Coupling effects of demand-side improvements ensemble on energy performance to monetary implications for UAE economy

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A B S T R A C T

An apparent transformation of energy trade in developing countries such as the UAE directly impacts and influences the global energy dynamics. UAE is the largest global exporter of fossil fuel for energy generation and it is therefore a necessity to analyze the regional in-house energy market as a first from the demand-side improvement perspective. Due to the arid climatic nature of the country, we performed simulations on air-conditioning unit performance, for the largest emirate of Abu Dhabi, using a convoluted parametric effect of coefficient-of-performance and set-point temperature to understand the long-term impact on energy operation and its monetary implications to the UAE economy. The targeted sectors included commercial and residential as leading energy hungry consumers. An assessment of the present situation to optimally determined using DesignBuilder and EnergyPlus, indicated clear change in energy generation, consumption and greenhouse gas emission reduction. The effects were forecasted using long-range energy alternatives planning simulation tool to predict the national wealth savings and to assist in governmental policy making until 2030 as per the Abu Dhabi Vision. The savings amounted to millions of dirhams per sector based on the unique upfront tariff & subsidy structure of the UAE and an emission reduction of approximately 2500 thousand metric tons of CO2 equivalent per sector by 2030 as per the Abu Dhabi Vision 2030.

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1. Introduction

Energy is the most important aspect in the economic development of countries. Sugathi and Samuel (2012) explains how energy demand increased with the age of industrialization and the significance of energy economics to the overall economic development of nations. Even more so, energy efficiency is of critical importance for sustainable progression and longevity. Energy efficiency in demand-side is considered as one of the cheapest ways to achieve reductions in heavy investments in production, transmission and distribution of electricity as well as greenhouse gas (GHG) emissions (Pina et al., 2010). In the context of the Emirate of Abu Dhabi (including Al Ain and Western region), UAE, where buildings consume about 87% of the electricity (Statistical Annual Report, 2014), at peak hours of the year the contribution of the air-conditioning load reaches 75% (Statistical Annual Report, 2014). Therefore, the individual and coupled effect of energy efficiency (coefficient-of-performance, COP) and set-point (SP) temperature of chilling units has a huge potential. In 2013, Abu Dhabi had a total population of 2.45 million and an average annual growth rate of 7.5% (Abu Dhabi Real, 2010). Population has been forecasted to reach approximately 4.62 million residents by the end of 2030 (Connecting Abu, 2008). The emirate has been experiencing tremendous growth in all aspects of life (The Abu Dhabi Economic, 2008). Monetarily, the Emirate is planning to target the GDP growth which is a five time multiple of 2013 (USD 187 million) by the end of 2030 (The Abu Dhabi Economic, 2008), according to Abu Dhabi economic vision 2030. This tremendous growth in population and economic targets coexist with an increase of demand in energy, therefore, a sustainable approach even in one aspect of end-user appliance, such as chilling units, at the present time could impact the long-term development goals and ambitions.

