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King Abdullah Petroleum Studies and Research Center

Energy Productivity: Evaluating Large-Scale Building Energy Efficiency Programs in Oman

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Acknowledgement

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Key Points

More than 75 percent of the total electricity consumed in Oman is attributed to buildings, with almost 50 percent used by households. The absence of mandatory energy efficiency regulations for buildings, coupled with population growth, has led to a significant increase in annual energy consumption and peak power demand in the country – both averaging growth rates of 10 percent over the last five years. We used an energy productivity analysis approach to analyze the benefits of large-scale energy efficiency programs in new and existing buildings. Our study finds:

> Investment in energy efficiency measures to retrofit existing buildings could lead to significant economic and environmental benefits. The potential for energy savings will vary depending on implementation costs and scale of retrofits. The benefits that can be realized for residential buildings are significantly higher than those obtained for commercial or governmental buildings.

> If a minimal Level-1 energy retrofit program is applied to existing residential buildings, savings of 957 GWh/year in electricity consumption and 214 MW in peak power demand can be achieved. Moreover, if a Level-3 deep retrofit of energy efficiency measures is implemented for the residential sector, savings soar to 6,000 GWh/year in electricity consumption and 1,300 MW in peak power demand. Also, 4 million metric tonnes per year of carbon emissions will be eliminated.

> A Level-3 retrofit of the entire building stock in Oman can result in savings of 10,000 GWh/year in electricity consumption and 2,300 MW in peak power demand. Additionally, there would be a 7 million metric tonnes per year of reduction in carbon emissions.

> The economic impact of the buildings' energy efficiency retrofit program is the potential to create new employment in Oman. The direct effects for retrofitting buildings include jobs needed to implement energy efficiency measures while the indirect effects are associated with work needed to produce and supply energy efficiency equipment and materials.

Executive Summary

This paper outlines the benefits of large-scale energy efficiency programs for new and existing buildings in Oman, which has seen electricity consumption grow rapidly due to a population boom and poor regulations for building power usage. Based on historical data, electricity demand growth has been consistent over the last decade with an annual increase of 1,900 GWh for national power consumption. If left unchecked, national electricity consumption and peak demand would double by 2030 to 55,288 GWh and 11,240 MW, respectively.

To evaluate these efforts, an energy productivity analysis is carried out on the programs to discover their overall impact on Oman's economy. We examine proven sets of energy efficiency measures and policies and their impact on the energy productivity for the building sector. The study is based on economic analysis to account for multiple non-energy benefits as well as on energy savings incurred from optimal set of energy efficiency measures. The developed optimization-based analysis approach is applied in this study to evaluate the impact of specific energy efficiency measures for new and existing buildings on the energy productivity of the building sector.

In order to determine the cumulative impacts of the benefits that can incur from building energy efficiency programs, the monetary values of these benefits are estimated and accounted for as part of the energy productivity analysis. Specifically, three main benefits are considered for the three levels of energy retrofit programs proposed for the existing building stock in Oman including:

> Energy consumption reduction that results in two impacts on the energy productivity of the Omani building sector (i) drop in final energy consumption and (ii) increase in value added benefit (VAB) associated with the avoided cost of oil required to generate electricity.

> Peak electricity demand reduction, lowering the number of power plants required to meet future energy needs of the building sector.

> Carbon emission reduction due to decline in the consumption of oil or gas to generate electricity in power plants.

More than 58 percent of the benefits can be achieved by just retrofitting residential buildings only, as shown in Table 1, using 2014 building stock estimates.

Table 1. Benefits of energy efficiency retrofit programs for residential buildings in Oman.

Retrofit Program	Investment Level-1	Investment Level-2	Investment Level-3
Peak Demand Savings (MW)	214	616	1,340
Annual Energy Savings (GWh/year)	957	2,751	5,980
Annual CO2 Savings (million metric tonnes/year)	0.660	1.900	4.125
Annual Avoided Fuel Costs (USD million/year)	80	230	500
Avoided Power Plant Costs (USD million)	365	1,050	2,275
Job years (during a 10-year period)	2,071	20,694	41,376

Source: KAPSARC analysis.

The results of the analysis show that the implementation of a government funded large-scale energy retrofit program for existing residential buildings is highly cost-effective.
We find that a basic Level-1 large-scale energy efficiency retrofit program of households can provide a saving of 957 GWh in annual electricity consumption and 214 MW in peak demand as well as in excess of 660,000 metric tonnes per year in carbon emissions reduction (see Table 1). However, if the residential building stock of Oman underwent a Level-3 deep retrofit the benefits are as follows: 5,980 GWh in annual electricity savings, 1,340 MW in peak demand and more than 4.125 million metric tonnes per year of reduction in carbon emissions.

Introduction

We evaluate the impacts of large-scale building energy efficiency programs in Oman using the energy productivity analysis approach. Energy efficiency programs targeting both new and existing buildings were considered in this study. As part of the analysis, the benefits of implementing a wide range of energy efficiency measures were first determined using a whole-building energy simulation analysis applied to energy models representing existing building stock.

An optimization analysis was then carried out to determine the best energy efficiency measure to improve the energy performance for prototypical building energy models in Oman.

Economic and environmental benefits of a wide range of energy efficiency programs were also quantified for the Omani building stock using a bottom-up analysis approach. In particular, the impacts of developing and enforcing new building energy efficiency codes were evaluated. In addition, different retrofit levels of existing buildings were considered. Finally, the implementation costs and impacts of energy efficiency programs on energy productivity were evaluated.

Energy Productivity in the Buildings Sector

In order to assess the effectiveness of large-scale energy efficiency programs, an energy productivity analysis approach was considered (KAPSARC 2015). In this paper, optimization-based analysis is used to evaluate energy efficiency measures and policies on the energy productivity of the building sector in Oman.

In order to assess the effectiveness of using energy by an economy or one of its sectors, energy productivity was introduced as a metric to assess how energy resources can be allocated to optimize economic growth. Generally, the term energy productivity is simply defined as the value of services and goods that can be produced by one unit of energy. For an economy, the energy productivity is typically estimated as the ratio of the gross domestic product (GDP) per total primary energy supply (TPES). The higher this ratio, the more effective and productive the economy is in extracting value to generate goods and services from the energy it consumes. It is clear that the service sector inherently has a higher energy productivity value than other energy intensive sectors such as industry and transport.

It has been argued that energy productivity can provide a better measure of a country's economy, energy and environmental performance (KAPSARC 2014). The energy productivity (EP_B) for any sector of an economy such as the building sector can be estimated as the ratio of the value added in buildings (VA_B) and the total final energy consumption in buildings (TFC_B) attributed to the sector:

$$EP_B = \frac{VA_B}{TFC_B} \tag{1}$$

The energy productivity indicator, as defined by Equation (1), can be utilized to assess how energy resources could be allocated to optimize the sector's economic growth (KAPSARC 2015). Based on combined IEA and UNSTAT data (see Appendix A), Figure 1 shows the annual variation of energy productivity of three sectors representing buildings, industry and transport in Oman (IEA 2016; UNSTAT 2016). As shown in Figure 1, the energy productivity for all three sectors, and thus the effectiveness of energy resource utilization, has been generally decreasing, especially since 2005.

The energy productivity metric has the advantage of being able to account for most of the benefits attributed to energy efficiency programs that can be quantified. As outlined in Krarti (2015), significant social, economic and environmental benefits can be derived from large-scale building energy efficiency programs including savings in energy consumption (avoided oil use), reduction in peak electricity demand (avoided construction of power plants), decrease in carbon emissions (mitigation of greenhouse gases) and creation of new job opportunities (investments that can be provided by the government initially and then supported by the private sector). Moreover, enhancing energy efficiency of buildings can provide additional non-energy benefits such as improved thermal comfort, healthy indoor environment and higher work productivity. Recent studies have attempted to quantify the non-energy benefits of building energy efficiency programs (Lebaron 2011; Hyland et al. 2013; WGBC 2013; Skumatz 2014 and Russell et al. 2015). The added value of the non-energy benefits, if it can be quantified, can further enhance the cost effectiveness of building energy efficiency programs.

