Modelling the energy and exergy utilisation of the Mexican non-domestic sector: A study by climatic regions

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Abstract

This paper presents the development of a bottom-up stock model to perform a holistic energy study of the Mexican non-domestic sector. The current energy and exergy flows are shown based on a categorisation by climatic regions with the aim of understanding the impact of local characteristics on regional efficiencies. Due to the limited data currently available, the study is supported by the development of a detailed archetype-based stock model using EnergyPlus as a first law analysis tool combined with an existing exergy analysis method. Twenty-one reference models were created to estimate the electric and gas use in the sector. The results indicate that sectoral energy and exergy annual input are 95.37 PJ and 94.28 PJ respectively. Regional exergy efficiencies were found to be 17.8%, 16.6% and 23.2% for the hot-dry, hot-humid and temperate climates respectively. The study concludes that significant potential for improvements still exists, especially in the cases of space conditioning, lighting, refrigeration, and cooking where most exergy destructions occur. Additionally, this work highlights that the method described may be further used to study the impact of large-scale refurbishments and promote national regulations and standards for sustainable buildings that takes into consideration energy and exergy indicators.

Keywords: Energy analysis, Exergy analysis, Bottom-up model, Stock modelling, Non-domestic sector, Mexico.

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1. Introduction

The constant development of “middle-income” countries represents a high environmental risk for achieving world sustainability. Emerging markets, mainly represented by the BRICS Group (Brazil, Russia, India, China, and South Africa) and the MITSK Group (Mexico, Indonesia, Turkey and South Korea), are considered to be a main concern in terms of future energy supply security (Asif and Muneer, 2007; Sadorsky, 2009). The current rates of economic development in these countries indicates that increased energy demand at all sectoral levels may therefore represent a threat to achieving global reduction objectives for 2050 (IPCC, 2007). One of the most important sectors in terms of energy use and emissions is the building sector. Worldwide, buildings account for 40% of the annual primary energy use and up to 30% of all greenhouse gas (GHG) emissions (UNEP-SBCI, 2009).

The thermodynamic analyses commonly undertaken to understand the most common processes found in the built environment are still only based on the first law that states that “energy neither can be created nor consumed but only transformed”. This represents both a challenge and a limitation to identifying process’ inefficiencies for further improvements. The concept of energy efficiency through first law analysis does not provide a real indicator of how a system or a process approaches an ideal state as this only identifies the losses of work and the effective use of a resource. In support of this concept, the second law of thermodynamics states that “every process where energy or matter is dispersed, entropy is inevitably generated”. This means that exergy (a measure of quality of energy or useful work potential of energy) can actually be lost as a result of the irreversibilities of a process. An exergy analysis reveals the losses of available energy and thus represents the real inefficiencies of any system. For this reason, the concept of exergy can be essential key method that can be utilized to inform both policy making and national standard design activities (Dincer, 2002).

Initially, exergy analysis was only performed for thermal plants, diesel engines, combined cycle operation, and combustion processes, and it is still a fundamental tool in locating inefficiencies in industrial processes. But building systems operate also as an exergy-entropy process; a building and its systems basically feeds on exergy, consumes exergy, generates entropy and finally the generated entropy is disposed. Disposing of the generated entropy from the system makes new room for feeding on new exergy and consuming it again, thus the process cycles (Shukuya, 1994). Even though the

second law concept is well described in scientific books, engineers and researchers still tend to neglect the use of this principle in the design, test and/or evaluation of thermodynamic systems found in the building sector (Bilgen and Takahashi, 2002; Hepbasli, 2012). Several attempts have been made in the past decade to improve the exergy consumption in buildings, mainly with the development of the International Energy Agency's Energy in Buildings and Communities Programme Annex 37 (ECB-Annex37, 2007) and Annex 49 (ECB-Annex49, 2011). These research efforts, amongst other outcomes, have developed methods and tools for exergy analysis in a steady state reference environment.

While extensive research has been carried out at individual building systems level, to improve the sectors' efficiency, information regarding the exergy baseline of the entire non-domestic sector is still required to provide a complete perspective. Sectoral exergy research, including the non-domestic sector, has been undertaken in the past 20 years in countries such as the U.K., Norway, Turkey, Saudi Arabia, Malaysia, Greece, Japan, U.S., and Canada (Al-Ghandoor, 2013; Dincer et al., 2004; Ertesvåg, 2001; Gasparatos et al., 2009; Hammond and Stapleton, 2001; Kondo, 2009; Reistad Gordon, 1980; Rosen, 2013; Rosen, 1992; Saidur et al., 2007; Utlu and Hepbasli, 2003; Xydis et al., 2009). The majority of these studies approach the sectoral exergy analysis from a top-down econometric approach. The obvious disadvantage of top-down modelling is that it does not have the capability to analyse different conservation measures and perform "what if" scenarios. An alternative to this approach is the bottom up engineering method (EM), which is described by Dineen and Gallachoir (2011) as a model which relies on information on the building characteristics and end uses to calculate the energy consumption based use and equipment characteristics and thermodynamic principles. A significant advantage of engineering bottom-up models over top-down approaches is their ability to model the energy demand of end-uses and (new) technologies in detail (Swan and Ugursal, 2009).

Generally, the EM approach involves the development of a database that is representative of the national stock supported by a whole-building energy simulation program to estimate energy use (Aydinalp et al., 2003). This technique has strengths such as the ability to model new technologies based solely on their technical characteristics. Also, EM is the only method that can fully develop the

energy use of the sector without the need of any historical energy use information; although a main drawback is that occupant behaviour must be assumed (Swan and Ugursal, 2009).

A sectoral analysis represents a higher degree of complexity because of the necessity of illustrate an entire stock in a few representative models. Single building modelling is useful in assessing the performance of a particular building; on the other hand, stock models are essential in informing national and regional policy addressing climate change, energy savings and the reduction of carbon emissions. From a review of related literature in the field, it can be noted that as yet no study on sectoral energy/exergy analysis in Mexico has been developed. In addition, a large gap of data and information about the energy use in buildings, especially in the non-domestic sector exists in Mexico. To address this gap, the objective of this study is to provide information of end use energy data and exergy indicators of the current situation (2014) of the non-domestic sector. These outputs could, in theory, lead to programs focused on energy efficiency under an energetic and exergetic approach. In this study, energy and exergy performance by end use in several climatic regions of Mexico are presented with the aim to analyze the impact of local climate on energy use and exergy destruction of the sector (Dovjak et al., 2010).

