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Economic, environmental and health co-benefits of the use of advanced control strategies for lighting in buildings of Mexico

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ABSTRACT

Merida, Mexico, is a city that spends 17% of its electricity for lighting purposes. This electricity comes from thermal power plants that use fossil fuels. These emit a large amount of particulate matter, around 2.5 micrometers ($PM_{2.5}$), which can penetrate deepest lung parts (alveoli), causing cardiovascular disease. Mexico has a policy (NOM-028-ENER-2010) that establishes the minimum efficiency for lighting in buildings. However, lighting is often used inappropriately (e.g. daytime or when there are no people using them). One solution for this problem is to use control device technology of multiple types (combination of daylight, motion and presence sensors). However, these strategies have not been fully implemented in Mexico, mainly due to the high cost of commercial control devices. This study aims to know the lost co-benefits when control devices are not implemented for lighting cost reduction, such as: energy saving (kw-h/yr), electricity bill reduction (USD/yr), $PM_{2.5}$ emission reduction (μg/m^3), cardiovascular death reduction (death/yr) and cardiovascular death cost reduction (USD/yr). For those reasons, it is recommended that energy policy decisions regarding building lighting efficiency include the implementation of control devices. Moreover, such policies should be preceded by research studies focused on detailed device cost, co-benefits and socio-economic analysis.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) is an association for the assessment of climate changes and its potential environmental and socio-economic impacts. Its annual Climate Change Report has mentioned changes in average temperature of the Earth, desertification, land degradation, sustainable land management, food security, sea level, and greenhouse emission. These changes are due mainly to anthropogenic pollutants, especially Climate Altering Pollutants (CAPs) (Pachauri et al., 2014). This happens when the pollutants emitted by anthropogenic activities exceed the absorption, assimilation, or adaptation capacity of ecosystem elements (Hydrosphere, Lithosphere, Biosphere, Atmosphere and Sociosphere), since interrelations and interactions exist between them (Wall and Gong, 2001; Gong and Wall, 2001; Diaz-Mendez et al., 2011, 2013). Evidence of these can be found in prestigious literature. Vallero reported that air pollutants can damage both ecosystem function and ecosystem structure, including biodiversity. Furthermore, the author evidenced damage in coral reefs and rain forests due to acid rain (Vallero, 2014). Snakin et al. explained variations of soil carbonate concentration and how these changes can increase carbon dioxides concentration in the atmosphere (Snakin et al., 2001). Xiaomin et al. studied the impacts of the changes of nitrogen deposition in soil, which affects nitrogen cycle in forest ecosystems; these changes are due to the nitrous oxides that come from burning fossil fuels (Zhu et al., 2015).

Also, Sociosphere is affected by pollutant emissions, such as CO, NO_x, SO_x, PM_{10}, $PM_{2.5}$, VOCs and others (Woodward et al., 2014). Air pollution comes from different sources, such as power plants used to generate electric power, oil production plants (offshore, inshore, and refineries), cars, and others (Diaz-Mendez et al., 2012). All of them contribute to chronic effects on human health such as respiratory, heart, lung and cancer diseases. Moreover, they can aggravate pre-existing conditions, such as asthma and cardiovascular diseases (Perez et al., 2010; Brook, 2008), increasing the rate of mortality in a population (Dockery et al., 1993; Kampa and Castanas, 2008).

However, problems related to pollutant emissions will most likely continue due to the strong dependence of the society on fossil fuels (Kampa and Castanas, 2008). The International Energy Agency (IEA) reported that primary energy source in countries of the Organization for Economic Co-operation and Development (OECD) are as follows: oil,

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Nomenclature

Br	breathing rate of a person (m^3/day-person)
C	percentage of electrical energy consumption increased or decreased
CD	mortality rate of cardiovascular death per year over 100,000 (person/year)
ΔC	change in exposure concentration of a pollutant over the population (μg/m^3)
ΔCD	change of cardiovascular death per year (death/year)
E	annual electrical energy consumed per residential building (MW-h/yr)
EF	emission factor of a specific pollutant from the power plant (kg/MW-h)
ΔEE	change of total annual electrical energy consumption (MW-h/yr)
ΔE	change of emission of a specific pollutant (μg/day)
F	percentage of the annual electrical energy used in lightings
iF	intake fraction
N	number of residential buildings that have electrical energy supply
P	population

Subscript

building	residential building
lighting	lighting
NOx	nitrous oxide
$PM_{2.5}$	particulate matter less than 2.5 μm
$PM_{2.5}$ by NOx	formation of $PM_{2.5}$ from nitrous oxide
$PM_{2.5}$ by SOx	formation of $PM_{2.5}$ from sulfur oxide
total $PM_{2.5}$	total formation of $PM_{2.5}$
rate	related to cardiovascular death per year over 100,000
SOx	sulfur oxide

31.2%; coal, 29.4%; natural gas, 21.2%; renewable, 13.4%; and nuclear, 4.3% (IEA and Energy Balances of OCDE Countries, 2015). Consequently, 82% of the primary energy sources in the world come from fossil fuels. Moreover, the report has mentioned that the consumption of primary energy sources by sector are divided as follows: transport 33%; industry, 31%; residential, 20%; services, 13%; and others, 3%, including agriculture, forestry, fishing and non-specified (IEA and Energy Balances of OCDE Countries, 2015). Thus, the primary energy sources in the present and in the immediate future are the fossil fuels.

