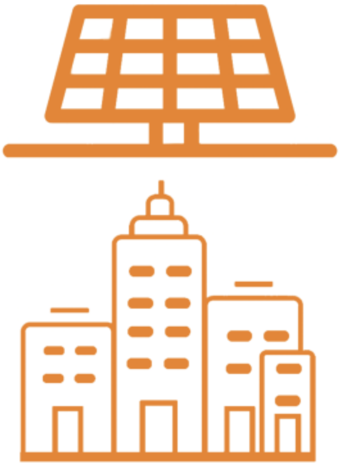


Solar assisted electrical & thermal demand reduction in Saudi Arabia housing

Project team conference abstracts for the solar assisted electrical & thermal demand reduction in Saudi Arabia housing project

Compiled by the Energy and Climate Change Division (ECCD)
Faculty of Engineering and Physical Sciences
energy.soton.ac.uk
University of Southampton
United Kingdom

April 2021

Preface

The Solar assisted electrical and thermal demand reduction in Saudi Arabia Housing research project will contribute to the Kingdom of Saudi Arabia's (KSA) renewable energy targets by addressing energy consumption in buildings. Building consumes around 60% of of the energy in KSA and the project aims to study the displacement of such fossil fuel supplied energy through the use solar photovoltaics (PV) electricity and solar thermal energy. This project is funded by the Ministry of Education, Saudi Arabia and was awarded to the Department of Electrical and Computer Engineering, King Abdulaziz University, KSA and the Energy and Climate Change Division (ECCD), University of Southampton, UK.

This document provides summaries of submitted abstracts some of which were generated through the above project and some through additional work by ECCD·

The summaries including abstracts submitted to the 16th CISBAT Conference (8-10 September 2021) and the International Conference on Evolving Cities (ICEC 2021) (22-24 September 2021).

About ECCD

The Energy and Climate Change Division (ECCD) is part of the Faculty of Engineering and Physical Sciences at the University of Southampton. It comprises the Sustainable Energy Research Group (SERG) and the Coastal and Climate Research Group, established since 1990. ECCD/SERG research profiles addresses the University's mission focusing on fundamental understanding applicable to renewable energy studies, energy efficiency and energy for development. ECCD/SERG research supports the United Nations Sustainable Development Goals (SDGs) with fundamental and applied research across our six research themes. These encompass (i) Renewable Energy, (ii) Energy Access, (iii) Cities & Infrastructure, (iv) Buildings & Communities, (v) Behaviour & Modelling and (vi) Climate & Emissions. Please check our website www.energy.soton.ac.uk for further information.

Disclaimer

Acknowledgment

The authors extend their appreciation to the Deputyship for Research & Innovation, Ministry of Education in Saudi Arabia for funding this research work through the project number 714.

Editor: A.S. Bahaj

ISSN 1747-0544
DOI: 10.5258/SOTON/P0096

Sustainable Energy Series
Report 11 - First published 2021

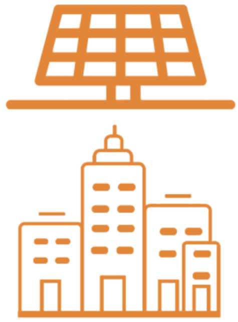
UNIVERSITY OF Southampton

وزارة التعليم
Ministry of Education

Contents

Project Team Abstracts

Reduction of A/C demand in hot climates using photovoltaics: a case study in the city of Jeddah, KSA



Majbaul Alam[1], Abdusalam Alghamdi[2], AbuBakr S. Bahaj[1], Luke Blunden[1], Mostafa Mahdy[1], Tom Rushby[1]

[1]Energy and Climate Change Division, Sustainable Energy Research Group, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, UK.

[2]Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah, Saudi Arabia.

Summary

Measurements of electrical power demand and temperature were made over a period of a year in a villa in Jeddah, Saudi Arabia as part of a wider study investigating the potential of PV to displace domestic loads in the country. Simulations were carried out using HOMER® software to determine the ability of different combinations of PV systems to support (a) the air-conditioning loads only, and (b) how much this PV would contribute to other loads. Monitored electrical demand data were fed into HOMER® software electrical load component. Daytime loads of the main living area varied between 38 kWh/d and 85 kWh/d with an average of 75 kWh/d. The study villa has a roof space of 227m^2, of which 200m^2 can be used for installing PV panels. the results indicate that, with sufficient capital expenditure, a 15 kWp PV array can be used to displace 99% of daytime electrical load within the villa, but that energy storage (whether chemical or thermal) would be required to meet night time cooling demands.

Introduction

Residential buildings in Saudi Arabia account for about half of the electricity consumed by the total building stock and total annual electricity consumption has been growing at a rate between 5% to 8% (Felimban et al., 2019). Mujeebu and Alshamrani (2016) estimated that about 70% of the electricity consumption in the residential buildings is due to air conditioning (A/C) units. The hot-arid climate of Saudi Arabia is the main driver for such cooling demand, coupled with poor energy performance of the older building stock (Alrashed and Asif, 2012).