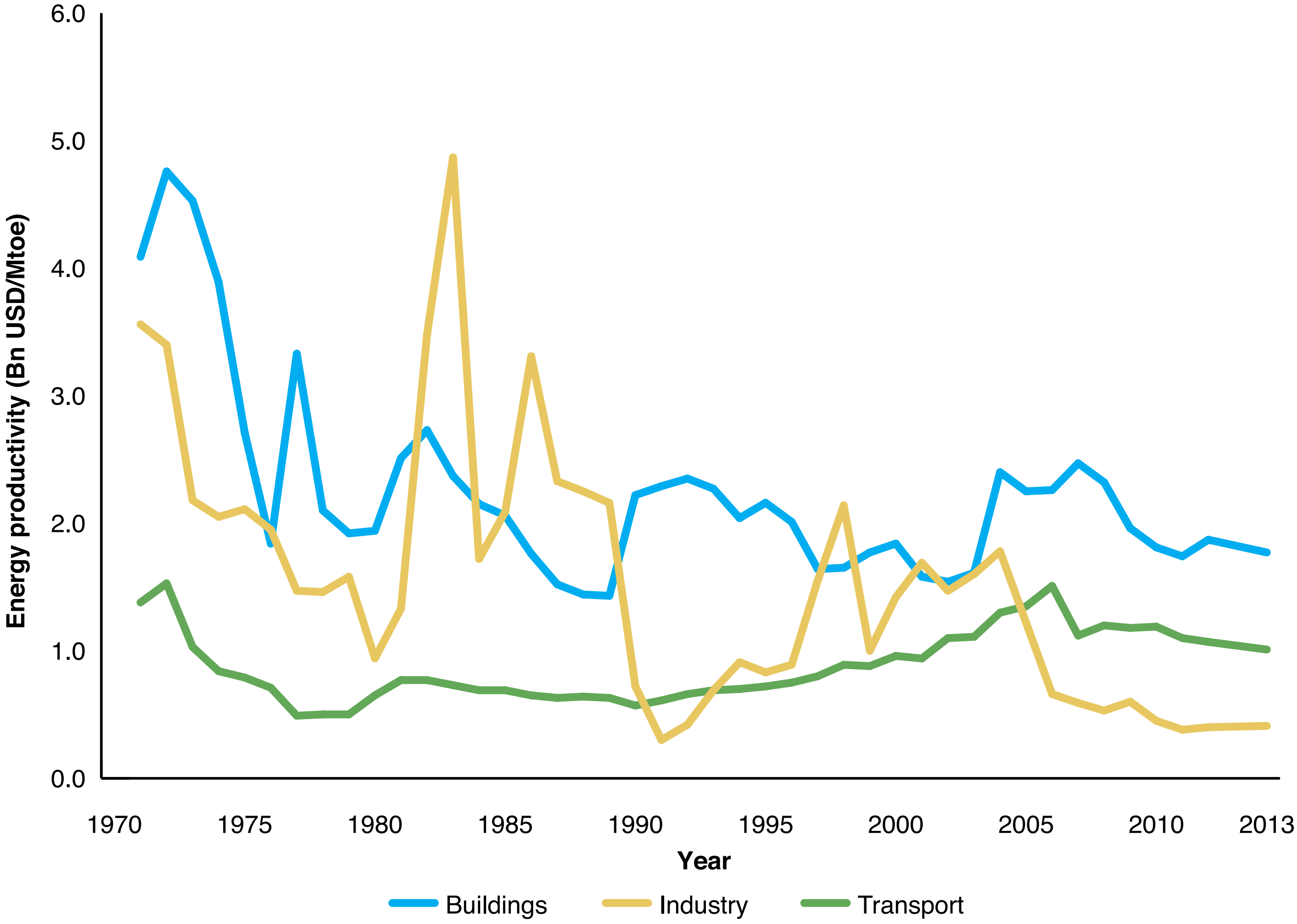


Figure 1. Annual energy productivity for three sectors in Oman.

Source: Sectorial analysis based on IEA Data 2016 and UNSTAT 2016.

Currently, there are no specific energy efficiency mandatory regulations for buildings in Oman. Due to high population growth and lack of any comprehensive energy efficiency program, electricity consumption and peak power demand have increased significantly, especially during the last few years as shown in Figure 2. The building sector alone consumes 77 percent of total electricity generated in Oman. Residential, commercial and governmental buildings account for 48 percent, 20 percent and 9 percent, respectively, of total electricity consumed in 2014. As illustrated in Figure 2, a regression analysis of available historical data shows that there is consistent growth of electricity demand over the last decade with an annual increase of 1,900 GWh for energy consumption and 365.7 MW for peak demand. If this growth remains unchanged, the annual electricity consumption and peak demand are forecast to rise to 55,288 GWh and 11,240 MW, respectively, by 2030 (i.e., double current demand).

In order to improve energy efficiency in the building sector, the Omani government has initiated some actions and pilot programs to promote sustainability of the entire building stock (TRC 2014; OBG 2013; TRC 2014). However, very limited studies and analyses have been published to assess the benefits of improving current practices for the design,

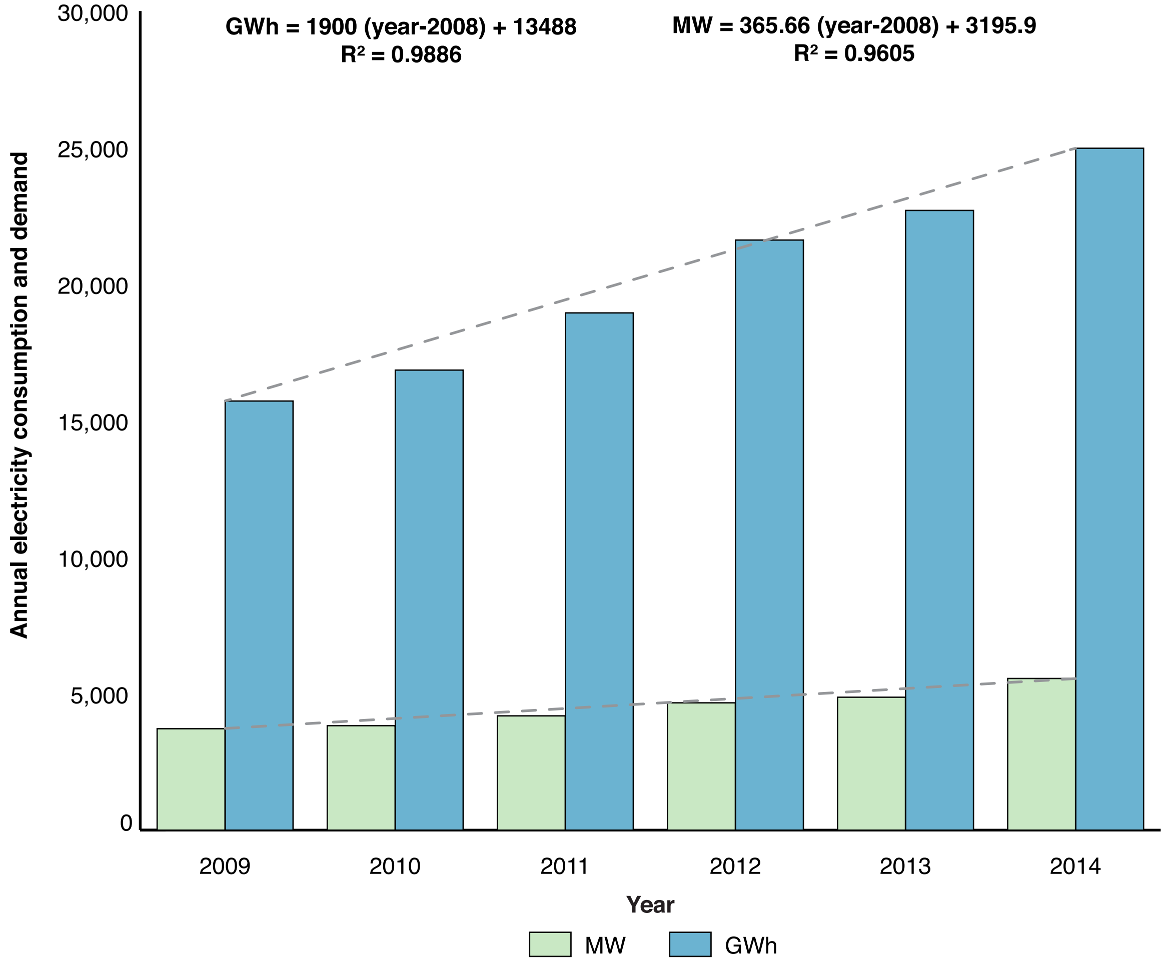


Figure 2. Annual electricity consumption and peak demand, 2009-2014.

Source: Oman Power and Water Procurement Corporation (OPWP), 2014.

construction and operations of Omani buildings to increase energy performance. For example, one analysis investigated the potential of load management strategies using gas cooling and ice storage systems to reduce peak electricity demand as well as the impacts of introducing time-of-use tariffs (JICA 1998). Another study found that implementing energy efficient air conditioning and lighting systems in commercial and governmental buildings can reduce peak demand by up to 596 MW and electricity consumption by as much as 44,000 GWh by 2024 (Malik 2007).

A simulation-based analysis showed that simple control strategies such as reducing lighting use by 25 percent and increasing cooling temperature from 20°C to 24°C can provide savings of 25.6 percent in annual energy consumption (Saleh and Alalouch 2015). Similarly, the benefits of clean power generation technologies including the use of renewable energy to generate electricity were evaluated by several studies (Malik and Gastli 2009; Gastli and Charabi 2010; Gastli and Charabi 2011; Al-Badi 2011a, 2011b; Solanki et al. 2013 and Al Hatmi et al. 2014). However, the lack of incentives and legal framework are the main reasons for the limited deployment of energy efficiency technologies in Oman. Through a survey of construction stakeholders, the main challenges to promote energy efficiency technologies and practices in the building sector were identified (Saleh and Alalouch 2015) and include:

> Economic challenges due to higher costs associated with energy efficient products including thermal insulation for building envelope systems. Indeed, most of these products are not manufactured locally and have to be imported. Moreover, high energy subsidies make any investment in energy efficiency cost ineffective for building owners or developers (Al-Badi et al. 2015; Powmya and Abidin 2014).

> Lack of knowledge and expertise on sustainable construction practices were identified as one of the barriers to promoting high performance buildings. There were also a lack of codes and standards to promote energy efficiency (Al-Badi et al. 2015; Powmya and Abidin 2014).

> Social challenges due to resistance from various building sector stakeholders to change conventional construction methods in order to adopt more sustainable practices. These challenges become more engrained due to a lack of legal and economic incentives to promote high energy performance buildings (Al-Badi et al. 2015; Powmya and Abidin 2014).

