KAPSARC

مركـز الملـك عبـدالله للدراسـات والبحوث البترولية
King Abdullah Petroleum Studies and Research Center

An Evaluation of High Energy Performance Residential Buildings in Bahrain

Kankana Dubey and Moncef Krarti

July 2017 / KS-2017--DP16

About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment, across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

Legal Notice

Acknowledgement

This paper has been prepared as part of the joint KAPSARC-UNESCWA project 'Energy Productivity in the GCC' and we would like to thank our UNESCWA colleagues for their helpful input and advice. The paper will be used as input to a joint report on improving energy productivity in the GCC region.

Key Points

This paper describes our analysis of the cost-effectiveness of designing and retrofitting residential buildings in Bahrain and outlines our analytical approach. The study focuses on residential buildings since households consume more than 48 percent of electricity used in the country. As expected, residential buildings constitute the vast majority of Bahrain's building stock, with about 76 percent of the total and projected annual growth in energy consumption of around 3 percent in the next few years.

The optimization analysis outlined in this paper assesses the potential benefits from retrofitting both individual buildings and the entire national building stock, as well as the benefits of applying proven measures and technologies to improve the energy efficiency of the building sector. Our conclusions are:

> The development and enforcement of a more stringent energy efficiency code can potentially improve the energy efficiency of the new building stock with a reduction of more than 320 GWh in annual electricity consumption and 87 MW in peak demand.

> Retrofitting the existing building stock in Bahrain has the potential to cost-effectively reduce energy consumption in the building sector by 62 percent, with a 55 percent reduction in peak electricity demand compared with the business as usual scenario. The avoided costs of building new power plants would be sufficient to offset the implementation costs for a basic level of energy retrofitting of existing residential buildings.

> We estimate that as much as 31,700 job-years of employment can be created when retrofitting the existing building stock. More than 3,000 jobs would be needed annually in order to retrofit existing buildings over a 10-year period.

Executive Summary

Bahrain is an island nation in the Middle East with a population of about 1.2 million. It is 780 square kilometers in size, making it the smallest member of the Gulf Cooperation Council. To conserve energy, it adopted an energy efficiency code for commercial buildings in 1999. This has prescriptive compliance requirements for thermal insulation in the walls and roofs as well as minimal specifications for window glazing. The application of this code was extended to all building types in 2013.

In our study, a sequential search technique is applied to optimize the design of residential buildings in the capital, Manama, to minimize life cycle energy costs using a wide range of energy efficiency measures. In our analysis, design features for air-conditioned single family homes are considered, including orientation, window location and size, glazing type, wall and roof insulation, lighting fixtures, appliances and efficiencies of heating and cooling systems.

Based on this optimization analysis, the economic and environmental impacts of developing and enforcing a more stringent energy efficiency code for new buildings, as well as the implementation of retrofit programs for existing buildings, are evaluated.

The analysis outlined here demonstrates that when a more stringent building energy efficiency code is developed and enforced for newly constructed residential and commercial buildings, Bahrain could reduce its electricity consumption by 320 GWh/year, peak demand by 87 MW and carbon emissions by 242,000 tons/year. Moreover, a basic energy retrofit program using easy to implement energy efficiency measures for existing residential buildings could reduce electricity consumption by about 495 GWh/year, peak demand by 116 MW and carbon emissions by 377,000 tons/year.

Table 1 summarizes the potential benefits from three levels of energy retrofits of existing residential buildings in Bahrain. The avoided costs associated with both the construction of power plants and fuel required for electricity generation can offset the cost of implementing a basic energy retrofit of residential buildings. A similar analysis was conducted for commercial buildings and these are also discussed in detail in the paper. The benefits outlined in Table 1 could double if both residential and commercial buildings were retrofitted.

In order to initiate an energy retrofit program for existing buildings in Bahrain, investments through energy services companies (ESCOs) can be considered. This would use the performance contracting concept, a means of financing energy efficiency investments that is based on future savings.

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

Retrofit Program	Investment Level-1	Investment Level-2	Investment Level-3
Peak demand savings (MW)	116	335	727
Annual energy savings (GWh/year)	495	1,422	3,091
Annual CO_2 savings (million metric tons/year)	0.377	1.083	2.355
Annual avoided fuel costs ($million/year)	37	106	230
Avoided power plant costs ($million)	140	401	873
Job years (during a 10-year period)	50	503	1,006

Source: KAPSARC analysis.

Overview of Energy Demand and the Buildings Sector

Over the last decade, Bahrain has seen both its population and its per capita energy consumption increase steadily at an annual rate of 5 percent, as shown in Figure 1, which uses data for 2000 to 2012 from the Ministry of Water and Electricity (MEW 2014). This population growth, combined with high energy use per person, has significantly increased the power generation required to meet the country's national needs, especially in the growing residential sector.

Figure 2 illustrates the annual electricity consumption and peak demand variations from 2000 through 2012 in Bahrain. As shown in Figure 2, a regression analysis of the data indicates that there is a consistent growth rate for both electricity consumption and peak demand of about 5 percent in the last decade (MEW 2014). Bahrain has five power stations with a combined capacity of 4,938 MW, to serve a peak load of 2,728 MW as of 2013 (Alnaser 2015). Thus, it has a sizable available generating capacity to meet any future increase in electricity demand. However, if the growth rate in electricity consumption follows the linear trend illustrated in Figure 2, and assuming business as usual with no significant energy efficiency improvements and any associated rebound effects, annual peak demand is predicted to rise to more than 5,400 MW – almost double current peak load – by 2030. Recent data obtained from the MEW shows peak electricity demand at 3,100 MW in 2014, which follows closely the linear model shown in Figure 2.

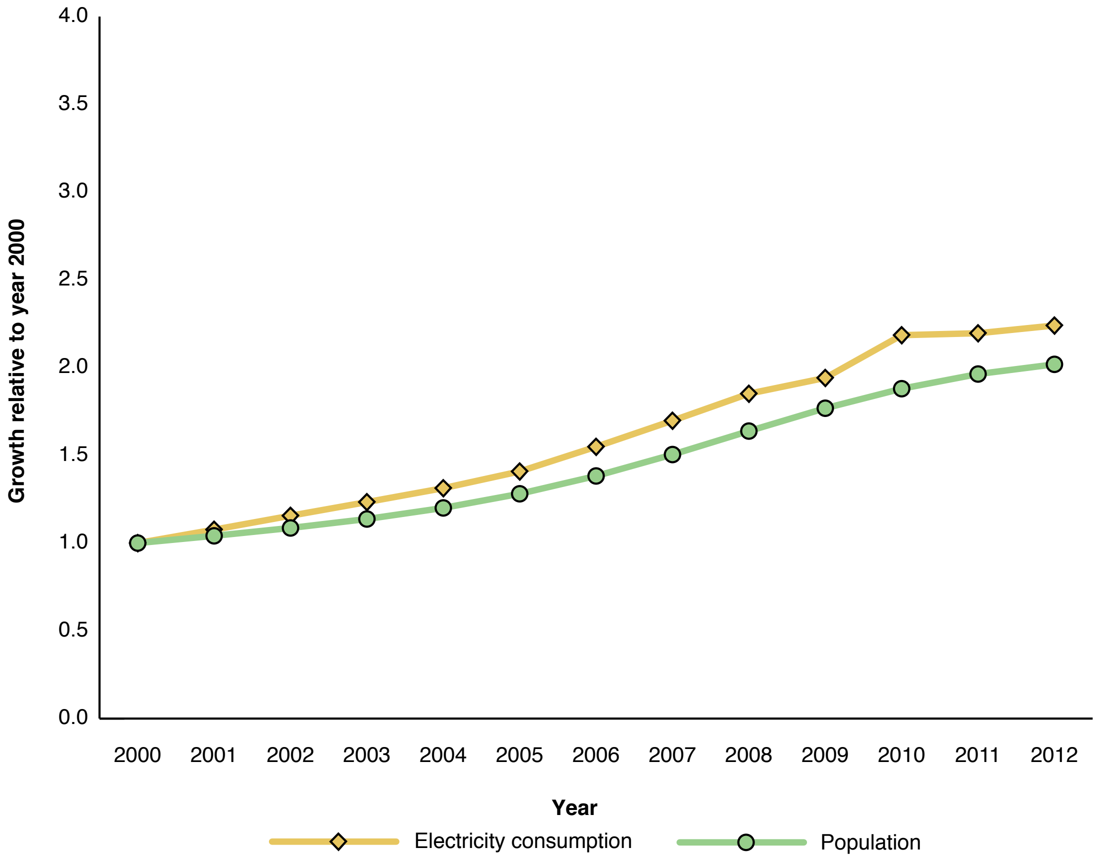


Figure 1. Variation of population and electricity consumption 2000-2012.

Source: MEW, 2014.

