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Energy consumption and GHG emission scenarios of a university campus in Mexico

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ABSTRACT

This study estimates energy consumption and related GHG emissions for the buildings and facilities of the main university campus at the National Autonomous University of Mexico (UNAM). The campus has a built area of 1.3 km^2. Based on the strategic plan of growth, a scenario analysis for 2020 was also developed estimating baseline and mitigation scenarios that include energy efficiency technologies and solar water heating. To estimate energy consumption, a representative sample of buildings and facilities by category was selected in order to develop level I and when possible level II energy audits. The study was complemented with results of level III energy audits performed in previous studies for some buildings. The bottom-up results from energy audits were compared to the electricity bill for the whole campus. We found that lighting represents 28% of total energy use, followed by special research equipment 17%, refrigeration 14%, and water heating that includes the Olympic swimming pool 9%. If energy efficiency technologies are applied for retrofitting and considered for new buildings in lighting, refrigeration, air conditioning; and a hybrid system (solar–electric–LPG) is used for water heating, energy consumption could be 7.5% less than in 2011 and CO_2 emissions 11.3% less than in 2011.

Introduction

This paper presents results from a study developed for the Environmental University Program (Programa Universitario de Medio Ambiente, PUMA) at the National Autonomous University of Mexico (UNAM in Spanish) to estimate energy consumption and related greenhouse gas (GHG) emission inventory, and project scenarios of buildings and facilities of the main university campus. The study was developed under the framework of the University *EcoPuma* project, whose ultimate objective is to reduce environmental impacts of the university's operation.

UNAM is the most important public university of Mexico and it has a long history. Its antecessor was the Royal and Pontifical University of Mexico, founded by King Philip II of Spain in 1551. In 1865, Emperor Maximilian closed the University, which was not re-opened until 1910 as the Mexico National University (Universidad Nacional de México). After the Mexican Revolution, the year 1929, the University reached autonomy in order to assure cultural development and scientific education[1] and it was given the name it holds till today: Universidad Nacional Autónoma de México (UNAM) (UNAM, 2013; UNESCO, 2013).

Since its creation, the University has occupied several locations in the historic center of Mexico City. Later, in the middle of the XX century, the central and older zone of the university city (Ciudad Universitaria, CU), located in the south of the city, was built by more than 60 architects, engineers, muralists and artists. In 2007, the UNESCO declared it a world heritage center (UNESCO, 2013). It was declared a patrimonial site. The CU has grown from a built area of 0.2 km^2 in 1952 to 1.3 km^2 in 2011, distributed in a total area of nearly 7.2 km^2 (UNAM, 2011a).

By 2012, the UNAM had several campuses that together incorporate around 325 thousand students from high school[2] to postgraduate studies, and 45 thousand academics, of which 27% are full time. The CU is the largest campus with 39% of the UNAM's students, 56% of the academics, and most of the science and engineering research (UNAM, 2011b).

This study estimates electricity, LPG and diesel consumption for the CU's buildings and facilities, and related GHG emissions. Levels I and II energy audits were performed on a representative sample of buildings that allowed for calculating energy indicators for buildings and facilities by category (Thumann et al., 2010). The study was complemented with the analysis of CU electricity bills, fuel consumption data for certain facilities and level III energy audits for certain buildings developed by previous studies (Escobedo, 2009; Sánchez, 2007). The level I energy audit

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[1] In general terms, Autonomy means that only the members of the university can define the University governance; the distribution of public resources, the study programs and plans, and the research themes and activities. Most of the University funds are public and from the Federal Government.

[2] Since 1910 when the Mexican National University (Universidad Nacional de México) was created, the National High School (Escuela Nacional Preparatoria — ENP) was incorporated to the University. The ENP was created in 1857 by President Benito Juárez as the first higher public education system with no relation to the church. There are now 14 high schools (9 "preparatorias" and 5 "colegios de ciencias y humanidades") that belong to the UNAM. There is also a whole public high school system in the country that is not part of UNAM.

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consisted in counting the energy appliances and its power capacity for all sample buildings. The hours of use was estimated based on manager building's and users interviews and direct observation. The surface area was obtained from university construction maps. Level II energy audit consisted in a more detail review of appliances in certain buildings that allow estimating energy saving costs. Level III energy audits include direct measurements in different buildings. Based on this information a CU's plans of growth, the study estimated a baseline energy consumption scenario for year 2020, and mitigation scenarios considering energy savings and the use of solar energy.

There are numerous articles on building energy audits, but considering the dimension of the CU and the characteristics of this study, some of them are more relevant to mention. For example, Yuan et al. (2012) evaluated energy consumption and conservation measures in university campus buildings in Northern China; and Su et al. (2012) developed a similar study for a university campus in Southern China.