Analysis of Building Energy Efficiency Measures

Baseline energy models for prototypical buildings

Using the bottom-up approach to evaluate the impacts and benefits of a wide range of energy efficiency measures on electricity consumption in the building sector, energy models were developed and utilized to represent existing building stock in Oman. Three energy models for residential buildings were established representing: a two-story villa, a five-story apartment building and a single-story traditional house. At the same time, three energy models for commercial and governmental buildings were considered: an office building, a school and a retail store. The characteristics of the baseline energy models for all building prototypes were defined using data collected from reported energy audit studies (Radhi et al. 2005; Malik 2007, Mallala et al. 2010; Alaidroos and Krarti 2015; Ameer and Krarti 2016). Building specifications for various prototypical building energy models are provided in Appendix B (Table B1). The energy analysis to assess the impact of several energy efficiency measures on both annual energy consumption and peak demand was carried out using a whole-building simulation analysis and hourly weather data for Muscat (EnergyPlus, 2015).

As expected, air conditioning to maintain indoor thermal comfort is responsible for most of the electricity used in buildings. For instance, cooling energy end-use represents 75 percent of total annual electricity consumed by prototypical villa models located in Muscat as shown in Figure 3 based on the results of a whole-building simulation analysis. Similar results are found for other prototypical building energy models defined in Appendix B (see Table B1).

Using monthly historical data for 2014, the impact of air conditioning to cool buildings on monthly total electricity consumed in Oman can be established by using a regression analysis with either cooling degree-days or average ambient outdoor temperatures as shown in Figures 4(a) and 4(b), respectively (Krarti 2012). The monthly base-load consumption associated with electricity needs for operating industrial facilities as well as buildings equipment, appliances and lighting is estimated at 969 GWh as illustrated in Figure 4(a). Building air conditioning energy consumption increases with outdoor air temperature, especially during summer months. In particular, Figure 4(b) shows that monthly electricity energy consumption tripled from 1,000 GWh in February to 3,000 GWh in July (OPWP 2014).

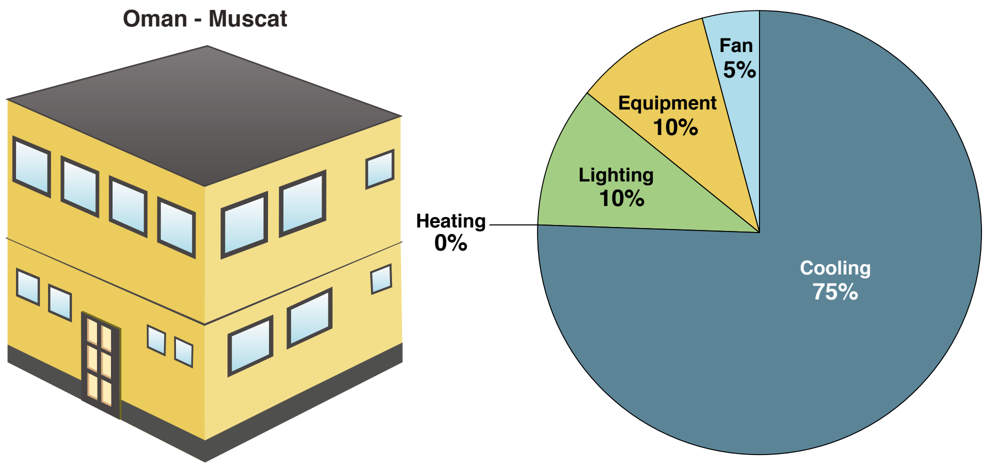
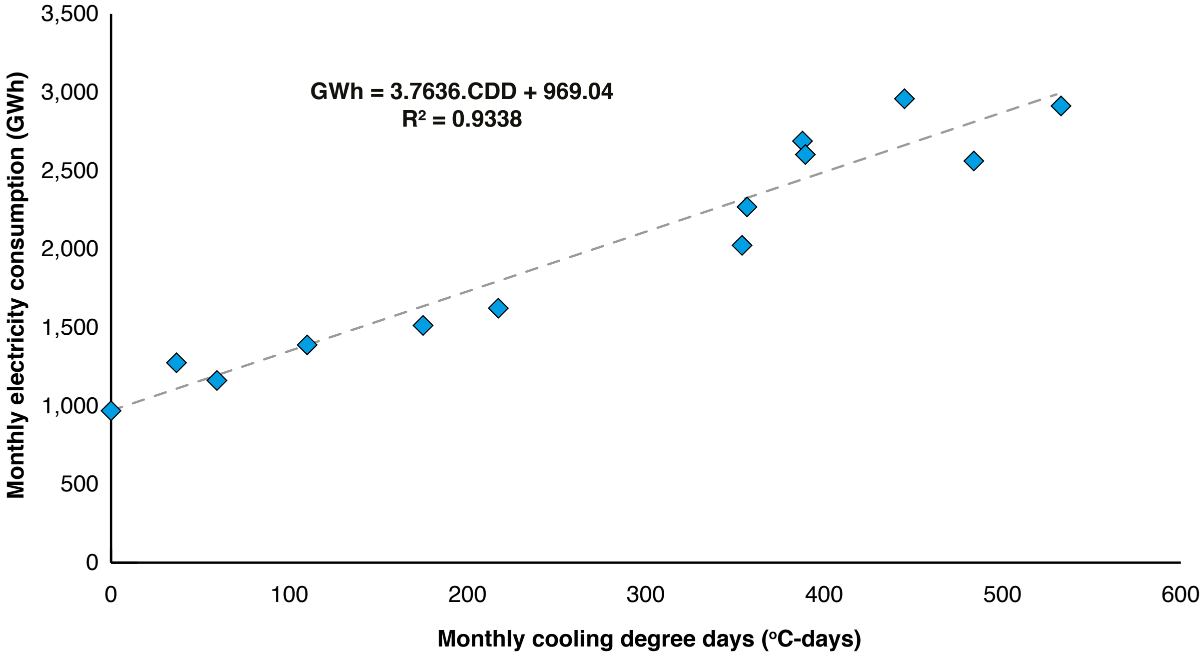


Figure 3. (a) 3-D rendering for energy model, (b) annual energy end-use distribution for a prototypical villa in Muscat.

Source: KAPSARC analysis.



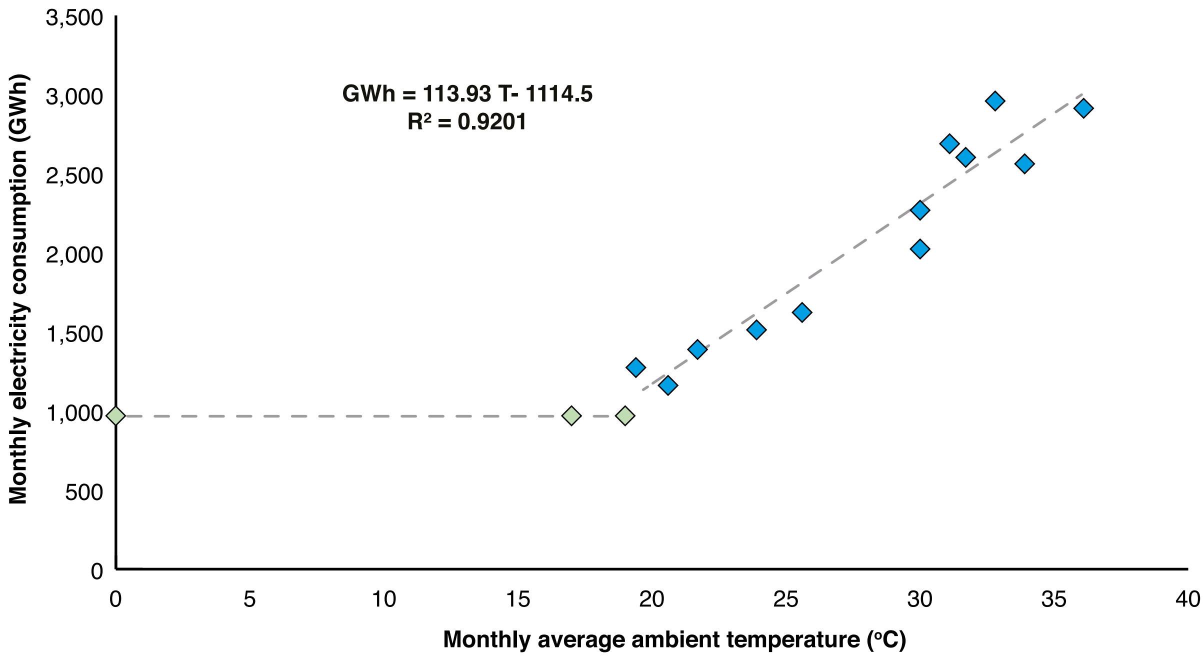


Figure 4. Monthly 2014 electricity consumption versus (a) monthly degree-days, (b) monthly average ambient.

Source: KAPSARC analysis.

Impact of individual energy efficiency measures

In order to determine the impacts of a wide range of design and operating energy efficiency measures on annual energy consumption as well as peak demand for the prototypical building energy models outlined in Appendix B (Table B1), a comprehensive parametric analysis was carried out using Muscat weather data. An example of the results is shown in Figures 5 and 6 of the percentage variations in annual energy consumption and peak electricity demand, respectively, with selected energy efficiency measures considered for the baseline villa energy model. As expected, installing an energy efficient air conditioning system has the most significant impact in reducing both annual energy consumption and peak demand. The measure that has the second-largest impact is (i) setting the cooling temperature at 26°C (79°F) instead of 24°C (75°F) to reduce energy consumption and (ii) reducing air infiltration to make the building shell airtight to decrease peak demand. Generally, measures that can reduce annual energy consumption are also effective in lowering peak electricity demand.