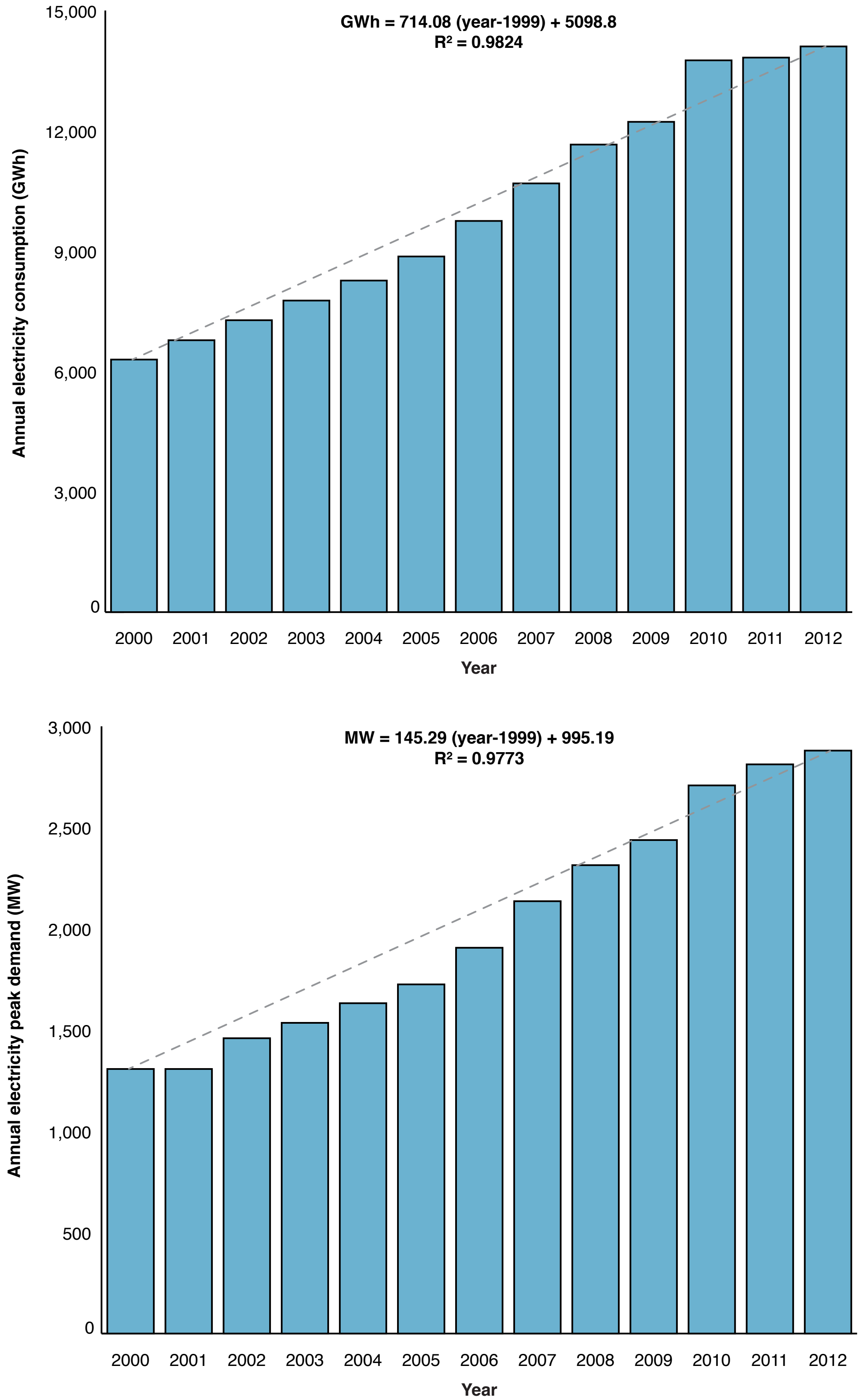


Figure 2. Variation of annual (a) electricity consumption and (b) peak demand 2000-2012.

Source: KAPSARC analysis using MEW data, 2014.

Most of the electricity consumed in Bahrain is attributed to residential buildings. As noted in Figure 3, the residential sector accounted for about 48 percent of total consumption in 2013 (Alnaser 2015). Data on the number of customers by type is not readily available from the MEW. However, total MEW customers are estimated to be around 200,000 in 2003 for all sectors, with an average annual increase of 3 percent. A recent quarterly report from the Bahrain Economic Board showed that there are 124,065 Bahraini households and 61,117 non-Bahraini households in 2010, which are projected to increase to 173,000 and 90,050, respectively, by 2020 (Alnaser 2015). Table A1 (Appendix A) lists the building types and their number estimated for the year 2013 based on historical MEW data and the number of households in 2010.

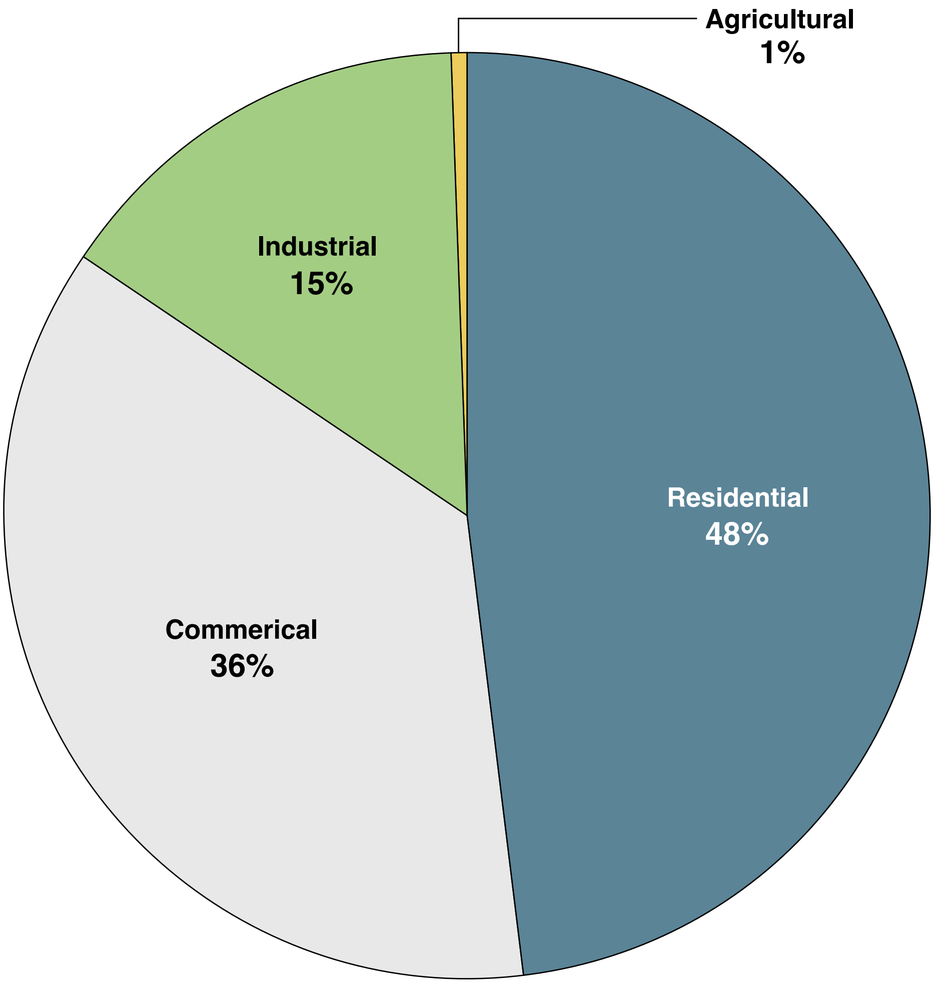


Figure 3. End-use sector distribution for annual electricity consumption in Bahrain in 2013.

Source: MEW 2014.

Due to its hot and dry climate, characterized by annual cooling degree days of 3,214°C-days, a significant proportion of electricity demand and consumption in Bahrain is associated with air conditioning of buildings, as illustrated in Figure 4. Specifically, Figure 4 correlates the monthly peak electricity demand as a function of monthly maximum outdoor temperature in 2014, using a three parameter inverse modeling approach (Krarti 2012). The baseload demand, represented by the square shaped points in Figure 4, associated with plug loads, appliances and lighting is estimated to be 1,300 MW. Air conditioning energy consumption increases with rising outdoor temperature during the summer months, represented by the diamond shaped points in Figure 4. Peak electricity demand, for example, increased from 1,360 MW in January to more than double in August at 3,140 MW (MEW 2014).

Limited studies have been published on the potential energy savings associated with improved energy performance of new and existing buildings in Bahrain. Using a calibrated energy model for an existing office building, Radhi (2008) carried out an analysis to assess the reduction in energy use for a few energy efficiency measures. These measures include: adding thermal insulation in the walls and roofs; installing low emissivity (low e) glazing; retrofitting lighting fixtures and office equipment with more energy efficient systems, including daylighting sensors; and increasing cooling set point temperatures. The results indicate that daylighting controls have the highest potential for energy savings, followed by an adjustment in cooling set point temperature. The combined effect of all these measures has the potential to provide a 42 percent reduction in energy use for office buildings. However, no economic analysis has been carried out to assess the cost-effectiveness of these measures. Analyses were carried out for both residential and commercial buildings to assess the impact of Bahrain's thermal insulation code, known as Article 32, on improving thermal comfort (Radhi et al. 2009) and reducing energy use and carbon emissions for the building sector (Radhi 2009). Both of these studies include a parametric analysis using whole-building energy analysis to assess the impact of various insulation levels, glazing types and window-to-wall ratios on thermal comfort as well as total building energy consumption. The reported analyses concluded that window size and type have a significant impact on thermal comfort for Bahraini residential buildings (Radhi et al. 2009) and that improving the building envelope alone is not sufficient to achieve a 40 percent reduction in both energy use and carbon emissions for commercial buildings (Radhi 2009). Again, no economic analysis was conducted as part of these studies. Other research studies considered integration of renewable energy systems in the buildings to reduce the energy and environmental impacts of buildings (Alnaser and Flanagan 2007; Alnaser 2015).