The key solutions suggested by studies are (i) improving efficiency of appliances, mainly air conditioning units, (ii) building retrofit to improve thermal efficiency and (iii) increased user awareness of the importance of energy conservation (Al-Ajlan et al., 2006; Al-Shaalan, 2012). Felimban et al. (2019) found in a study of households in Jeddah that any solution leading to indoor temperatures above 25°C would not be accepted by households. Alshahrani, and Boait, (2018) concluded that with the use of smart controls (i.e., scheduling advanced control of A/C operations, time varying thermostats setting) along with occupancy behavioural adjustments, 30% to 40% reduction in A/C energy consumption could be achieved.

To meet the Saudi government’s new renewable energy target of 27.3 GW by 2023 and 57.8 GW by 2030, as part of its ‘Vision 2030’ strategy, solar photovoltaics will play a vital role (Climate Action Tracker, 2020). Integration of domestic rooftop PV would bring power directly to where it is consumed, in contrast to large solar farms located outside cities.

Methods

As a pilot study prior to a larger study of a sample of dwellings, the electricity consumption of a single villa in Jeddah was monitored at ~30 sec resolution for approximately 1 year. All three floors of the villa were measured separately. This paper includes data that has not been published previously including from the highest consumption months (July-August 2019). In this work, in order to model appropriate PV systems for rooftop mounting (see Fig. 1 for view of rooftop area), only the first floor energy consumption data was used, as this floor is the main living area (300 m2) and presents highest load among three floors of the villa. This is the floor where all the bedrooms are located for the household members and cooling is used most of the time. It is clear from the collected data that the electrical loads are higher for the period between May and September in line with ambient temperatures.

Figure 1. Case study rooftop showing area available for PV mounting of around 200 m2 which would entail a raised structure to allow space underneath for existing A/C units and plant and to prevent shading.

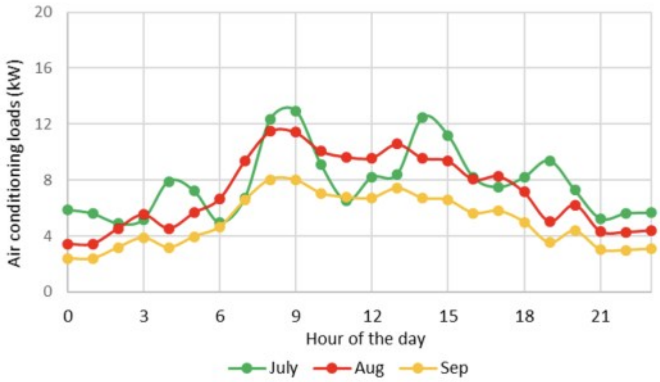


Figure 2. Estimated hourly average electrical loads (kW) for air conditioning of the whole study villa (all three floors and auxiliary) in Jeddah for July, August and September 2019 (total estimated from measurement of two of three phases).

Household air conditioning electricity consumption profiles of the three hottest months are presented in Fig. 2. July presents the highest total electricity consumption (267 kWh/d) followed by August (247 kWh/d) and September (241 kWh/d) respectively. Cooling loads for each of these three months were determined from the monitored power data. Simulations were carried out using the HOMER® software to determine the ability of different combinations of PV systems to support (a) the air-conditioning loads only, and (b) how much this PV would contribute to other loads, for the first floor only. To have a clear indication of PV systems' seasonal performance in relation to load variations in different months, the collected data was scaled over a year period, with gaps imputed to develop a timeseries database. This was fed into HOMER®'s electrical load component, along with global horizontal irradiance data drawn from NREL. Parameters considered for the PV system simulation as follows:

Table 1. Rooftop array simulation parameters

Parameter	Value/Range
Total electrical load	66 kWh/d - 167 kWh/d
Module capacity	325 Wp
Array capacity	{2, 4, 6, 8, 10, 12, 15} kWp
Export to grid	Allowed

Results

Measured electrical loads of the floor of the study villa indicated the similar pattern, where the hottest months of the year (May – September) coincide with relatively very high energy consumption. Total yearly capacity to serve daily total load of the simulated PV systems (2 kWp – 15 kWp) of the first floor of the study villa is presented in Tab. 2. Performance of a 15 kWp PV system is elaborated in Fig. 3 and Fig. 4 shows three critical incidents of this system in December when it may not be able to support full electrical load to a very small extent.

Table 2. First floor electrical demand met by PV arrays of different capacities

Array size (kWp)	2	4	6	8	10	12	15
% total demand met	9	19	28	37	46	55	69
% daytime demand met	13	26	40	53	66	79	99

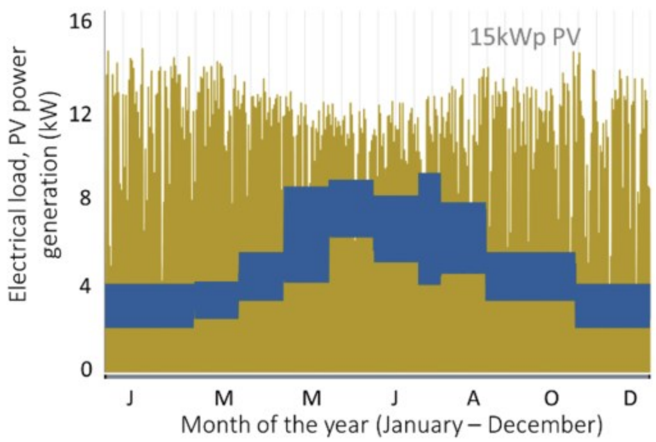


Figure 3. Power generation by 15kWp PV systems and the scaled electrical load of the study house (1st floor, scaled load 110kWh/d). Blue stacks indicates electrical load (kW) and brown indicates PV power generation. .

