Bedroom 2	[hours/year]	0	0	0
A_Living & Kitchen	[hours/year]	1	205	22
A_Bedroom 1	[hours/year]	0	2	0
A_Bedroom 2	[hours/year]	0	0	0
PROMEDIO	[hours/year]	0	48	4
Yearly Portion	[%]	0.0%	0.5%	0.0%

Table 6-18 Puebla non-A/C_Annual Temperature Distribution. Frecuency in hours

Reference Building non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	2006	913	1318	1731	1559	939	291	3	0	0	0	0	0	0	0	0	0	0	0
B_Bedroom 1	1850	985	1547	1870	1578	769	161	0	0	0	0	0	0	0	0	0	0	0	0
B_Bedroom 2	2365	964	1347	1725	1501	726	132	0	0	0	0	0	0	0	0	0	0	0	0
A_Living & Kitchen	1700	862	1171	1550	1536	1234	582	120	2	0	1	1	0	1	0	0	0	0	0
A_Bedroom 1	1772	984	1480	1868	1629	835	190	1	1	0	0	0	0	0	0	0	0	0	0
A_Bedroom 2	2321	927	1320	1710	1540	777	165	0	0	0	0	0	0	0	0	0	0	0	0

Projected Building BASELINE non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	1575	772	907	898	882	866	755	624	531	429	292	149	74	6	0	0	0	0	0
B_Bedroom 1	1249	746	993	1031	1075	988	878	739	541	341	137	41	1	0	0	0	0	0	0
B_Bedroom 2	1614	855	1066	1139	1062	903	726	613	399	259	97	27	0	0	0	0	0	0	0
A_Living & Kitchen	1686	811	887	870	866	775	720	596	514	366	271	193	116	64	25	0	0	0	0
A_Bedroom 1	1243	756	986	1043	1052	987	889	727	528	344	156	47	2	0	0	0	0	0	0
A_Bedroom 2	1590	836	1073	1142	1061	922	742	628	395	258	96	17	0	0	0	0	0	0	0

Projected Building LINE NOM-020 non-A/C

Temperature °C	< 15 °C	15 °C	16 °C	17 °C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	> 31°C
B_Living & Kitchen	1776	937	1026	1027	1050	880	792	674	357	172	54	15	0	0	0	0	0	0	0
B_Bedroom 1	1405	971	1283	1340	1320	1192	798	355	85	11	0	0	0	0	0	0	0	0	0
B_Bedroom 2	2183	1116	1376	1329	1134	880	494	205	43	0	0	0	0	0	0	0	0	0	0
A_Living & Kitchen	1902	966	1018	1011	930	834	696	552	375	264	136	54	22	0	0	0	0	0	0
A_Bedroom 1	1405	962	1279	1341	1328	1190	776	376	91	12	0	0	0	0	0	0	0	0	0
A_Bedroom 2	2152	1089	1368	1340	1196	919	460	205	31	0	0	0	0	0	0	0	0	0	0

PUEBLA NON-A/C

For the BASELINE case in Puebla according to the non-A/C evaluation the yearly portion of hours above 25°C is 1 %, which would be reduced to zero by the applied energy efficiency strategy in the LINE NOM-020 scenario (see table 6-17).

The yearly portion of hours below 18°C would increase from 49 % for the BASELINE case to 60 % for the LINE NOM-020, and to 69 % for the Reference Building. The energy efficiency measures applied to comply with the standard have a negative effect on the hours below the defined lower comfort limit of 18°C for the non-A/C scenario, as the measures block solar gains through the roof (see chart 6-10).

The yearly portion of hours of 49 % for the BASELINE case below the lower comfort level of 18°C is significant. The analysis of table 6-18 reports a yearly portion of hours below 15°C of 17% for the BASELINE case.

Chart 6-9 Puebla non-A/C_Comfort hours

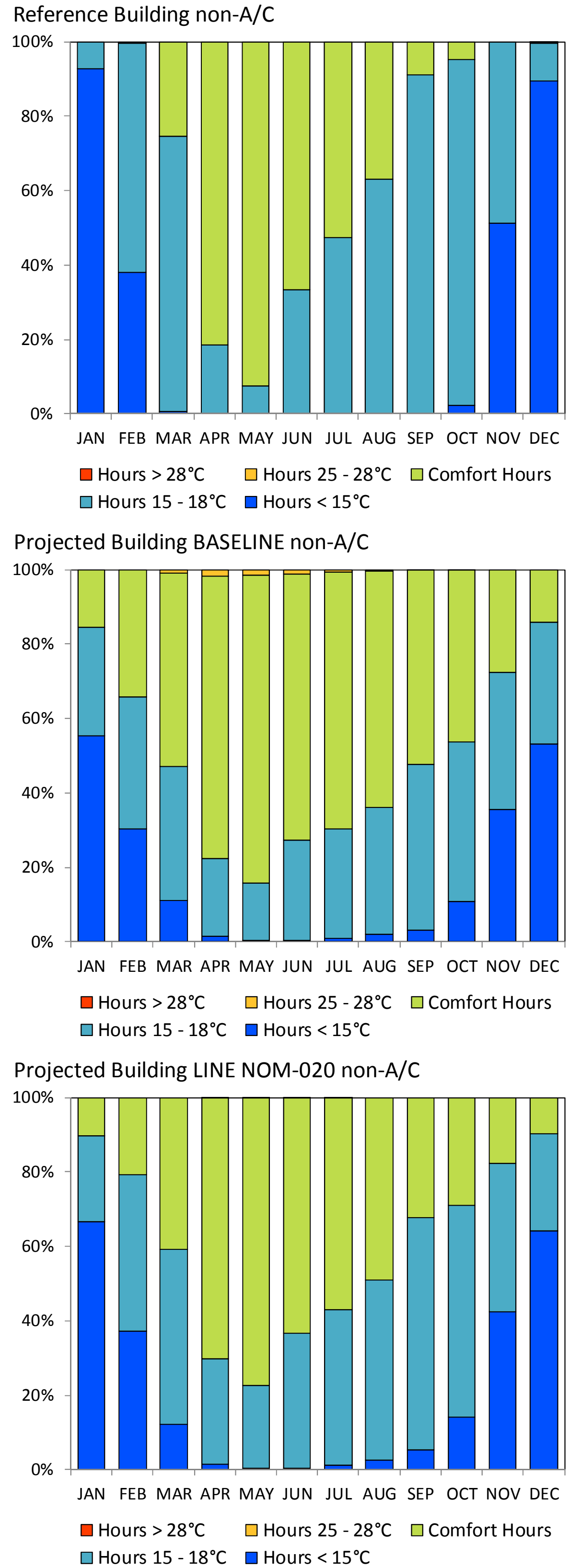


Table 6-19 Puebla intermittent-A/C_Energy consumption and CO2 emissions

CAPACITY COOLING AND HEATING				
		Reference Building	PB_BASELINE	PB_LINE NOM-020
Total Capacity Heating Design	[kW]	16.51	8.11	12.94
Total Capacity Cooling Design	[kW]	3.38	0	0.99

ENERGETIC CONSUMPTION				
		Reference Building	PB_BASELINE	PB_LINE NOM-020
Heating Load	[kWh/m^2 year]	132.7	101.4	135.1
Cooling Load	[kWh/m^2 year]	0.8	0.0	0.0
Energy Demand	[kWh/m^2 year]	133.6	101.4	135.2
Reduction of Energy Demand	[kWh/m^2 year]		32.2	-1.6

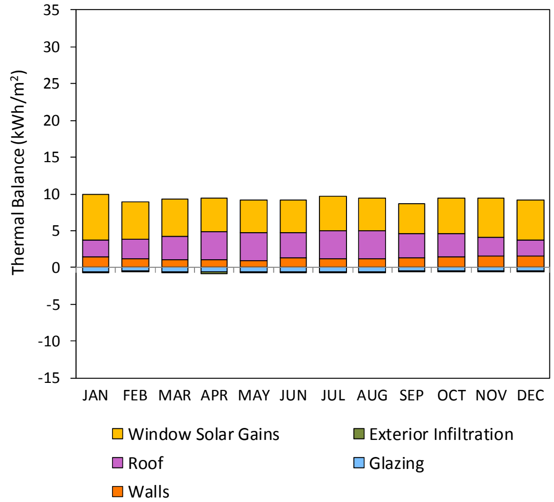
CO^2 EMISSIONS				
		Reference Building	PB_BASELINE	PB_LINE NOM-020
Heating Energy Consumption	[kWh/m^2 year]	194.7	148.7	198.2
Cooling Energy Consumption	[kWh/m^2 year]	0.9	0.0	0.0
Yearly Emissions CO^2	[kg/m^2]	25.9	19.3	25.9
Reduction of Yearly Emissions CO^2	[kg/m^2]		6.6	0.1

PUEBLA INTERMITTENT-A/C

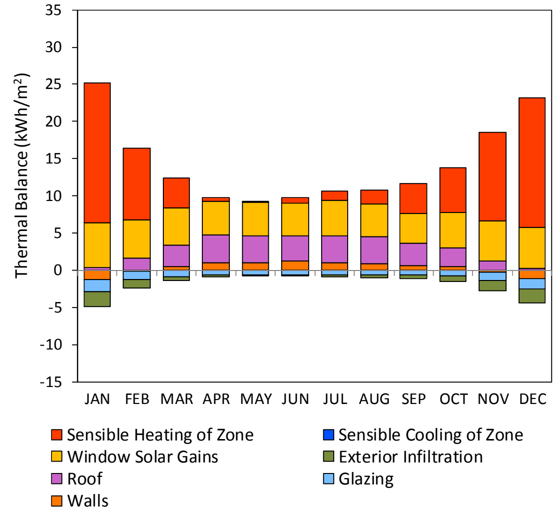
For the BASELINE case in Puebla according to the intermittent-A/C evaluation with *Design Builder* the cooling load is zero. The annual heating load accounts for 101 kWh/m^2y for the BASELINE case. The LINE NOM-020 case increases the annual heating load by 33%, leading to an increase of CO_2 emissions of 7 kg/m^2y. The energy efficiency strategy to comply with the standard, this is to say the insulation of the roof with 2.0 inches of XPS, worsened the thermal behavior of the building.