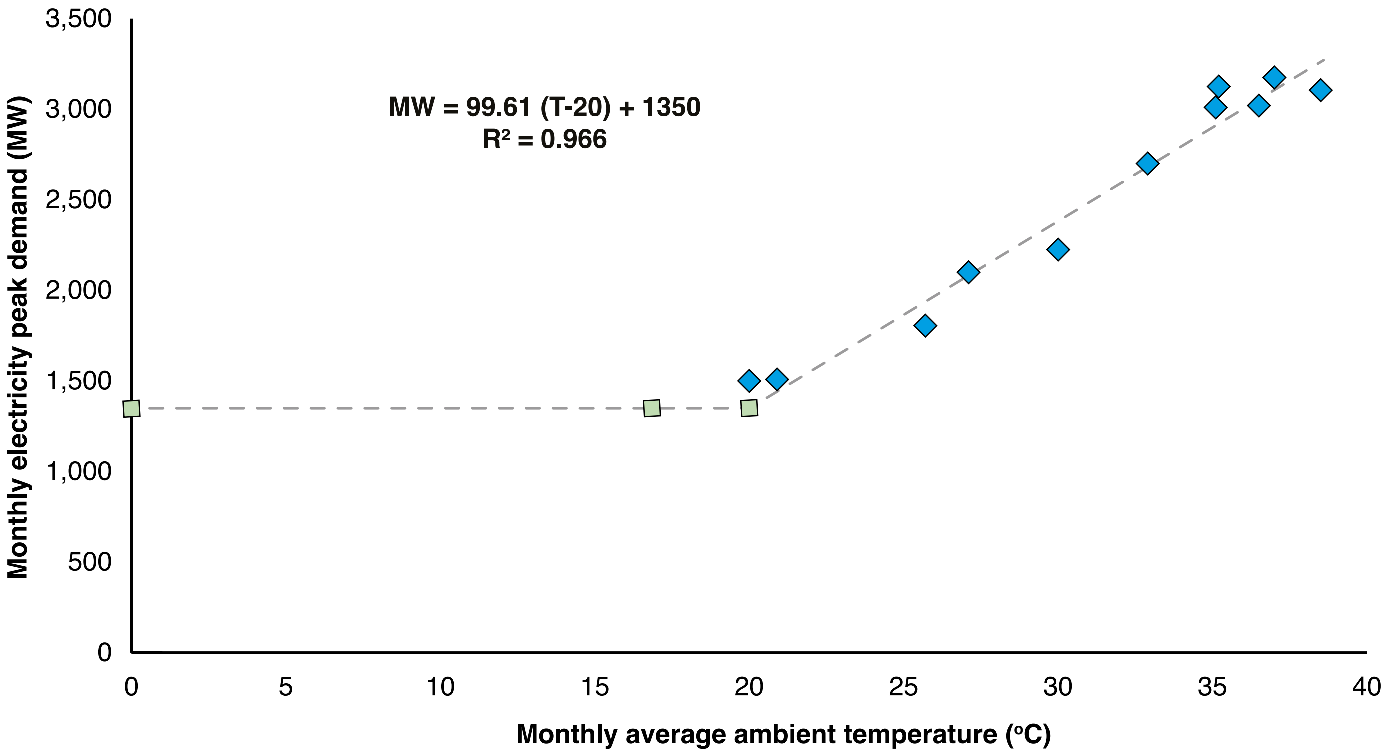


Figure 4. Monthly 2014 electricity peak demand versus monthly average ambient temperature.

Source: KAPSARC analysis using MEW data, 2014.

Description of Current Building Energy Efficiency Policies

Bahrain adopted an energy efficiency code for commercial buildings in 1999 which has prescriptive requirements for thermal insulation in the walls and roofs and specifications for window glazing (Radhi et al. 2009). The application of this code was extended to all building types in 2013 (Alnaser 2015). Bahrain also has set minimum energy performance standards for lighting bulbs, based on the European Union Commission regulation 244/2009, to phase out all inefficient lighting (EU 2009). The regulation calls for the phasing out of all incandescent lamps by 2013 and use of energy efficient bulbs by 2018. It adopts a step-by-step approach to phase out inefficient lighting in stages between 2009 and 2018.

The current building efficiency code in Bahrain requires the use of thermal insulation in all air-conditioned buildings. These requirements were set by the Ministry of Housing and Municipality in 1999 and called for specific U-values for both roofs and exterior walls, as well as specific glazing types for windows, as summarized in Table 2.

To provide guidance for the design and installation of thermal insulation in buildings, the MEW issued a code of practice in Arabic in 2002 and in English in 2006, as well as a guide to outline specific implementation and enforcement procedures for the code. The specified procedure consists of two stages:

Planning Stage: During this stage, building designers are required to provide architectural plans detailing the walls and roofs to be insulated in order to obtain a building permit from the municipality. A specific thermal insulation form is used for the permit application.

Construction Stage: During this stage, the Electricity and Water Conservation Directorate (EWCD), part of the Electricity and Water Authority (EWA), is contacted to inspect the construction phase and ensure that thermal insulation and proper glazing are installed.

Table 2. Bahrain insulation requirements for building envelope.

Building Envelope	Maximum U-value (W/m².ºC)	Maximum Shading Coefficient (SC)	Minimum Visible Transmittance	Notes
Roofs	0.60	--	--	For all buildings
Walls (1)	0.75			For all buildings
Window glazing				
WWR(2)= 10-20%	5.10	0.50	25%	Single insulated glazing
WWR > 20%	2.40	0.44	27%	Double insulated glazing
Skylight glazing	2.00	0.25	15%	

Source: KAPSARC analysis.

Notes: (1) In addition to exterior walls, other walls and floors that are connected to non-air-conditioned spaces required to be insulated. (2) WWR = Window-to-wall ratio.

Table 3 shows current electricity prices for both residential and non-residential customers in Bahrain. Since the cost of generating electricity is 28 fills/kWh ($0.0743/kWh), the Bahraini government provides generous subsidies, especially for residential customers who may pay only 10 percent of the actual cost. It is estimated that total energy subsidies amount to $4.47 billion, or around 13 percent of GDP, with electricity subsidies of $1.47 billion (IMF 2015).

Table 3. Electricity prices for Bahraini customers.

Consumption Block (kWh)	**Consumer Type [fills/kWh ($/kWh)]**	
	Residential	**Non-residential**
1-3,000	3 (0.0080)	16 (0.0424)
3,001-5,000	9 (0.0239)	16 (0.0424)
5,001-250,000	16 (0.0424)	19 (0.0504)
250,001-500,000	16 (0.0424)	21 (0.0557)
More than 500,000	16 (0.0424)	29 (0.0769)

Source: EWA, 2016.

Analytical Approach

In order to assess the optimal building envelope design for residential buildings in Bahrain, a typical villa is considered for detailed energy analysis. The 3-D rendering, as well as floor plans for the villa, are shown in Figure 5. Each floor is defined as a separate thermal zone using a whole-building simulation analysis tool. The characteristics of the energy model for a typical villa are defined based on data obtained from reported studies (Radhi et al. 2005 and Alaidroos and Krarti 2015). The building construction details and heating, ventilation and air conditioning (HVAC) specifications for the base case energy model for the villa are summarized in Table B1 (Appendix B).

In the optimization analysis carried out in this study, common and easy to implement design and operating energy efficiency measures (EEMs) are considered, with the aim of improving the energy efficiency of a typical residential building. Table B2 (Appendix B) lists 10 EEMs considered for the optimization analysis, including building envelope, lighting, appliances, temperature settings and HVAC systems. All possible options are listed in Table B2 (Appendix B) for each EEM with the baseline design option highlighted in bold.

The simulation environment developed for the analysis is able to consider a wide range of cost functions and sets of constraints to perform the optimization analysis. In this study, the optimization cost function consists of the life cycle cost (LCC), as defined by Equation (1) (Krarti 2012).

$$LCC= IC + USPW(N,r_d) * EC \tag{1}$$

where,

> IC is the initial cost for implementing all the design and operating features for both the building envelope and HVAC system. For this study, cost data collected from various sources on construction in the GCC region are used in the economic analysis (AECOM 2013; Krarti 2015; Alaidroos and Krarti 2015).

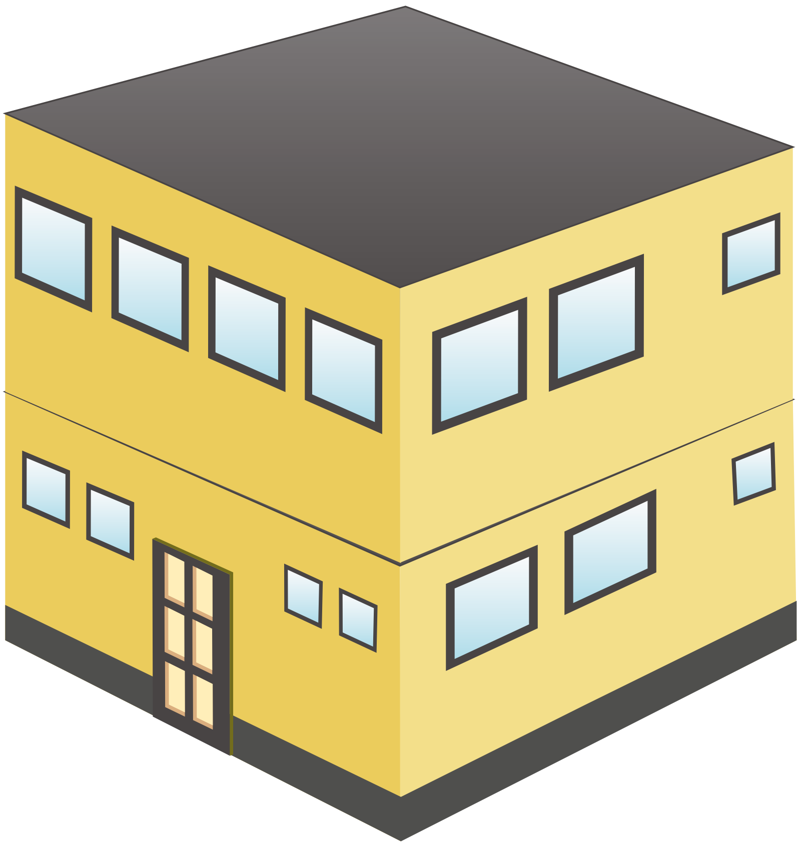
> EC is the annual energy cost required to maintain indoor comfort inside the residential building for selected design and operating features.

