Institution: Edinburgh Napier University

Unit of Assessment: UoA12 - Engineering

Title of case study: Solar Radiation: Enabling International Innovative Design Applications for Professional Practice.

Period when the underpinning research was undertaken: 2002 - 2015

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
T. Muneer	Professor of Energy Engineering	September 1990 - present

Period when the claimed impact occurred: 2013 - 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Research undertaken at Edinburgh Napier University (ENU) into solar radiation and daylight has been at the forefront of applications for international standards, professional practice guidelines and product innovations. The impacts of the work include adoption in the Chartered Institution of Building Services Engineers (CIBSE) Guide A 'Environmental Design' for buildings, utilised by over 70,000 engineers in 98 countries. The research has resulted in new international standards Commission Internationale Eclairage (CIE) 713, Malaysian Government building design guide and projects for the Arabian Gulf Co-operation Council. New products developed by UK companies from this applied research have led to new monitoring devices for global markets including solar array in China.

2. Underpinning research (indicative maximum 500 words)

Solar energy is vital to maintaining life on earth. It is a key source of heat and energy for the planet, and due to climate change, is increasingly being looked to globally as a source of renewable and affordable energy. To utilise solar energy efficiently, it is vital to be able to quantify the amount intercepted by different surfaces on the Earth. Unfortunately, recording of solar energy is uncommon worldwide. For example, the UK had only 4 measuring stations as late as 2003. As such, physical and mathematical models are required to accurately predict levels of solar radiation, the results of which can be used to perfect renewable building and energy solutions. This research, performed since 2002 by Professor Tariq Muneer, has developed solutions for modelling solar radiation, as well as mapping future levels, and assisting in the development of new technologies. The work involved collaboration with BRE, UK Met Office, Universite de Liege, and universities of Sheffield, Manchester and Geneva.

Muneer's research first focused on creating mathematical models to better understand solar irradiation, the process by which surfaces on the earth are exposed to solar energy **[O1]**. This work allowed Muneer to create a number of models which calculate the quantity of solar radiation in contact with a given surface, as well as models which calculate the predicted energy transfer to the surface. For example, the models can assist in the calculation of the decomposition of total solar irradiance into its constituent beam and sky-diffuse components, giving an accurate measurement of the final energy received by the surface. Following on from this, Muneer conducted applied research to develop a slope irradiance model, an algorithm which accurately calculates solar irradiation in sloped areas. This research **[O2]**, undertaken for the Chartered Institute of Building Service Engineers, investigated solar data for locations around the UK, and used the algorithm to accurately measure irradiation.

Having established models to accurately calculate levels of solar energy and slope irradiance, Muneer applied solar radiation models to future climate change predictions **[O3, O4]**. In 2011, the UK Climate Impacts Programme (UKCIP) provided the latest climate projection data to a

resolution of 5 km square grids for the UK. Muneer used this data to analyse the likely changes that may occur in the sol-air temperature, sky clarity and daylight illuminance profiles in the UK by 2080. Muneer used the previously mentioned **[O1]** slope radiation algorithm, and CIBSE established long-wave thermal radiation exchange models to generate this data. Drastic increments of sol-air temperature and a radical change in the characteristics of solar climate were identified using this method, for example from the present diffuse fraction of total irradiation of 0.37 (that indicates mild turbidity) to a drop of 0.13 indicating clear skies with exceptionally low turbidity. These calculations have an important bearing on the potential future design and function of buildings and building services, for example the need for excessively high summer cooling demand for buildings.

Muneer has since utilised his expertise in solar energy calculation to research potential innovative solutions. Tubular daylight guidance systems are specially designed pipes which distribute daylight from the roof level throughout buildings, and are a novel and energy efficient replacement for electrical lighting. In 2002, Muneer used mathematical models to assess the viability of tubular lighting solutions in all UK weather conditions **[O5]**. Straight pipes and elbow pipes were assessed to understand their performance in a variety of conditions, resulting in an understanding of the optimum design and positioning of lights in terms of efficiency. This resulted in a design guide for use in practice. The increased importance of solar energy has led to increasing measurement worldwide. However, the cost of conventional sensors can be prohibitive. In 2003, Muneer evaluated a new sensor produced by the company Delta-T that enables a two-third cost reduction **[O6]**. The research involved validating the accuracy of Delta-T sensors using concurrent field measurements of established, reference class pyranometers, and found that the product measured sunlight consistently and accurately.

Though exposed to a large source of potential solar energy there is a lack of measured data within the Arabian Gulf countries. A measurement and analysis study undertaken in 2007 by Muneer's research team has resulted in the production of quality-controlled sub-hourly radiation datasets for the Gulf. Application of such data analysis can be used in the monitoring of large solar farms that have now been installed in UAE, Saudi Arabia, Kuwait and Qatar.