Nomenclature

Symbol	Description	Units
EUI	Energy Use Intensity	[kWh/m²-year]
T0	Reference temperature	[K]
Tp	Product temperature	[K]
Qp	Heat product	[J]
We	Work (electric)	[J]
COP	Coefficient of Performance	[J]/[J]
η	Energy efficiency or first law efficiency	[%]
ψ	Exergy efficiency or second law efficiency	[%]
q_{fuel}	quality factor of an energy source	[-]
fi	fraction of total utilisation of an end-use	[%]

2. Case study: Mexico and its non-domestic sector

Mexico is located between the 32° and 14° north latitudes and 86° and 118° west longitudes comprising a total surface area of almost 2 million km². The country has a very diverse climate, where hot climate dominates with several types of sub-climates. Mexico can be divided into a tropical and a temperate zone; but the relief characteristics of the territory together with the large oceans that surround the country it greatly influence the configuration map of the climates. In this study the country has been segregated into 3 main climates: hot-dry, hot-humid and temperate (Fig. 1).

[Fig. 1 about here]

Mexican buildings are responsible for 19% of the national energy use and 12% of the total emissions of the country (de Buen, 2009). In particular, the demand of electricity and gas represents 31% and 38% respectively of the national "consumption". According to the National Energy Balance (SENER, 2013), the "commercial and service" sector mainly uses gas and electricity to meet its end use demands, representing 95% of the total use of resources in the sector (Fig. 2).

[Fig. 2 about here]

2.1 An overview of the Mexican non-domestic sector energy use

Recent studies show that the National Energy Balance highly underestimates the non-domestic sector as it does not reflect an accurate energy use of the sector. The main problem is in the inappropriate tariff allocations determined by the public electric company, where all buildings above100 kW of power installed are considered as industrial buildings (de Buen, 2009). Also, data on floor area, number of buildings, and energy use by building or by end use is very limited and dispersed. The only detailed information on energy use (only electricity) by building type that does exist originates from energy audits undertaken by the Mexican Electric Energy Saving Trust *(Fideicomiso para el Ahorro de Energía Eléctrica*) (FIDE, 2011). These audits are related to energy efficiency projects undertaken by the organization in the past 20 years. Based on these audits, seven different types of non-domestic buildings and seven types of end uses can be identified (Table 1). In this study it was possible to differentiate supermarkets from shopping centres as different archetypes thanks to recently published

data by the *National Association of Supermarkets and Department Stores* (ANTAD, Accessed: 25 August 2014) and thus giving us a higher level of detail.

[Table 1 about here]

The use of the abovementioned classification in this study will allow the presentation of more complex outcomes than those presented in previous investigations of this nature in Mexico.

3. Methodology and data sources

Despite the limited availability of data on energy use by building type in the country, a limited but highly detailed database of end-use information for each type of building was compiled. This information was derived from the audits carried out by *FIDE* in the last decade and is the only information available in the country. It is important to note that while these cases might not be considered statistically representative of the sector, this limitation was overcome by performing a detailed building physics simulation. The aim of which was to estimate a baseline on electric and gas demand of each type of non-domestic building located in the three different climates of the country. Sector modelling requires a great deal of information on the built form, construction materials, installed building services and the activities carried out in buildings and premises, as well as an in-depth understanding of the dynamics of non-domestic building energy use (Bruhns, 2007). The following section presents the development of the modelling framework and discusses its limitations.

3.1 Development of the Mexican non-domestic energy/exergy (MEN-DEEX) model

3.1.1 Archetype development and assumptions

In developing the *MEN-DEEX* model, an archetypal simulation model approach was applied. This approach generalises the characteristics of a particular building type, and represents variability in the building stock by parameterising construction elements, components, design features, and occupancy/usage patterns (Korolija et al., 2013). The basis of the bottom-up archetype approach is to

calculate the energy use of a set of archetype buildings using the engineering method, i.e. based on technical factors like the floor area, glazing area, U-value of walls, etc., and then using statistical methods (e.g. extrapolation) to give the consumption for the sector as a whole (Dineen and Gallachoir, 2011). Also, they are particularly helpful in stock aggregation, and can be used to make future energy projections at a sectoral level (Famuyibo et al., 2012). The method used to determine the consumption patterns of the different types of buildings is similar to that described in Huang and Broderick (2000) and Griffith and Crawley (2006), however minor changes were introduced in order to adapt *MEN-DEEX model* to the limitations of current data available for the Mexican stock.

a) Data Sources

To develop the archetypes, key variables that impact energy use were identified from relevant literature (Famuyibo et al., 2012). These were then combined with data on installed power by facility and installed power by end-use surveyed from the 120 *FIDE* case studies representing almost 1.75 million m² of constructed surface. Also, additional data on number of floors, schedules, number of people, activities and technical information about internal equipment was extracted from these cases. For missing data, information from current national and international energy standards for energy efficiency in buildings such as standards related to the envelope, HVAC systems, motors, and lighting were taken into consideration. The sources from each main parameter can be seen in Table 2.

[Table 2 about here]

b) Building size, form, and fenestration

The 120 buildings from the FIDE Cases were virtually surveyed using a Google Maps Area Calculator Tool (Daft Logic, 2014) with the aim of calculating the average building footprint. Furthermore, Google Street View (Google, 2014) was used to approximately determine characteristics such as floor to floor height and fenestration percentage. In the case of building geometry, to simplify the modelling exercise the models are represented by rectangular forms.

c) Envelope characteristics

In developing the archetypes, it was assumed that a proportion of the current building stock was constructed in the last two decades of the last century. Consequently, the fabric values were taken

from a previous ASHRAE Guide (ASHRAE, 1977) and cross-checked with information from the national building regulation NOM-008-ENER-2011. As a result, it is assumed that all models façades characteristics have the same levels of U-values, infiltration, type of glazing (single) and G-values.

d) Schedules, Occupancy and Internal Gains

Schedules, occupancy patterns, and internal gains from people have a large effect on the modelling outputs. For this study to the key reference document in this regard was the ASHRAE 90.1-2010 (ASHRAE, 2010). This includes standardized occupancy diversity factors for different building types. Furthermore, additional information was derived from the U.S. Department of Energy (DOE) commercial reference buildings (Deru et al., 2011). As an example of the diversity of the models, typical weekday occupancy from the studied buildings is illustrated in Fig.3.