> USPW is the uniform series present worth factor, which depends on the discount rate, rd, and lifetime, N:(2).

For the optimization analysis in this study, the lifetime is set to be N = 30 years and the discount rate is assumed to be rd = 5 percent. In order to assess the potential for designing high performance public buildings, the unsubsidized electricity price of $0.10/kWh is used in the analysis. As noted earlier, the actual generation costs are reported by MEW (2014) to be $0.0743/kWh. However, the unsubsidized electricity prices are estimated to be $0.10/kWh when the transmission and distribution costs are accounted for. The effect of varying the villa's lifetime as well as the electricity price and discount rate have been discussed in the literature (Ihm and Krarti 2012; Alaidroos and Krarti 2015).

In this study, the sequential search optimization technique is adopted to determine the most cost-effective set of EEMs for designing or retrofitting residential buildings in Bahrain. This technique can identify not only the optimal solution but also the path to reach the optimal solution, as outlined in Figure 6 (Krarti 2015). Specifically, Figure 6 illustrates the general approach of the sequential search optimization to determining a path that achieves the best package of EEMs for minimizing cost. First, the effectiveness of each of the EEMs is individually evaluated in terms of its LCC and energy use reduction, relative to the baseline building energy model. Then, the most cost-effective EEM option is chosen, based on the steepest slope representing the LCC to energy savings ratio. The selected EEM option is then removed from the parameter search space for future evaluation, and finally the remaining EEMs are simulated to find the next best option in reducing LCC and maximizing savings in energy use. This process is repeated until the optimal solution is achieved. The approach can provide, in addition to the optimal set of EEMs, the best combinations of EEMs that achieve any set of desired energy use savings with the lowest life cycle cost.

Typical results of the optimization analysis using the sequential search technique are illustrated in Figure 7, which shows the normalized life cycle cost, expressed as a percentage of baseline LCC, as a function of annual energy savings. In addition to the baseline, three designs or retrofit options can be identified as part of the optimal path toward achieving net zero energy buildings as noted in Figure 7.



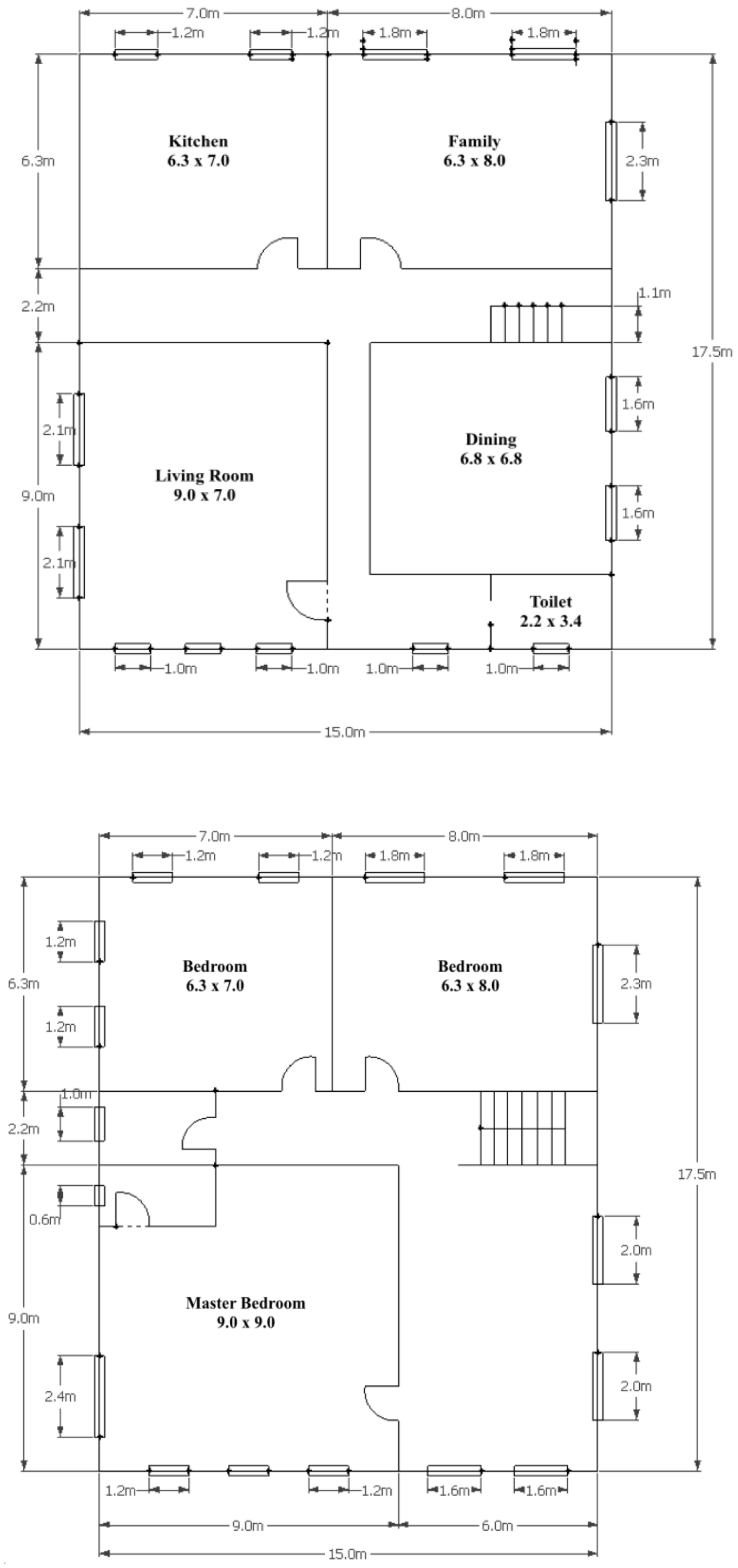


Figure 5. (a) 3-D rendering for energy model (b) ground floor layout plan and (c) first floor layout plan for a typical villa in Bahrain.

Source: KAPSARC analysis.

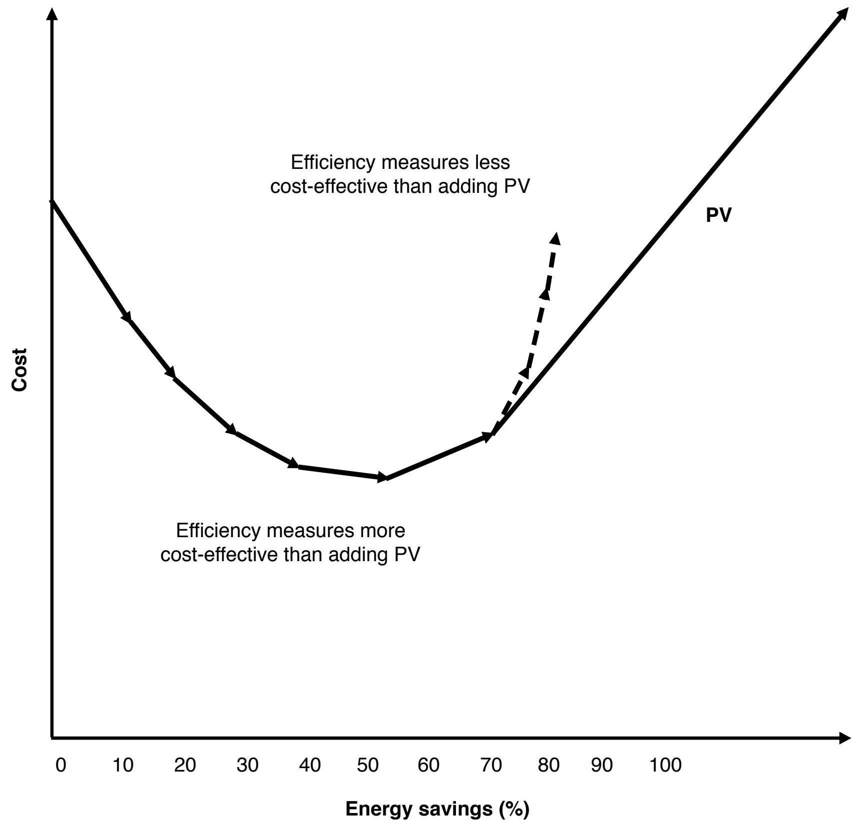


Figure 6. Sequential selection procedure for the path to net-zero energy building design.

Source: KAPSARC analysis.