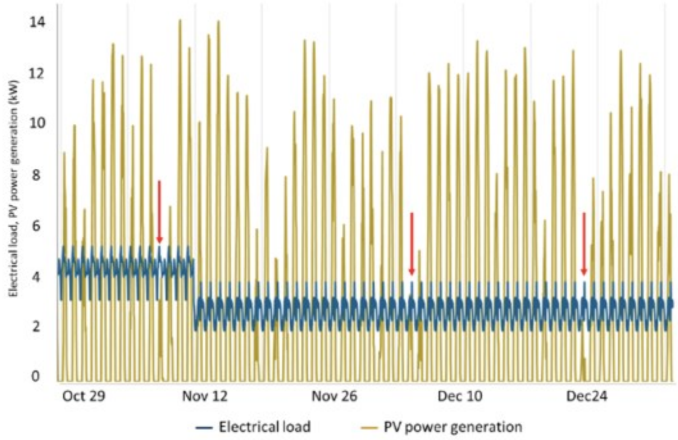


Figure 4. Example of a 15kWp PV system where it suffers few days of capacity shortage to support the daytime required loads. Three days of capacity shortages indicated between Oct 29 and Dec 24 by red arrows.

Conclusions

Power generated by smaller PV systems ranging from 2 kWp to 8 kWp would have significant shortfall, especially in during the months of peak demand between May and September. While a 10 kWp PV system only able to meet the 46% of the total load and 66% of the daytime load, it can meet the daytime cooling load with only about 3 kWh/d shortfall energy. In this case, the 12 kWp PV system can serve daytime cooling load with a 7 kWh/d surplus energy. Simulation results show that a 15 kWp PV as the optimum size to meet the daytime total loads for the first floor (99% of daytime load met by PV). However, this system may incidentally suffer few instances of energy shortfall as shown in Fig. 3. Increasing the size of PV system to >15 kWp would result in oversizing the system if an energy storage system is not integrated.

The PV sizing described in this paper will be used to inform the forthcoming field trials of rooftop PV on a sample of households. More detailed techno-economic analysis of such systems with the provision of grid connection, battery storage and potential thermal storage will be carried out in future work.

Acknowledgements

Funding for this work was provided by the Kingdom of Saudi Arabia Ministry of Education.

References

Felimban, A., Prieto, A., Knaack, U., Klein, T. and Qaffas, Y., 2019. Assessment of Current Energy Consumption in Residential Buildings in Jeddah, Saudi Arabia. Buildings. 163(9). doi:10.3390/buildings9070163

Mujeebu, M.A., Alshamrani, O.S., 2016. Prospects of energy conservation and management in buildings: The Saudi Arabian scenario versus global trends. Renew. Sustain. Energy Rev. 58, 1647–1663.

Alrashed, F., Asif, M., 2012. Prospects of renewable energy to promote zero-energy residential buildings in the KSA. Energy Procedia, 18, 1096–1105.

Alshahrani, J. and Boait, P., 2018. Reducing high energy demand associated with air conditioning needs in Saudi Arabia. Energies. 87(12). doi.10.3390/en12010087.

Al-Ajlan, S.A., Al-Ibrahim, M.A., AbdulKhaleq, M. and Alghamdi, F., 2006. Developing sustainable energy policies for electrical energy conservation in Saudi Arabia, Energy Policy, 34, pp 1556-1565.

Al-Shaalan, A.M., 2012. EER improvement for room air-conditioners in Saudi Arabia, Energy Power Eng. 4. doi:10.4236/EPE.2012.46058.

Climate Action Tracker, 2020. Saudi Arabia. Available at: https://climateactiontracker.org/countries/saudi-arabia/ [accessed 03.04.2021]

Scaling rooftop photovoltaics in cities of varying climate: an essential step towards low carbon cities

AbuBakr S. Bahaj[1], Abdusalam Alghamdi[2], Phil Wu[1], Mostafa Mahdy[1], Luke Blunden[1]

[1]*Energy and Climate Change Division, Sustainable Energy Research Group, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, UK.*

[2]*Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah, Saudi Arabia.*

Summary

Cities are central to development as they generate more than 80% of global GDP and urbanization is advancing at a fast pace where approximately 70% of global population will reside in cities by 2050. This creates challenges for city operations as resources such as energy are distributed through ever more congested supply networks. Here we explore the deployment of solar photovoltaic systems in cities at scale using Geographic Information Systems (GIS). The research uses the cities of Southampton in the UK and Jeddah in Saudi Arabia as case studies for analyzing energy consumption and how this can be linked to power generation from building installed photovoltaic systems. The result for Southampton shows that approximately 25% of the city's electricity can be produced from buildings whilst the work on Jeddah is progressing with the goal of reducing air-conditioning loads. For the latter the paper further explores thermal solutions to assist in reducing such loads. The work is related to both United Nations Sustainable Development Goals SDG 11 and SDG 7.