Chart 6-10 Puebla non-A/C & intermittent-A/C_Thermal Balance

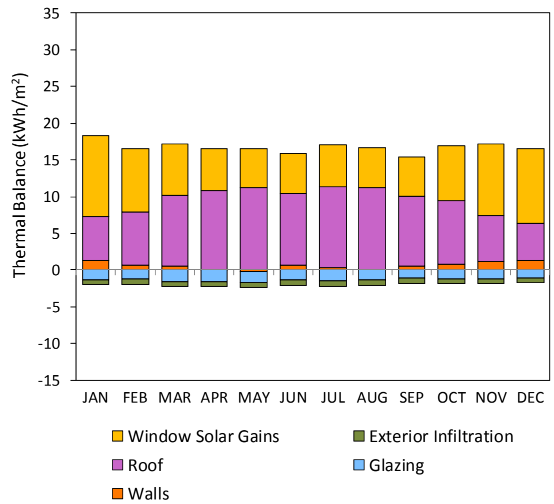
Reference Building non-A/C



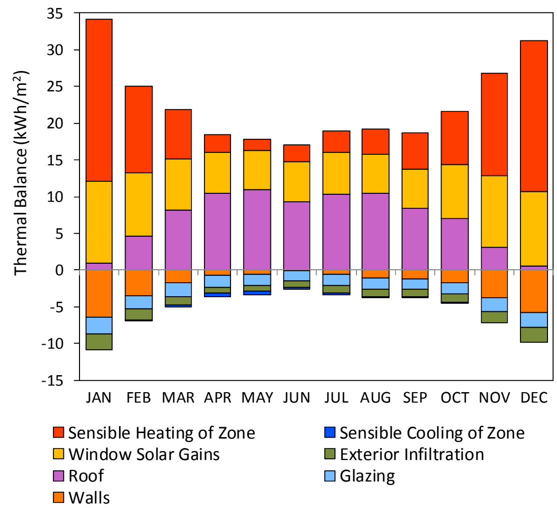
Reference Building intermittent-A/C



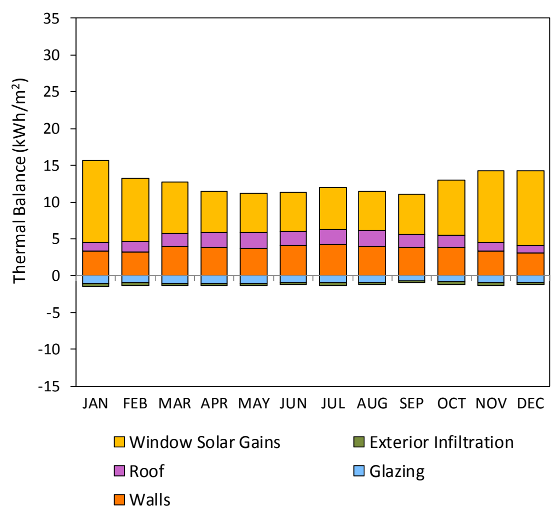
Projected Building BASELINE non-A/C



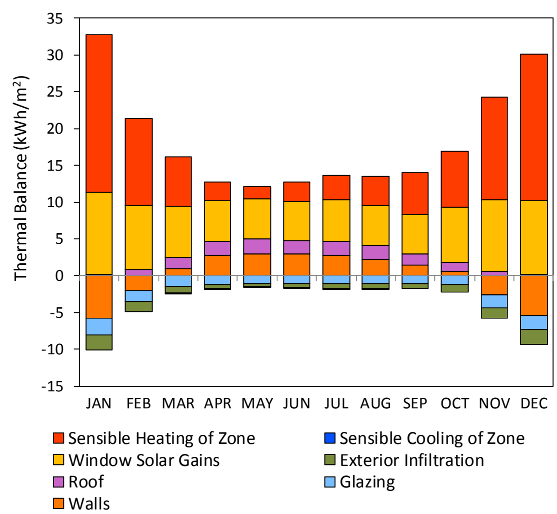
Projected Building BASELINE intermittent-A/C



Projected Building LINE NOM-020 non-A/C



Projected Building LINE NOM-020 intermittent-A/C



6.4.7 Comparison of results NOM-020, PHPP, Design Builder

The main findings summarized below indicate that the implementation of the standard can be recommended in the extremely hot humid climate of Cancún and the extremely dry hot climate of Hermosillo. The evaluation with the PHPP, as well as the dynamic thermal simulation of the intermittent-A/C scenario indicate that the cooling load will be reduced or eliminated by the proposed energy efficiency measures allowing for compliance with the standard. The dynamic thermal simulation of the non-A/C scenario indicates for Cancún, that thermal comfort can be achieved without air-conditioning by the implementation of the standard. In Hermosillo mechanical cooling is necessary, but the hours above 31°C are reduced by 7%.

For the location of Guadalajara the evaluation with the PHPP, as well as the dynamic thermal simulation of the intermittent-A/C scenario indicate that the cooling load will be reduced or eliminated by the proposed energy efficiency measures allowing for compliance with the standard. The dynamic thermal simulation of the non-A/C scenario indicates a yearly portion of 31% of hours between 18°C. This portion would increase by 5-9% by the proposed energy efficiency measures.

In Puebla the evaluation with the PHPP indicates, that the heating load would be reduced significantly. Contrarily the dynamic thermal simulation for the intermittent-A/C case indicates that the heating load increases. The dynamic thermal simulation of the non-A/C scenario indicates a yearly portion of 49% of hours between 18°C. This portion would increase by 11-20% by the proposed energy efficiency measures.

It has to be mentioned that the energy efficiency strategy applied in Puebla took advantage of the phenomenon of “negative” heat gains, and the fact that the standard is not designed for reducing the heating load. In order to explore the deficits of the standard a wall without thermal insulation and a high U-Value has been selected, and solar thermal gains through windows have been blocked by a LowE coating of the windows. Conduction gains through the roof have been blocked by a 2.0 inches layer of XPS. Following it can be concluded that the compliance with the standard in the temperate cold location of Puebla does not guarantee an improvement of the thermal behavior and could even have a negative effect when the energy efficiency measures are poorly planned.

The BASELINE case without any heating appliance would account for a yearly portion of 49% of hours below the defined lower comfort limit of 18°C. An energy efficiency standard that technically addresses the temperate and temperate cold climate zones should implement a minimum thermal practice, so as to guarantee a minimum interior comfort for the inhabitants.

Cancún - *extremely hot humid climate* -

- PHPP, intermittent-A/C & non-A/C indicate that NOM-020 reduces the cooling load, and increases portion of comfort hours.
- For the non-A/C case thermal comfort is possible without A/C by complying with NOM-020.

Hermosillo - *extremely dry hot climate* -

- PHPP, intermittent-A/C & non-A/C indicate that NOM-020 reduces the cooling load, and increases portion of comfort hours.
- For non-A/C the hours above 31°C are reduced by 7%. Mechanical cooling is necessary.

Guadalajara - *temperate climate* -

- PHPP indicates a better performance with NOM-020.
- Intermittent-A/C indicates better performance with NOM-020.
- Non-A/C indicates a yearly portion of 31% of hours between 18°C. This portion would increase (5-9%) by the proposed energy efficiency measures.

Puebla - *temperate cold climate* -

- PHPP indicates that heating load would be reduced significantly.
- Intermittent-A/C indicates heating load increases.
- Non-A/C indicates a yearly portion of 49% of hours between 18°C. This portion would increase (11-20%) by the proposed energy efficiency measures.

Table 6-20 Comparison of results NOM-020, PHPP, Design Builder 1/2

			PUEBLA			GUADALAJARA		
			Reference Building	Projected Building BASELINE	Projected Building LINE NOM-200	Reference Building	Projected Building BASELINE	Projected Building LINE NOM-200
NOM-020	Total Heat Gain (per unit)	*[W]*	894	1,914	896	1,024	2,605	946
	Total Heat Gain (per m^2)	*[W/m^2]*	11	23	11	12	32	12
	Total Heat Gain (per m^2 year)	*[kWh/m^2 y]*	95	204	95	109	278	101
	Reduction of Total Heat Gain	***[kWh/m^2 y]***		**-109**	**0**		**-169**	**8**
PHPP	Heating Load	*[kWh/m^2 y]*	19	148	57	0	24	2
	Cooling Load	*[kWh/m^2 y]*	12	13	18	34	26	23
	Energy Demand[1]	*[kWh/m^2 y]*	31	161	75	34	50	25
	Reduction of Heating Load	*[kWh/m^2 y]*		-130	-39		-24	-2
	Reduction of Cooling Load	***[kWh/m^2 y]***		**0**	**-6**		**8**	**11**
	Reduction of Energy Demand	*[kWh/m^2 y]*		-130	-44		-16	9
	Heating Energy Consumption[2]	*[kWh/m^2 y]*	25	198	0	0	32	3
	Cooling Energy Consumption[2]	*[kWh/m^2 y]*	5	5	0	14	10	9
	Total Energy Consumption	*[kWh/m^2 y]*	30	203	0	14	42	12
	Reduction of TOTAL Consumption	*[kWh/m^2 y]*		-173	-173		-29	2
DB intermittent-A/C	Total capacity heating design	*[kW]*	17	8	13	8	17	13
	Total capacity cooling design	*[kW]*	3	0	1	0	4	2
	Heating Load	*[kWh/m^2 y]*	133	101	135	72	99	95
	Cooling Load	*[kWh/m^2 y]*	1	0	0	0	7	1
	Energy Demand[1]		134	101	135	72	106	96
	Reduction of Heating Load	*[kWh/m^2 y]*		31	-2		-27	-23
	Reduction of Cooling Load	***[kWh/m^2 y]***		**1**	**1**		**-7**	**-1**
	Reduction of Energy Demand	*[kWh/m^2 y]*		32	-2		-34	-24
	Heating Energy Consumption	*[kWh/m^2 y]*	195	149	198	106	145	139
	Cooling Energy Consumption	*[kWh/m^2 y]*	1	0	0	0	8	1
	Yearly Emissions CO^2	*[kg/m^2]*	26	19	26	14	24	19
	Reduction of Yearly Emissions CO^2	*[kg/m^2]*		7	0		-10	-5
DB non-A/C	Hours of comfort (18°C - 25°C)		31%	50%	40%	60%	63%	63%
	Hours above 25°C	*[%]*	0%	1%	0%	0%	6%	1%
	Hours below 18°C	*[%]*	69%	49%	60%	40%	31%	35%
	Hours above 28°C	*[%]*	0%	0%	0%	0%	1%	0%
	Hours below 15°C	*[%]*	23%	17%	21%	20%	14%	17%

[1] Represents final energy, not primary energy.