[Fig. 3 about here]

e) General Equipment

Information on internal equipment, lighting power, and HVAC equipment was taken directly from the *FIDE* case studies. According to the data, with regard to lighting power installed, no significant difference between similar buildings in different regions was found. On the other hand, differences between the installed powers of internal equipment were found. For example, in hospitals, more power installed for equipment can be found in the temperate region than in the hot regions; this may be due to the regional differences in infrastructure and the fact that the majority of specialized hospitals in the urban areas are mainly located in the temperate region. On the other hand, due to increased tourism activity in the hot-humid region more luxury hotels are located and thus present larger values. These differences found in the database analysis were considered in the development of the archetypes. Also, greater electrical efficiencies in pumps and electrical motors were found in buildings located in the temperate and hot-dry region than those in the hot-humid region.

For HVAC and refrigeration equipment, the FIDE case studies showed no heating equipment installed. Conversely, cooling equipment was found on all premises in the hot regions and in almost 50% of premises in the temperate region (mainly in offices, hospitals and hotels). For water heating boilers it was assumed ~80% efficiency according to current regulations. Finally, with regard to

cooking services at schools, restaurants, hospitals and hotels, as no information on cooking equipment exists, the data was derived from the US DOE reference buildings (Deru et al., 2011).

Based on the preliminary analysis of the *FIDE* database and the national and international energy standards and studies, the main features of the seven non-domestic archetypes models are described in Table 3.

[Table 3 about here]

To simulate the energy use of the archetypes developed, EnergyPlus (EnergyPlus, 2012) was selected as the calculation tool for energy analysis. This software is a dynamic simulation tool based on a number of modules that work together to calculate the energy requirements of a building with the potential to model a variety of systems and energy sources. It implements this by simulating the building and associated energy systems when they are exposed to different environmental and operating conditions. EnergyPlus calculated the cooling loads necessary to maintain thermal control setpoint as well as the total electric and thermal energy use by building type and by end use. To model the HVAC, refrigeration and, water heating equipment the function “Autosize” was applied. As previously stated, the COPs and efficiencies were derived from national regulations.

3.1.2 Weather data and other regional assumptions

Relevant weather data was taken from the TMY2 format weather files used in the energy simulation process and validated against the national average from climatic data from *CONAGUA-SMN (CONAGUA, Accessed: 26 April 2014)*. This approach allowed to the undertaking of hourly simulations that considered all the dynamic interactions between the building and the external weather throughout the year. The representative cities chosen for this study were Mexico City (temperate climate), Acapulco (hot-humid climate), and Monterrey (hot-dry climate) (Fig. 4).

[Fig. 4. about here]

Furthermore, an additional parameter that was considered to have an important effect on energy use and energy efficiency of end-uses such as cooking and water heating, was the cities’ altitude. At higher altitudes energy use increases while efficiency is usually lower. Regularly this is due to the

change in the boiling point of water, which leads to lower system temperatures and increased cooking time. Considering the most representative cities for every selected climatic region, the average altitudes obtained were 1800 m.a.s.l. (meters above sea level) for the temperate region, 550 m.a.s.l. for the hot dry region, and 20 m.a.s.l. for the hot humid region. Bressani and Chon (1996) investigated the effects of altitude on cooking time in the Central-American region. From the results it was found that between sea level and an altitude of ~500 m.a.s.l., there is an increase of 38% in the cooking time, and for an altitude of ~1600 m.a.s.l. an increase of 64% in the cooking time was found. Currently EnergyPlus does not model the effects of altitude on cooking, thus in implementing this study these factors were applied for the gas consumption at the corresponding climatic regions.

3.1.3 Analysing EUI results

Due to the significant degree of uncertainty regarding archetype characteristics, an important step in the development of the models is the comparison of the simulation results against the real data from the *FIDE* energy audits. This is undertaken to better match the simulation results to the measured energy end-use intensities and fuel/electric ratios by building type, end-uses, and type of climate. In total twenty-one detailed simulations were performed to obtain EUI's by type of building, by end use and by climatic region. As a comprehensive dynamical simulation was performed, hourly results were obtained from the simulation process. The normalized energy uses from the First Law analysis are shown in Table 4 and Fig. 5. These disaggregated results represent the first instance that such outputs have been produced for Mexican non-domestic stock.

[Table 4 about here]

[Fig.5. about here]

3.1.4 Stock aggregation

As was previously mentioned, the lack of information on the exact number of premises and/or floor area (m²) at a national level is a significant limitation affecting this study. The only study that does include an estimation of the national floor area by type of non-domestic building at a national level

was undertaken by the United Nations Environment Programme (UNEP) (de Buen, 2009). As mentioned in section 2.1, for the particular case of shopping centres and supermarkets, it has been possible to make a differentiation between these building types thanks to data on floor area recently published (ANTAD, 2014). Through the use of these values, the regional floor area by building type by using the percentage of urban population at each climatic region was estimated. To obtain these values, data from *Instituto Nacional de Estadística y Geografía* (*INEGI*) (INEGI, Accessed: 20 April 2014) was used to estimate the urban population by region in an attempt to roughly estimate total regional floor area (m²). According to latest *INEGI* population census in 2010, the temperate, the hot-dry region and the hot-humid region encompass 56.14%, 24.19% and 19.67% respectively of the national urban population. Using these values combined with the data on national floor area an estimation of non-domestic floor area by building and by climatic region was approximated (Table 5).

[Table 5 about here]

The results of energy use by region as well as the national energy use were assessed by using the EUI by end use obtained from the model multiplied by the estimated floor area based on the following eq. 1:

*Regional energy input = * regional floor area building (n) * (3.6 x))*[1] [PJ] *(1)*

3.2 Sectoral exergy analysis

The method used to quantify exergy efficiencies for end uses and temperature product assumptions was adapted from Utlu and Hepbasli (2003) and Dincer et al. (2004) and is summarised in this section. Following this, the use by region, by building and by end-use was quantified and finally the exergy efficiency of the non-domestic sector was determined. A simplistic energy balance based on the first law can be expressed as:

Energy input – Energy output = Energy accumulation *(2)*

Conversely, exergy is the part of energy that has the potential to be fully converted into mechanical work due to interactions with the environment, and this will occur until the system and the

[1] (3.6 x) represents the conversion value from kWh to PJ

environment reach a “dead-state”. If a reversible process takes place then exergy is conserved, but exergy is always degraded in an irreversible process. This concept can be expressed as:

Exergy input – Exergy output – Exergy consumption = Exergy accumulation *(3)*

3.2.1 Reference temperature:

The most important concept that should be considered when performing an exergy analysis of a given system is the establishment of a reference environment. This is because exergy is not only a property of the system but of both the system and the environment. Gallo and Milanez (1990) noted that since the environmental pressure and temperature may vary and the components environment are not in chemical equilibrium, characterization of the reference state presents large difficulties and can therefore be complex to define. To compare different processes, e.g. in the case of different building systems, this can be done by the exergy efficient concept, but the choice of an appropriate reference state is still the major concern. The reference environment used for the *MEN-DEEX model* is taken from the same TMY2 file used in the energy analysis, however to simplify the results the mean monthly daily outdoor temperature of each of the regions analysed is considered (Table 6). This approach can determine the differences on monthly exergy destruction in each region with a specific focus on the regions with high temperature fluctuations throughout the year (e.g. hot -dry region).