Introduction

Cities are central to development as they generate more than 80% of global GDP. Furthermore, the world is becoming more urbanized with more than half its population (55%, 4.2 billion) is now living in cities which is likely to reach 70% by 2050 (World Bank, 2021). However, this rapid growth creates challenges for cities, including demand on resources (water, energy, waste management etc.), housing, transport and increasing pollution. In the UN Sustainable Development Goals (SDGs), Goal 11 and its sub-targets addresses these issues requiring the stated goals to be achieved by 2030 (United Nations, 2021). In addition, cities also account for more than 70% of energy consumption and commensurate carbon emissions. Hence, they impact on energy and SDG 7 (sustainable energy access for all). However, cities are where wealth, growth and innovation are generated and stimulated. They can provide leadership in the transitioning of aspirational regions and nations toward international targets.

The Covid-19 pandemic has created a lasting impact on cities across the world, not only affecting public health, but created economic instabilities that are threatening city communities. The pandemic resulted in imposed lockdowns in many cities, demanding working from home which requires additional resources to provide a comfortable environment, especially those related to online working and how it impacts on energy use in different climates.

Photovoltaics on buildings whether integrated or otherwise can play a significant role in contributing to sustainable electrical power generation in cities when deployed at scale. This is acknowledged as an effective way to produce power in cities especially from underused areas and where there are support mechanisms and policies for such interventions. Such deployment also entails negligible land costs as, on the whole, they use unoccupied infrastructure space in buildings.

This paper explores the deployment of solar photovoltaic systems in cities at scale. It uses the cities of Southampton in the UK and Jeddah in Saudi Arabia as case studies for analyzing energy consumption and how this can be linked to power generation from building installed photovoltaic systems.

Methods

In recent decades the capability of Geographic Information Systems (GIS) for assessing solar energy resources has been demonstrated (Brito et al. 2012). This is largely facilitated by the improvements in remote sensing technologies such as Light Detection And Ranging (LiDAR), which provides high fidelity digital elevation models (DEM) of buildings that can be efficiently obtained with higher reliability and accuracy of outcomes (Borfecchia et al. 2014). High resolution DEM datasets are able to reveal topographic features, as well as geometric characteristics of roofs of buildings.

The authors of the present paper developed a new approach using GIS which has been used to support research in a wide range of resource assessments in Southampton and other cities in the UK ([Citation removed for double blinding], 2018). The developed GIS model automatically selects rooftop areas that are suitable for PV system installations. The novel method identifies roof edges uses a non-linear filter to detect curvature jumps. The conventional solar assessment approach of providing an estimation of three factors—solar radiation area, slope, and aspect—was avoided as these are computationally burdensome; only the solar radiation area factor was retained to provide an indication of the potential of various roof areas that can receive solar radiation over the course of a year. The components of the methodology have been validated in the UK by field survey of a proportion of buildings. In order to the test the approach, two case study cities with widely varying climate conditions were selected, Southampton, UK and Jeddah, Kingdom of Saudi Arabia.

Results

City of Southampton, UK

Southampton is located on the south coast of the UK and is one of the largest cities in southeast England. It covers an area of 50 km², and according to 2011 census the population of 237,000 are divided into around 100,000 households resident in approximately 31,000 domestic buildings. Using gazetteer data provided by the local authority, the location of all domestic dwellings has been specified on the GIS system, together with all non-domestic buildings, which number over 7,000. The total building footprint area is 7.4 km², covering 15% of the land within the city boundary. For the UK, the climate is mild, with insolation (GHI) of 1100 kWh/m2 and mean monthly temperatures varying from 8°C in January up to 22°C in June.

City of Jeddah, Saudi Arabia

The Kingdom of Saudi Arabia (KSA) is blessed with high annual solar radiation (GHI) exceeding 2100 kWh/m2 culminating in a hot climate (Jeddah average monthly temperatures vary between 26°C in February up to 35°C in July) requiring large energy input to support modern living conditions and provide comfort in the built environment. Due to high humidity, Jeddah has the highest cooling requirement of all Saudi cities, with a typical annual household electrical consumption of over 220 kWh/m2 (Felimban 2019). To put this in perspective, annual energy consumption of detached dwellings in the UK is around 125 kWh/m2, dominated by winter heating (UK Department for Business, Energy and Industrial Strategy, 2019). The resultant high and ever-growing energy consumption, derived from fossil fuels, is recognized as problematic in terms of pollution, carbon emissions and security of supply. Under its Vision 2030 the KSA has embarked on reforms of its economy including the energy sector, where renewable energy targets have been set coupled with large investment to support this expansion.

Figure 5. Selected Jeddah city regions where representative samples of buildings are analyses to estimate PV potential based on available roof area.

PV deployment and energy potential

This section provides initial results for the city of Southampton. As buildings have different roof areas, the analysis determined three size criteria: small (<3 kWp), medium (3–15 kWp) and large (>15 kWp). The overall results indicated that approximately 250 MWp can be installed on both domestic and nondomestic buildings in Southampton. The energy production distribution is shown in Fig. 6.