[2] Walls, Roof, Glazing

[3] Windows

Table 6-21 Comparison of results NOM-020, PHPP, Design Builder 2/2

			HERMOSILLO			CANCÚN		
			Reference Building	Projected Building BASELINE	Projected Building LINE NOM-200	Reference Building	Projected Building BASELINE	Projected Building LINE NOM-200
NOM-020	Total Heat Gain (per unit)	*[W]*	1,506	5,516	1,505	1,416	4,926	1,379
	Total Heat Gain (per m²)	*[W/m²]*	18	67	18	17	60	17
	Total Heat Gain (per m² year)	*[kWh/m² y]*	160	588	160	151	525	147
	Reduction of Total Heat Gain	***[kWh/m² y]***		**-427**	**0**		**-374**	**4**
PHPP	Heating Load	*[kWh/m² y]*	0	63	0	0	0	0
	Cooling Load	*[kWh/m² y]*	129	223	109	172	289	148
	Energy Demand[1]	*[kWh/m² y]*	129	286	109	172	289	148
	Reduction of Heating Load	*[kWh/m² y]*		-63	0		0	0
	Reduction of Cooling Load	***[kWh/m² y]***		**-93**	**20**		**-117**	**24**
	Reduction of Energy Demand	*[kWh/m² y]*		-157	20		-117	24
	Heating Energy Consumption[2]	*[kWh/m² y]*	0	84	0	0	0	0
	Cooling Energy Consumption[2]	*[kWh/m² y]*	52	89	44	69	116	59
	Total Energy Consumption	*[kWh/m² y]*	52	173	44	69	116	59
	Reduction of TOTAL Consumption	*[kWh/m² y]*		-121	8		-47	10
DB intermittent-A/C	Total capacity heating design	*[kW]*	6	16	6	4	14	4
	Total capacity cooling design	*[kW]*	5	7	5	2	4	2
	Heating Load	*[kWh/m² y]*	18	40	21	0	0	0
	Cooling Load	*[kWh/m² y]*	61	95	60	28	69	26
	Energy Demand[1]		79	135	80	28	69	26
	Reduction of Heating Load	*[kWh/m² y]*		-22	-2		0	0
	Reduction of Cooling Load	***[kWh/m² y]***		**-34**	**1**		**-41**	**3**
	Reduction of Energy Demand	*[kWh/m² y]*		-56	-1		-41	3
	Heating Energy Consumption	*[kWh/m² y]*	27	59	30	0	0	0
	Cooling Energy Consumption	*[kWh/m² y]*	66	102	64	31	74	28
	Yearly Emissions CO²	*[kg/m²]*	48	77	48	21	51	19
	Reduction of Yearly Emissions CO²	*[kg/m²]*		-29	0		-30	2
DB non-A/C	Hours of comfort (18°C - 25°C)		33%	34%	34%	52%	38%	53%
	Hours above 25°C	*[%]*	48%	49%	47%	48%	62%	47%
	Hours below 18°C	*[%]*	20%	17%	19%	0%	0%	0%
	Hours above 28°C	*[%]*	37%	38%	37%	1%	20%	2%
	Hours below 15°C	*[%]*	2%	5%	3%	0%	0%	0%

[1] Represents final energy, not primary energy.
[2] Walls, Roof, Glazing
[3] Windows

7 Conclusions and recommendation

The following paragraph will give a *résumé* of the discussion and findings reported after each chapter. The paragraph is structured according to the three dimension of investigation defined by the research model. The answers to the research questions are embedded into these three dimensions.

POTENTIAL IMPACT DIMENSION

In the location of **Cancún** of extremely hot humid climate, the compliance with the standard reduces the cooling energy consumption and the related CO_2 emissions significantly in comparison to the performance of the studied reference projects. No heating energy consumption is reported for Cancún. The investment cost for the additional energy efficiency measures necessary to comply with the standard range from $9,000 to $18,500, which represents between 0.5% and 5.3% of the value of the building. After the reported investment payback time of 2 to 6 years (based on the accounting cost) there would be a yearly benefit of a reduction of the heating energy consumption of 22 up to 38 kWh/m^{2}y. In 2012 this represents a yearly saving of $2,000 up to $8,000 per household.

In **Hermosillo**, of extremely dry hot climate, the compliance with the standard leads to a significant reduction of the cooling energy consumption and the related CO_2 emissions, in comparison to the performance of the studied reference projects. The heating energy consumption as well is reduced significantly, which increases the comfort during the cold month. The investment cost for the additional energy efficiency measures necessary to comply with the standard range from $9,000 to $18,500, which represents between 0.5% and 5.3% of the value of the building. After the reported investment payback time of 2 to 5 years (based on the accounting cost) there would be a yearly benefit of a reduction of the heating and cooling energy consumption of 32 up to 148 kWh/m^{2}y. In 2012 this represents a yearly saving of $1,000 up to $5,000 per household.

In the location of **Guadalajara**, of temperate climate, the requirements of the standard are met by current standards of the housing sector, and can be met with very little investment. It is suspected that the standard will not fulfill its objective of “rationalizing the energy use in cooling appliances” by reducing “the heat gain through the building envelope of residential buildings” [NOM-020], for it is most probably that the houses in Guadalajara are not conditioned by cooling appliances. This is underlined by the fact that the monthly average electricity sales per customer indicate that there is no increase of electricity consumption during the summer month due to the use of air-condition. Nevertheless the implementation of the standard in Guadalajara would assure an easily achievable minimum thermal standard that enhances the interior climate. Especially the hours of underheating would be reduced significantly in comparison to residential buildings lacking any thermal insulation. In Guadalajara investment cost for the additional energy efficiency measures necessary to comply with the standard range from $2,500 to $9,500, which represents 1.0 ± 0.5 % of the value of the buildings. Under the assumption that the houses are conditioned to a comfort zone of 20°C to 25°C the reported theoretical yearly benefit due to the reduction of the heating and cooling energy consumption represents between $40and $800 per household.

In the location of **Puebla**, of temperate cold climate, the standard will not fulfill its objective of “rationalizing the energy use in cooling appliances” by reducing “the heat gain through the building envelope of residential buildings” [NOM-020]. The evaluation with the PHPP reports an important heating demand for all studied housing types. The NOM-020-ENER-2011 evaluates the cooling load of the buildings, and does not contemplate the heating loads. If applied in Puebla the standard would give a misleading signal. For example the *Vertical* type, accounting for a heating energy consumption of 90 kWh/m^2y, would receive the label “energy saving (ahorro de energía) 48%”. For the climate of Puebla the phenomenon of “negative” heat gains or heat loss occurs (explained in detail in paragraph 2.4.1). In consequence thermal heat gains become negative values, and thus are subtracted from the total heat gains. The higher the U-Value (the less insulated the building part); the bigger is the reduction on the total of the heat gains. This particular issue needs to be object to a revision or an addendum of the standard.

In Cancún the influence that the **subsidies** on electricity have on the investment payback time shortens the period for large consumers (inefficient or large surface) and extends the period for small consumers (efficient and small surfaces). In Hermosillo the reduction of the subsidy or a lowering of the consumption for the application of the surplus tariff would reduce the investment payback time. Whilst incentivizing energy efficiency, instead of energy consumption, this measure would save the state the current expenses on energy subsidy, which amounted to more than US$ 10 billion, are about 1 percent of Mexico’s GDP in 2006.

Cancún - *extremely hot humid climate* -

- the compliance with the standard reduces the cooling energy consumption significantly.
- the energy efficiency measures have a positive return on investment.

Hermosillo - *extremely dry hot climate* -

- the compliance with the standard reduces the cooling energy consumption significantly.
- the energy efficiency measures have a positive return on investment.

Guadalajara - *temperate climate* -

- the standard will not fulfill its objective of “rationalizing the energy use in cooling appliances”.
- the standard would assure a minimum thermal standard, enhancing the interior climate.

Puebla - *temperate cold climate* -

- the standard will not fulfill its objective of “rationalizing the energy use in cooling appliances”.
- the standard does not consider heating loads and would give a misleading signal.

Subsidies

- the reduction of the subsidy or lowering the limit for the surplus tariff reduces the ROI.
- incentivizing EE would diminish the peak load and save the state the expenses on energy subsidy.

METHODOLOGICAL DIMENSION

In all four study location the attached housing types *Adosada* and *Medio* present the lowest CO_2 emissions. In the extremely hot dry and extremely hot humid study locations the *Aislada* type presents the highest CO2 emissions, followed by the *Dúplex* type. In the temperate and temperate cold study locations the *Dúplex* type presents the highest CO_2 emissions.

The comparison of the reported CO_2 emissions per m^2 and year (PHPP) and the reported Energy Savings (NOM-020) reveals that there is no lineal relationship between both indicators. The results showed that two housing types, providing the same use and an identical habitable area, reached significantly different CO_2 emissions, whilst the reported percentage of energy savings (ahorro de energía) according to the standard was identical. Contrary to the "whole building approach", applied by the PHPP, the "reference methodology" does not deliver indicators that allow comparing the performance of different housing types. The reference building assumes the boundary conditions of the projected building for granted, thus allowing for a higher energy demand, than if architectural means to achieve primary energy reduction were included. However, if the conformity with the NOM-020-ENER-2011 is determined in combination with the use of the DEEVi, the incorporation of architectural measures to achieve energy efficiency is assured by the use of the DEEVI. In this sense the DEEVi represents a valuable extension to the NOM-020-ENER-2011.

If the NOM-020-ENER-2011 is used to define the baseline for the Mexican NAMA, the result are different levels of energy consumption (kWh/m^2y) and CO_2 emissions (kg/m^2y) for the different typologies. In consequence each housing type will then have an individual baseline in terms of energy consumption and CO_2 emissions. The results obtained by the validation with the PHPP or the DEEVi allow for a classification of housing typologies in terms of their energy efficiency performance.