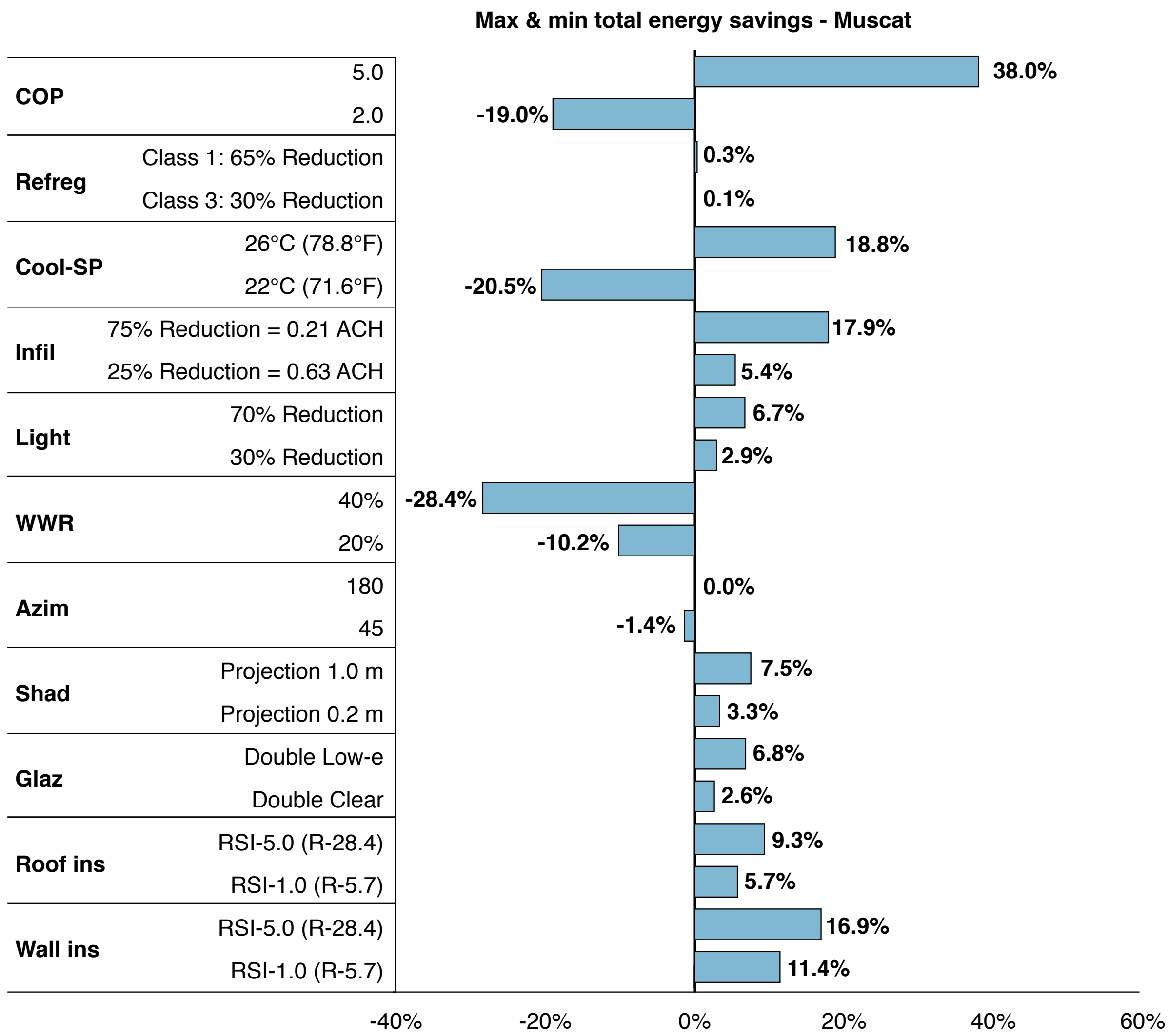


Figure 5. Impact of each EEM on energy savings for a villa in Muscat.

Source: KAPSARC analysis.

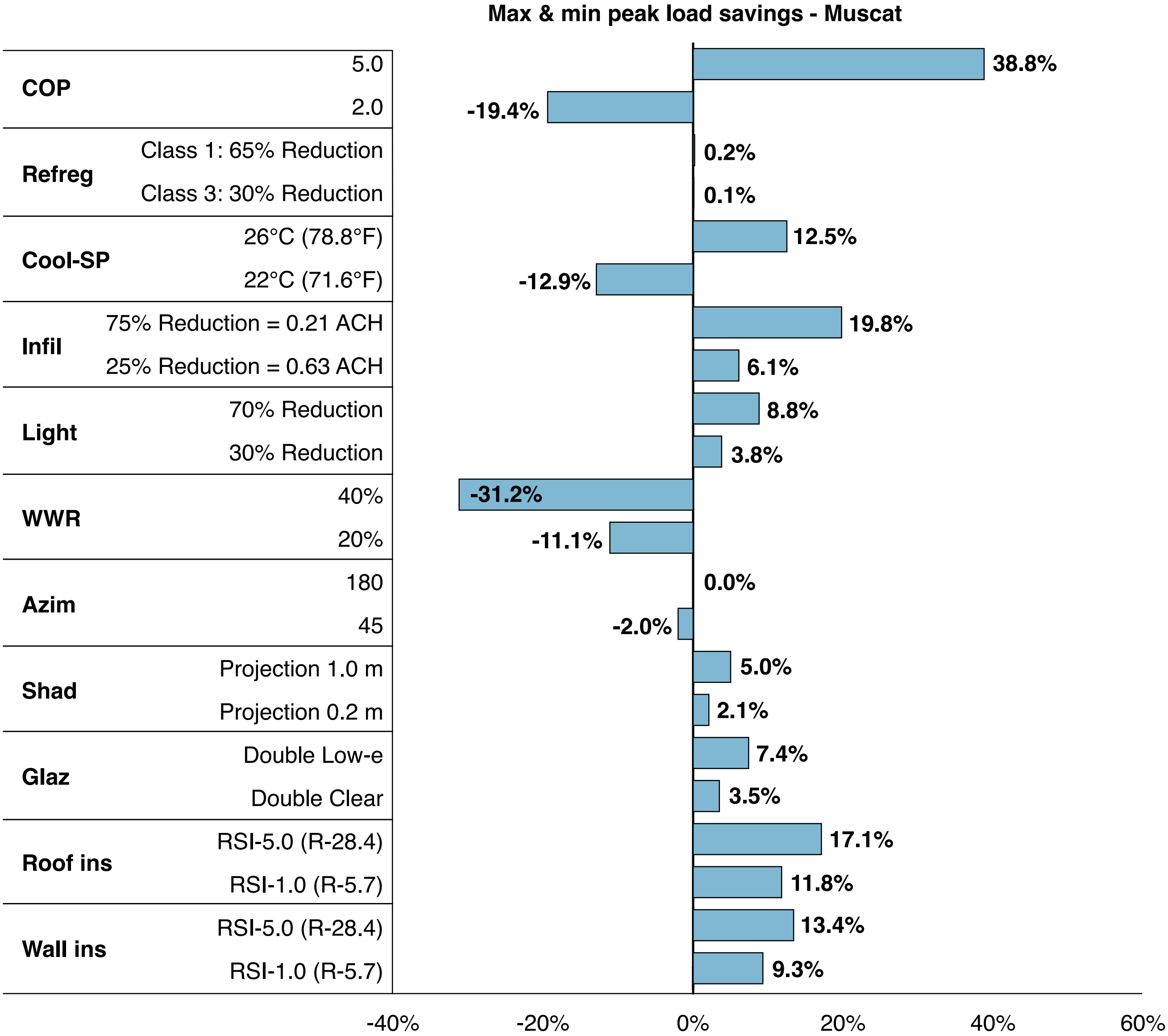


Figure 6. Impact of each EEM on peek demand for a villa in Muscat.

Source: KAPSARC analysis.

Impact of combined energy efficiency measures

In order to determine the best energy efficiency measures to implement for residential and commercial buildings, life-cycle cost based optimization analysis was carried out for each building energy model considered in Appendix B (Table B1). The optimization analysis was performed using the sequential search technique described by Alaidroos and Krarti (2015). The reported production cost of $0.08347/kWh for generating electricity in Oman was considered in the optimization analysis (AER 2014). Implementation costs of various energy efficiency measures were obtained from several sources (Krarti and Ihm 2015; Ameer and Krarti 2016; Alaidroos and Krarti 2015). Figure 7 represents the Pareto graph obtained from the optimization results, which shows the optimal path to achieve net-zero energy building design or retrofit for the prototypical villa in Muscat. Results from the life-cycle cost optimization analysis reveal that optimal cost-effective designs or retrofits can achieve reduction of about 61 percent in total energy consumption and 64 percent in peak electricity demand for the prototypical 2-story villa. The optimal set of energy efficiency measures as well as the associated savings in annual energy consumption and peak demand for all prototypical buildings are summarized in Appendix C (Table C1). Savings range from 53 percent to 68 percent for all residential and commercial building energy models.