Several studies report the effect and impact of individual, technical and physical, building parameter improvement on energy performance (Azar and Menassa, 2012; Sekki et al., 2015; Gul and Patidar, 2015; Ge and Baba, 2015), examples include building envelope and thermal characteristics (e.g., U-values, infiltration rates) (De Lieto Vollaro et al., 2015; Lam et al., 2008; Afshari et al., 2014; Al Naqbi et al., 2012; Al Awadhi et al., 2013), chiller COP (Sekki et al., 2015; Gul and Patidar, 2015; Ge and Baba, 2015; De Lieto Vollaro et al., 2015; Lam et al., 2008; Afshari et al., 2014; Al Naqbi et al., 2012), air flow rates (Ge and Baba, 2015), insulation (Gul and
concrete building blocks, window glazing characteristics (Lam et al., 2008; Afshari et al., 2014; Al Naqbi et al., 2012; Al Awadhi et al., 2013; Tavares and Martins, 2007; Abu Bakar et al., 2015; Hong et al., 2010; Egelioğlu, 2001), to name a few. Lam et al. (2008) conducted a sensitivity on 10 key building parameters to identify impact on energy consumption levels. The results indicated that individually, chilling unit COP and light intensity, had the highest influence for the particular structure under study. Afshari et al. (2014) performed a life-cycle analysis of building retrofits, specifically COP performance of chilling units in different building types, to validate the importance of COP. Other studies can be found where energy models are used to evaluate building retrofitting options (Ge and Baba, 2015; De Lieto Vollaro et al., 2015; Lam et al., 2008; Afshari et al., 2014; Al Naqbi et al., 2012; Al Awadhi et al., 2013; Tavares and Martins, 2007; Abu Bakar et al., 2015; Hong et al., 2010; Egelioğlu, 2001; Lee and Chang, 2007; EnergyPlus; Nogales and Contreras, 2002), for instance, Al Awadhi et al. (2013) estimated the potential energy savings of refurbishing existing public federal housing in the United Arab Emirates. The study covered representative Ministry of Public Works (MoPW) existing public federal housing in the United Arab Emirates. The 2013 estimated the potential energy savings of refurbishing where energy models are used to evaluate building retrofitting options (Ge and Baba, 2015; De Lieto Vollaro et al., 2015; Lam et al., 2008; Afshari et al., 2014; Al Naqbi et al., 2012; Al Awadhi et al., 2013; Tavares and Martins, 2007; Abu Bakar et al., 2015; Hong et al., 2010; Egelioğlu, 2001; Lee and Chang, 2007; EnergyPlus; Nogales and Contreras, 2002), for instance, Al Awadhi et al. (2013) estimated the potential energy savings of refurbishing existing public federal housing in the United Arab Emirates. The study covered representative Ministry of Public Works (MoPW) houses built over the period of 1974–2012. Afshari et al. (2014). Further studies on the impact of building design and air conditioning settings, individually, on building performance of one commercial and one residential building to evaluate retrofit options such as wall & roof insulations, glazing, chiller COP, envelope air-tightness and cooling set-point temperatures. The study concluded that changing cooling temperature set-point (SP) by a few degrees was most effective of means of energy savings. The coupled ensemble response of two or more performance indicators of the same or different appliance(s) has not been reported in literature. Present and long-term implications of the coupled chilling unit parameter ensemble of COP and SP is an interesting proposition for governmental correction action plan and future policy making for the country.

In this work, we modelled the building design, geographic and performance features, from demand-side as an ensemble of chilling unit characteristics for the commercial and residential sector in Abu Dhabi using EnergyPlus with building specifications and simulated characteristics to locate the optimal end-user settings; for minimized consumption, generation and GHG emission; as opposed to the currently applicable case of business-as-usual (BAU) as a coupled study of two performance indicators of an appliance. Both forms of building energy consumption require four types of end-user appliances with the highest intake, lighting & equipment, chillers, pumps and fans (Ge and Baba, 2015; De Lieto Vollaro et al., 2015; Lam et al., 2008; Afshari et al., 2014; Al Naqbi et al., 2012; Al Awadhi et al., 2013). In our study, we focused on the chilling unit convoluted parameter impact; as it is the most significant due to the arid nature of the region (Sugath and Samuel, 2012; Pina et al., 2010; Statistical Annual Report, 2014; Abu Dhabi Real, 2010; Connecting Abu, 2008; The Abu Dhabi Economic, 2008); on the overall energy consumption and per appliance participation, of the buildings and forecast the behavior over an extended period of time. This has previously not been attempted or reported in literature. Projections of this joint ventured indicator influence over an extended timeline is important for understanding the science and vital to justify our motivation for this study.