[Table 6 about here]

For the exergy analysis, apart from the aforementioned reference temperatures () it was also necessary to identify the product temperature () of all the processes (as presented in the next section), and the quality of the main energy sources (*qfuel*). The exergy values or quality from the energy sources analysed were assumed to be 0.92 for gas (natural gas and LPG) and 1.0 for electricity.

3.2.2. Energy and exergy efficiencies

The energy and exergy efficiencies for the main end uses identified in the Mexican non-domestic sector are based in the following definitions:

η = energy in products / total energy input *(4)*

ψ = exergy in products / total exergy input *(5)*

If the energy quality factor of fuels are assumed to be 1.0 (like in the case of electricity), exergy efficiencies can be defined as a function of energy efficiency (Dincer et al., 2004). The following section presents the exergy efficiency formulas used for electrical-based and gas-based end-uses.

3.2.2.1 Efficiencies for electric-based end uses

Space conditioning (Cooling)

Based on the audits performed by *FIDE* and the results from the energy modelling it is assumed that the energy use for heating is 0; hence cooling represents the total demand for space conditioning. The first law modelling results showed that the energy use at a regional level from space conditioning represents 42.1%, 40.6% and 12.1% for the hot-dry, hot-humid and temperate climate respectively of the regional energy demand. Nationally, cooling in the non-domestic sector represents 29.5% of the total energy input. Although theoretically the energy efficiency is described in equation 6, the energy efficiency values were obtained from relevant EnergyPlus outputs.

(6)

The second law efficiency was calculated using the following equation:

(7)

The reference temperatures (represent the regional monthly average (Table 6). was considered to be 23 °C (296.15 K) for all regions. The average COP or obtained from the simulation outputs and the results for monthly exergy efficiency are listed in Table 7.

[Table 7 about here]

Theoretically in months where the setpoint temperature is above the external temperature (e.g. all year for the temperate region, and 6 months for the hot dry region) the buildings will not require cooling. However, since a dynamic energy analysis was performed, hourly temperature fluctuations are considered in particular instances where the external temperature exceeds the reference setpoint. Additionally, the model considers the heat gains from occupant activity, lighting and electrical equipment. Therefore, the results of the energy analysis illustrated that cooling demand is present even though the external temperature is lower than the setpoint due to the internal gains listed. In this case, loads will mainly be met by ventilation, infiltration, transmission and to a lesser extent by the artificial cooling; on the other hand, when it is warmer outside than it is inside, the demand is mainly met by the artificial cooling process. Hence, internal gains are the main reason why cooling is needed almost every day of the year in the temperate region and in the winter season in the hot-dry region. To illustrate this, a comparison of monthly cooling demands between regions for a typical office building is shown in Figure 6.

[Fig. 6. about here]

In energy analysis, when a cooling demand is presented a required energy output from the system is required. But in exergy terms a cooling load can represent a demanded exergy input or exergy output, depending on the reference temperature. When the outside temperature is higher (e.g. hot humid), input exergy is required to remove the heat. On the other hand, when outside is cooler and still a cooling demand exist, the building has an unwanted warm exergy inside the building and thus it has to be removed (ECB-Annex 49, 2009). The latest scenarios are represented in Table 7 by the underlined exergy efficiency results.

Refrigeration

Refrigeration is not as representative as space conditioning but also has a large impact on total energy use. Of the total energy use by region, this end use represents 10.8%, 15.3% and 17.7% for the hot-dry, hot-humid and temperate climate respectively. Nationally, represents 14.7% of the total energy input for the sector. The second law efficiency was calculated using equation 8.

(8)

Both (or and the mean monthly reference temperatures (in this case represented by the internal environment of buildings and not by the outside temperature are taken from the simulation outputs. Meanwhile was considered to be -8 °C (265.15 K) for all regions. The considered reference temperatures and monthly exergy efficiency results for refrigeration can be seen in Table 8.

[Table 8 about here]

Electrical equipment (Lighting, lifts and pumps, and internal equipment)

Not only does lighting demand a significant amount of energy in the country, it is also extremely energy inefficient (≈ 20%). Of the total energy use by region, lighting represents 23.4%, 24.7% and 31.4% for the hot-dry, hot-humid and temperate climate respectively. Nationally represents 27.0% of the total energy input for the sector. As the electromagnetic radiation has similar energy and exergy contents, the energy and exergy efficiencies of lighting are almost similar (Rosen and Bulucea, 2009). Other electric end-uses such as motors and pumps, and miscellaneous equipment represent 4.4% and 9.4% respectively of the national energy use in the non-domestic sector. Also, it is considered that energy and exergy efficiency are similar to the conversion of electricity into high quality work. The second law efficiency for electric-based equipment is defined as:

(9)

For the analysis, lighting is considered to have a constant monthly exergy efficiency of 18.1%. For lift and pumps is considered 50.0%, and for internal equipment 70.0%.

3.2.2.2 Efficiencies for gas-based end uses

Water heating

The modelling results indicate that regional energy use for water heating from gas consumption represents 2.7%, 2.9% and 6.9% for the hot-dry, hot-humid and temperate climates respectively. The national energy use is estimated to be 4.4% of the total energy input. In this study it is assumed that 100% of water heating is produced by gas boilers with an efficiency (of 78-82% according to national regulations (SENER, 2011). Due to the higher altitudes, lower efficiencies are assumed for the hot dry

and temperate regions. By building type, hotels and restaurants have a larger share of heated water than the other sectors. The second law efficiency was calculated using equation 10.

(10)

The reference temperatures ( ) represent the regional monthly average temperature (Table 6) and was considered to be 82 °C (355.15 K) for all regions. The results can be seen in Table 9.