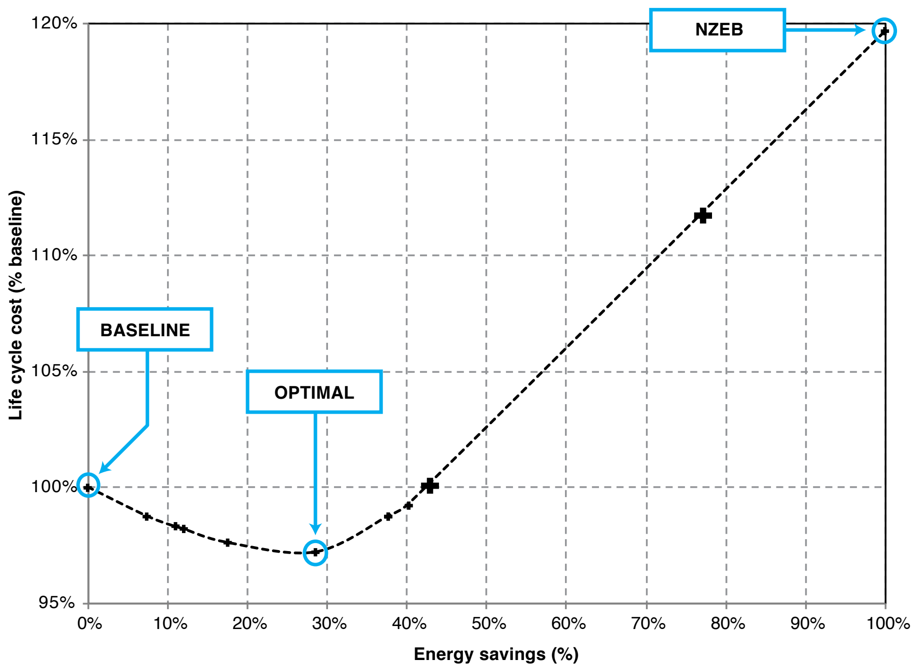


Figure 7. Sequential selection procedure for achieving optimal energy efficiency design for buildings.

Source: KAPSARC analysis.

Baseline residential building energy performance

Based on detailed simulation analysis, the energy end-use for a typical home in Bahrain is estimated as shown in Figure 8. The total annual energy consumption and peak electricity demand for a typical two-storey villa are estimated to be 88,810 kWh and 36 kW, respectively.

Impact of individual energy efficiency measures

In order to determine the impact of design and operating measures on the annual energy consumption and peak electricity demand for the base case of a typical villa in Bahrain, a comprehensive parametric analysis is carried out to account for a wide range of design and operating measures (Krarti 2015). Figure 9 shows the minimum and maximum percentage variations in both annual energy consumption and peak electricity demand associated with all options for a specific design and operating measure. It should be noted that changes in occupant behavior are not considered in the analysis. Indeed, the typical villa is assumed to be air conditioned throughout the day and thus limited rebound effect is to be expected from improving its energy efficiency and reducing its thermal loads. The rebound effect is related to the fact that people tend to use more air conditioning or other energy systems when they cost less to operate. 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 highest impact is reducing air leakage from the building shell. In general, the measures that can cut annual energy consumption are also effective in reducing peak electricity demand.

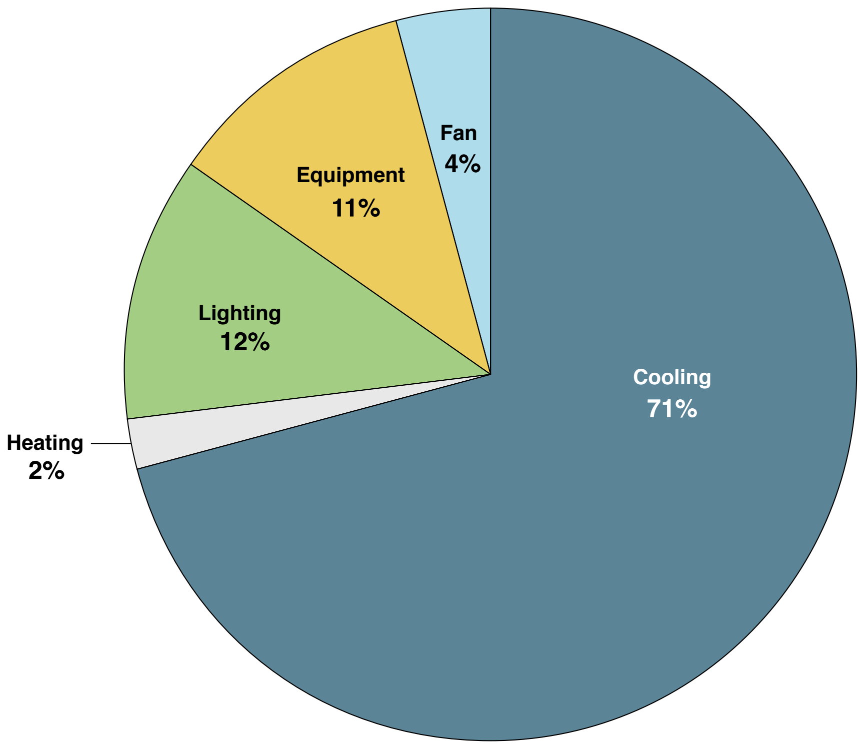
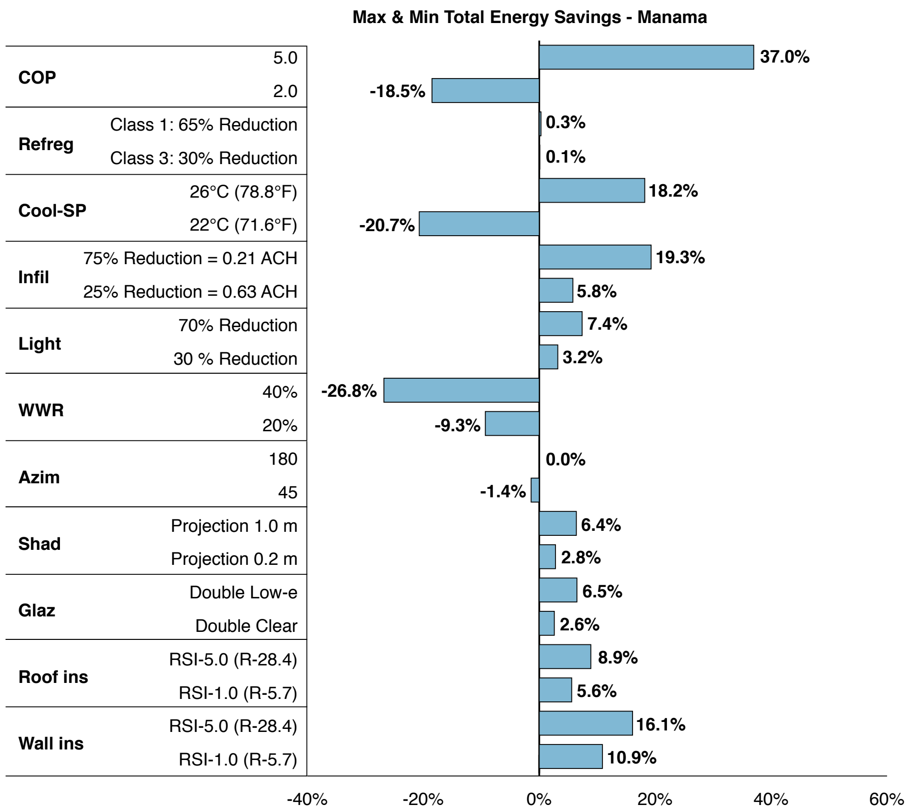


Figure 8. Annual energy end-use distribution for a typical villa in Bahrain.

Source: KAPSARC analysis.



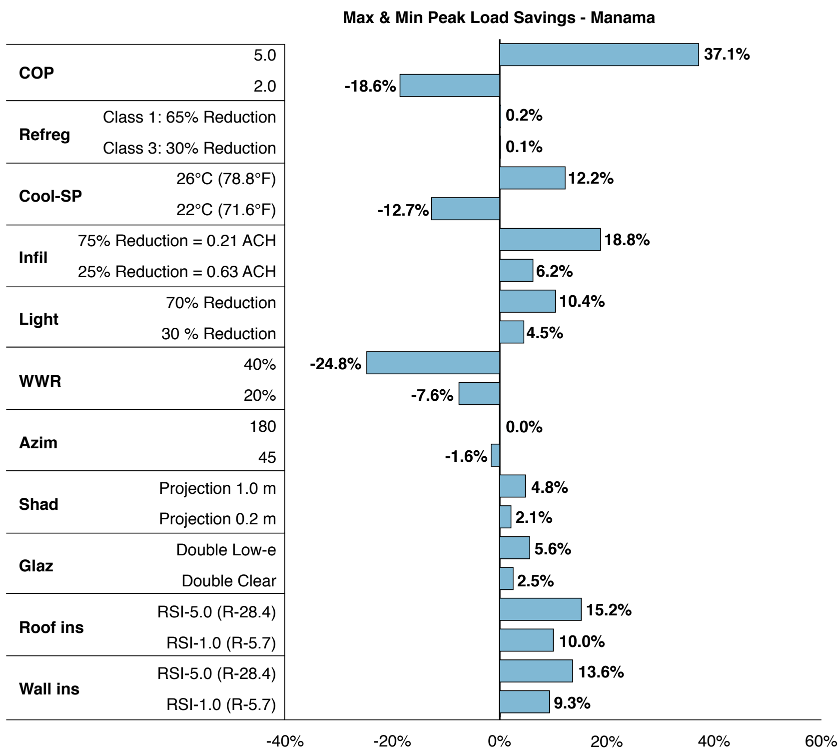


Figure 9. The impact of each optimal EEM on (a) energy savings and (b) peak demand for Bahrain.

Source: KAPSARC analysis.

As noted earlier, the energy conservation code in Bahrain is limited to thermal insulation requirements for exterior walls and roofs as well as the use of insulated glazing for windows. If actually enforced, the building efficiency code can result in an estimated reduction of annual energy consumption of about 25 percent for skin dominated buildings (Riadhi 2009), those where energy consumption is mainly related to the influence of the exterior climate on the building envelope. Using the same analysis carried out by Krarti (2015), the impact of the Bahraini code on the new building stock can be estimated as shown in Table 4. The carbon emissions from electricity generation are assumed to be 0.762 kCO2/kWh (IEA 2015) and the cost of building a power plant is estimated to be $1,200/kW (Krarti 2015).