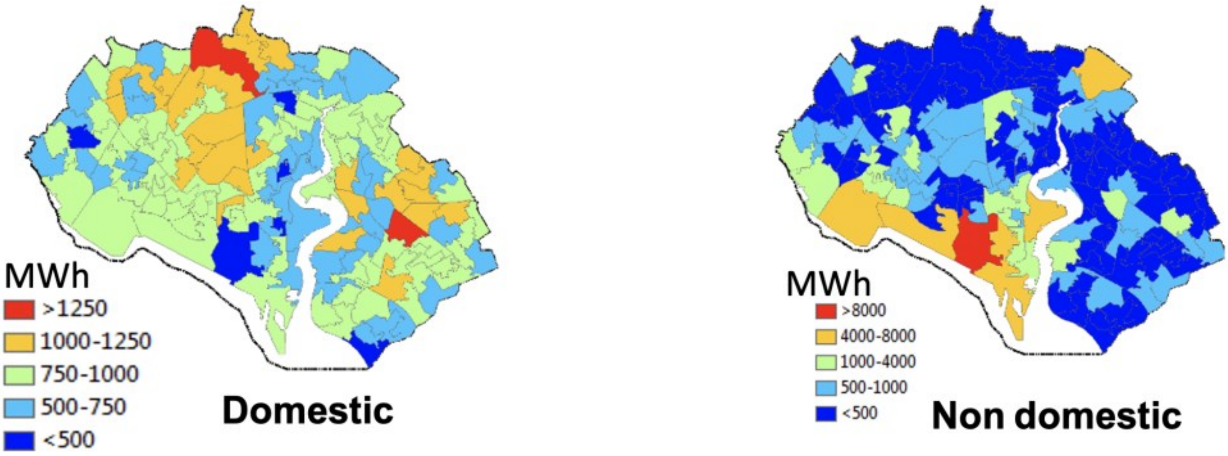


Figure 6. Domestic and non-domestic distribution of energy yields in MWh in the City of Southampton, UK.

The initial step of training the model for Jeddah has begun and will be verified by visual inspection and on-the-ground survey of a sample of buildings. This will allow us to provide comparative analyses of power generation and consumption profiles derived from 120 monitored homes in Southampton and three consumption profiles from villas in Jeddah.

Conclusions

The work compares two cities in different climates (one requiring heating and other cooling). The results show promise of using building fabric to generate power where in Southampton the analysis indicates a 250 MWp can be achieved from roofs of buildings, supplying over 1 kWp per resident of the city. Ongoing research is considering buildings in Jeddah to estimate power outcomes using the highlighted methodology. This work will inform policy and identify approaches to promote PV in buildings.

References

Borfecchia, F., Caiaffa, E., Pollino, M., De Cecco, L., Martini, S., La Porta, L., Marucci, A., 2014. Remote Sensing and GIS in planning photovoltaic potential of urban areas. Eur. J. Remote Sens. 47, 195–216. https://doi.org/10.5721/EuJRS20144713

Brito, M.C., Gomes, N., Santos, T., Tenedório, J.A., 2012. Photovoltaic potential in a Lisbon suburb using LiDAR data. Sol. Energy 86, 283–288. https://doi.org/https://doi.org/10.1016/j.solener.2011.09.031

ESRI, 2021. Introducing pre-trained geospatial deep learning models. Available online: https://www.esri.com/arcgis-blog/products/arcgis/imagery/introducing-ready-to-use-deep-learning-models/https://www.gov.uk/government/collections/national-energy-efficiency-data-need-framework. Accessed 1 May 2021.

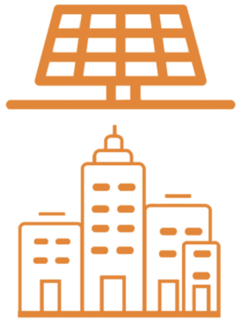
Felimban, A., Prieto, A., Knaack, U., Klein, T. and Qaffas, Y., 2019. Assessment of Current Energy Consumption in Residential Buildings in Jeddah, Saudi Arabia. Buildings. 163(9). https://dx.doi.org/10.3390/buildings9070163

UK Department for Business, Energy and Industrial Strategy, National Energy Efficiency Data-Framework (NEED). Online. Available: https://www.gov.uk/government/collections/national-energy-efficiency-data-need-framework. Accessed 1 May 2021.

United Nations, 2021. Goal 11: Make cities inclusive, safe, resilient and sustainable. Online. Available: https://www.un.org/sustainabledevelopment/cities/. Accessed 1 May 2021.

World Bank, 2021. Urban Development. 20 April 2020. Online. available: https://www.worldbank.org/en/topic/urbandevelopment/overview#:~:text=Withper%20cent20moreper%20cent20thanper%20cent2080per%20cent25per%20cent20of,andper%20cent20newper%20cent20ideasper%20cent20toper%20cent20emerge. Accessed 1 May 2021.

Residential rooftop PV power generation to support cooling loads



Majbaul Alam[1], Abdusalam Alghamdi[2], AbuBakr S. Bahaj[1], Patrick James[1], Luke Blunden[1]

[1]Energy and Climate Change Division, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, UK.