[Table 9 about here]

Cooking

It is estimated that all the cooking activities directly use fossil fuels and thus electric cooking is estimated to be 0. From the model outputs, cooking represents 6.7%, 6.3% and 16.4% for the hot-dry, hot-humid and temperate climates respectively. The national energy use is estimated to be 10.6% of the total energy input. At higher altitudes since the air pressure is lower and the boiling point of water is lower, cooking times need to be increased. Hence, first law efficiency for natural gas and LGP cooking was assumed to be 50% at sea level (Utlu and Hepbasli, 2003), 45% at 800 m.a.s.l. and 40% at 1500 m.a.s.l. The second law efficiency was calculated using equation 11.

(11)

The reference temperatures ( ) represent the regional monthly average temperature (Table 6). As water boils at a lower temperature at higher altitudes was considered to be 140 °C (403.15 K) for the humid region, 135 °C (398.15 K) for the dry region and 130 °C (393.15 K) for the temperate region. Cooking at lower temperatures increases cooking time. These factors were already considered in the energy analysis model as mentioned in section 3.1.2. The exergy efficiency results are shown in Table 10.

[Table 10 about here]

3.2.2.3 Overall energy/exergy efficiencies

The classification presented in this paper allows for a deeper understanding of the energy and exergy utilisation of the sector. Efficiencies at the building, regional and national level can be calculated using the obtained exergy efficiencies and multiplying them by the calculated exergy input by end-use. Later, to obtain the regional energy and exergy efficiency we aggregate the energy data obtained from the energy analysis; for this purpose we use equations 12 and 13. Finally, a national energy/exergy efficiency of the sector is obtained using the similar equations to known the efficiency of the sector as a whole and to make direct comparison with other international studies.

(12)

(13)

refers to the fraction of the total energy/exergy utilisation of a specific end-use, to the energy efficiency, and to the exergy efficiency of each end-use.

4. Results and Discussion.

4.1 Energy use in the non-domestic sector

The model output showed a total energy input of 95.43 PJ; 81.10 PJ in form of electricity and 14.32 PJ in for of gas (LNG and Natural Gas). Although schools are the type of building with the lowest EUI of all analysed buildings, nationwide the constructed surface of schools represents 71% of the total non-domestic sector floor area, thus schools comprise 46.6% of the total yearly energy input (44.49 PJ) in the sector. Schools in the hot-dry climate are the major “consumers” with a use of 19.78 PJ of energy. Of that amount, 8.97 PJ are used to cover the energy demand for space conditioning. This individual end-use represents 9.4% of the total sectoral energy input. Also, schools in the hot-humid and temperate climates are large users with a total use of 9.57 PJ and 15.14 PJ respectively. Other large nationwide energy users are supermarkets and hotels representing 20.3% and 12.7% respectively.

By end-use at a national level, HVAC and Lighting are the dominant end-users, representing 29.5% and 27.0% of the total energy input. From a first law perspective special attention has to be put on these end-uses to minimize the energy demand. The overall energy efficiency of the sector was found

to be 66.4%. The total values for total annual energy input per region, type of building, and type of end-use obtained by the model can be seen in Table 11.

[Table11 about here]

4.1.1 Comparative validation

In the past years, the National Commission for Efficient Energy Use (a sub-department of the Energy Department) attempted to alleviate the lack of national energy statistics for non-domestic buildings by cleaning and analysing data on what is considered to be “Medium Industry” buildings (CONNUE, 2013) . A recent study reported that the non-residential sector have an actual annual energy input of 25,220 GWh (90.79 PJ). The results for energy use from the simulation model were found to be in strong agreement with those published by CONNUE with a prediction error of 4.86%.

4.2 Exergy use of the Mexican non-domestic sector

As a result of the high quality of the sources used in the non-domestic sector (electricity =1 and gas = 0.92) the exergy input values look similar to those listed in table 11. The total exergy input for the Mexican non-domestic sector was calculated to be 94.28 PJ (81.10 PJ for electricity and 13.18 PJ for gas). However the values of interest to this study are the total exergy output with the intention to obtain building, regional, and national exergy efficiencies and exergy destructions. Based on the aforementioned exergy analysis methodology described these values are presented in Table 12.

[Table 12 about here]

4.3 Irreversibilities/Exergy destructions

Exergy losses or irreversibilities by regions, end-uses and types of buildings were also estimated. These values represent the true thermodynamic inefficiencies of the sector. This occurs mainly because electricity (a high grade source) is used in low-grade demands such as space conditioning or

refrigeration; and gas in the case of water heating. Therefore these end-uses will naturally have low exergy efficiency values and high exergy destructions. Overall, the national exergy destruction is calculated to be in the order of 75.71 PJ annually.

4.3.1 By building

At a national level, the largest destructions by type of building occur in schools, accounting for 46.9% of the total irreversibilities (35.48 PJ). Supermarkets and hotels have a share of 20.0% (15.16 PJ) and 13.1% (9.89 PJ) respectively. This is due to the fact that these buildings represent the largest percentage of floor area in the country. Fig. 7 shows the total exergy destruction percentage by building.

[Fig. 7. about here]

4.3.2 *By climatic region*

The hot-dry and hot-humid regions combined have an exergy destruction in the order of 46.27 PJ, accounting for 61.1% of the total destruction in spite of this only representing less than half of the estimated total non-domestic floor area (43.9%). The temperate region has destruction of around 29.44 PJ annually. Further detailed analysis of these results highlights that in the hot-dry region the largest exergy destruction is caused by HVAC systems, accounting for 49.7% (14.07 PJ) of the total regional destructions. Lighting also contributes a significant share, with almost a quarter of the regional destructions (6.61 PJ). A similar trend can be observed in the hot-humid region, with 46.7% (8.39 PJ) and 24.2% (4.35 PJ) from HVAC and lighting systems respectively. Finally, in the temperate region the major destruction occur in lighting systems and accounts for 33.8% (9.96 PJ), while refrigeration and cooking systems account for 18.9% (5.55 PJ) and 17.7% (5.22 PJ) of the total regional destructions. Monthly regional exergy destructions can be seen in Figure 8.

[Fig.8. about here]

This analysis indicates that the temperate region and the hot-humid region have constant monthly destructions throughout the year. However, this is not the case for the hot-dry region, where a peak can be observed during the “cooling” season (from May to October); even though the temperate region has more than half of the constructed m², the hot dry region between these months has the largest destructions having a big impact on the national exergy destructions.

4.3.3 *By end use*

From a national perspective the largest irreversibilities for end uses occur in HVAC and lighting systems with 35.5% (26.86 PJ) and 27.6% (20.91 PJ) respectively. For gas-based end uses, cooking represents 10.8% (8.18 PJ) of the total exergy destructions. The national exergy destruction share by end-use is illustrated in Fig. 9.