Typologies

- *Adosada* and *Medio* present the lowest CO2 emissions in all study locations.
- *Aislada* and *Dúplex* present the highest CO2 emissions in hot climates.
- *Dúplex* presents the highest CO2 emissions in temperate and cold climate.

"Reference methodology"

- different levels of CO_2 emissions for typologies offering same use and habitable surface.
- no lineal relationship between energy and carbon intensity and reported energy savings.

IMPLEMENTATION & COMPLIANCE DIMENSION

A key point for a successful implementation of the standard is the adoption by local construction regulations. Due to the authority of the State and Municipal governments organizations of the Federal Executive branch like CONAVI cannot force the adoption and implementation of its recommendations at municipal level. The strategies and programs of the federal institutions like the PRONASE and the PNV target the adoption of the standard into local construction regulations. In general three different approaches can be distinguished:

i) Adoption of the standard as a prerequisite for existing housing subsidies. (Financial incentives and market-transformation approach.)

ii) Standard as a baseline for a certification system for the supported NAMA-schemes. (Financial incentives and market-transformation approach.)

iii) Adoption of the standard into construction regulations in form of a set of "Sustainability" NTCs, specifically adapted to the ten different bioclimatic regions. (Mandatory approach.)

Today there is a more beneficial context for the implementation of an energy efficiency standard, compared to the promulgation of the NOM-008-ENER-2011. This is due to the efforts made by the private sector, and institutions like INFONAVIT and CONAVI. The strategies and programs of the federal executive institutions have the potential to tackle different barriers to the implementation of the standard NOM-020-ENER-2011, like for example, the resistance due to high-upfront investment costs, or the lack of institutional capacity to supervise the establishment and implementation of the standard.

The development of a Manual for the standard will tackle the issue of a lack of information amongst professionals in the field of social housing construction, amongst personal of local and federal authorities. It further provides the necessary information to the possible future verification units.

International financing schemes like the Mexican NAMA will have to respect the minimum requirements set by the valid standard NOM-020-ENER-2011, according to international standards. The current levels of thermal insulation in social housing construction in Mexico are likely not to meet the minimum requirements of the standard in the majority of the cases. The standard therefore reduces the mitigation potential.

The adoption of the standard into the SiSeViVe Housing Qualification System of INFONAVIT will foster the implementation of the standard and provide for training of professionals in the field, as the standard is embedded in the calculation tools. It can be observed that the sustainable housing policies and housing programs, as well as the efforts of organizations like INFONAVIT and CONAVI, support and stimulate the implementation of the standard NOM-020-ENER-2011.

7.1 Constraints and opportunities of the standard

Following the constraints and barriers derived from literate review in (see chapter 4.3) will be commented. According to the research model, the findings of the three studied dimensions shall identify new opportunities, as well as persistent constraints.

- *Lack of agreement between the different actors.*

The progress that can be witnessed with regard to the development of the SiSeViVe shows, that currently the different actors in Mexico are bundling their efforts, pursuing the same target. It is most likely, that this new Housing Qualification System will be adopted by organizations like Fovissste, SHF, and also by CONAVI in the frame of the Mexican NAMA. A successful implementation of the SiSeViVe would represent an important milestone in energy efficiency and sustainability policy implementation.

- *Lack of information of the importance of building energy use by local authorities and lack of knowledge of energy efficiency standards at the appropriate political level, in combination with local autonomy over construction.*

Different capacity building activities are directed at federal and local authorities (see chapter 4.4.3). The implementation of standards into local construction regulations is a time consuming process. The development of a set NTCs for each of the different climatic zones, serving as a reference, seems to be the most efficient and realistic measure in the short to medium term.

It is most likely, that the mortgage and subsidy schemes by Infonavit and CONAVI might foster the adoption of the standard at state and municipal level. These financing schemes do not give financial incentives for the compliment with the standard, but as an officially valid standard the NOM-020-ENER-2011 will be a prerequisite to get access to the financing. Thus the large number of buildings covered by these programs will create the need for a verification and certification infrastructure.

- *Resistance from the construction industry. Due to cost of compliance caused by sunk investment in very specific technologies that have costs at a competitive level, and new investment in the equipment and training in the new process and in new supply lines for the new materials.*

Today the boundary conditions for the implementation of an energy efficiency standard are more favorable than at the time of the promulgation of the NOM-008-ENER-2001. INFONAVIT played an important role in breaking the resistance from developers by gradually implementing the use of thermal insulation into the *Hipoteca Verde*. The creation of the association Vivienda y Entorno Sustentable (VESAC) can be seen as a proof of a rising awareness on the fact that energy efficiency also is beneficial to developers.

- *Lack of institutional capacity to supervise the establishment and implementation of the proposed norms.*

The program of the Mexican NAMA for housing will provide funding to tackle these issues. Furthermore the implementation of the SINTRAV software by CONAVI will facilitate an efficient tool for the integration and supervision of the proposed standard at municipal level.

- *Lack of resources from the local authorities to ensure compliance and review of building codes.*

As mentioned earlier, the implementation of the SINTRAV, as well as the preparation of reference sets of NTCs for the different climatic zones tackle this issue.

- *Highly subsidized energy tariffs. Elimination of most subsidies and enforcement of BEECs would substantially diminish peak loads due to air conditioning and eliminate the need for additional peak load capacity.*

The results reported by this study underline this argument. Currently the World Bank is studying policy alternatives for a reform of the subsidy system in Mexico. According to García [53] INFONAVIT is in favor of changing from a “subsidy on energy consumption” to a “subsidy of energy efficiency”.

7.2 Recommendations for a revision of the standard

Temperate cold climate zones

- The phenomenon of “negative” heat gains, occurring in temperate cold climate (see chapter 5.4.1 for a detailed explanation), has to be addressed in the *short term*.
- In the *long term* the integration of a calculation of the heating load has to be discussed. According to the reported results of this study there is an important heating load for the studied typologies in the temperate cold climate of Puebla.

Calculation of the U-Value of inhomogeneous building components

- The formula used by the standard for the calculation of the U-Value of inhomogeneous building components is differs from the one, used by the international standard EN ISO 6946.

Absorptivity

- The absorptivity of exterior surfaces influences the thermal performance of a building. The developers of the code opted to not consider the absorptivity into the calculation, as the color of a building was not considered a permanent element.
- Further research is necessary to investigate the consequences of considering absorptivity in the calculation methodology.

[53] E. García, INFONAVIT, lecture during the training course by the Passive House Institute, DEEVi train the trainer, Mexico City, July 2012.

7.3 Final conclusion

The results of this thesis show that the standard fulfills its objective of rationalizing the energy use in cooling appliances by reducing the heat gain through the building envelope of residential buildings in the hot dry and hot humid climate zones. The standard does not fulfill this objective in the temperate and the temperate cold zones. Adaptations have to be made to the standard to technically address those climate zones. The additional cost for the energy efficiency measures have a positive return of investment in the hot dry and hot humid climate zones. The investment payback period is currently enlarged due the subsidies on electricity. The additional investment in the temperate and the temperate cold zones only accounts for a small percentage of the total building value (less than two percent). It can be observed that the sustainable housing policies and sustainable housing programs in Mexico foster the implementation of the standard.

7.4 Future research needs / recommendation for further studies

Further studies are recommended to investigate the following topics:

- More extensive investigation of the impact of the standard to buildings that are not equipped with cooling or heating appliances – extend the analysis by dynamic building simulations for the **intermittent-A/C** and **non-A/C** cases (chapter 6) to all six studied housing types in the temperate and temperate cold climate zones.

- Investigation for the consequences of considering the **absorptivity of exterior surfaces** in the calculation methodology.

- Investigation of the cost-benefit relation, considering **different levels of thermal insulation**.

- Investigation of the cost-benefit relation, considering **more climate zones** (comprising the CFE residential tariff zones 1A – 1E). This could be done in an efficient way when the first official version of the DEEVi calculation tool is available.

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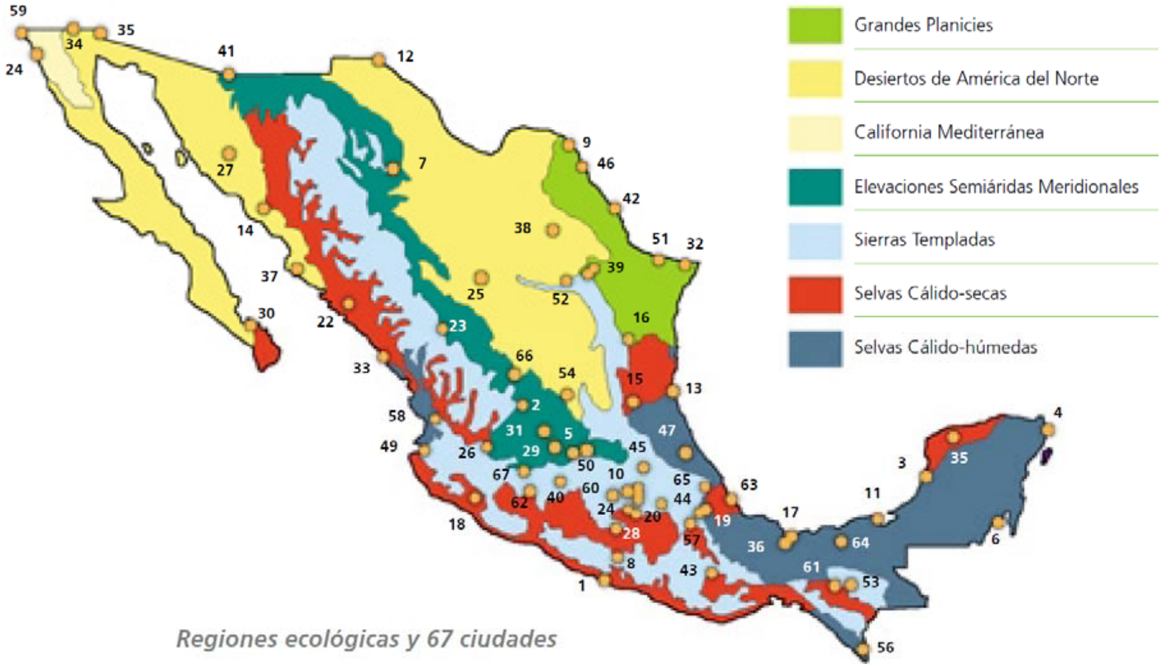
I Appendix - Climatic zones of Mexico