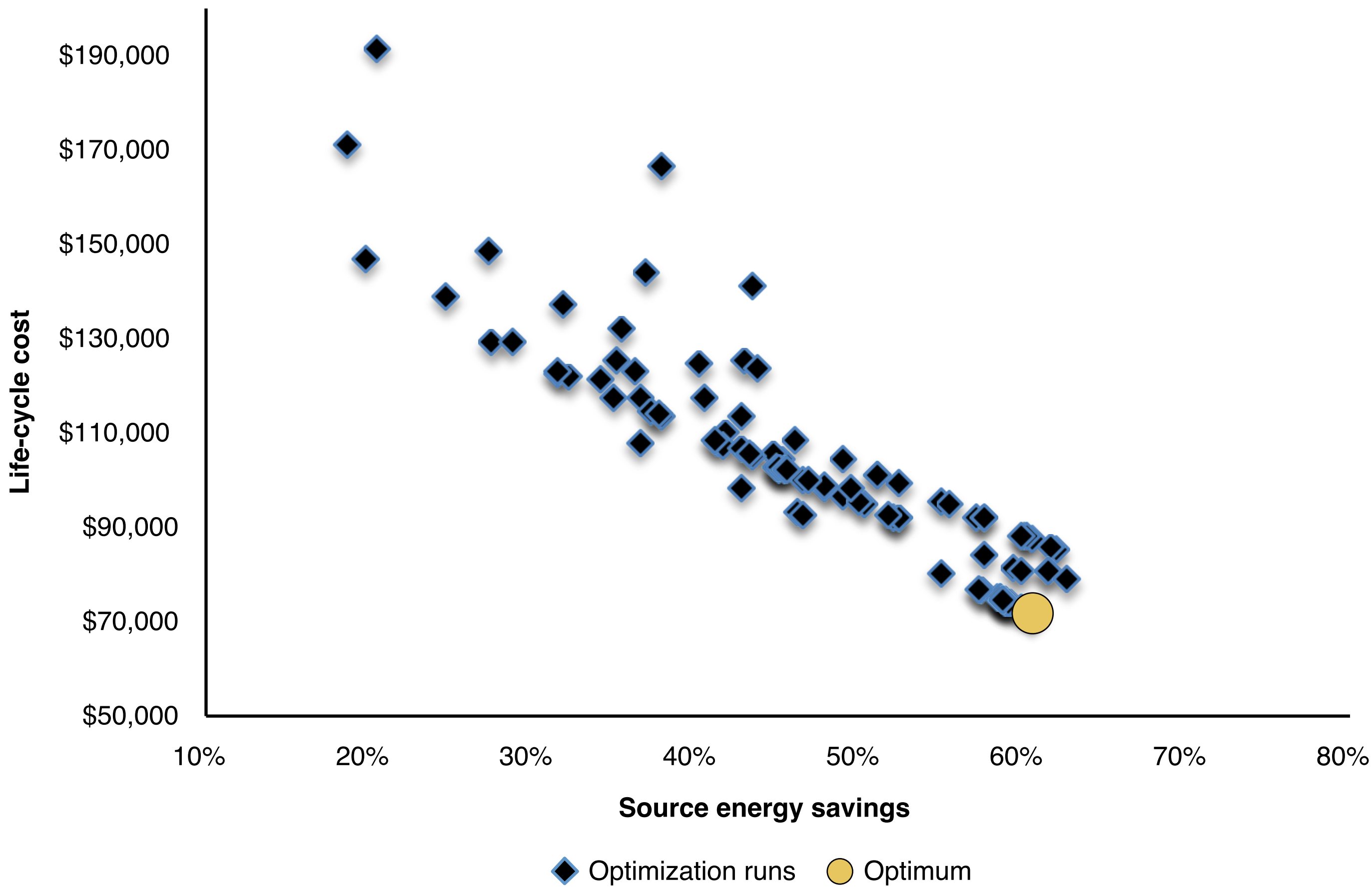


Figure 7. Optimization analysis showing energy savings vs. life-cycle cost for a 2-story villa in Muscat.
Source: KAPSARC analysis.

Evaluating Benefits of Energy Efficiency Programs

Energy efficiency programs for new buildings

Thermal insulation requirements

As noted earlier, there are no mandatory energy conservation requirements for buildings in Oman. If thermal insulation for walls and roofs as well as better glazing for windows are required for new buildings, an estimated reduction of at least 25 percent in annual energy consumption and peak electricity demand can be achieved based on the parametric analysis results obtained for the buildings listed in Appendix B (Table B1). Using the same bottom-up analysis carried out by Krarti (2015), the economic and environmental benefits of thermal insulation requirements on new buildings can be estimated as summarized in Table 2. The carbon emissions for generating electricity are assumed to be 0.690 kgCO2/kWh and the cost of a power plant is projected to be $1,700/kW. It is estimated that new buildings represent 6 percent of the existing building stock for 2014.

Table 2. Economic and environmental benefits after insulation improvements.

Building Type	**Annual Energy Use Savings** (GWh/yr)	**Peak Demand Savings** (MW)	**Annual CO2 Emissions Savings** (million metric tonnes/yr)	**Annual Energy Cost Savings** (USD million/yr)	**Peak Demand Savings** (USD million)
Residential Buildings	179	40	0.124	15	68
Commercial Buildings	76	17	0.037	6	29
Governmental Buildings	55	12	0.027	5	20
Total	310	69	0.188	26	117

Note: Results based on better insulated building envelope systems for all new buildings in Oman using 2014 building stock estimates.

Source: KAPSARC analysis.

Comprehensive energy efficiency requirements

Using the results of the optimization analysis illustrated in Figures 7 and in Table 2, more stringent building energy efficiency regulations can be developed and adopted in Oman for all new buildings. The impact of such a stringent code is assumed (Table B2) to be 50 percent savings in both energy consumption and peak demand associated with the new building stock. These savings are set lower than the potential levels that could be achieved for all building prototypes as shown in Appendix B (Table B2). The conservative values account for behavioral variations including some rebound effects (Majcen et al. 2013; Jabobsen and Kotchen 2013). The benefits of a comprehensive building energy efficiency code applied to new buildings are estimated and are summarized in Table 3.

Table 3. Economical and environmental benefits of a stringent building code.

Building Type	**Annual Energy Use Savings** (GWh/yr)	**Peak Demand Savings** (MW)	**Annual CO2 Emissions Savings** (million metric tonnes/yr)	**Annual Energy Cost Savings** (USD million/yr)	**Peak Demand Savings** (USD million)
Residential Buildings	359	80	0.248	30	136
Commercial Buildings	152	34	0.075	13	58
Governmental Buildings	109	24	0.054	9	41
Total	620	139	0.377	52	236

Note: Results following implementation of an exacting building energy efficiency code for all new buildings in Oman based on 2014 building stock estimates.

Source: KAPSARC analysis.

Energy retrofits for existing buildings

Three levels of energy efficiency building retrofits are suggested for Oman with different economic and environmental benefits (ASHRAE 2011; Hong et al. 2015; Krarti 2015):

> **Level-1 of energy efficiency retrofit:** involves low-cost energy efficiency measures such as installation of programmable thermostats, use of CFL or LED lighting fixtures and weatherization of building shell to reduce air infiltration. As detailed in Table 4, the estimated average savings from a Level-1 retrofit program are 8 percent for residential building stock based on the simulation analysis carried out for this study as well as case studies reported for residential, commercial and governmental buildings.

> **Level-2 of energy efficiency retrofit:** includes use of energy efficient cooling systems as well as temperature and lighting controls. Based on the simulation results obtained in this study as noted in Table 4 and confirmed by findings in the literature, average savings of 23 percent can be achieved for Level-2 retrofits of residential building stock (Hong et al. 2015; Ameer and Krarti 2016).

> **Level-3 of energy efficiency retrofit:** requires the implementation of capital-intensive measures including addition of roof thermal insulation, cooling system replacement and installation of daylighting control systems. While deep retrofits are typically costly, they can provide significant energy use savings exceeding 50 percent as noted in the results from the simulation analysis, which are outlined in Table 4.

Table 4 provides specific packages of simple yet proven energy efficiency measures that can be considered for the three building energy retrofit levels using the results of the simulation analysis carried out for this study. The potential annual energy use savings for each package is also given in Table 4. Moreover, ranges for the rebound effects associated with changes in occupant behaviors are estimated for each energy efficiency package and building retrofit level using results from reported analyses (Majcen et al. 2013 and Jabobsen et al. 2013; Borenstein 2013).

Table 4. Options for energy efficiency measures specific to three retrofit levels of residential buildings.

Recommended Options	Retrofit Description (a)	Retrofit Level for Residential Buildings		
		Level-1	Level-2	Level-3
1	List of EEMs	EEM-1	EEM-1, EEM-2, and EEM-3	EEM-1, EEM-2, EEM-3 and EEM-4
	Energy use savings	12%	28%	54%
	Range of reduction in savings due to behavioral and rebound effects (b)	0 – 6 %	0 – 6 %	0 – 6 %

2	List of EEMs	EEM-1	EEM-1, EEM-2, and EEM-3	EEM-1, EEM-2, EEM-3 and EEM-4
	Energy use savings	10.0%	29%	51.0%
	Range of reduction in savings due to behavioral and rebound effects (b)	0 - 4%	0 - 4%	0 - 4%
3	List of EEMs	EEM-1	EEM-1, EEM-2, and EEM-3	EEM-1, EEM-2, EEM-3 and EEM-4
	Energy use savings	10%	28%	52%
	Range of reduction in savings due to behavioral and rebound effects (b)	0 - 4%	0 - 6%	0 -6%

Source: KAPSARC analysis.

Notes: (a) Description of EEMs:

EEM-1: Increase the cooling set from 21°C to 23°C, from 22°C to 24°C, or from 23°C to 25°C depending on the existing operating conditions.

EEM-2: Replace existing lighting fixtures by LEDs

EEM-3: Seal air leakage sources around building envelope (i.e., window and door frames so ACH =0.21)

EEM-4: Replace the existing AC unit with high efficiency system (COP=4.0)

EEM-5: Better lighting controls including dimming daylighting and occupancy sensors for commercial buildings

EEM-6: Insulate the roof using RSI-3

(b) The behavioral and rebound effects are estimated based on previous studies. Typically, the effects are higher for measures that rely on temperature and lighting controls (i.e., EEM-1 and EEM-5).