OECD countries use one part of their primary energy sources to generate electric power. Most of the electricity is produced in power plants, and around 59% of these plants use fossil fuels. The additional 41% of electricity is produced from other sources, such as nuclear, 19%; hydro, 13%; and others, 9% (geothermal, solar, wind, tide, biofuels, waste and heat) (IEA and Energy Balances of OCDE Countries, 2015). Most of the electricity is used in the industrial, residential, commercial, and public service sectors. This represents around 93% of the total electricity consumption in the world (IEA and Electricity Information, 2015).

Mexico has the same world trend in energy uses. The last energy balance mentioned the primary energy sources used in Mexico are divided as follows: fossil fuels, 88.09%; renewable, 7.5%; coal, 3.51%; and nuclear, 1.36%. Consequently, fossil fuels are the main primary energy source in Mexico (SENER, 2013). Moreover, the same report presents the final consumption of primary energy sources by sector as follows: transport, 44.1%; industry, 31.4%; residential, 17.7%; agriculture, 3.1%; and others, 3.7% (SENER, 2013).

One part of this primary energy sources is used to produce electricity: fossil fuels, 72.4%; hydro, 21.9%; nuclear, 3%; and renewable, 2.7% (geothermal, solar, and wind) (SENER, 2014). The fossil fuels used in electric power generation are: natural gas 83.4%; oil, 13.0%; diesel, 0.9%; and coal, 2.8% (SENER, 2014). The consumption of electricity by sector is: industrial, 62.7%; residential, 32.4%; agriculture, 4.4%; and transport, 0.5% (SENER, 2014). Nearly 95% of the total electric power produced in Mexico is consumed in industrial and residential activities, mainly buildings.

Mexico has a vast resource of fossil fuels, being the fifth larger fossil fuel producer in the world, which strengthen its dependency on them. On the other hand, Mexico has significant environmental and social problems that arise from the large amount of pollutant emitted from power plants to generate electricity. These pollutants are mainly emissions of SOx from combustion of fossil fuels with high-sulfur contents (López et al., 2005), and $PM_{2.5}$ emitted from combustion of heavy fuels (Herrera Murillo et al., 2012). Environmental and health concerns related to air pollution also depends on weather conditions of the power plant location (Mugica et al., 2009).

A solution for those environmental and health concerns in Mexico due to pollutant emission could be the use of renewable energy sources. Mexico has a large solar and wind energy potential (Hernández-Escobedo et al., 2015, 2010). However, only 7.5% of the primary energy sources comes from renewable resources (SENER, 2013). Only 2.7% of the electric power generated in Mexico comes from renewable sources (SENER, 2014). Furthermore, for industrial and residential owners in Mexico the total cost of solar or wind energy technologies are still more expensive than conventional generation. In consequence, high costs of solar and wind energy technologies, and the socio-economical aspects of Mexico are the main obstacles to implement alternative energy conversion in Mexican buildings.

As mentioned by Woodward, energy improvement using efficient technology and policy could mitigate pollutant emissions (Woodward et al., 2014). Energy control strategies represent another solution to reduce pollutant emissions that arise from electricity consumption in buildings, focusing on equipment with large power consumption, such as cooling, heating (Diaz-Mendez et al., 2014; Diaz et al., 2013), and lighting (Van De Meugheuvel et al., 2014). Lighting is the second major power consuming application in Mexican buildings. Due to Mexican diverse climate conditions, there are buildings where air conditioning is indispensable, representing around 51–77% of the total electric bill. while lighting does around 8–17%., Lighting represents around 35% of the electrical bill in buildings where air conditioning is not indispensable (CONUEE, 2015). The average electric energy used for lighting in Mexican buildings is around 2200 kW-h/yr (CONUEE, 2015). For these reasons, lighting is the focus of study in this work.

Economic, environmental, and health co-benefits energy consumption reduction could be reached using lighting control devices, bringing economic, environmental, and health co-benefits. However, these strategies are not fully implemented in Mexican buildings, since commercial control devices are too expensive. Furthermore, reduction of electrical energy usage from lighting could help to reduce pollutant emissions from thermal power plants that use fossil fuels, thus bringing global and local climate benefits (Argyriou et al., 2012). These can be specially extended as health benefits to the population living in the surroundings of those power plant (Woodward et al., 2014).

A solution to reduce energy consumption for lighting in buildings could be the use of control strategies (Abdelaziz et al., 2011). As mentioned by Aghemo et al. Aghemo et al. (2014) that carried out a study to evaluate the energy efficiency of a control system for lighting in buildings, the results obtained indicates the importance of a correct design or implementation of control strategies, the authors suggested