Appendix - Figure 1 Ecologic regions of Mexico and location of 67 cities, CONAFOVI 2006

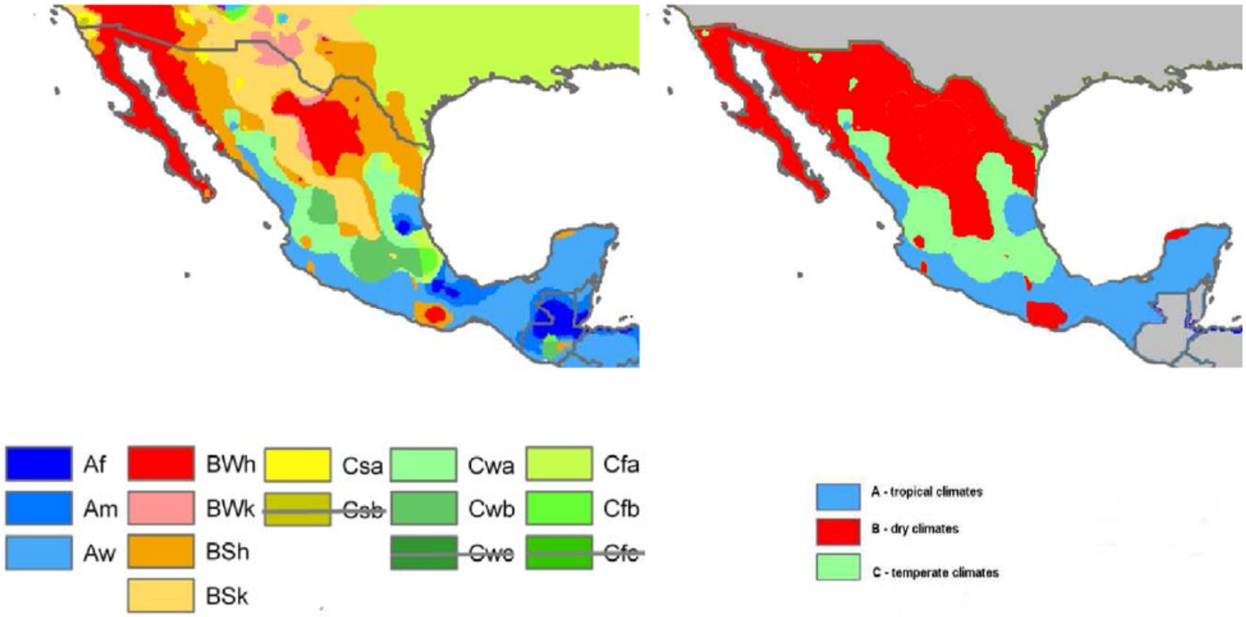


Source: Conafovi 2006

Appendix - Figure 2 Ecologic regions of Mexico, CONAVI 2008

Source: CONAVI 2008

Appendix - Figure 3 Different climate zones of Mexico - Köppen-Geiger classification.



Source: Peel 2007. Cited by: Kraft 2012

Appendix - Table 1 Description of the climate categories that occur in Mexico

A - TROPICAL			Coldest month > 18°C
Af	(A) Tropical	- (f) Rainforest	
Am	(A) Tropical	- (m) Monsoon	
Aw	(A) Tropical	- (w) Savannah	

B - ARID			Precipitation below a certain limit
BWh	(B) Arid	- (W) Desert	- (h) Hot
BWk	(B) Arid	- (W) Desert	- (k) Cold
BSh	(B) Arid	- (S) Steppe	- (h) Hot
BSk	(B) Arid	- (S) Steppe	- (k) Cold

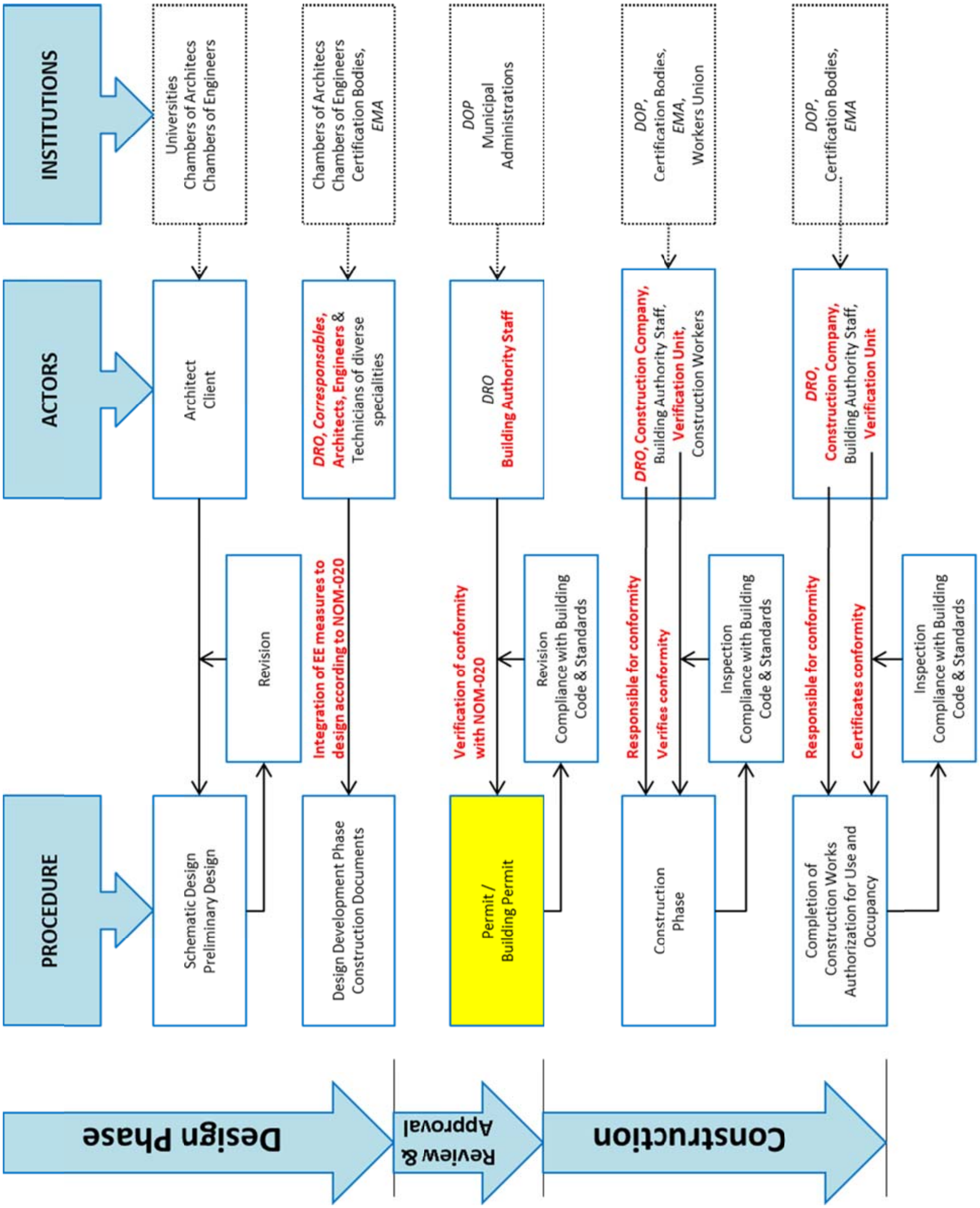
C - TEMPERATE			Hottest month > 10°C; 0°C < Coldest month < 18°C
Csa	(C) Temperate	- (s) Dry Summer	- (a) Hot Summer
Csb	(C) Temperate	- (s) Dry Summer	- (b) Warm Summer
Csc	(C) Temperate	- (s) Dry Summer	- (c) Cold Summer
Cfa	(C) Temperate	- (f) Without dry season	- (a) Hot Summer
Cfb	(C) Temperate	- (f) Without dry season	- (b) Warm Summer
Cfc	(C) Temperate	- (f) Without dry season	- (c) Cold Summer
Cwa	(C) Temperate	- (w) Dry Winter	- (a) Hot Summer
Cwb	(C) Temperate	- (w) Dry Winter	- (b) Warm Summer
Cwc	(C) Temperate	- (w) Dry Winter	- (c) Cold Summer

Source: Peel 2007

Appendix - Figure 4   Thermal zoning of Mexico according to NMX-C-460-ONNCCE-2009

Source: NMX-C-460-ONCCE-2009

II Appendix - Steps and actors for the implementation of EE measures

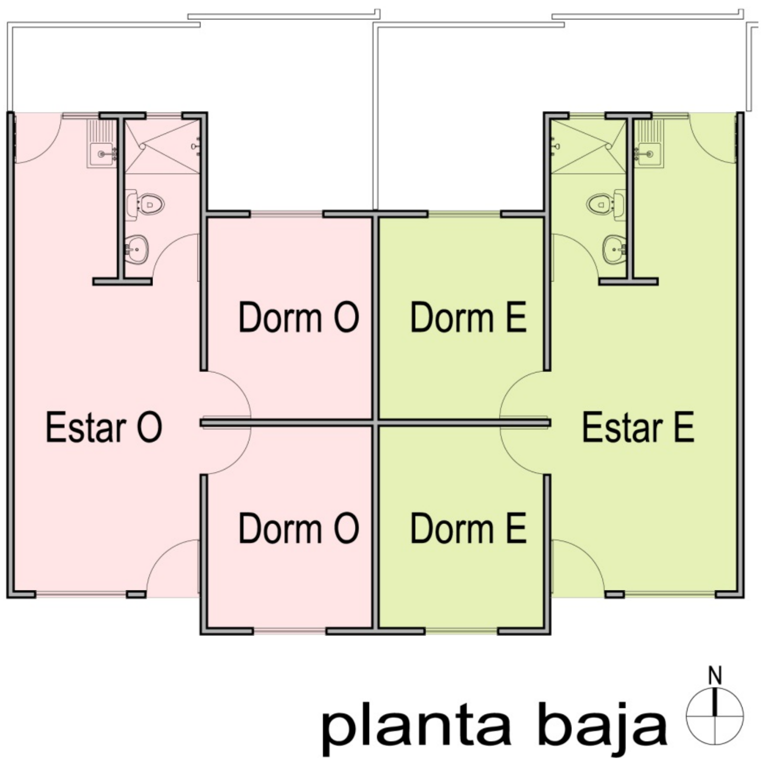


Source: Own elaboration, after: Energía sustentable en la Edificación, CONUEE / GTZ.