3. References to the research (indicative maximum of six references)

O3, O4, O5 and O6 are peer reviewed journal articles

[O1] Muneer, T., Gueymard, C., & Kambezidis, H. (2003). Solar radiation and daylight models. Elsevier ISBN 978 0 7506 5974 7. 541 citations.
https://www.sciencedirect.com/book/9780750659741/solar-radiation-and-daylight-models
[O2] Chartered Institution of Building Services Engineers (CIBSE), *Solar and weather data* in CIBSE Guide A, CIBSE, London, 2015. ISBN: 978-1-906846-54-1 (T Muneer as its principal author completed the work on solar data).
https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I79JAAS
[O3] Tham, Y. W., & Muneer, T. (2011). Sol-air temperature and daylight illuminance profiles for the UKCP09 data sets. Building and Environment, 46, 1243-1250. 22 citations.
https://doi.org/10.1016/j.buildenv.2010.11.014
[O4] Tham, Y., Muneer, T., Levermore, G., & Chow, D. (2011). An examination of UKCIP02 and UKCP09 solar radiation data sets for the UK climate related to their use in building design. Building Services Engineering Research and Technology, 32(3), 207-228. 19 citations.
https://doi.org/10.1177/0143624410389396
[O5] Zhang, X., Muneer, T., & Kubie, J. (2002). A design guide for performance assessment of solar light-pipes. Lighting Research and Technology, 34(2), 149-168. 84 citations.
https://doi.org/10.1191/1365782802li041oa
[O6] Wood, J., Muneer, T., & Kubie, J. (2007). Evaluation of a new photodiode sensor for measuring global and diffuse irradiance, and sunshine duration. Journal of Solar Energy Engineering, 125, 1-6. doi:10.1115/1.1531149. 46 citations.
https://asmedigitalcollection.asme.org/solarenergyengineering/article/125/1/43/447194/Evaluation-of-a-New-Photodiode-Sensor-for

Citations data accessed on 11/4/2020 from Google Scholar

4. Details of the impact (indicative maximum 750 words)

Muneer's pioneering research into measuring and predicting solar radiation has led to important impact on a range of sectors. Findings have been used to create an international industry standard building guide, downloaded 70,000 times in 98 countries since 2015, as well as international guidance on the use of tubular lighting, and EU guidance on solar energy calculations. Solar radiation modelling has been utilised in Malaysia, on behalf of the Gulf Co-operation Council for Arab States, and US innovation companies. The UK Met Office has utilised Muneer's models in forecasting climate projections to the year 2080, and two UK companies have achieved significant commercial benefit from Muneer's expertise.

Impact on international technical guidance

The Chartered Institution of Building Services Engineers (CIBSE) is an international professional engineering association, which sets industry standards and guidance in building services. In 2015, CIBSE utilised Muneer's algorithms to measure solar irradiation **[O1]**, and his slope irradiance model **[O2]**, and UK climate predictions **[O3-O4]**, along with long-term Meteorological Office measured data from 14 locations across the UK, to generate the following parameters:

- Hourly and monthly-averaged hourly horizontal diffuse radiation, used for slope radiation estimation.
- Hourly and monthly-averaged hourly radiation for all cardinal directions and slopes, used for applications such as solar heating and photovoltaic design.
- Hourly clear-sky radiation for horizontal and sloping surfaces needed for cooling load estimation.
- Hourly sol-air temperatures that in turn estimate design cooling loads for buildings.

In practice, CIBSE then incorporated these UK statistics into a full set of design models and guidance for buildings services professionals to use in the construction and maintenance of buildings, known as the Guide A 'Environmental Design' for buildings [**C1]**. This has provided an easy way for professionals in the industry to quickly and easily understand distributions of solar radiation in any given area, and has been a critical component in making buildings more energy and heat efficient. Since 2015, globally over 70,000 purchased downloads, from 98 countries, of the CIBSE Guide A 'Environmental Design' were made by building services engineers and other professional members **[C10]**. CIBSE guides are used the world over by professional building services personnel. This is the only guide used for this purpose in the world.

Likewise, in 2006 Muneer's work on tubular daylight guidance systems **[O5]** was incorporated in the Paris-based Commission Internationale de l'Eclairage guidance (CIE) **[C9]**. This is the international standardization body recognized by ISO (International Standardization Organization) and is involved in the worldwide development on all matters relating to the science and art of lighting. Muneer's research had mathematically modelled tubular lighting performance against UK climate to understand optimal design and positioning, and these findings were used to co-author the CIE: 173 Tubular Daylight Guidance Systems, which has set international standards in the passive design of buildings using such devices. The Guidance is of use by manufacturers of tubular daylight systems as well as practitioners such as architects and building services engineers.

Published in 2000 by Ecole de Mines, Paris on behalf of a cross-EU panel, the European Solar Radiation Atlas (ESRA) is the definitive guide for all manner of solar energy calculations. ESRA panel tested nine leading radiation models that enable calculation of solar energy on any given inclined surface. The Atlas utilised Muneer's slope irradiance model for the production of inclined surface solar energy tables **[O2]**. An extract of ESRA is, "*Finally, the fact that the Muneer diffuse model seemed also to have a sounder theoretical basis, and thus more potential for improvement was additionally taken into account. This model was therefore selected*".