[2]Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah, Saudi Arabia.

The Kingdom of Saudi Arabia (KSA) is one of the highest electricity consuming country with an annual per capita consumption of 9400kWh, and its energy sector is predominantly based on fossil fuel. Total year on year electricity consumption has been growing at a rate between 5% to 8%. KSA Government 'energy sector transition plan 2030' sets renewable energy generation target of 58.7GW of which 40GW to come from solar photovoltaic (PV). Residential sector in Saudi Arabia accounts for about half of the electricity consumption about 70% of such consumption comes from cooling loads. The daily phase matching during the period 11:00 and 17:00 between the country abundant solar resource and peak cooling demands presents a great potential of solar power generation to satisfy some of the air conditioning loads within this period. The aim of this research is to investigate the role of rooftop solar PV systems that can support this aim and play a role in reducing electricity demand in residential buildings in KSA. The research also aims to provide evidence of technoeconomic feasibility of such distributed power generating systems, its contribution to national renewable energy aspirational targets as well as environmental and sustainability impacts.

To ascertain the daily load profile and year-round electrical demand energy and environmental monitoring systems were installed in a villa in Jeddah. In addition to captured total building demand, cooling loads for different months were determined from the monitored consumption data. A range of PV systems were simulated using a commercial software to determine (a) their ability to support the air-conditioning loads only, and (b) contribution to support other loads. To have a clear indication of the PV systems' seasonal performance in relation to load variations in different months, scaled 12 months' timeseries data was fed into the software's electrical load component. The analysis of the monitored data indicates that the total electrical demand varied between 66kWh/d to 167kWh/d which includes a day time load ranging from 38kWh/d and 85kWh/d. This gives the demand base range to investigate PV system sizes that can support various demand load capacities.

The simulation conduced covered PV system capacities in the range 2 – 15 kWp. The results indicate that power generated by PV systems ranging from 2kWp to 8kWp would have significant shortfall to support the full demand, especially during the months of peak demand between May and September. While a 10kWp PV system will only able to meet the 46% of the total demand and 66% of the daytime demand. The analysis shows that a 12kWp PV system can serve daytime cooling load with around 7kWh/d surplus energy that can be used within the building. The results show that a 15kWp PV system is the optimum size to meet the daytime total loads (99%), with few instances of energy shortfall. Increasing the size of PV system to capacities >15kWp would result in oversized systems which will require an energy storage to be integrated. The above analyses provides an understanding of systems capacities to support typical buildings' demand loads which will also be governed by available roof areas. The paper includes scenario analyses for such areas based on building types, consideration of storage systems and techno-economic understanding especially in the case of Saudi Arabia where electricity tariffs are heavily subsidised. Overall the findings of this research gives appropriate examples of PV rooftop systems sizing that can shave peak air conditioning loads and support utility grid, while creating a substantial path toward the renewable energy targets and sustainability of the country.

Satellite imagery to classify and select domestic dwellings for rooftop PV in Jeddah, Saudi Arabia

Mostafa Mahdy[1], Luke Blunden[1], Abdusalam Alghamdi[2], AbuBakr S. Bahaj[1],

[1]*Energy and Climate Change Division, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, UK.*

[2]*Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah, Saudi Arabia.*

In hot, humid areas such as the city of Jeddah on the Red Sea coast of the Kingdom of Saudi Arabia (KSA), demand for electricity for air conditioning is very high, driven in part by low historic electricity prices. Despite an abundance of solar resource there is an extremely low level of penetration of rooftop-mounted photovoltaic (PV) electricity generation, with its potential benefits of reducing consumer electricity bills in addition to reducing carbon dioxide emissions. Furthermore, utility prices are rising and rooftop solar PV could provide a mitigation of these. In addition, KSA has an ambitious programme to diversify its economy from fossil fuel production and install 58.7 GW of renewable energy generation capacity (including 40 GW of PV) by 2030, starting from a base of almost exclusively oil- and gas-based electricity generation. Hence deploying rooftop PV could contribute to such a targets as well as environmental and sustainability impacts.

The work presented in this paper is part of a longitudinal study in Jeddah, KSA, aimed at evaluating the effectiveness of interventions to reduce air-conditioning electrical demand at the household level, known to make up around 70% of household electrical demand in KSA. The interventions to be tested are in the form of installations of various rooftop PV array sizes, with or without energy storage, on domestic dwellings. In the case of no energy storage, the temperature set point and on/off timing of the air conditioning can be adjusted to make best use of the PV and to use the building fabric itself as a thermal store. In the case of the energy storage system, there would be flexibility and scope for optimizing self-consumption over the whole 24-hour cycle. In the study, there will be three groups in an appropriately selected sample of households: a control group which is only monitored; a group where only PV is installed and a group where PV is installed along with an energy storage system. The target population consists of dwellings that have high roof area to internal volume and are owner-occupied. In Jeddah, these typically take the form of detached or semi-detached villas. Air-conditioning electricity consumption in these dwellings can exceed 200 kWh/day in the summer months. The households resident in these dwellings will see the most financial benefit from installing PV on their rooftop and are therefore the ideal target sector for rapid increases in PV generation in KSA cities.