As noted earlier, the economic benefits of the building energy efficiency retrofit programs are estimated using actual cost of 32.4 Bz/kWh, which is required for generating and distributing electricity (i.e., $0.08347/kWh) rather than the average subsidized price of 15.7 Bz/kWh (i.e., $0.040/KWh) based on AER data (AER 2014). The environmental benefits are estimated using an average carbon emission factor of 690 gCO2/kWh (Solanski 2013). Table C1 (see Appendix C) summarizes the annual CO2 emissions, annual energy cost and peak demand savings for Level-1, Level-2 and Level-3 building energy efficiency retrofit programs. As shown in Table C1, significant economic and environmental benefits can be achieved for all levels of the building energy retrofit programs. While requiring larger implementation costs, higher benefits and savings can be achieved for Level-2 and Level-3 retrofits compared with Level-1. The economic and environmental benefits that can be realized for residential buildings are significantly higher than those for commercial or governmental buildings for all levels of energy retrofit. Indeed, more than 58 percent of the benefits can be achieved by solely retrofitting residential buildings as illustrated in Table C1.

It is anticipated that the implementation of large-scale building energy efficiency retrofit programs will be gradual, generally over several years, due to two main reasons: (i) significant investments are needed to renovate the entire existing building stock as estimated in the Cost-Effectiveness Analysis section and (ii) lack of qualified energy efficiency contractors in Oman as discussed in the Job Creation section that is to follow. However, any of the three energy retrofit programs can result in significant economic and environmental benefits even if only a small fraction of the existing building stock is targeted.

Program Implementation Considerations

Energy prices are highly subsidized in Oman. Table 5 shows current electricity prices for residential, governmental and commercial customers. While commercial buildings have a flat rate of $0.05194/kWh, residential and governmental customers are charged based on the level of their consumption ranging from a low of $0.026/kWh to $0.078/kWh. The Omani Authority for Electricity Regulation estimated that the average price charged to all its customers is 15.7 Baiza/kWh ($0.0408/kWh) in 2014 (AER 2014). Since the minimal economic cost of generating electricity is reported to be 25.3 Baiza/kWh (i.e., $0.0743/kWh) for 2014, the Omani government provides subsidies of about 9.7 Baiza/kWh ($0.0252/kWh) or 38 percent of the economic cost of generating electricity. The subsidy is estimated to be even higher reaching 46 percent in 2015 (AER 2014). Overall, the IMF estimates that in 2015 total energy subsidies amounted to $7.27 billion, or 8.9 percent of GDP (IMF 2015).

The cost-effectiveness of implementing large-scale energy efficiency programs for existing buildings are estimated in this study from the perspective of the Omani government. Investing in energy efficiency measures are generally not cost-effective for building owners due to highly subsidized energy prices. As discussed earlier, the overall economic, environmental and social benefits of the retrofit programs are significant for Oman and, therefore, their cost-effectiveness should be evaluated from the perspective of the government. First, the costs needed to fully implement the three building energy efficiency retrofit programs are estimated. Then, the cost-effectiveness analysis of the energy efficiency retrofit programs are carried out for various building types. Finally, the job creation potential required for the implementation of the energy retrofit programs is determined and discussed in this section.

Table 5. Electricity prices for residential, governmental and commercial buildings.

Commercial Buildings (flat rate) **Residence/Government Buildings**	**20 BZ/kWh ($0.05194/kWh)**
0-3,000 kWh	10 Bz/kWh ($0.026/kWh)
3,001-5,000 kWh	15 Bz/kWh ($0.039/kWh)
5,001-7,000 kWh	20 Bz/kWh ($0.052/kWh)
7,001-10,000 kWh	25 Bz/kWh ($0.065/kWh)
10,000+ kWh	30 Bz/kWh ($0.078/kWh)

Source: Authority of Electricity regulation, 2014.

Cost-Effectiveness Analysis

The specific implementation costs for the building energy retrofits depend on several factors including the building size and physical conditions of the building energy systems. Based on various sources including cost of labor and materials in the GCC, the average costs of completing energy retrofit for buildings are estimated (Krarti 2011; Krarti 2012; Krarti and Ihm 2014; and Ameer and Krarti 2016). Table 6 summarizes the implementation costs for all three levels of energy retrofit programs for residential, commercial and governmental buildings including the costs for performing energy audits as well as for installing any recommended energy efficiency measures.

The cost benefit analysis for building energy efficiency retrofit programs to upgrade existing buildings are estimated using the latest available building stock statistics (NCSI 2015). The results, summarized in Table C2 (Appendix C), show that the three levels of energy retrofit programs are highly cost-effective when deployed for residential buildings. In fact, the implementation costs for Level-1 retrofit would be recovered from the avoided costs of building new power plants to generate the electricity needed to meet the energy requirements of households if no efficiency actions were taken. The payback periods for all three retrofit levels are found to be longer for commercial and governmental buildings, and this is most probably due to the high estimated implementation costs of energy efficiency measures for these buildings. It is, therefore, highly recommended that a retrofit program be developed first to improve the energy efficiency of existing residential buildings as summarized in Table C2 (Appendix C).

Table 6. Average costs in USD for energy retrofits of buildings in Oman.

Building Type	Level-1	Level-2	Level-3
Residential Buildings	250	2,500	5,000
Commercial Buildings	5,000	25,000	50,000
Governmental Buildings	10,000	50,000	100,000

Source: KAPSARC analysis.

Job Creation and Market Potential Estimates

Another economic impact of building energy efficiency retrofit programs is the potential to create new employment. As outlined by Pollin et al. (2009), Hyland (2013) and Krarti (2015), the direct effects of retrofitting buildings include jobs needed to implement energy efficiency measures while the indirect effects are associated with works needed to produce and supply energy efficiency equipment and materials. Most of the jobs created for building retrofits are within the construction and manufacturing industries with a wide range of pay level and technical specialization including electricians, heating, ventilation and air conditioning (HVAC) technicians, insulation installers, energy auditors, building inspectors and construction managers.

Using the job creation model considered in the analysis performed by Krarti (2015), a $1 million investment in building energy retrofit can create 12 job-years with seven direct and five indirect jobs. Direct jobs are those required to audit and implement energy efficiency measures in the buildings while the indirect ones are associated with producing and supplying energy efficiency equipment and materials (Pollin et al. 2009). In the case of Oman, up to 41,376 new job-years can be created when renovating existing residential buildings using Level-3 retrofit as illustrated in Table 7. When the entire building stock is considered, as much as 143,633 job-years would be created to implement a Level-3 retrofit. If a Level-3 energy efficiency retrofit is implemented over a 10-year period, 14,363 jobs per year can be created. It should be noted that most of the jobs including energy auditors, HVAC technicians and electricians can be filled by Omanis instead of expatriates if an intensive national building capacity initiative is implemented as part of the retrofit program. Further investigation is needed to assess the specific number of jobs that can be carried out by locals.

Table 7. Number of job-years that can be created from a building energy retrofit program.

Building Type	Level-1	Level-2	Level-3
Residential	2,071	20,694	41,376
Commercial	6,914	34,581	69,984
Governmental	3,308	16,553	33,094
Total	12,293	71,817	143,633

Source: KAPSARC analysis.

Impact of Building Energy Efficiency on Energy Productivity

In order to determine the cumulative impacts of the benefits that can be incurred from building energy efficiency programs, the monetary values of these benefits are estimated and accounted for as part of the energy productivity analysis outlined earlier. Specifically, three main benefits are considered for the three levels of energy retrofits proposed for existing buildings in Oman:

- Energy consumption reduction that results in two impacts on energy productivity of the building sector as defined by Equation (1): (i) reduction in final energy consumption, (TFC_B) and (ii) increase in (VA_B), associated with the avoided cost of oil required to generate electricity. To estimate the value added of avoided oil consumption, an oil price of $45/bbl, production cost of $5.30/bbl (Knoema 2016) and average efficiency of 36 percent for power plants (IEA 2015) were utilized.

- Reductions in peak electricity demand lowers the number of power plants required to meet the future energy needs of the building sector. An average cost of $1,700/kW is considered to estimate the increase in added value, VA_B, due to the avoided power plant capacities.

- Carbon emission reduction due to a decrease in the need to combust oil or gas to generate electricity in power plants. A value of $10/tonne is used to estimate the increase in added value, VA_B, due to the lower carbon emissions (EPA 2016; Russell et al. 2015).

Figure 8 shows the effects of the three levels of energy retrofits considered in this study on the energy productivity of the Omani building sector. The impacts of the benefits outlined above are evaluated gradually for the three retrofit programs. When accounting for only the savings in energy consumption, without accounting for the potential monetary added value of avoided oil use, energy productivity can increase from $1.76 million/TOE to $2.86 million/TOE (i.e., 62 percent) when Level-3 retrofit is applied to the building stock. However, when considering all the benefits and their added values, assuming the private sector can provide the necessary investments needed for the programs, the energy productivity can double when the entire building stock is retrofitted. When the government finances the entire retrofit programs, energy productivity can increase by up to 160 percent for the entire building stock. Figure 9 illustrates the progression of the building sector energy productivity when all the benefits are considered for the three retrofit levels when the implementation period is set for 20 years (so that each year 5 percent of the building stock is retrofitted) with a two-year startup period for planning and the building of a pool of energy auditors. As shown in Figure 9, Level 3 retrofit provides the best option to increase the energy productivity of the building sector. It should be noted that the sole implementation of mandatory building energy efficiency codes, thermal insulation (walls and roof) for new buildings leads only to a 2 percent increase in the energy productivity (from $1.76 to $1.80 million/TOE) of the Omani building sector but it increases by 4 percent (from $1.76 to $1.83 million/TOE) when a comprehensive set of requirements are considered as shown in Figure 10.