Impact on UK government climate projections

As discussed, Muneer undertook research with the UK Climate Impacts Programme to accurately forecast sol-air temperature and solar radiation levels up to 2080 **[O3, O4]**. The UK

Climate Projections 2030-80 via UKCP09 **[C2]** and UKCP18 have utilised this research in design tools, and Muneer has co-advised and reviewed new UK Meteorological Office software applications **[C3]** to assist future benchmarking of climate projections. The work of Muneer centred on forecasting of hourly clear-sky radiation and sol-air temperatures of building surfaces. That information will enable estimation of increased cooling loads for buildings due to climate change.

Impact on foreign government policy and practice
The application of Muneer's research and findings are global as evidenced by citations of his research in the Malaysian Government's Public Works Department new design guidance for passive buildings **[C4]**. Chapter 4 on 'daylight harvesting' incorporates material from Muneer's monograph on 'solar radiation and daylight' **[O1]**.

Likewise, the Gulf Research Centre's **[C5]** 'Renewable energy for the GCC countries design guidance' published on behalf of the Gulf Co-operation Council for Arab states has incorporated statistics from Muneer's measured solar energy record for Bahrain which provides a means of sizing up of air-conditioning plant for buildings. The measured data showed the need for a higher capacity.

Leading USA industry innovation companies have also cited his work **[C6]**.

Impact on commercial companies – UK
In 2003, Muneer collaborated with Delta-T of Cambridge for field tests of their new solar radiation sensor **[O6]**, finding that the sensor was fit for purpose in terms of accurately and cost-effectively measuring solar radiation. That innovative product was then developed by Delta-T for global markets for solar energy monitoring **[C7]**. The sensor was subsequently used to monitor the largest solar array in China **[C8]**. Furthermore, researchers from Universite de La Reunion installed the Delta-T sensor on the edge of one of world's most active volcanoes. A sales and Marketing Manager from Delta-T states "*Professor Tariq Muneer and the team at Napier University's work has been instrumental in helping Delta-T enter and develop several new markets across the globe… Professor Muneer's report was further used in our marketing, sales and conference materials to win customers in several other new sectors. Our products have been used:*

- *Extensively in the Chinese Solar Farms Sector*
- *Successfully used in USA Solar farms market*
- *In global climate change monitoring including the MOSAiC (multidisciplinary drifting observatory for the study of the arctic climate) in the central Arctic*
- *By several major European countries in the development of their PV Farm capability.*

The benefit of this collaboration continues to this day in sales of our product into many global markets." **[C11]**.

When developing their ROOM passive solar design software, ARUP, one of UK's largest architecture and building services consultants, independently evaluated Muneer's slope radiation model, which was then incorporated within ARUP software **[C12].**

Public engagement
- Edinburgh Science and Mathematics festivals. Attendees: 220 and 28, respectively.
- Energy Saving Trust Live webinar on 'How clean are electric vehicles'. Audience on web: 122.
- Energy Technology Partnership renewable energy event. Attendees: 45.
- Awarded Millennium Fellowship by Millennium Commission for developing solar energy projects for local schools.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[C1] CIBSE Guidance: Publication in 2015 of new CIBSE Guide A "Environmental Design" http://www.cibse.org/Knowledge/CIBSE-Guide/CIBSE-Guide-A-Environmental-Design-NEW-2015
This Guide provides a complete algorithmic chain of obtaining incident slope energy and frequency distributions for solar radiation and daylight calculations aligned to nation's meteorological data.
[C2] UK Climate Projections (UKCP09) Background to UKCP09 - http://ukclimateprojections.metoffice.gov.uk/21684
[C3] Updated 2014 referencing Muneer and others - http://ukclimateprojections.metoffice.gov.uk/24004
[C4] Malaysian Government Guidance: Building Energy Efficiency Technical Guideline for Passive Design – Page 76 http://bseep.gov.my/App_ClientFile/df08bc24-99fb-47a3-937f-dc25df9d3997/Assets/Building%20Energy%20Efficiency%20Technical%20Guideline%20for%20Passive%20Design.pdf
[C5] Cited by the GULF Research Centre – Renewable Energy in the GCC Countries, page 36. http://library.fes.de/pdf-files/bueros/amman/09008.pdf
[C6] Leading industry experts cite work in the web articles – e.g. Chief Scientist - Lighting Analysts Inc. http://agi32.com/blog/category/daylighting/
[C7] https://www.delta-t.co.uk/wp-content/uploads/2016/10/BF3-Sunshine-Sensor-Evaluation-v1.0.pdf
[C8] Delta-T news article on 2015 contract for China: http://www.delta-t.co.uk/delta-t-news.asp?$=242&PageNo=3
[C9] CIE Publication
http://www.cie.co.at/index.php?i_ca_id=575&pubid=115
[C10] Email from Lewis Cook of CIBSE on Guide A (26 February 2018)
[C11] Testimonial letter from Delta-T (11 January 2021)
[C12] Email from Michael Holmes of ARUP (30 April 2020)