Here we report on the first stage of the project, which is to generate a sample from the target population of households. The challenge in this case is to use satellite imagery to firstly classify residential areas of the city; secondly to identify those areas and buildings with the characteristics of the target population and finally to draw a probability-based sample from this population of dwellings. In order to reduce bias introduced by manual identification of areas and buildings and also to enhance the reproducibility of the work, the process should be automated. To ensure that the sample is balanced, a spatially stratified approach is used. The advantages of this approach are that roof area (a key variable) is automatically evaluated during the sample process and possible effects of spatial correlation are avoided. The paper provides the results of progress on the above challenges and how these are addressed in a geographical information system (GIS) applied to sections of the city of Jeddah. The paper also discusses the approach used for classifying and identifying areas and buildings within cities and reports on the systematic methods applied using high resolution satellite imagery as input to the case study in Jeddah. The classification and identification steps is validated by checking a proportion of the sampled buildings and the results obtained provided an indication of suitable areas for PV deployment, contributing to the country target and sustainability.

Environmental assessment platform for cities racing to net zero

AbuBakr S. Bahaj[1], Philip Turner[1], Mostafa Mahdy[1], Abdusalam Alghamdi[2], Steve Leggett[1,3], Naomi Wise[1,4]

[1]Energy and Climate Change Division, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, UK.

[2]Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah, Saudi Arabia.

[3]Southampton City Council, Civic Centre, Southampton, UK.

[4]Winchester City Council, The Guildhall, City Offices, Winchester, UK.

The UK was the first major economy to pass a Climate Change Act in 2008 committing the Government to 80% reduction in emissions from 1990 levels by 2050, which was revised in 2019 to achieve net zero emissions by the same date. In addition to contribution to the UN Sustainable Development Goals, the benefits brought out by net zero are vast, including improved air quality and enhanced natural environments leading to improved health, enhanced productivity and potentially reducing hospital admissions. Nationally, 68% of cities and local authorities have declared a climate emergency with some setting quantifiable targets to net zero by certain dates. In 2019, Southampton City Council (SCC) and Winchester City Council (WCC) declared climate emergencies and announced ambitious targets for their cities to become carbon neutral and create greener, cleaner cities. SCC set these targets under the banner Green City Charter (GCC) which was signed by around 70 of the city's organisations. Whilst WCC set action plans for their city/district to be carbon neutral by 2030. There are, however, no specific principles to measure the success or otherwise of declared commitments, nor a methodology to quantify progress towards the targets. Each of these cities has a plan that focuses on their perceived themes (e.g. largest sources of carbon emissions) and here we present an approach to transfer these themes into a structured online tracker that is suitable for most organisations regardless of sector or size.

Here we present the outcomes from developing the Green City Tracker in collaboration with local authorities and city-based organisations. The approach is based on the Analytical Hierarchy Process (AHP) where the themes were transferred to specific criteria with expertise agreed weights to measure the success or otherwise of carbon environmental commitments. The outcome is the Green City Performance Tracker encompassing an assessment matrix and carbon accounting that provides ratings and quantifies annual progress for achieving the committed targets. The Tracker was applied to 10 city-based institutions and the results show their ratings as a function of each criteria and as an overarching rating per institution. The approach highlighted the importance of generating a universally applicable, fair, engaging and time/resource efficient Tracker processes in order to incentivise organisation participation. The Tracker and its processes are widely accepted by regional local authorities as a vehicle to support their sustainability credential with a plan to widely adapt it to other cities that declared environmental targets.

Displacing Cooling Loads with Solar PV in Saudi Housing Sector

Majbaul Alam[1], Abdusalam Alghamdi[2], AbuBakr S. Bahaj[1], Luke Blunden[1]

[1]*Energy and Climate Change Division, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, UK.*

[2]*Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah, Saudi Arabia.*

Electrical power generation in the Kingdom of Saudi Arabia (KSA) is dominated by fossil fuels. The annual electricity consumption per capita in 2018 is approximately 10.5 MWh representing one of the highest in the world with a commensurate carbon emission. Subsidised electricity tariffs and arid climate, coupled with economic growth have persistently fuelled electricity demand growth in all sectors.

The residential sector, which the subject of this research, accounts for over 50% of the total national demand. Cooling loads through the use of air conditioning in the residential sector constitutes about 70% of the total electrical demand, impacting peak daytime loads especially in the summer months. Peak load in the KSA, which has almost doubled in the last decade, is a key challenge for the national grid and is not sustainable.

This research investigates the applicability of building integrated PV systems to (a) serve/dent residential cooling loads, and (b) identify opportunities of such interventions at scale to reduce the burden of peak loads on national grid. The work is linked to KSA's 'Vision-2030' addressing the electricity sector where renewable energy is planned to contribute 50% of the its installed capacity by 2030. Modelling approaches based on simulation of PV systems ranging from 2kWp to 15kWp with and without battery storage were undertaken. Power outputs under KSA weather conditions were determined and linked to monitored household electricity consumption profiles ranging between 2.4MWh and 61MWh annually.