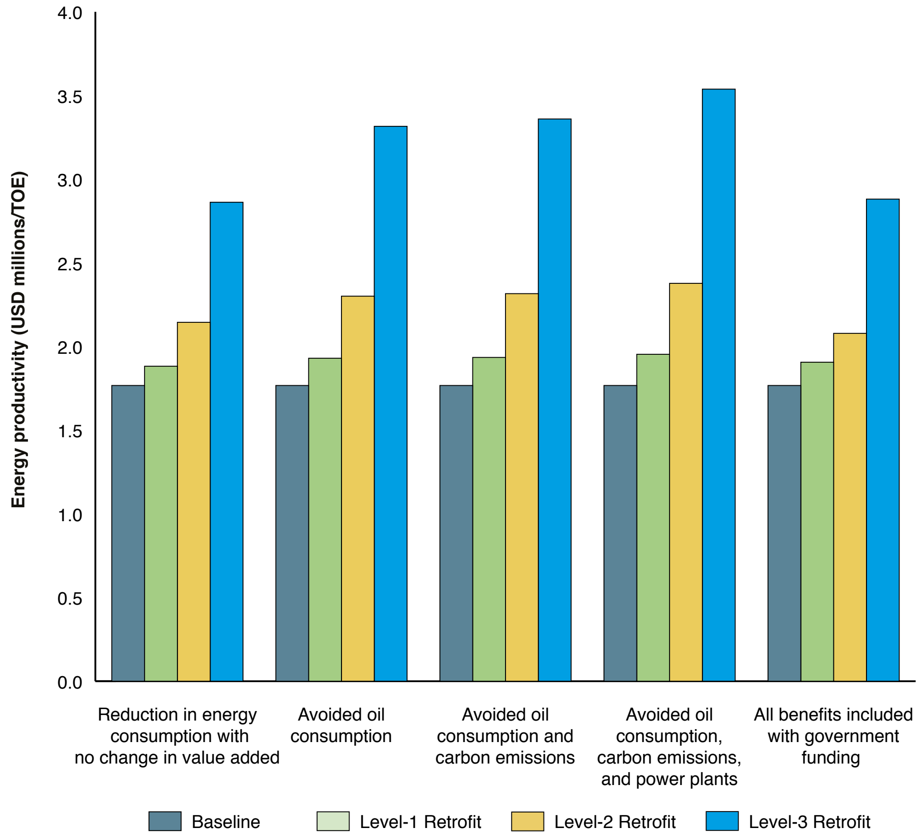


Figure 8. Impact of three energy retrofit programs for the entire building stock in Oman.

Source: KAPSARC analysis.

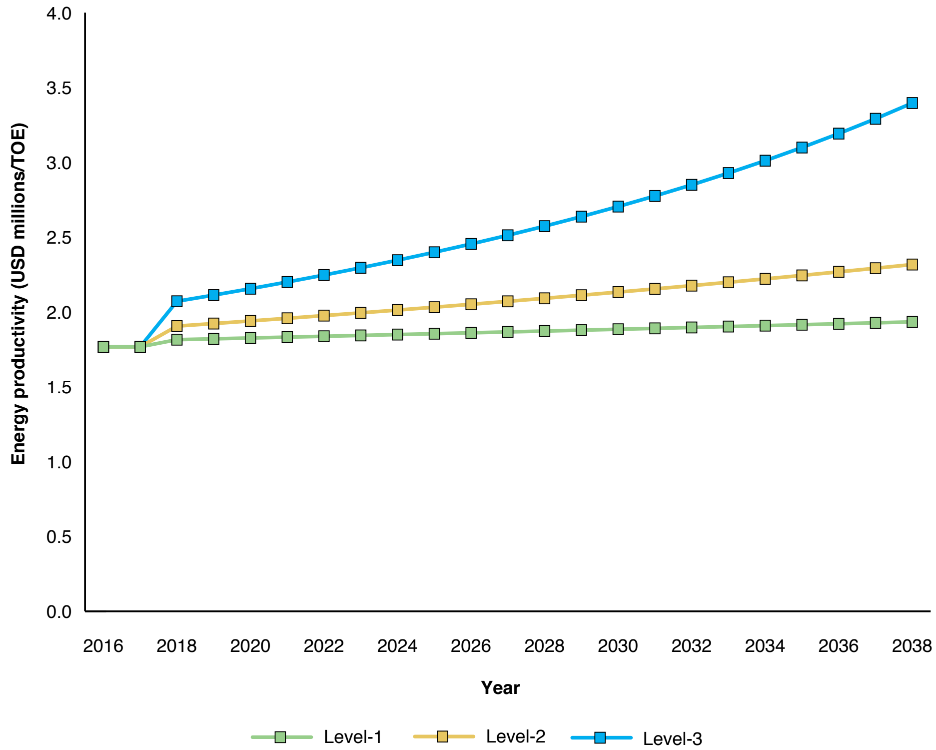


Figure 9. Building sector energy productivity for three retrofit programs of entire Oman building stock over 20 years.

Source: KAPSARC analysis.

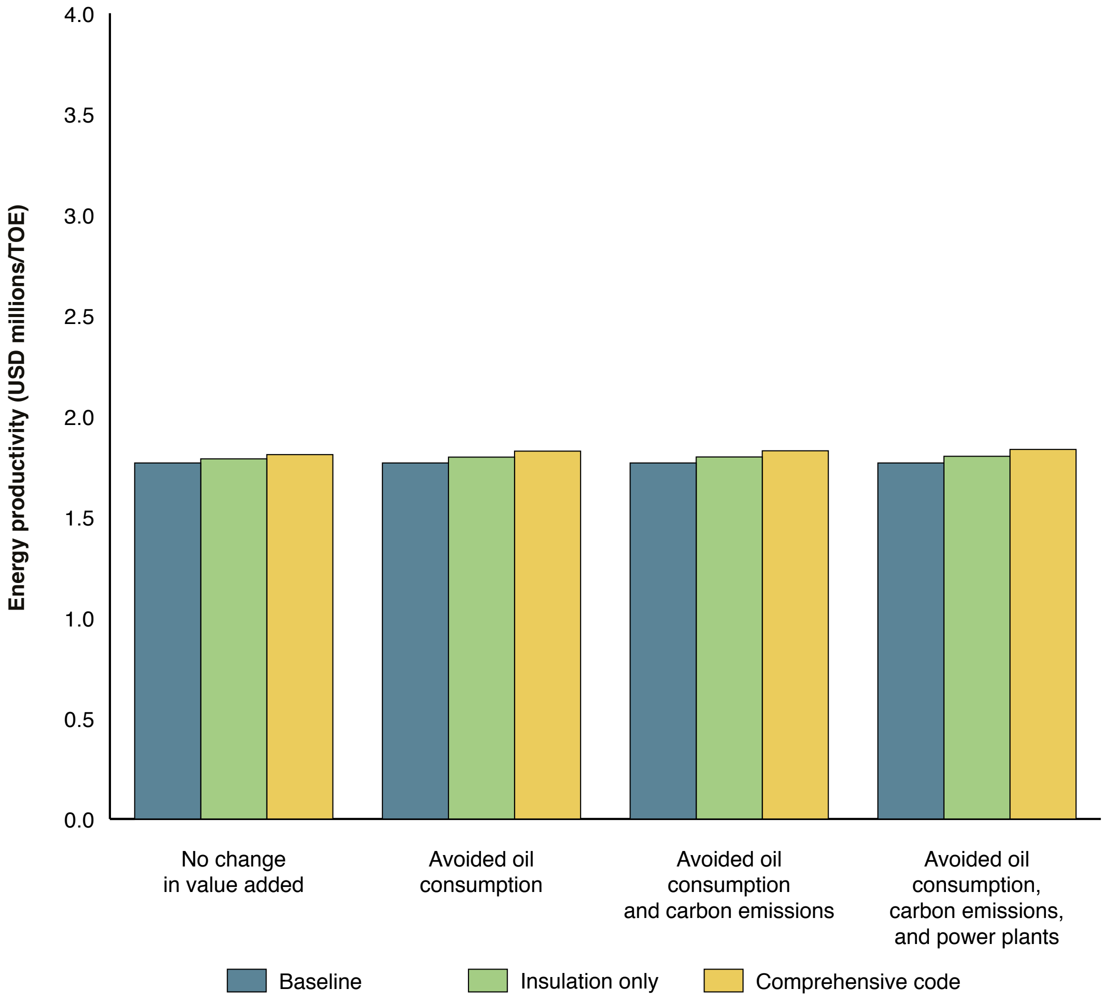


Figure 10. Implementation of building energy efficiency code on new buildings.

Source: KAPSARC analysis.

Conclusion

The analysis outlined in this paper shows that improving the energy efficiency of the building stock in Oman has several benefits including reduction in electricity consumption, peak power demand and carbon emissions, as well as the creation of a sizable number of employment opportunities. In particular, we found that a Level-1 energy retrofit of residential buildings is highly cost-effective even when the government has to finance the implementation costs for all existing households.

A Level-1 energy retrofit program, when applied to existing Omani residential building stock, could achieve savings of 957 GWh/year in electricity consumption, 214 MW in peak electricity demand and reduce 660,000 metric tonnes/year in carbon emissions. Moreover, the results summarized in this paper show that a large-scale Level-3 energy retrofit program for residential buildings can create a significant number of jobs, with up to 41,376 full time job-years. Over 143,633 job-years are estimated if the entire Omani building stock is retrofitted.