Impact of combined energy efficiency measures

Figures 10 and 11 present Pareto graphs of the optimization results, showing the optimum point for a typical villa in Bahrain (Radhi et al. 2009; Alaidroos and Krarti 2015). The Pareto graphs summarize all the simulation results for all the potential combinations of energy efficiency measures considered in the optimization analysis. The graphs show the LCC values needed to achieve a specific percentage of building energy savings. The optimal cost-effective combinations of energy efficiency measures would achieve reductions of about 59 percent in total energy consumption and 67 percent in peak electricity demand for a typical Bahraini residential building.

The results of Figures 10 and 11 are summarized for various design configurations of the typical villa:

> Baseline design: As noted earlier, Tables B1 and B2 (Appendix B) list the basic features of the baseline design for the villa. A villa with this design consumes 88,810 kWh per year, with a peak demand of 36 kW.

> Optimal design: Table C1 (Appendix C) shows the design features of a villa that can provide the minimum life cycle costs (LCC), considering the unsubsidized electricity prices. This design can achieve reductions of about 70 percent in total energy consumption and 77 percent in peak electricity demand for a two-storey residential building. Annual electricity consumption and peak demand are reduced to 36,400 kWh and 12 kW, respectively.

Using the results of the optimization analysis illustrated in Figures 10 and 11, a more stringent energy efficiency code can be developed and adopted in Bahrain for all new residential and commercial buildings. The impact of this stringent code on the new building stock can be estimated as shown in Table C2 in line with the analysis described in Krarti (2015).

Table 4. Economic and environmental benefits from insulation improvements.

Building Type	Annual Energy Use Savings (GWh/yr)	Peak Demand Savings (MW)	Annual CO_2 Emissions Savings (million metric tons/yr)	Annual Energy Cost Savings ($million/yr)	Peak Demand Savings ($million)
Residential Buildings	77	18	0.059	6	21
Commercial Buildings	58	14	0.045	4	17
Total	136	32	0.103	10	39

Source: KAPSARC analysis.

Note: Results based on improved insulation requirements of building envelope systems for all new buildings in Bahrain, using 2013 building stock statistics.

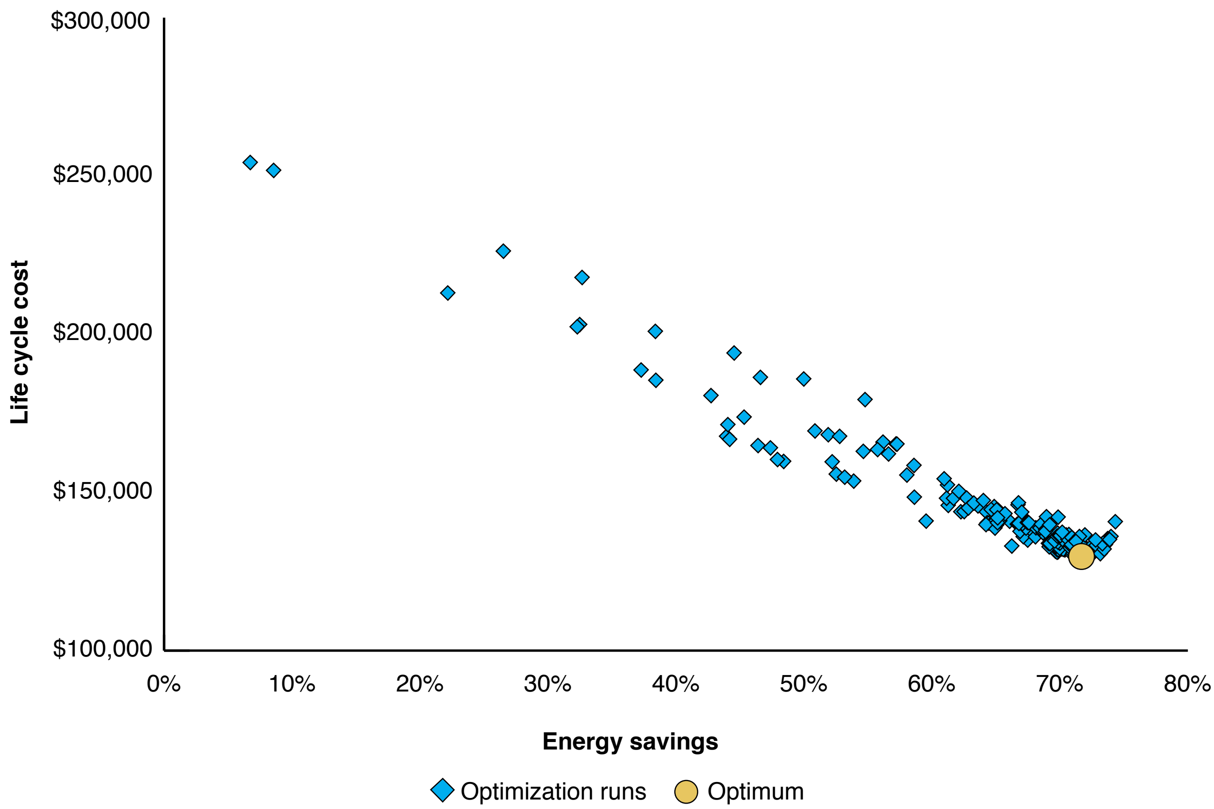


Figure 10. Optimization path of energy savings and life cycle cost for Bahrain.

Source: KAPSARC analysis.

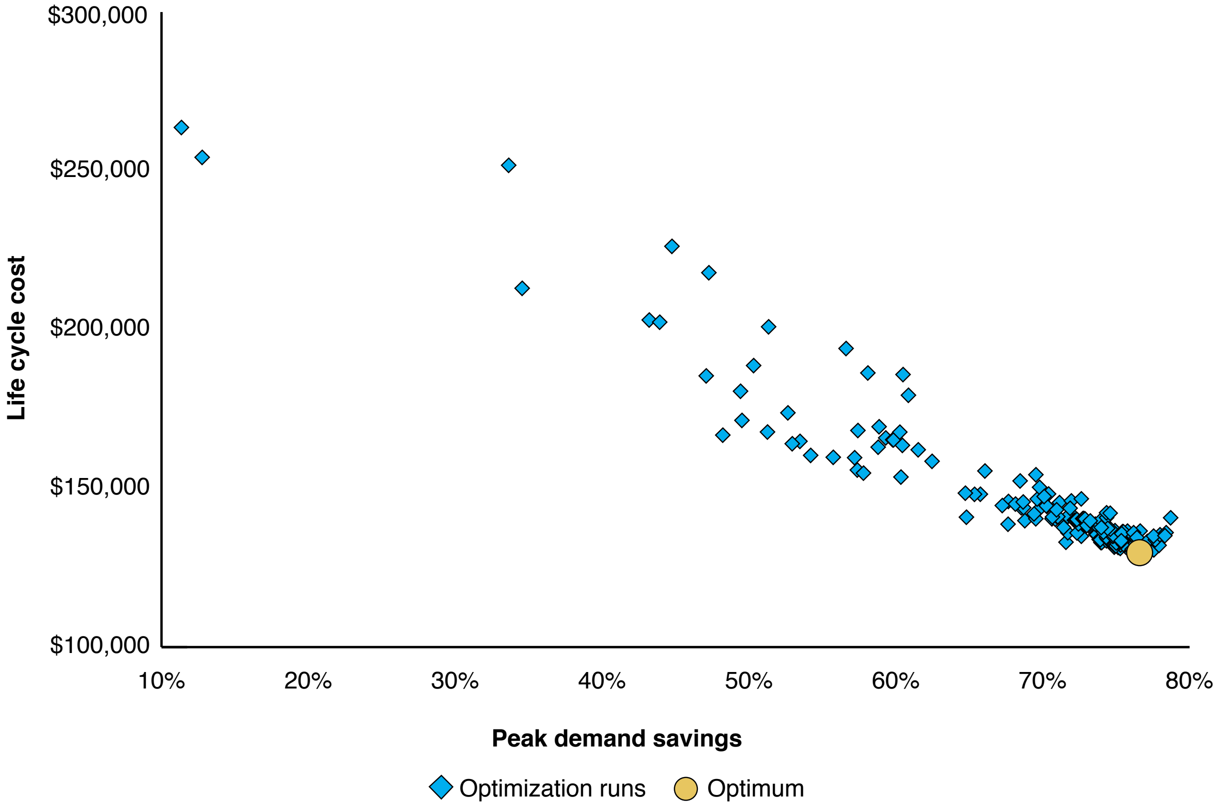


Figure 11. Optimization Pareto plot of demand savings and life cycle cost for Bahrain.

Source: KAPSARC analysis.

Cost-Effectiveness Analysis of Energy Efficiency Retrofit Programs

The benefits of energy efficiency could be increased significantly if the existing building stock were to be retrofitted to enhance its energy performance. To quantify the impact of retrofit programs in Bahrain, an analysis similar to that performed by Krarti (2015) is carried out. Specifically, three levels of energy building retrofits, which yield different economic and environmental benefits (Krarti 2015), are considered for the existing building stock:

> **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 shells to reduce air infiltration. The estimated average savings from a Level-1 retrofit program are 8 percent for all building types, based on documented studies and case studies reported for residential, commercial and governmental buildings.

> **Level-2 of energy efficiency retrofit:** Seeks to improve the building envelope components as well as the use of energy efficient cooling systems and appliances. Based on the analysis shown in Figure 9 and existing literature, average savings of 23 percent can be achieved for Level-2 retrofits for a typical residential villa (Radhi et al. 2009; Radhi 2009).

> **Level-3 of energy efficiency retrofit:** Requires the implementation of capital intensive measures including cooling system replacement and installation of daylighting control systems. While deep retrofits are typically costly, they can provide significant energy savings, which can exceed 50 percent, as noted in this study and by Krarti and Ihm (2014).