[Fig. 9. about here]

4.3.4 *Normalized exergy destruction*

Normalization of results allows the comparison of all the variables that may affect buildings and is considered a “perfect” metric to compare between similar buildings. Fig. 10 shows normalized exergy destruction by floor area (MJ/m²) at a region level and by end use. As it can be seen, depending on the building and the region, HVAC, refrigeration, and cooking have the largest destructions per square meter.

[Fig.10. about here]

4.4 Exergy efficiency by region and by building

4.4.1 Regional efficiencies

The monthly exergy efficiency is presented to illustrate the impact of fluctuating temperatures on exergy efficiency. The hot humid region and temperate region do not show significant fluctuations

throughout the year. The hot-humid has a range of between 16.4% and 16.8% and the temperate region between 22.7% and 24.0%. On the other hand, the hot-dry region is lowest at 14.8% in August and highest at 24.2% in December. The regional efficiencies throughout the year can be seen in Figure 11.

[Fig.11. about here]

4.4.2. Efficiencies by building

The highest exergy efficient building types highlighted by the model are hospitals and shopping centres located in the temperate climate with annual efficiencies of almost 30%. This is due to the small share of space conditioning that this type of building uses in the temperate region; the great majority of buildings rely on natural ventilation unless the areas have high heat gains due to people and/or internal equipment. In the same region, hotels and restaurants exhibit low exergy efficiencies due to a larger demand of space conditioning, where thermal comfort standards are higher than in the other types of buildings analysed by the model. Therefore an intensive use of a high grade use to cover a low exergy demand (e.g. use of electricity for cooling) causes lower efficiencies. This behaviour is more noticeable by the buildings located in the hot-dry and hot-humid region, with exergy efficiencies no more than 18%. Overall, these regions have lower efficiencies than the temperate region due to the high needs of cooling throughout the year where hospitals and restaurants have the lowest efficiencies of all analysed buildings, thus the largest irreversibilities by m². The exergy efficiency by all types of buildings located in the analysed regions can be seen in Fig. 12.

[Fig. 12. about here]

The low exergy efficiency of the Mexican non-domestic sector is given by the ineffective match between the quality of the sources and the quality demand of the buildings. In summary, an “exergy flow” diagram (Fig 13) can be constructed for the Mexican non-domestic sector. This diagram sets out and clarifies the analysis undertaken in this paper and highlights the most important outcomes of the model. This diagram also shows the exergy product and exergy destruction by region. These values represent the true thermodynamic efficiency of the regional sectors. According to these outputs, the non-domestic sector has an efficiency of 17.8% in the hot-dry region and 16.6% in the hot-humid

region. These low efficiencies are caused by the extensive use of electricity for cooling. The non-domestic sector in the temperate region has an efficiency of 23.2%, a very low value considering the bioclimatic benefits of this region where the potential to use passive systems such as natural ventilation and natural lighting is very high. Finally, the Mexican non-domestic as a whole has an exergy efficiency of 19.7%.

[Fig. 13. about here]

4.5 Comparison with other countries

The national exergy indicators obtained were compared against some similar international indicators to analyze the main factors that influence the energy performance of buildings from several regions. From Table 13 it can be seen outputs from other sectoral exergy studies. The results for Mexico appear to have much higher efficiencies but this is due to two main reasons: a) the indicators from other studies are from past years (up to 30 years like in the case for Finland), and b) the mild climate located in Mexico has a high potential to use passive techniques such as natural ventilation and natural light, thus reducing exergy destructions. If the main analysis is based on the latter, it can be concluded that the exergy efficiency of the Mexican non-domestic sector is actually very low. Because of the colder climates in countries such as Japan, Canada, Sweden, US and the UK, high energy inputs for heating is required, an end-use with typical low exergy efficiency due to the use of high grade sources like natural gas or electricity to cover this demand. Countries with higher indicators are due to the use of low carbon sources such as the implementation of heat waste district systems, as in the case of Norway and Canada. In hot countries such as Brazil, Malaysia, Indonesia and Singapore, present lower efficiencies than Mexico because space conditioning represents more than half of the total energy use in the sector (in Mexico, space conditioning only represents 29.5% of the total energy use). Higher efficiencies in these countries could be achieved from two approaches: a) passive improvements by using natural ventilation and/or b) a more extensive use “low carbon” technologies such as heat pumps, CHP, and/or district cooling networks.

[Table 13 about here]

5. Policy Implications

The disaggregation of the energy use and exergy destructions by region, buildings and end-uses, allows for a more straightforward identification process regarding where policy and programs should focus. The energy usage indicators (EUI) presented represents a powerful tool for the smart deployment of efficiency measures. The granularity that is presented may enhance the development of more targeted energy efficiency programs. As a first step to achieving a sustainable building sector, local governments should adopt benchmarking and disclosure requirements for all non-domestic buildings. In addition, exergy benchmark (especially for space conditioning process in hot climates) may help in the thermodynamic optimization of these systems.

Despite the efforts made in the last decades to reduce energy use in the Mexican non-domestic sector, it is still necessary to reduce the energy use of common processes in existing buildings, with particular focus on cooling, lighting, refrigeration, and water heating. The theoretical background to this work suggests that only performing energy analysis can be misdirecting. For example, current regulations estimate that cooling services are very efficient in energy terms (hypothetically >100%), but the model used in this study showed that the exergy efficiency is regularly lower than 10%. In some regions depending on the month, this can get closer to 1%. The same behavior can be found in water heating processes. A limitation of current regulations is that they are only based on the first law of thermodynamics; therefore the addition of exergy to the policy-making process may provide an effective tool to improve resource utilisation, energy conservation, and energy security in the country.

Public programs should focus on areas where more potential for improvements can be achieved. As a result of the monthly analysis of exergy destructions and exergy efficiency, the main focus of these policies should include buildings in the hot-dry climate, where total irreversibilities account for the same amount as in the temperate region in spite of having less than half of the constructed surface. Furthermore, some potential does exist for the implementation of a mixed approach between active and passive systems refurbishments such as mechanical/natural ventilation systems. Additionally, urban areas in this region have high development rates, therefore preventive policies should be applied to new buildings. For the temperate region, the deployment of passive strategies such as natural ventilation, natural lighting and solar water heating can greatly improve the regional efficiency and should be the focus of local programs. The hot-humid region presents a great challenge,

especially for the constant cooling demand of the buildings. In order to bring the quality of the fuels closer to the quality demanded by some end-uses, more policies and incentives are needed to support technologies that work with low-quality sources. Consequently, to increase the exergy efficiency in cooling in all regions, the creation of programs that could encourage the deployment of low carbon technologies such as heat pumps, CHP with absorption chillers, and the development of district cooling networks combined with bioclimatic strategies should be implemented. Furthermore, the development of codes to set minimum envelope requirements is needed to lower the space cooling demands.