When all the benefits are considered, the analysis shows that Level-3 retrofit program has the highest impact and can double the energy productivity of the Omani building sector, allowing the release of significant funds from avoided oil revenues and power plant investments that can be utilized for other government initiatives.

If a minimal Level-1 energy retrofit program is applied to all existing Omani buildings, savings of 1,650 GWh/year in electricity consumption, 370 MW in peak power demand and 1.1 million metric tonnes per year in carbon emissions can be achieved. Furthermore, when a Level-3 deep retrofit of energy efficiency measures are implemented to the entire building stock savings increase to 10,000 GWh/year in electricity consumption and 2,300 MW in peak power demand. Additionally, there would be a reduction of 7 million metric tonnes per year in carbon emissions.

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Appendix A

Table A1. Sectoral classification for value added and total final energy consumption.

Sector	**Total final energy consumption** Source: IEA	**Value added** Source: UNSTAT ISIC Rev 3.1
Buildings	**Residential:** households, excluding fuels used for transport. Includes households with employed persons, which is a small part of total residential consumption. **Commercial and public services** **Others:** includes residential, commercial/public services, agriculture/ forestry, fishing and non-specified (other).	**Section: G – wholesale and retail trade:** repair of motor vehicles, motorcycles and personal and household goods. **Section: H – Hotels and restaurants**
Industry	**Industry:** excluding mining and construction and including non-energy use (covers those fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel).	**Section: D – Manufacturing** Comprises units engaged in the physical or chemical transformation of materials, substances or components into new products. The materials, substances, or components transformed are raw materials that are products of agriculture, forestry, fishing, mining or quarrying as well as products of other manufacturing activities.
Transport	**Transport:** covers all transport activity (in mobile engines) regardless of the economic sector.	**Section: I – Transport, storage and communications** Includes activities related to providing passenger or freight transport, whether scheduled or not, by rail, pipeline, road, water or air: • Supporting activities such as terminal and parking facilities, cargo handling, storage etc. • Postal activities and telecommunication. • Renting of transport equipment with driver or operator.

Source: KAPSARC analysis.

Appendix B

Table B1. Building construction specifications for prototypical villa.

Building Model	Villa	Apartment Building	Traditional House	Office Building	School	Retail Store
Number of Floors	2	5	1	4	1	1
Total Floor Area	525 m^2	3,750 m^2	200 m^2	11,600 m^2	7,000 m^2	1,400 m^2
Wall Construction	20 mm plaster outside + 200 mm concrete hollow block + 20 mm plaster inside			200 mm light concrete + 20 mm plaster inside		
Roof Construction	10 mm built-up roofing + 150 mm concrete roof slab + 12.7 mm plaster inside			10 mm built-up roofing + 200 mm concrete roof slab + 12.7 mm plaster inside		
Glazing	Single-clear with wood frames			Single-clear with aluminum frames		
Window-to-Wall Ratio	10%	10%	10%	20%	10%	20%
Infiltration	0.84 ACH	0.84 ACH	0.84 ACH	0.60 ACH (Perimeter only)	0.70 ACH	0.60 ACH (Perimeter only)
Cooling Set Point	24°C (75.2°F)	24°C (75.2°F)	24°C (75.2°F)	23°C (73.4°F)	24°C (78.8°F)	23°C (73.4°F)
HVAC System	Split DX	Roof-Top	AC Window	Central with VAV	Roof-Top	Roof-Top
HVAC COP/EER	COP=2.5	COP=2.5	COP=2.5	EER= 8.5	EER=4.5	EER=4.5
Occupancy Period	24 hour/day	24-hour/day	24-hour/day	8:00-16:00 (weekdays)	7:00-17:00 (weekdays)	8:00-23:00 (daily)

Source: KAPSARC analysis.

Table B2. List of optimal design and operating strategies; and potential energy use and peak demand savings for prototypical buildings in Muscat.

EEM	2-story Villa (525 m²)	5-story Apartment Building (3,750 m²)	1-story Traditional House (200 m²)	4-story Office Building (7,000 m²)	1-story School (7,000 m²)	1-story Retail Store (1,400 m²)
Wall insulation	RSI-3.0 (R-17.0) Polystyrene	RSI-3.0 (R-17.0) Polystyrene	RSI-3.0 (R-17.0) Polystyrene	RSI-3.0 (R-17.0) Polystyrene	RSI-3.0 (R-17.0) Polystyrene	RSI-3.0 (R-17.0) Polystyrene
Roof insulation	RSI-4.0 (R-22.7) Polystyrene	RSI-4.0 (R-22.7) Polystyrene	RSI-4.0 (R-22.7) Polystyrene	RSI-4.0 (R-22.7) Polystyrene	RSI-4.0 (R-22.7) Polystyrene	RSI-4.0 (R-22.7) Polystyrene
Glazing	Double Low-e	Double Low-e	Double Low-e	Double Low-e	Double Low-e	Double Low-e
Shading	Projection 0.5 m	Projection 0.5 m	Projection 0.5 m	Projection 0.5 m	Projection 0.5 m	Projection 0.5 m
Lighting	70% Reduction	70% Reduction	70% Reduction	50% Reduction	50% Reduction	50% Reduction
Daylighting	No	No	No	Dimming Controls	No	Dimming Controls
Infiltration	75% Reduction = 0.21 ACH	75% Reduction = 0.21 ACH	75% Reduction = 0.21 ACH	75% Reduction = 0.21 ACH	75% Reduction = 0.21 ACH	75% Reduction = 0.21 ACH
Cooling Set Point	26°C (78.8°F)	26°C (78.8°F)	26°C (78.8°F)	26°C (78.8°F)	26°C (78.8°F)	26°C (78.8°F)
Appliances	Efficient Refrigerator 45% Reduction	Efficient Refrigerator 45% Reduction	Efficient Refrigerator 45% Reduction	Energy Star Appliances 40% Reduction	Energy Star Appliances 40% Reduction	Energy Star Appliances 40% Reduction
Air Economizer	No	No	No	Yes	Yes	Yes
HVAC COP	4.5	4.5	4.5	4.5	4.5	4.5
Baseline Total Energy Use (kWh)	98,812	651,070	36,926	2,322,100	1,410,400	412,550
Total Energy Use (kWh)	38,214	263,040	13,849	1,028,400	610,030	141,720
Total Energy Savings	61.3%	59.6%	62.5%	55.7%	56.8%	65.7%
Baseline Peak Demand (kW)	38.0	214.4	13.2	1,055	623	168
Case Peak Demand (kW)	11.1	80.3	4.2	491	284	66
Peak Demand Savings	-	62.6%	68.1%	53.4%	54.3%	65.9%

Source: KAPSARC analysis.

Appendix C

Table C1. Economic and environmental benefits for three levels of building energy efficiency retrofit programs for Oman based on 2014 building stock estimates.

Retrofit Program	Level-1	Level-2	Level-3
Annual Energy Savings (GWh/year)			
Residential Buildings	957	2,751	5,980
Commercial Buildings	404	1,162	2,525
Governmental Buildings	291	836	1,817
Total Existing Building Stock	1,652	4,748	10,322
Peak Demand Savings (MW)			
Residential Buildings	214	616	1,339
Commercial Buildings	90	260	565
Governmental Buildings	65	187	407
Total Existing Building Stock	370	1,063	2,311
Annual CO2 Savings (Thousand tonnes/year)			
Residential Buildings	660	1,898	4,126
Commercial Buildings	279	802	1,742
Governmental Buildings	201	577	1,254
Total Existing Building Stock	1,140	3,277	7,122
Annual Avoided Fuel Costs (USD million/year)			
Residential Buildings	80	230	499
Commercial Buildings	34	97	211
Governmental Buildings	24	70	152
Total Existing Building Stock	138	396	862
Avoided Power Plants Costs (USD Million)			
Residential Buildings	364	1,047	2,276
Commercial Buildings	153	442	961
Governmental Buildings	111	318	692
Total Existing Building Stock	628	1,807	3,929

Source: KAPSARC analysis.

Table C2. Cost-effectiveness analysis of three energy efficiency retrofit programs in Oman.

Retrofit Program	Level-1	Level-2	Level-3
Implementation Program Costs (USD million)			
Residential Buildings	174	1,739	3,477
Commercial Buildings	581	2,906	5,881
Governmental Buildings	278	1,391	2,781
Total Existing Building Stock	1,033	6,035	12,070
Annual Avoided Fuel Costs (USD million/year)			
Residential Buildings	80	230	499
Commercial Buildings	34	97	211
Governmental Buildings	24	70	152
Total Existing Building Stock	138	396	862
Avoided Power Plants Costs (USD million)			
Residential Buildings	364	1,047	2,276
Commercial Buildings	153	442	961
Governmental Buildings	111	318	692
Total Existing Building Stock	628	1,807	3,929
Payback Period (years)			
Residential Buildings	0	3.0	2.4
Commercial Buildings	12.6	25.4	23.3
Governmental Buildings	7.0	15.3	13.7
Total Existing Building Stock	2.9	10.7	9.4

Source: KAPSARC analysis.

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About the Project

Increasing energy productivity holds some of the greatest possibilities for enhancing the welfare countries get out of their energy systems. It also recasts energy efficiency in terms of boosting competitiveness and wealth, more powerfully conveying its profound benefits to society. KAPSARC and UNESCWA have initiated this project to explore the energy productivity potential of the Arab region, starting with the six GCC countries and later extending to other countries. Aimed at policymakers, this project highlights the social gains from energy productivity investments, where countries are currently at, and pathways to achieving improved performance in this area.

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