The economic benefits are estimated using a cost of generating and distributing electricity of 28 fills/kWh (\$0.0743/kWh) rather than the subsidized rate of 3-16 fills/kWh (\$0.008-0.0424/kWh). The environmental benefits are estimated using an average carbon emission factor of 762 gCO2/kWh. Tables D1-D3 (Appendix D) summarize the annual CO2 emission savings (associated with reducing the amount of fuel needed to generate electricity), annual energy cost savings (associated with using less fuel to generate electricity) and peak demand savings (associated with avoiding the construction of new power plants) for Level-1, Level-2 and Level-3 building energy efficiency retrofit programs, respectively. As shown in Tables D1 to D3 (Appendix D), significant economic and environmental benefits can be achieved for all levels of retrofit programs. Greater benefits can be obtained for Level-2 and Level-3 programs compared with Level-1. However, these programs require larger investments, as discussed in the following section. The benefits are significantly larger for residential buildings than for commercial or governmental buildings for any level of retrofit. Indeed, 50 percent of the benefits can be obtained from solely retrofitting residential buildings.

Implementation of the proposed national building energy efficiency retrofit program is expected to be gradual and to take place over several years due to investment requirements (refer to the Cost-Effectiveness Analysis section) as well as the lack of qualified energy efficiency contractors. However, we have shown that such a retrofit program can lead to significant economic and environmental benefits, even if only a small fraction of the existing building stock is considered.

Program Implementation Considerations

First, the investments required to fully implement the building energy retrofit program are evaluated. Then, the cost-effectiveness of the energy efficiency program is determined for various building types and levels of energy efficiency retrofit. The job creation potential associated with the energy retrofit program is also discussed in this section.

Cost-effectiveness analysis

The implementation cost for each level of building energy retrofit depends on several factors, including the building size and physical condition of the building energy systems. Based on various sources for cost data in the GCC region, including, when available, cost of labor and materials for Bahrain, the average costs of completing energy retrofit for buildings are estimated (Krarti 2011; Krarti 2012; Krarti and Ihm 2012; and Ameer and Krarti 2015). Table 5 summarizes the costs for the three levels of energy retrofit specific to residential and commercial buildings, including costs for performing energy audits as well as for installing suitable energy efficiency measures.

The total costs of implementation for each level of the building energy efficiency retrofit program to upgrade the existing building stock are provided in Appendix E, Table E1 (for Level-1), Table E2 (for Level-2) and Table E3 (for Level-3). The cost-effectiveness of the retrofit program for the entire building stock is summarized in Table E4. The results indicate that the best option is to carry out a Level-1 retrofit for the existing building stock, since the payback period is less than five years with a total retrofit cost of $545 million. When only the residential building stock is retrofitted, as shown in Table E5, Level-2 and Level-3 retrofit programs become attractive, with a payback period of 5.9 years and 5.8 years, respectively. The Level-1 retrofit program would pay for itself from the reduction in peak electricity demand and thus eliminate the need to construct new power plants.

Table 5. Average costs for energy retrofits of buildings in Bahrain (expressed in USD per unit/building).

Building Type	Level-1	Level-2	Level-3
Residential buildings	500	5,000	10,000
Commercial buildings	10,000	50,000	100,000

Source: KAPSARC analysis.

Estimation of job creation and market potential of energy efficiency industry

The other economic impact of the building energy retrofit program outlined above is its potential to create new employment in Bahrain. As outlined by Krarti (2015), the direct effects of retrofitting buildings include jobs required to implement the energy efficiency measures, while the indirect effects are associated with work needed to produce and supply energy efficiency equipment and materials. Most of the jobs created in building retrofits would be in the construction and manufacturing industries, with a wide range of pay level and technical specialization, including electricians, HVAC technicians, insulation installers, energy auditors, building inspectors and construction managers.

Using the job creation model considered in the analysis by Krarti (2015), up to 31,713 new job-years of employment could be created when retrofitting the existing building stock, as illustrated in Table E6 (Appendix E). It should be noted that most of the jobs, including energy auditors, HVAC technicians and electricians, can be filled by Bahrainis instead of expatriates. However, an investigation should be carried out to evaluate building capacity needs to ensure that locals can meet the job requirements to effectively implement the large scale building energy retrofit programs considered in this analysis.

Summary and Conclusions

The analysis detailed in this paper demonstrates that improving the energy efficiency of the building stock in Bahrain 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. Specifically, the analysis shows that:

> The application of thermal insulation to new buildings can provide savings of 138 GWh/year in annual energy consumption, 38 MW in peak electricity demand and 104,000 tons/year in carbon emissions.

> If a more stringent building energy code is developed and enforced for newly constructed buildings, Bahrain could reduce its energy consumption by 320 GWh/year, peak electricity demand by 87 MW and carbon emissions by 242,000 tons/year.

> A Level-1 energy retrofit of residential buildings would be highly cost-effective even if the government has to fund all the implementation costs of the program. Indeed, a Level-1 energy retrofit program, when applied to the existing residential building stock, could achieve savings of 495 GWh/year in electricity consumption, 116 MW in peak power demand and 377,000 tons/year in carbon emissions.

Moreover, the analysis summarized here indicates that energy retrofit programs can create significant employment, with up to 31,713 full time job-years if all the existing building stock is retrofitted. When fully implemented, the energy efficiency programs for both new and existing buildings have the potential to reduce the annual fuel consumption that is required for electricity generation by 62 percent, with the added benefits of decreasing the generating capacity needed to meet future demand by 55 percent, when compared with a business as usual scenario.

It should be noted that the impact of behavioral changes on energy efficiency savings, including the rebound effect, is ignored in this analysis (Borenstein 2015). While some studies have shown that implementing building energy programs for households can have less impact than expected due to the rebound effect (Majcen et al. 2013 and Jabobsen et al. 2013), this effect is not well documented in the GCC region. It is presumed in the analysis conducted in this study that this effect would have minimal impact since households in the GCC region, including Bahrain with its highly subsidized electricity prices, consume energy without much tradition of conservation, including continuous use of air conditioning. Thus, any improvement to the energy efficiency of building energy systems – i.e., building envelope, lighting and appliances – would not lead to a significant change of behavior and would have limited, if any, rebound effect. However, additional and specific studies of the behavioral changes and attitudes of GCC households should be conducted as part of a future work.

References

AECOM. Middle East Construction Handbook. AECOM, 2013.

Alaidroos, Alaa and Moncef Krarti. "Optimal design of residential building envelope systems in the Kingdom of Saudi Arabia." Energy and Buildings 86 (2015), 104-117. doi:10.1016/j.enbuild.2014.09.083.

Alnaser, N.W. "Building integrated renewable energy to achieve zero emission in Bahrain." Energy and Buildings 93 (2015), 32-39. doi:10.1016/j.enbuild.2015.01.022.

Alnaser, N.W., and R. Flanagan. "The need of sustainable buildings construction in the Kingdom of Bahrain." Building and Environment 42, No. 1 (2007), 495-506. doi:10.1016/j.buildenv.2005.08.032.

Borenstein, Severin. "A Microeconomic Framework for Evaluating Energy Efficiency Rebound and Some Implications." The Energy Journal 36, No. 1 (2014). doi:10.5547/01956574.36.1.1.

Electricity and Water Authority. Guide Lines for Thermal Insulation Implementation in Buildings. Bahrain: EWA, n.d. http://www.mew.gov.bh/media/pdf/2015/guidelines%20for%20thermal%20insulation.pdf.

European Union. "Commission regulation (EC) no 244/2009." EU. Last modified March 24, 2009. eur-lex.europa.eu/eli/reg/2015/1428/oj.

EWA. "Electricity and Water Tariff (2016)." Electricity & Water Authority. Last modified 2016. http://www.mew.gov.bh/media/pdf/tariff_a4_brochore_eng.pdf.

Ihm, Pyeongchan and Moncef Krarti. "Design optimization of energy efficient residential buildings in Tunisia." Building and Environment 58 (2012), 81-90. doi:10.1016/j.buildenv.2012.06.012.

IMF. "Country Report No. 15/220." International Monetary Fund home page. Last modified 2015. http://www.imf.org/external/pubs/ft/scr/2015/cr15220.pdf.

International Energy Agency. CO2 Emissions from Fuel Combustion. Paris: IEA Publications, 2015.

Jacobsen, Grant and Matthew Kotchen. "Are Building Codes Effective at Saving Energy? Evidence from Residential Billing Data in Florida." 2010. doi:10.3386/w16194.

Krarti, Moncef. 2012. Weatherization and energy efficiency improvement for existing homes: an engineering approach. New York: Taylor & Francis Group.

Krarti, Moncef. "Evaluation of large scale building energy efficiency retrofit program in Kuwait." Renewable and Sustainable Energy Reviews 50 (2015), 1069-1080. doi:10.1016/j.rser.2015.05.063.

Majcen, Daša, Laure Itard and Henk Visscher. "Actual and theoretical gas consumption in Dutch dwellings: What causes the differences?" Energy Policy 61 (2013), 460-471. doi:10.1016/j.enpol.2013.06.018.

MEW. Annual Report from the Ministry of Electricity and Water of Bahrain. Bahrain: Ministry of Electricity and Water of Bahrain, Kingdom of Bahrain, 2014.

Radhi, H. "Can envelope codes reduce electricity and CO2 emissions in different types of buildings in the hot climate of Bahrain?" Energy 34, No. 2 (2009), 205-215. doi:10.1016/j.energy.2008.12.006.

Radhi, Hassan. "A systematic methodology for optimising the energy performance of buildings in Bahrain." Energy and Buildings 40, No. 7 (2008), 1297-1303. doi:10.1016/j.enbuild.2007.11.007.