III Appendix - Floor plans

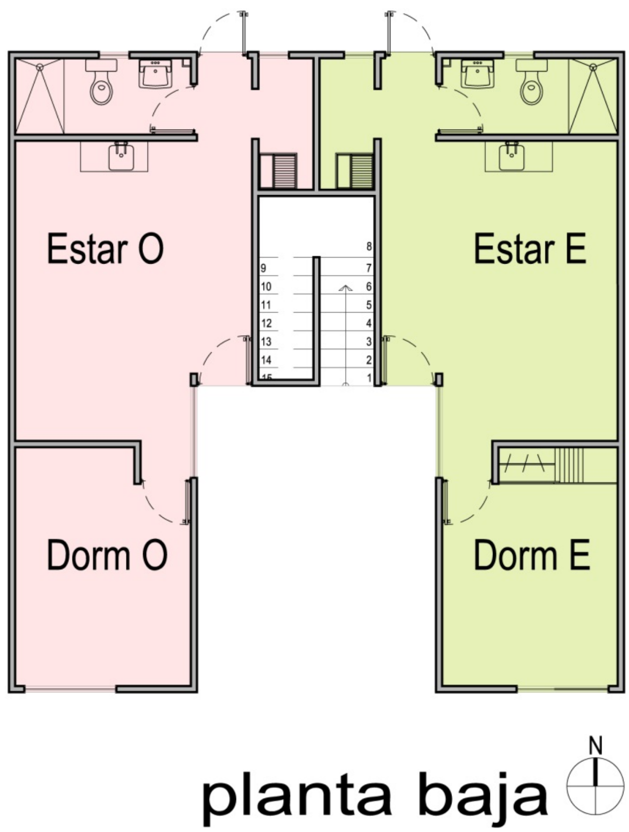
PLANTA TIPO TIPOLOGÍA ADOSADA

Constructora	Consorcio ARA, prototipo Almendros conjunto Vista Real II
Tipo de vivienda	Adosada
Ubicación	Ejido Isla Mujeres, Quintana Roo
Superficie de desplante	44.7 m^2
Superficie piso acondicionado	41.1 m^2



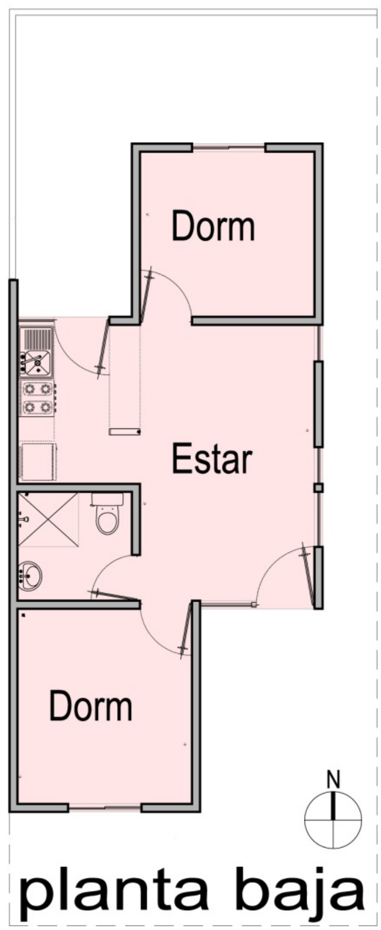
PLANTA TIPO TIPOLOGÍA DUPLEX

Constructora	SADASI, prototipo conjunto Prada Norte
Tipo de vivienda	Dúplex, adosada
Ubicación	Cancún, Quintana Roo
Superficie de desplante	39.7 m^2
Superficie piso acondicionado	36.0 m^2



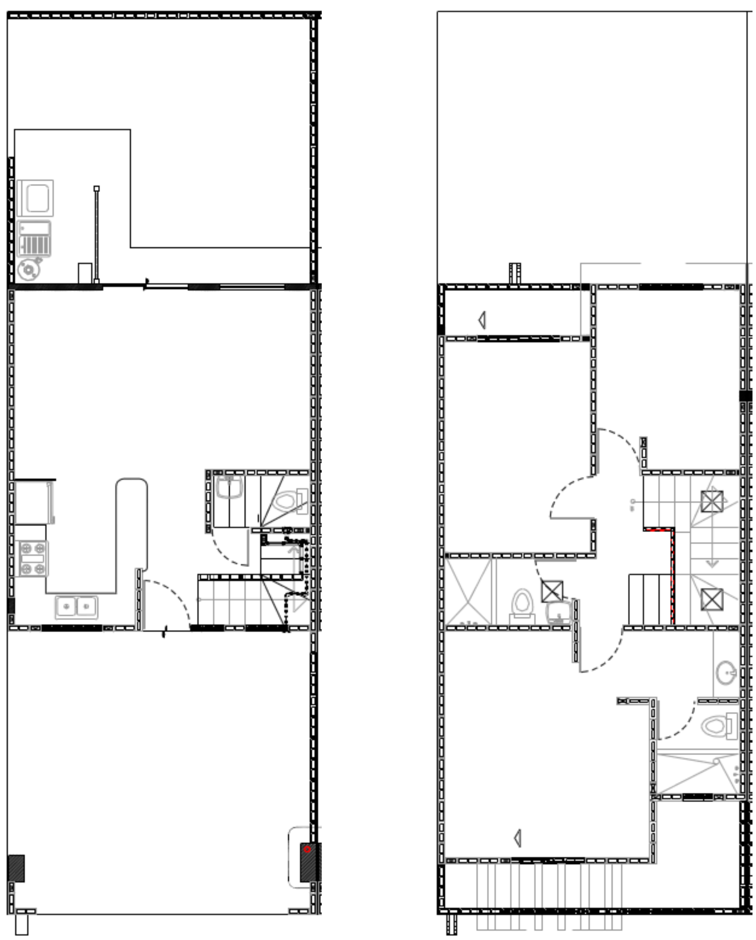
PLANTA TIPO TIPOLOGÍA AISLADA

Constructora	Consorcio Hogar, prototipo Sierra, Valle Floresta
Tipo de vivienda	Aislada
Ubicación	Municipio de Pesquera, Nuevo León
Superficie de desplante	43.5 m^2
Superficie piso acondicionado	38.5 m^2



PLANTA TIPO TIPOLOGÍA MEDIO

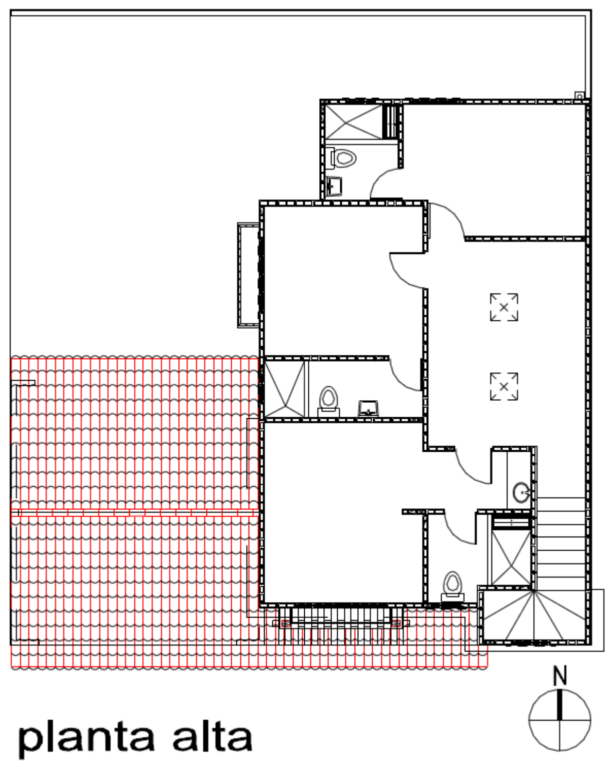
Constructora	Consorcio Hogar, prototipo Sierra del desarrollo
Tipo de vivienda	Aislada
Ubicación	Municipio de Pesquera, Nuevo León
Superficie de desplante	43.5 m^2
Superficie piso acondicionado	38.5 m^2