Finally, policies should encourage the development and implementation of an energy/exergy directive applied to Mexican buildings. Exergy indicators should be mandatory when reduction strategies are assessed to gain a clearer picture of the potential improvements. Although more research is needed on the subject, exergy indicators can be also used to apply penalties to buildings with low efficiencies.

6. Conclusion

This study presented the development of an archetype-based bottom-up building energy model supported with an exergy method developed by Dincer et al. (2004) to assess the energy/exergy use of the Mexican non-domestic sector. The analysis was undertaken based on very detailed database of 120 non-domestic buildings located in different regions of the country. First law or energy analysis was implemented to give a first insight into a sector that lacks detailed energy information. The methodology for the development of a stock model implemented for this study could serve as a basis for other similar studies, especially those were data is limited and several assumptions have to be made. On the other hand, the exergy approach was included in the model to identify locations and magnitudes of exergy destructions. In extending the work undertaken in similar research, it is the first time that energy and exergy stock model has been developed through the use of archetype buildings and building physics modelling with the potential to undertake the modelling of future refurbishment programs based on exergy improvements. Furthermore, the exergy model presented in this research can be an essential method for policy making and national standard design activities

According to the Mexican model, the non-domestic sector demands 95.43 PJ of energy and 94.28 PJ of exergy. These inputs are mainly used for space conditioning, lighting, refrigeration, and cooking. Also, it was possible to quantify the impact of local climate at end-uses, buildings, and regions. It is concluded that Mexican climatic conditions have a large impact on the exergy efficiency in the sector. Regionally, the exergy efficiencies found was in the order of 17.8%, 16.6%, and 23.2% for the hot-dry, hot-humid, and temperate climate respectively. The national exergy efficiency of the sector was found to be 19.7% with an output of 18.57 PJ and exergy destructions of 75.71 PJ. On the other hand, the overall energy efficiency of the sector was calculated at 66.4%. A large difference exists because of the use of high quality sources for low quality demands. The use of high-grade sources for low-grade demands in buildings is still a constant in our societies and should be a major concern for the world energy security.

A high potential of decarbonizing the Mexican building sector exist, especially in hot climates. This outcomes will help the policy makers to identify where the main destructions occur and what kind of policies should be focus on reduce this inefficiencies. The model showed that the main irreversibilities occur at the HVAC systems; therefore special attention has to be put in this area. By following the exergy concept, the total CO_2 emissions for the building stock can be substantially reduced as a result of the use of more efficient energy conversion processes. Exergy theory applied to the built environment have the benefit of using resources in a smarter way, and try to put more attention in the efficient use of renewable energy and the development of bioclimatic or passive design strategies for buildings that eventually would lead to an increase of the energy/exergy efficiency of the Mexican building sector.

7. Future work

It is important to note that since the modelling methodology presented is still under development and further improvements are intended, this includes:

- Undertaking of in-depth analysis to ground the archetype models in more robust data: This will include the collection of more defined data on a number of buildings, floor area and installed energy systems to improve the model.

- Extension of building types covered: More detailed specification of non-domestic building subtypes.
- Development of a retrofit module: This will be included to explore the future technical potential of different refurbishment strategies and identify the impact on national building sustainability under energetic and exergetic indicators.

As this model is considered to be useful in the evaluation of a single subsector or a whole building sector energy and exergy performance, the application of the modelling framework to other countries is currently being investigated. An analysis of the UK non-domestic sector is currently under way with the intention of investigating the current performance of the sector and modelling the impact of different refurbishment measures based on exergetic terms.

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References

Al-Ghandoor, A., 2013. Evaluation of energy use in Jordan using energy and exergy analyses. Energy and Buildings 59, 1-10.

ANTAD, (2014). Asociación Nacional de Tiendas de Autoservicio y Departamentales, A.C. [Online]. Data on footprint, Accessed: 25 Aug 2014. url: http://www.antad.net/

ASHRAE. (1977). ASHRAE 1977 Handbook: Fundamentals, U.S.A.

ASHRAE. (2010). ASHRAE 90.1 Appendix G: Building Performance Rating Method, U.S.A.

Asif, M., Muneer, T., 2007. Energy supply, its demand and security issues for developed and emerging economies. Renewable and Sustainable Energy Reviews 11, 1388-1413.

Aydinalp, M., Ugursal, V.I., Fung, A.S., 2003. Modelling of residential energy consumption at the national level. INTERNATIONAL JOURNAL OF ENERGY RESEARCH 27, 441-453.

Bilgen, E., Takahashi, H., 2002. Exergy analysis and experimental study of heat pump systems. Exergy, An International Journal 2, 259-265.

Bressani, R., Chon, C., 1996. Effects of altitude above sea level on the cooking time and nutritional value of common beans. Plant foods for human nutrition (Dordrecht, Netherlands) 49, 53-61.

Bruhns, H., 2007. Identifying Determinants of Energy Use in the UK nondomestic Stock. Bartlett School of Graduate Studies, University College London, London, United Kingdom.

CONAGUA. 2014., Normales Climatológicas por Estación . Accessed: 26 April 2014, url: http://smn.cna.gob.mx/.

CONNUE, 2013. La importancia de los edificios del sector comercial y de servicios como usuarios de electricidad y las estrategias para la eficiencia energética, Presentation by Odon de Buen, March 2013.

Daft Logic. (2014). Google Maps Area Calculator Tool [Online]. Map of Mexico, retrieved on Jan 20th, 2014. url: http://www.daftlogic.com/projects-google-maps-area-calculator-tool.htm

de Buen, O., 2009. Greenhouse Gas Emission Baselines and Reduction Potentials from Buildings in Mexico: A Discussion Document, in: SBCI, U. (Ed.), France.

Deru, M., Field, K., Studer, D., Benne, K., Griffith, B., Torcellini, P., Liu, B., 2011. U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. Technical Report NREL/TP-5500-46861, 118.

Dincer, I., 2002. The role of exergy in energy policy making. Energy Policy 30, 137-149.

Dincer, I., Hussain, M.M., Al-Zaharnah, I., 2004. Analysis of sectoral energy and exergy use of Saudi Arabia. International Journal of Energy Research 28, 205-243.