Zhang and Xu (2012) evaluated end use consumption in a university campus based on energy consumption surveys; Vance and Boss (2012) developed an energy use comparative study for US colleges; and Hong et al. (2011) presented an energy consumption study for the University of Korea. On the other hand, Li (2008) developed a study of energy performance and efficiency improvement procedures of government offices in Hong Kong special administrative region; Eskin and Türkmen (2008) performed an analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey; Escrivá-Escrivá et al. (2010) modeled space conditioning load curves in a university building in the Universidad Politécnica de Valencia in Spain; Rahman et al. (2010) developed a study of energy conservation measures (ECMs) on heating, ventilating and air conditioning (HVAC) and lighting systems for a four-storied institutional building in sub-tropical (hot and humid climate) Queensland, Australia; Aljami (2012) performed an energy audit of an educational building in a hot summer climate in Kuwait; Zhou et al. (2012) analyzed the different functional areas and energy consumption data of large-scale public buildings according to the energy audit on 48 buildings in Shanghai; Desideri et al. (2012) presented results from the European project Educa-RUE: an example of energy efficiency paths in educational buildings.

The paper is divided into five sections. After the introduction, an overview of the CU's energy consumption is presented. The third section presents the methodology developed in the study. The fourth section presents results divided by inventory, baseline and mitigation scenarios and the fifth section presents the conclusions.

Overview of energy consumption in the CU

Electricity

The CU is powered by an electricity grid at 23,000 kV with four substations. Electricity is distributed by an underground network at 6500 kV and 111 transformers. The CU does not have electricity meters in buildings and installations, only in the substations; thus the electricity bill is paid by the central university administration.

The electricity bill is under a national electricity tariff called HM, the M is for medium voltage and the H is for hourly rates. HM tariff has charges for maximum power demand, as well as base, medium and peak energy consumption (CFE, 2013).

In September 2009 the public power utility that used to serve central Mexico (Luz y Fuerza del Centro) was shut down by presidential mandate and all its customers were absorbed by the national public power utility (Comision Federal de Electricidad, CFE). The adjustment of this change provoked that from September 2009 to February 2011 the electricity bills were estimated by the power utility based on the electricity consumption of previous months. The measurement of power demand and electricity consumption started again in April 2011.

Fig. 1 presents the electricity consumption based on electricity bills as a sum up from the four substations in the period January 2007 to December 2011 (skipping the period with no real metering). As shown, peak, medium and base load increased since September 2008. Also, in July 2011 the medium load consumption decreased, mainly because of the holiday period (although it is not clear why it did not decrease in previous years); and peak load in 2011 is considerably higher than the previous years. The decrease in peak load for the last months of 2011 is followed by an increase in medium load for the same months. This is due to the way medium and peak loads are measured for summer daylight and winter daylight.

Average monthly charge increased from 7.2 million pesos (700 thousand USD) in 2007 to 14.2 million pesos (1 million USD) in 2011. During the same time interval, average price per kWh in HM tariff only grew by 20% reaching 0.11 USD/kWh. This increase in electricity consumption can be explained by the fact that from January 2007 to December 2011 the CU floor constructed area augmented by 129.6 thousand of m^2 (Table 1). The CU's electricity consumption in 2011 reached 81.3 GWh (11 million of USD). This consumption represented 0.6% of the total CFE's electricity sales in Mexico City in that year (CFE, 2011).

LPG and diesel

Besides electricity, the fuels used in buildings and facilities in the CU are LPG and diesel. In contrast to electricity, these fuels are acquired by each university Department, so there is no record of total fuel consumption from the central administration of UNAM. In this case, quantification is made from a bottom-up energy audit, and only for the observations made in the study. LPG is used for water heating in the Olympic swimming pool, sports showers, cooking and restaurants, and for research purposes. Diesel is used for water heating in some isolated showers and for emergency plants. For these uses LPG and diesel annual consumption for 2011 was 53.4 TJ and 0.3 TJ respectively.

Methodology

Energy by surface area and end use

The study comprised buildings, green areas, exterior roofed corridors, and sporting campuses including the Olympic stadium. According to UNAM's records, in 2011, there were 2053 buildings and facilities occupying an area of 1.3 km^2 (UNAM, 2011c). A representative sample of buildings and facilities by category was selected in order to estimate energy consumption by end use. The representative of the sample was taken with a 95% confidence interval with a Margin of Error of almost $\pm 1\%$ with the exception of the vending kiosk where the Margin of Error was 5% (Schuenemeyer and Drew, 2011). Table 2 presents the total and selected buildings and surface area by category.

A level 1 and partial level 2 energy audits were carried out in the selected buildings and facilities (ANSI/ASHRAE, 2006; Thumann et al., 2010). The study was completed with information from constructed building maps that the research team had access to, and data from previous studies developed by Sánchez (2007) and Escobedo (2009) whom developed level III energy audits for certain university buildings. The energy audits were carried out by nearly 20 engineering students previously capacitated and coordinated by two masters in engineering with experience in building's energy audits.

In line with previous studies, the energy audits gathered information on power and time of use per day of the following electricity end use equipment: lighting, air conditioning, refrigeration, computer equipment, heating, special research equipment, motors, and miscellaneous; and for the following LPG and diesel end use equipment: water heating, cooking, emergency plants, and science research equipment.

Based on data collected from energy audits, an indicator of energy use by end use per square meter by category of building or facility was estimated. Once this indicator was obtained, it was multiplied by the total building and facility area in order to obtain total energy