planta baja   planta alta

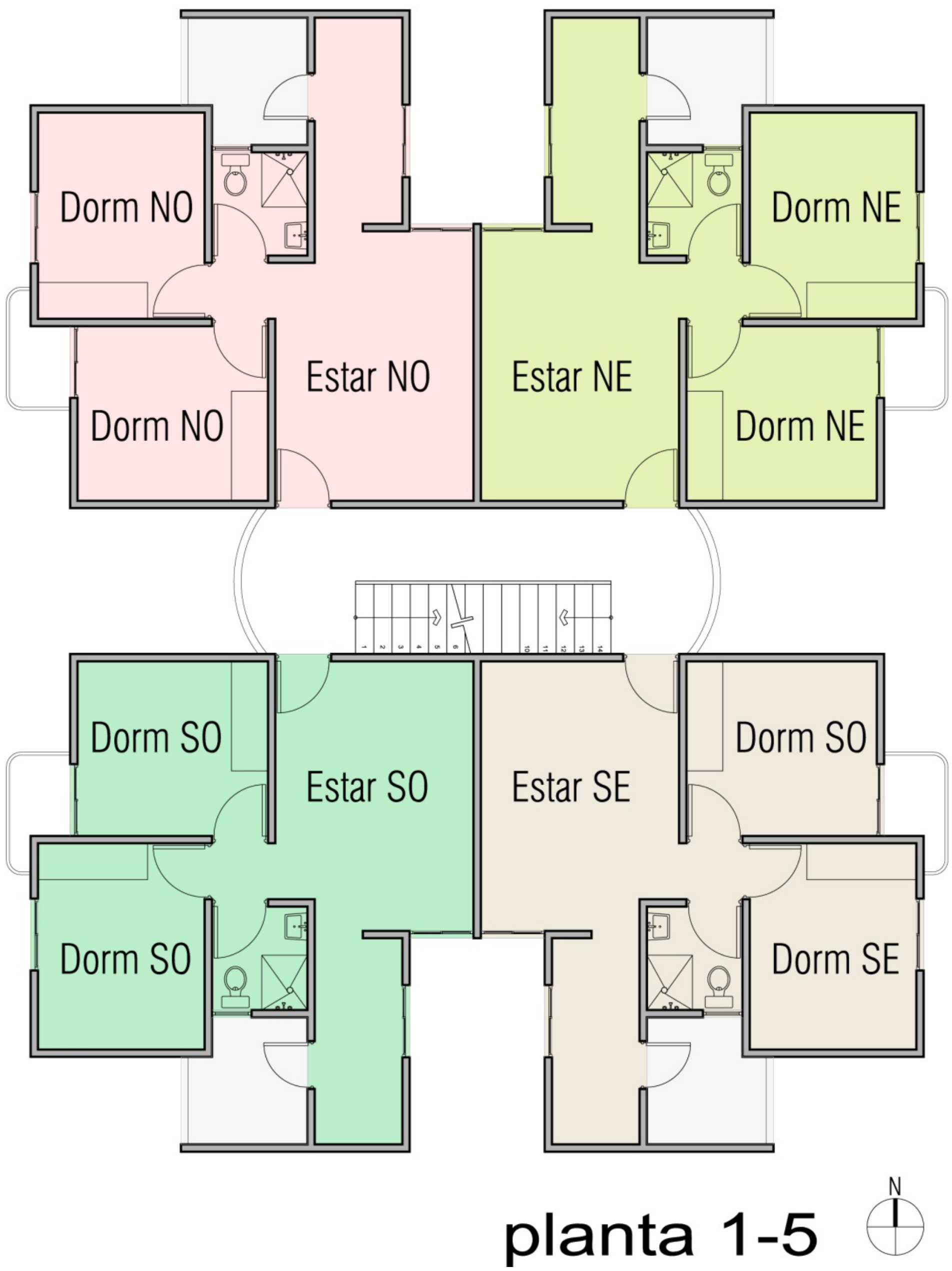
PLANTA TIPO TIPOLOGÍA RESIDENCIAL

Constructora	Consorcio Hogar, prototipo Sierra del desarrollo
Tipo de vivienda	Residencial
Ubicación	Municipio de Pesquera, Nuevo León
Superficie de desplante	43.5 m^2
Superficie piso acondicionado	38.5 m^2



PLANTA TIPO TIPOLOGÍA VERTICAL

Constructora	AISA, prototipo Torres 475
Tipo de vivienda	Vertical
Ubicación	Puebla, Puebla
Superficie de desplante	46.1 m^2
Superficie piso acondicionado	41.3 m^2



IV Appendix - Electricity consumption and tariffs

Appendix - Table 2 Electricity consumption by season, 2007

Location	Tariff CFE	Average temperature summer	Average temperatue winter	Sales per customer summer	Sales per customer winter
		[°C]	[°C]	[kWh per month]	[kWh per month]
Oaxaca, Oax.	1	21.6	18.6	74.8	77.0
Zacatecas, Zac.	1	16.6	13.0	88.4	90.9
Guadalajara, Jal.	1	22.9	19.4	112.9	110.5
Frontera, Chis.	1A	27.2	24.0	72.2	76.8
Tepic, Nay.	1A	24.0	20.3	117.4	107.1
Acapulco, Gro.	1B	28.7	26.6	130.7	130.7
Chihuahua, Chih.	1B	25.3	15.2	164.8	140.0
Mérida, Yuc.	1C	29.8	25.2	214.7	167.0
Veracruz, Ver.	1C	27.9	23.8	240.2	163.3
Monterrey, N.L.	1C	28.2	18.7	250.1	185.1
Apatzingán, Mich.	1D	29.8	26.7	165.7	145.1
La Paz, B.C.S.	1D	29.8	22.2	322.2	181.7
Reynosa, Tamps.	1E	27.8	19.4	322.5	203.0
Culiacán, Sin.	1E	31.6	24.4	449.6	207.6
Hermosillo, Son.	1F	30.7	20.1	531.0	204.4
Mexicali, B.C.	1F	31.4	17.4	750.3	251.7

Source: SENER with information by CFE, (SENER 2008, chapter 4.4, table 62 & 63)

Appendix - Table 3 Estimated levels of energy consumption CFE tariff 1

Household appliance	Average power [Watts]	Typical period of use	Time of use per month [hours]	Consumption per month [kWh]
Incandescent bulb (2 of 75W)	150	3 hrs per day	90	13.5
Refridgerator (10 cubic feet)	250	6 hrs per day	180	45.0
Color Televisión (13-17 inches)	50	4 hrs per day	120	6.0
Radio recorder	40	2 hrs per day	60	2.4
Iron	1000	2 h, 4 day/month	8	8.0
TOTAL				75.0

Source: CFE, (SENER 2008, chapter 3.3, table 44)

Appendix - Table 4 Electricity concumption BASELINE

CANCUN BASELINE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ø verano	Ø fuera de verano	Year
ADOSADA	174	189	216	268	389	419	483	494	472	427	297	197	447	224	4,025
DUPLEX	209	231	267	339	483	513	597	612	583	523	358	232	552	273	4,948
AISLADA	183	207	247	331	541	585	696	717	680	587	353	204	634	254	5,330
MEDIO	327	359	408	491	704	767	862	853	803	748	541	383	790	418	7,246
RESIDENCIAL	512	596	734	936	1,268	1,314	1,526	1,545	1,449	1,301	899	589	1,401	711	12,669
VERTICAL	214	240	292	352	452	464	534	545	516	467	338	238	496	279	4,653
												Average	**720**	**360**	**6,479**
												Average social interest[1]	**532**	**257**	**4,739**
												Ventas por usuario CFE	**240**	**163**	**2,421**

HERMOSILLO BASELINE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ø verano	Ø fuera de verano	Year
ADOSADA	84	83	95	122	309	601	676	588	418	152	92	83	457	93	3,302
DUPLEX	88	88	109	151	386	743	826	714	506	176	100	87	558	104	3,973
AISLADA	86	86	102	132	397	899	1,017	850	545	143	94	85	642	97	4,436
MEDIO	85	86	112	173	582	1,035	1,142	992	735	274	107	86	793	108	5,409
RESIDENCIAL	105	111	208	459	1,208	1,999	2,117	1,804	1,287	442	144	102	1,476	188	9,985
VERTICAL	83	84	115	186	445	696	734	638	474	193	95	82	530	107	3,824
												Average	**743**	**116**	**5,155**
												Average social interest[1]	**547**	**100**	**3,884**
												Ventas por usuario CFE	**531**	**204**	**4,412**

GUADALAJARA BASELINE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ø verano	Ø fuera de verano	Year
ADOSADA	84	87	93	103	119	103	97	96	92	93	88	85	100	90	1,140
DUPLEX	90	95	109	131	155	122	113	112	104	105	96	90	118	102	1,321
AISLADA	89	92	102	118	137	112	106	105	99	100	93	88	110	97	1,240
MEDIO	92	99	117	155	219	183	155	141	122	117	101	93	156	109	1,593
RESIDENCIAL	126	152	236	390	520	313	263	253	201	189	152	126	290	197	2,919
VERTICAL	86	93	118	170	208	134	121	119	106	103	93	86	132	108	1,438
												Average	**151**	**117**	**1,609**
												Average social interest[1]	**115**	**99**	**1,285**
												Ventas por usuario CFE	**113**	**111**	**1,340**

PUEBLA BASELINE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ø verano	Ø fuera de verano	Year
ADOSADA	79	82	83	85	86	86	85	84	83	83	82	79	84	82	997
DUPLEX	85	87	92	95	96	95	93	91	90	90	88	83	93	88	1,086
AISLADA	84	86	90	93	94	93	91	89	88	88	87	82	91	87	1,065
MEDIO	82	86	90	98	108	114	107	97	95	92	88	82	102	88	1,139
RESIDENCIAL	97	117	145	174	182	168	160	146	135	130	114	93	153	123	1,661
VERTICAL	81	84	91	98	99	95	93	90	88	87	83	80	92	86	1,072
												Average	**103**	**92**	**1,170**
												Average social interest[1]	**90**	**86**	**1,055**
												Ventas por usuario CFE	**88**	**91**	**1,076**

[1] Considering the housing types classified as aocial interest, popular: *Adosada* , *Dúplex* , *Aislada* , *Vertical*

Appendix - Table 5 Electricity concumption LINE NOM-020

CANCUN LINE NOM-020

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ø verano	Ø fuera de verano	Year
ADOSADA	131	137	153	179	235	252	282	288	275	253	195	149	264	157	2,530
DUPLEX	218	218	240	266	319	333	371	377	362	346	283	233	351	243	3,566
AISLADA	202	212	242	281	370	394	444	453	433	401	301	225	416	244	3,959
MEDIO	229	250	283	345	484	526	591	590	555	513	377	273	543	293	5,016
RESIDENCIAL	362	434	530	697	967	1,008	1,169	1,187	1,113	992	671	429	1,073	521	9,560
VERTICAL	156	173	202	238	300	309	350	357	340	312	235	176	328	197	3,147
Average													**496**	**276**	**4,630**
Average social interest[1]													**340**	**210**	**3,301**
Ventas por usuario CFE													**240**	**163**	**2,421**

HERMOSILLO LINE NOM-020

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ø verano	Ø fuera de verano	Year
ADOSADA	77	77	81	89	173	310	360	333	253	131	83	78	260	81	2,046
DUPLEX	87	87	112	141	283	421	463	432	356	198	116	88	359	105	2,784
AISLADA	86	85	102	146	333	552	608	544	412	192	100	86	440	101	3,247
MEDIO	78	78	85	110	361	663	752	675	506	175	89	78	522	86	3,650
RESIDENCIAL	77	77	84	120	283	435	462	409	312	125	82	76	338	86	2,540
VERTICAL	77	77	84	120	283	435	462	409	312	125	82	76	338	86	2,540
Average													**376**	**91**	**2,801**
Average social interest[1]													**349**	**93**	**2,654**
Ventas por usuario CFE													**531**	**204**	**4,412**