Current traditional energy forecasting methods, such as, regression (Lee and Chang, 2007; EnergyPlus; Nogales and Contreras, 2002; Hamilton, 1994; González-Romera et al., 2006), ARIMA (BMDP, 1983), time series (Nogales and Contreras, 2002; Hamilton, 1994; González-Romera et al., 2006; BMDP, 1983) and even the soft computing techniques like; the genetic algorithm and fuzzy logic (Valenzuelaa et al., 2007) are inadequate. However, bottom-up, Long range Energy Alternative Planning (LEAP); developed by Stockholm Environment (Stockholm, Sweden); has been in use for energy supply-demand, resources, cost-benefit analysis and environmental loading for medium to long-term planning with an annual time-step or unlimited number of years (Nogales and Contreras, 2002; Hamilton, 1994; González-Romera et al., 2006; BMDP, 1983; Valenzuelaa et al., 2007; LEAP; Heaps, 2008; Qingsong et al., 2010; Vashishtha and Ramachandran, 2003). Its characteristics include accounting frameworks, scenario-based studies and integrated energy-environment model building. The model includes a database of over 1000 energy technologies for local/national/regional geographic applicability with an addition of greenhouse gas mitigation analysis (Vashishtha and Ramachandran, 2003). Some examples of applications include energy and carbon scenarios (U.S. National Labs) (Scenarios of U.S., 1997), APERC energy outlook (energy forecasts for each APEC economy) (Energy Demand and Supply Outlook, 2013), global energy studies (Tellus Institute) (LEAP) and East-Asia energy future project (Nautilus Institute) (Southeast Asia Energy Outlook, 2013), Vashishtha and Ramachandran (2003); suggested the possibility of using demand side management (DSM) programs such as LEAP for modeling demand-side programs in Indian utilities. Gul and Qureshi (2012) forecast the long-term elasticity of electricity demand in the residential sector in Pakistan. The authors were able to project different scenarios that would affect the rate of electricity consumption including urbanization, complete electrification, energy use efficiency and population & economic growth. Similarly, Leila and Rubble (2011) modelled the Lebanese electricity sector using LEAP. The reporting included a scenario based analysis, contributing factor examining and implications on Lebanon’s national economy. Furthermore, Qingsong et al (2010) based their research on Shandong province case study, objectively predicting the energy demand for regional policy decision making. The findings showed an increase in demand as a result of the rapid economic development. The authors proposed the adoption of sustainable development strategies and improved energy efficiency through technological interventions. Huang et al (2011) simulated energy supply and demand for Taiwan country as a case study. Along with “business-as-usual” (BAU), scenarios based support studies for energy-efficiency improvement policies which resulted in retiring three existing nuclear power plants. Therefore, LEAP is a powerful tool for simulating & assessing energy kinetics, adapting real-time scenarios, scientific of mechanics of different technology, environmental impact elements and tolerance of multiple variables, all of which led to devising intelligent mitigation strategies and policies. Therefore, in this study, we explore LEAP modeling to understand the energy supply-demand, power systems engineering such as the consumption, generation, end-user human engineering behavioral characteristics and greenhouse (GHG) emission.

The capital of UAE is the largest of the emirates and possess two most energy demand intensive sectors, commercial and residential, respectively. Our model design relies on using actual concurrent statistical input data from UPC (Statistical Annual Report, 2014; Abu Dhabi Real, 2010; Connecting Abu, 2008; The Abu Dhabi Economic, 2008; Sustainable Development in Practice, 2012; Vine and Al Abed, 2001; United Arab Emirates, 2015; Seven Year Electricity Planning, 2013) for generation and consumption patterns as a total and as a breakdown per power plant in the UAE to meet demand and supply, including building structural design specifics and human engineering characteristics per building type. We treat 2013 as the base-year (BAU) as it is the most recent of information available (Sustainable Development in Practice, 2012; Vine and Al Abed, 2001; United Arab Emirates, 2015; Seven Year Electricity Planning, 2013; Statement of Future Capacity, 2008; Al Jasmi et al., 2015; Al Abd et al., 2015; The Report, 2014; Nuclear Power,
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