Radhi, Hassan, Ali Eltrapolsi and Stephen Sharples. "Will energy regulations in the Gulf States make buildings more comfortable – A scoping study of residential buildings." Applied Energy 86, No. 12 (2009), 2531-2539. doi:10.1016/j.apenergy.2009.04.003.

Appendix A

Table A1. Types and numbers of customers for electricity in Bahrain, 2013.

Type	Number of Customers	Percentage of Total
Residences	205,315	76.51
Commercial buildings	44,189	16.47
Industrial facilities	18,358	6.84
Agricultural units	474	0.18
Total	268,336	100

Source: Adapted from MEW (2014) and Alnaser (2015).

Appendix B

Table B1. Building construction specifications for the typical villa.

Number of storeys	2
Total height	7.0m
Floor dimensions	15.0m × 17.5m
Gross floor area	525
Gross wall area	455
Window area	13.29 percent of gross wall area
Type of glass	Single pane window
External walls	20mm plaster outside + 200mm concrete hollow block + 20mm plaster inside
Roof	10mm built-up roofing + 150mm concrete roof slab + 12.7mm plaster inside
Floor	150mm slab on grade
Number of occupants	6
Lighting	3.0 kW (lower level), 2.0 kW (upper level)
Appliances	2.0 kW (lower level), 1.0 kW (upper level)
HVAC system type	Constant volume DX air-cooled A/C system with electric heating
Temperature settings	22.2°C (72°F) for heating and 24.4°C (76°F) for cooling
COP	2.17

Source: KAPSARC analysis.

Table B2. Building construction specifications for the typical villa.

EEM	Specification	Options
Azimuth	Orientation of the building relative to the north	**0**, 45, 90, 135, 180, 225, 270
Exterior wall construction	Wall insulation (Outdoor installation)	**No insulation** RSI-1.0 (R-5.7) polystyrene (2cm thickness) RSI-2.0 (R-11.4) polystyrene (4cm thickness) RSI-3.0 (R-17.0) Polystyrene (6cm thickness)
Roof construction	Roof insulation	**No insulation** RSI-1.0 (R-5.7) polystyrene (2cm thickness) RSI-2.0 (R-11.4) polystyrene (4cm thickness) RSI-3.0 (R-17.0) polystyrene (6cm thickness)

Appendix B

WWR	Window to wall ratio	**10%**, 20%, 25%, 30%, 40%
Window type	Glazing type for window	**Single Clear (6mm, U: 6.172 W/m²•°C),** Single bronze (6mm, U: 6.172 W/m²•°C), Single low energy (6mm, U: 4.270 W/m²•°C) Double clear (6/6/6mm, U: 3.163 W/m²•°C), Double bronze (6/6/6mm, U: 3.160 W/m²•°C), Double low energy (6/12/6mm, U: 1.658 W/m²•°C)
Lighting density	Building lighting level	**Typical (7.3 W/m2)** 30% reduction 50% reduction 70% reduction
Infiltration	Air infiltration level	**Typical (0.7 L/s/m2)** 25% reduction 50% reduction 75% reduction
Cooling set point	Temperature set point for cooling	**24°C (75.2°F),** 25°C (77°F), 26°C (78.8°F)
Refrigerator	Electricity consumption level	**Typical (180W: 800 kWh/year)** Class 3: 30% reduction Class 2: 45% reduction Class 1: 65% reduction
Air conditioner	Coefficient of performance (COP)	**2.2** 2.6 3.0 3.3 3.5

Source: KAPSARC analysis.

Note: Insulation R-value is expressed in RSI (m2.°C/W) and R (hr.ft2.°F/Btu). Data in bold indicates baseline design options.

Appendix C

Table C1. List of optimal design and operating strategies, potential energy use and peak demand savings for residential buildings in Bahrain.

EEM	Bahrain
Wall insulation	RSI-3.0 (R-17.0) polystyrene
Roof insulation	RSI-3.0 (R-17.0) polystyrene
Glazing	Single clear
Shading	Projection 0.7m
Azimuth	0
WWR	10%
Lighting	70% reduction
Infiltration	75% reduction = 0.21 ACH
Cooling set point	24°C
Refrigerator	Typical (180W: 800 kWh/year)
HVAC COP	3.5
Total energy savings	59%
LCC ($)	66422
Peak demand (kW)	11.70
Peak time	08/10 18:00

Source: KAPSARC analysis.

Table C2. Economic and environmental benefits for thermal insulation building code, applied to all new buildings in Bahrain, based on 2013 building stock statistics.

Building Type	Annual Energy Use Savings (GWh/yr)	Peak Demand Savings (MW)	Annual CO_2 Emissions Savings (million metric tons/yr)	Annual Energy Cost Savings ($million/yr)	Peak Demand Savings ($million)
Residential buildings	182	49	0.138	14	59
Commercial buildings	138	38	0.104	10	45
Total	320	87	0.242	24	104

Source: KAPSARC analysis.

Appendix D

Table D1. Economic and environmental benefits for Level-1 building energy efficiency retrofit program for Bahrain, based on 2013 building stock statistics.

Building Type	Annual Energy Use Savings (GWh/yr)	Peak Demand Savings (MW)	Annual CO_2 Emissions Savings (million metric tons/yr)	Annual Energy Cost Savings ($million/yr)	Peak Demand Savings ($million)
Residential buildings	495	116	0.377	37	139
Commercial buildings	374	88	0.285	28	106
Total	869	204	0.662	65	245

Source: KAPSARC analysis.

Table D2. Economic and environmental benefits for Level-2 building energy efficiency retrofit program for Bahrain, based on 2013 building stock statistics.

Building Type	Annual Energy Use Savings (GWh/yr)	Peak Demand Savings (MW)	Annual CO_2 Emissions Savings (million metric tons/yr)	Annual Energy Cost Savings ($million/yr)	Peak Demand Savings ($million)
Residential buildings	1,422	335	1.083	106	402
Commercial buildings	1,076	253	0.820	80	304
Total	2,498	588	1.903	186	706

Source: KAPSARC analysis.

Table D3. Economic and environmental benefits for Level-3 building energy efficiency retrofit program for Bahrain, based on 2013 building stock statistics.

Building Type	Annual Energy Use Savings (GWh/yr)	Peak Demand Savings (MW)	Annual CO_2 Emissions Savings (million metric tons/yr)	Annual Energy Cost Savings ($million/yr)	Peak Demand Savings ($million)
Residential buildings	3,091	727	2.355	230	873
Commercial buildings	2,339	550	1.782	174	660
Total	5,430	1,278	4.138	403	1,533

Source: KAPSARC analysis.

Appendix E

Table E1. Total implementation costs for Level-1 building energy efficiency retrofit program.

Building Type	Number of Units	Per Unit Retrofit Cost ($/unit)	Total Retrofit Cost ($million)
Residential buildings	205,315	500	103
Commercial buildings	44,189	10,000	442
Total	249,504		545

Source: KAPSARC analysis.

Table E2. Total implementation costs for Level-2 building energy efficiency retrofit program.

Building Type	Number of Units	Per Unit Retrofit Cost ($/unit)	Total Retrofit Cost ($million)
Residential buildings	205,315	5,000	1,027
Commercial buildings	44,189	50,000	2,209
Total	249,504		3,236

Source: KAPSARC analysis.

Table E3. Total implementation costs for Level-3 building energy efficiency retrofit program.

Building Type	Number of Units	Per Unit Retrofit Cost ($/unit)	Total Retrofit Cost ($million)
Residential buildings	205,315	10,000	2,053
Commercial buildings	44,189	100,000	4,419
Total	249,504		6,472

Source: KAPSARC analysis.

Table E4. Cost-effectiveness analysis of the energy retrofit program in Bahrain for all building stock.

Retrofit Level	Total Retrofit Cost ($million)	Peak Demand Savings ($million)	Annual Energy Cost Savings ($million/yr)	Simple Payback Analysis (yrs)
Level-1	545	245	65	4.6
Level-2	3,236	706	186	13.6
Level-3	6,472	1,533	403	12.3

Source: KAPSARC analysis.

Table E5. Cost-effectiveness analysis of the energy retrofit program in Bahrain for residential building stock.

Retrofit Level	Total Retrofit Cost ($million)	Peak Demand Savings ($million)	Annual Energy Cost Savings ($million/yr)	Simple Payback Analysis (yrs)
Level-1	103	139	37	0
Level-2	1,027	402	106	5.9
Level-3	2,053	873	203	5.8

Source: KAPSARC analysis.

Table E6. Number of job-years that can be created from building energy retrofit program in Bahrain.

Building Type	Number of Units	Per Unit Retrofit Cost ($/unit)	Total Retrofit Cost ($million)
Residential buildings	505	5,032	10,060
Commercial buildings	1,027	10,824	21,653
Total	2,053	15,856	31,713

Source: KAPSARC analysis.

Notes

Notes

About the Authors

Kankana Dubey

Kankana is a senior research associate at KAPSARC working on the Energy Productivity in the GCC project. Her work focuses on economic growth, energy productivity, energy efficiency and developing energy policy toolkits for government action, particularly in the building sector. Kankana has an M.Sc. in Energy Management from the University of Stirling, U.K.

Moncef Krarti

Moncef is a visiting research fellow at KAPSARC with over 30 years of experience in designing, testing, and assessing innovative energy efficiency and renewable energy technologies applied to buildings. He is a professor and coordinator of the Building Systems Program, Civil, Environment and Architectural Department at the University of Colorado.

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.

مركز الملك عبدالله للدراسات والبحوث البترولية
King Abdullah Petroleum Studies and Research Center

www.kapsarc.org