GUADALAJARA LINE NOM-020

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ø verano	Ø fuera de verano	Year
ADOSADA	82	84	89	98	112	98	94	92	89	89	85	82	96	87	1,094
DUPLEX	93	93	93	93	93	93	93	93	93	93	93	93	93	93	1,116
AISLADA	82	84	89	98	112	98	94	92	89	89	85	82	96	87	1,094
MEDIO	82	86	95	112	136	132	119	112	101	97	88	83	116	91	1,243
RESIDENCIAL	126	152	236	390	520	313	263	253	201	189	152	126	290	197	2,919
VERTICAL	86	93	118	170	208	134	121	119	106	103	93	86	132	108	1,438
Average													**137**	**110**	**1,484**
Average social interest[1]													**104**	**94**	**1,185**
Ventas por usuario CFE													**113**	**111**	**1,340**

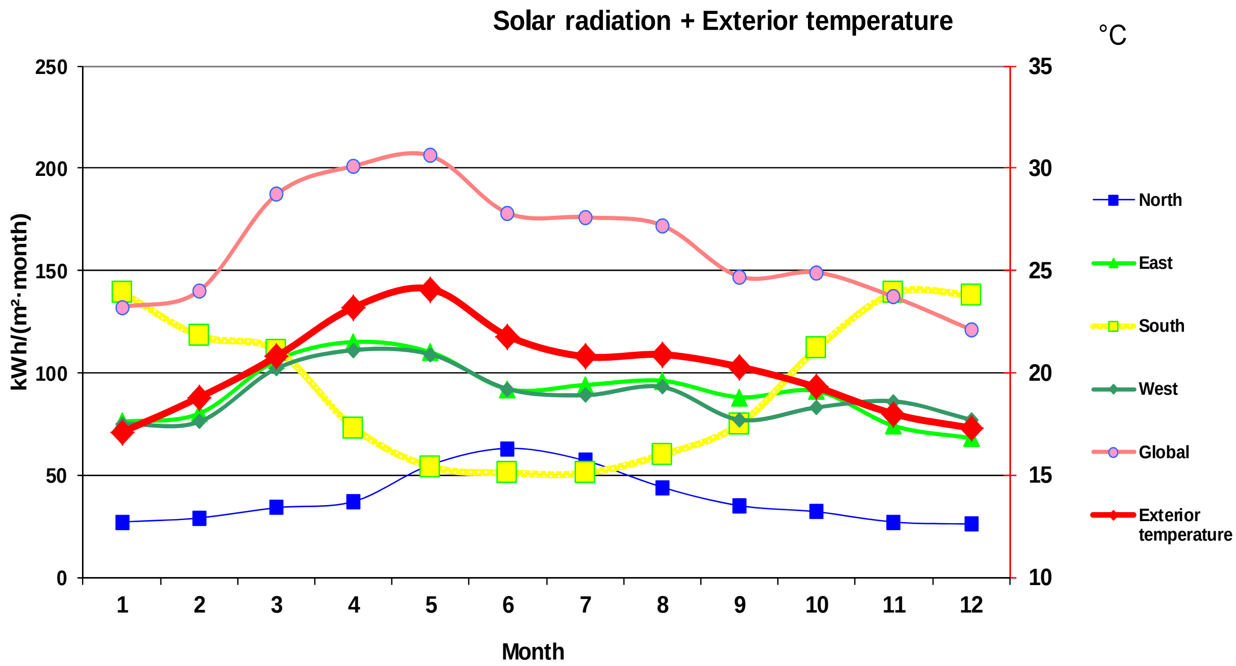
PUEBLA LINE NOM-020

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ø verano	Ø fuera de verano	Year
ADOSADA	79	82	83	85	86	86	85	84	83	83	82	79	84	82	997
DUPLEX	85	87	92	95	96	95	93	91	90	90	88	83	93	88	1,086
AISLADA	85	89	95	98	100	98	97	94	93	92	90	84	96	90	1,115
MEDIO	82	86	90	98	108	114	107	97	95	92	88	82	102	88	1,139
RESIDENCIAL	97	117	145	174	182	168	160	146	135	130	114	93	153	123	1,661
VERTICAL	81	84	91	98	99	95	93	90	88	87	83	80	92	86	1,072
Average													**103**	**93**	**1,178**
Average social interest[1]													**91**	**87**	**1,067**
Ventas por usuario CFE													**88**	**91**	**1,076**

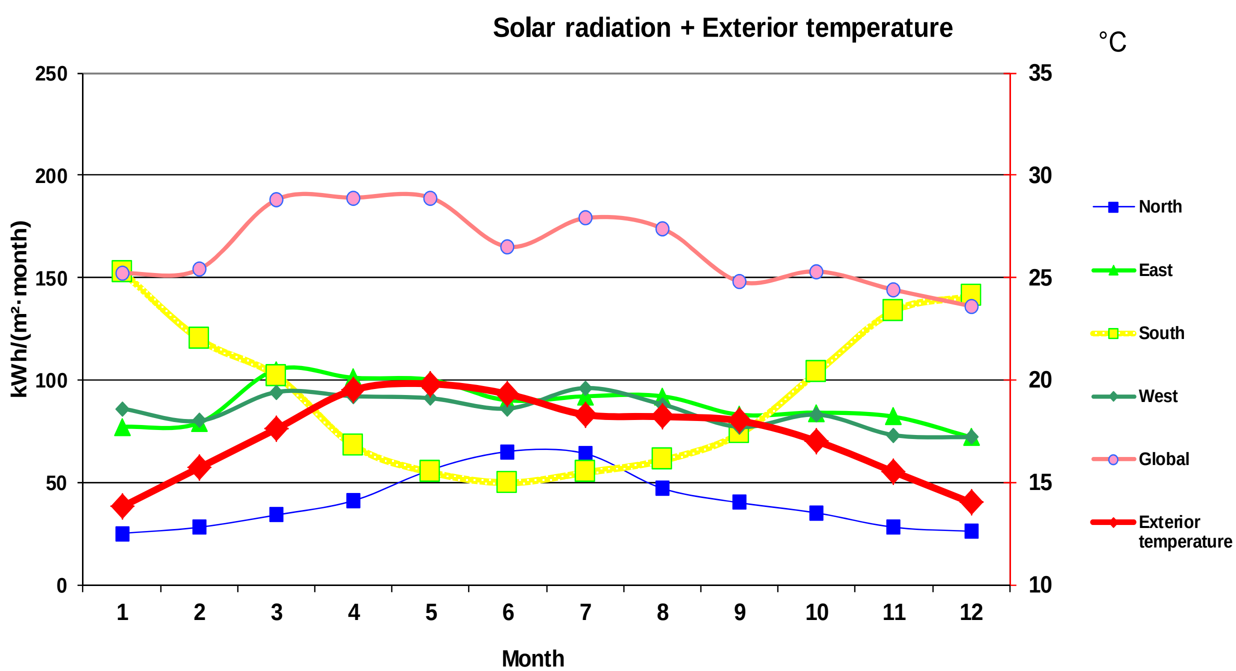
[1] Considering the housing types classified as aocial interest, popular: *Adosada* , *Dúplex* , *Aislada* , *Vertical*

V Appendix - Solar radiation & exterior temperature

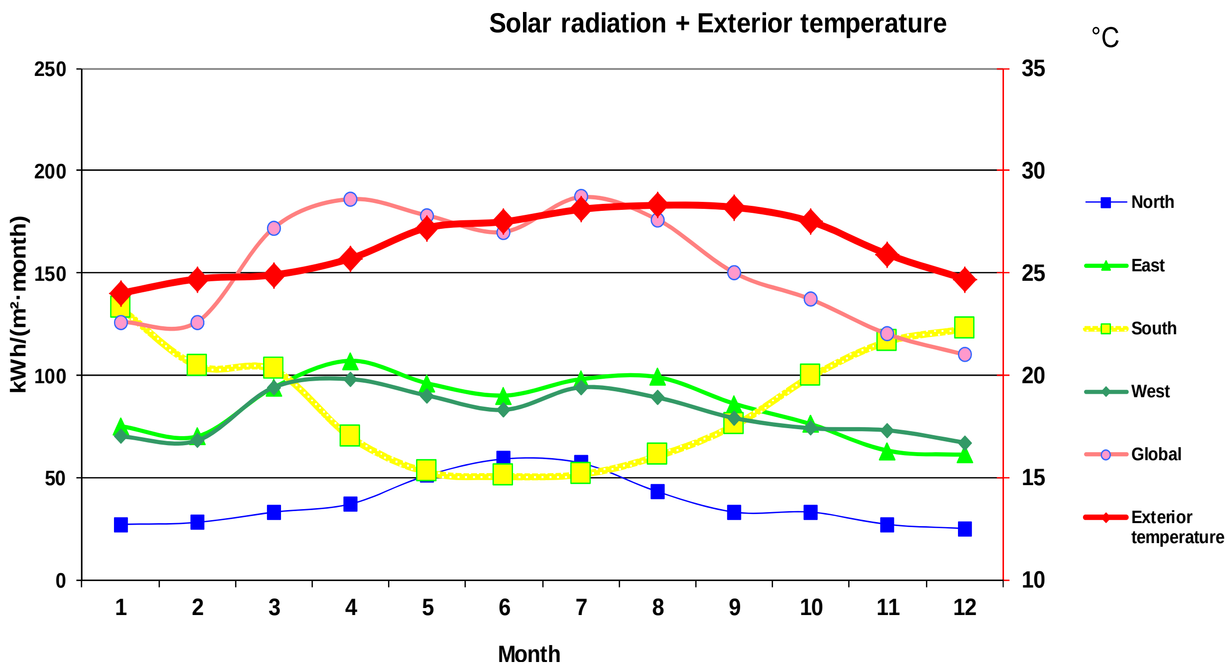
Guadalajara



Puebla



Cancún



Hermosillo