Results show that some of the selected PV systems can substantially meet peak cooling loads and are likely to reduce the peak demands on the utility grid if deployed at scale. The paper also presents a techno-economic suitability analyses of such systems both in grid connected and standalone modes. The study highlights that the existing electricity tariff in KSA is likely to create a major barrier of deploying such PV systems at scale, and an appropriately targeted feed in tariff or capital cost subsidy are likely to alleviate such barriers in the short term.

Tools for transparency and reproducibility in 'big' data driven energy demand research: case-studies of open data, open code and open science

Tom Rushby[1], Ben Anderson[1], Luke Blunden[1], AbuBakr S. Bahaj[1], Abdusalam Alghamdi[2],

[1]Energy and Climate Change Division, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, UK.

[2]Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah, Saudi Arabia.

Research in energy systems has been under the spotlight in terms of reproducibility and replicability, with questions over the validity and trustworthiness of some findings. Following similar initiatives within other disciplines, there is a push to improve research practices, to deliver research with "…greater transparency, reproducibility and quality" as well as industry-academia collaboration. A further challenge is provided by the sheer scale of data now collected and being made available. To exploit the wealth contained in this resource, and to ensure that quality (and trust) is maintained, new 'open science' practices are being promoted/embedded into the research process to make the sharing of data and analysis, and collaboration, less onerous. Reproducible research encompasses the whole research pipeline from study design, sampling and data collection, through analysis methods to data archival; however, we focus on a single segment, 'open data and open code', highlighting the elements related to data collection, pre-processing and analysis using a number of recent fieldwork data collection case-studies.

This paper describes datasets collected by the University of Southampton through a number of research projects and involving primary data collection in Saudi Arabia, China and the UK and detail the development of an 'open science' approach. We discuss tools to support the use (and re-use) of new datasets as well as share code used in data preparation, processing and analysis. We describe how, in addition to increasing transparency, reproducibility and trust in the research process, such practices also have added benefits for research teams.

Environmental assessment platform to support organisations sustainability pathways

AbuBakr S. Bahaj[1], Philip Turner[1], Mostafa Mahdy[1], Abdusalam Alghamdi[2], Steve Leggett[1,3], Naomi Wise[1,4]

[1]*Energy and Climate Change Division, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, UK.*

[2]*Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah, Saudi Arabia.*

[3]*Southampton City Council, Civic Centre, Southampton, UK.*

[4]*Winchester City Council, The Guildhall, City Offices, Winchester, UK.*

The UK was the first major global economy to pass a Climate Change Act in 2008 committing the country to 80% reduction in emissions from 1990 levels by 2050. In 2019, this target was subsequently revised to achieve net zero emissions by the same date. In addition to contribution to the UN Sustainable Development Goals, the benefits brought out by net zero are vast, including improved air quality and enhanced natural environments leading to improved health, enhanced productivity and potentially reducing hospital admissions.

Nationally, 68% of UK cities and local authorities have declared a climate emergency with some setting quantifiable targets to net zero by certain dates. In 2019, Southampton City Council (SCC) and Winchester City Council (WCC) declared climate emergencies and announced ambitious targets for their cities to become carbon neutral and create greener, cleaner cities. SCC set these targets under the banner Green City Charter (GCC) which was signed by around 70 of the city's organisations. Whilst WCC set action plans for their city/district to be carbon neutral by 2030. All these aspiration are also sustainability driven including waste reduction and introduction of low/zero carbon transport. However, in spite of these aspirations, there are no specific principles to measure the success or otherwise of declared commitments, nor a methodology to quantify progress (annual) towards the targets.

The highlighted cities have different pillars to achieve their required targets leading to an overall scope of environmental action plan to achieve these. The pillars or themes are somehow similar and can be exchangeable. In this work, we present an approach to transfer these themes into a structured online environmental tracker that is suitable for most organisations regardless of sector or size. The approach is based on the Analytical Hierarchy Process (AHP) where the themes were transferred to specific criteria with weights agreed by experts to measure relative importance of each theme against each other. The outcome is the Green City Performance Tracker encompassing an assessment matrix that includes carbon accounting and provides ratings for each theme which is combined into quantifiable progress for achieving the committed targets.

The paper presents the outcomes from such development - the Green City Tracker - in collaboration with local authorities and city-based organisations and a robust methodology devised to be applied to organisations and cities across the UK and globally. The Tracker was applied to the first 10 SCC city-based institutions. The outcomes are presented in the paper in terms of ratings for each criteria coupled with a combine overarching rating per institution. Such ratings were design to show areas of successes and those that need improvement, providing a basis for needed actions to enhance progress in the themes. The approach highlighted the importance of generating a universally applicable, fair, engaging and time/resource efficient Tracker with less taxing processes in order to incentivise organisation participation. The Tracker and its processes have been developed so that they are widely accepted by regional local authorities as a vehicle to support their sustainability credential and can be adapted to cater for other cities/organisations that declared environmental targets.

UNIVERSITY OF Southampton

Energy and Climate Change Division
University of Southampton
Southampton, United Kingdom
www.energy.soton.ac.uk
@EnergySoton
serg@soton.ac.uk

Department of Electrical and Computer Engineering
King Abdulaziz University
Jeddah, Saudi Arabia
www.kau.edu.sa

UNIVERSITY OF Southampton

وزارة التعليم
Ministry of Education