Dineen, D., Gallachoir, B.P.O., 2011. Modelling the impacts of building regulations and a property bubble on residential space and water heating. Energy and Buildings 43, 166-178.

Dovjak, M., Shukuya, M., Olesen, B.W., Krainer, A., 2010. Analysis on exergy consumption patterns for space heating in Slovenian buildings. Energy Policy 38, 2998-3007.

ECB-Annex37, 2007. Technical Synthesis Report: Low Exergy Systems for Heating and Cooling of Buildings, IEA ECBCS, in: Jagpal, R. (Ed.), UK.

ECB-Annex49, 2011. Detailed Exergy Assessment Guidebook for the Built Environment, IEA ECBCS, in: Torio, H., Schmidt, D. (Eds.). Fraunhofer IBP.

EnergyPlus, 2012. Getting Started with EnergyPlus. BasicConcepts Manual - Essential Information You Need about Running EnergyPlus. The Board of Trustees of the University of Illinois and the Regents of the University of California through the Ernest Orlando Lawrence Berkeley National Laboratory., 73.

Ertesvåg, I.S., 2001. Society exergy analysis: a comparison of different societies. Energy 26, 253-270.

Famuyibo, A.A., Duffy, A., Strachan, P., 2012. Developing archetypes for domestic dwellings—An Irish case study. Energy and Buildings 50, 150-157.

FIDE, 2011. Proyectos de Ahorro de Energia. Casos de Estudio. Fideicomiso para el Ahorro de Energia Electrica, Mexico, D.F.

Gallo, W.L.R., Milanez, L.F., 1990. Choice of a reference state for exergetic analysis. Energy 15, 113-121.

Gasparatos, A., El-Haram, M., Horner, M., 2009. Assessing the sustainability of the UK society using thermodynamic concepts: Part 2. Renewable and Sustainable Energy Reviews 13, 956-970.

Griffith, B., Crawley, D., 2006. Methodology for Analyzing the Technical Potential for Energy Performance in the U.S. Commercial Buildings Sector with Detailed Energy Modeling. Conference Paper NREL/CP-550-40124, 10.

Google. (2014). Google Maps. [Online], Map of Mexico, retrieved on Feb 2nd, 2014, url: http://maps.google.com.mx

Hammond, G.P., Stapleton, A.J., 2001. Exergy analysis of the United Kingdom energy system. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 215, 141-162.

Hepbasli, A., 2012. Low exergy (LowEx) heating and cooling systems for sustainable buildings and societies. Renewable and Sustainable Energy Reviews 16, 73-104.

Huang, Y.J., Broderick, J., 2000. A Bottom-Up Engineering Estimate of the Aggregate Heating and Cooling Loads of the Entire U.S. Building Stock. ACEEE Summer Study on Energy Efficiency in Buildings, 135-148.

INEGI, Accessed: 20 April 2014. Poblacion, Hogares y Vivienda, url: http://www3.inegi.org.mx/sistemas/temas/default.aspx?s=est&c=17484.

IPCC, 2007. Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Kondo, K., 2009. Energy and exergy utilization efficiencies in the Japanese residential/commercial sectors. Energy Policy 37, 3475-3483.

Korolija, I., Marjanovic-Halburd, L., Zhang, Y., Hanby, V.I., 2013. UK office buildings archetypal model as methodological approach in development of regression models for predicting building energy consumption from heating and cooling demands. Energy and Buildings 60, 152-162.

Reistad Gordon, M., 1980. Available-Energy Utilization in the United States, Thermodynamics: Second Law Analysis. AMERICAN CHEMICAL SOCIETY, pp. 93-109.

Rosen, M., 2013. Using Exergy to Assess Regional and National Energy Utilization: A Comparative Review. Arab J Sci Eng 38, 251-261.

Rosen, M., Bulucea, C.A., 2009. Using Exergy to Understand and Improve the Efficiency of Electrical Power Technologies. Entropy 11, 820-835.

Rosen, M.A., 1992. Evaluation of energy utilization efficiency in Canada using energy and exergy analyses. Energy 17, 339-350.

Sadorsky, P., 2009. Renewable energy consumption and income in emerging economies. Energy Policy 37, 4021-4028.

Saidur, R., Sattar, M.A., Masjuki, H.H., Abdessalam, H., Shahruan, B.S., 2007. Energy and exergy analysis at the utility and commercial sectors of Malaysia. Energy Policy 35, 1956-1966.

SENER, 2001. NOM-008-ENER-2001, Eficiencia energética en edificaciones, envolventes de edificios no residenciales., Mexico, D.F.

SENER, 2005a. NOM-007-ENER-2004, Eficiencia energética en sistemas de alumbrado en edificios no residenciales., Mexico, D.F.

SENER, 2005b. NOM-014-ENER-2005, Eficiencia energética de motores de corriente alterna, monofásicos, de inducción, tipo jaula de ardilla, enfriados con aire, en potencia nominal de 0,180 a 1,500 KW. Límites, método de prueba y marcado., Mexico, D.F.

SENER, 2007. NOM-011-ENER-2006, Eficiencia energética en acondicionadores de aire tipo central paquete o dividido. Límite, métodos de prueba y etiquetado., Mexico, D.F.

SENER, 2008. NOM-022-ENER/SCFI-2008, Eficiencia energética y requisitos de seguridad al usuario para aparatos de refrigeración comercial autocontenidos. Límites, métodos de prueba y etiquetado., Mexico, D.F.

SENER, 2011. NOM-003-ENER-2011, Eficiencia térmica de calentadores de agua para uso doméstico y comercial. Límites, método de prueba y etiquetado., Mexico, D.F.

SENER, 2013. Balance Nacional de Energía 2012, Mexico, D.F.

Shukuya, M., 1994. Energy, Entropy, Exergy and Space Heating Systems, in: Bánhidi, L. (Ed.), Healthy Buildings '94: proceedings of the 3rd international conference. Technical University of Budapest, pp. 369-374.

Swan, L.G., Ugursal, V.I., 2009. Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. Renewable and Sustainable Energy Reviews 13, 1819-1835.

UNEP-SBCI, 2009. Buildings and Climate Change Summary for Decision-Makers. UNEP Sustainable Buildings & Climate Initiative.

Utlu, Z., Hepbasli, A., 2003. A study on the evaluation of energy utilization efficiency in the Turkish residential-commercial sector using energy and exergy analyses. Energy and Buildings 35, 1145-1153.

Xydis, G., Koroneos, C., Polyzakis, A., 2009. Energy and exergy analysis of the Greek hotel sector: An application. Energy and Buildings 41, 402-406.