Institution:
Glasgow Caledonian University

Unit of Assessment:
13 - Architecture, Built Environment and Planning

Title of case study:
Renewable Energy from Waste Water and the Atmosphere in the Glasgow Underground Tunnels

Period when the underpinning research was undertaken:
2012-2019

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:
N Hytiris	Professor & Project Leader	1995 - present
R Emmanuel	Professor & Director, BEAM Centre	2008 - present
K Ninikas	KTP Associate / PhD Researcher	2014 - 2016
B Aaen	Lecturer	2015 - present

Period when the claimed impact occurred:
2015-2019

Is this case study continued from a case study submitted in 2014?
No

1. Summary of the impact

Based on longstanding work on geotechnical engineering and energy efficiency in the built environment, Hytiris and colleagues demonstrated provision of renewable heat by turning a waste (water ingress in underground tunnels) into a resource (renewable heat) in the Strathclyde Passenger Transport (SPT) underground transport system in Glasgow. Using Water Source Heat Pump (WSHP) and Air Source Heat Pumps (ASHP), the team showed up to 350% renewable heat return in just one underground station, leading to an on-going system wide harvesting of renewable heat in excess of 745kW, and the impact contributed to renewable heat policy formulation in Scotland.

2. Underpinning research

Hytiris and colleagues, benefitting from national and international academic and industrial collaborators (University of Glasgow; British Geological Survey (BGS) [R1, R2]; Scottish Power Energy Networks (SPEN) [G1]; Mijnwater B.V. Heerlen, the Netherlands; Veitch-Copper Ltd) undertook early work into harvesting geothermal energy from water stored within abandoned mine workings in Glasgow as a sustainable source for low temperature heat for homes and businesses. Initial exploration of shallow geothermal mineworking conditions (water temperature and water quality) as well as a mapping exercise were supported by SPEN.

A subsequent Knowledge Transfer Partnership [G2] analysed and evaluated the water seepage and the atmospheric temperature in SPT's underground tunnels, between May 2014 and July 2015 to establish whether heat could be extracted from this source. The water ingress caused environmental (polluted water in public areas) and maintenance (corrosion and defects that necessitate frequent re-railing) issues and negatively affected customer satisfaction (unsightly appearance in public areas, noisier system that contributes to poor ride quality).

Having established the near constant temperatures of the ingress water [R3] as well as the ambient air within the subway tunnels [R4], the team demonstrated renewable energy harvesting at two trial sites in the subway network – a WSHP system at St George's Cross Station and an

ASHP at Bridge Street Station in late 2015, followed by a period of commissioning and monitoring [R5].

- ASHP system: a performance ratio of 3.5:1 (output energy: input energy) resulted in reduced costs (from £1.2 /kW to £0.36 /kW) of heating premises and significant reduction in CO2 emissions (from 0.47 kgCO2/kWh to 0.14 kgCO2/kWh). ASHP has been implemented in six more subway stations [R5].

- WSHP system: a performance ratio of 2.5:1 (output energy: input energy) resulted in reduced costs (from £0.96 /kW to £0.36 /kW) of heating premises and significant reduction in CO2 emissions (from 0.47 kgCO2/kWh to 0.14 kgCO2/kWh) [R6].

By September 2019 one WSHP system and six ASHP systems had been installed. Due to a number of factors (sufficient quantity of water in other stations, and distance from the “source” (water) to the “sink” (station’s office)) the WSHP hasn’t been selected in other stations. Together, these save SPT approx. £20,000 per year in heating costs and 67 tonnes of CO2 per year at the six installed stations.

These benefits enabled the SPT to incorporate the work of the team within its station refurbishment element of the subway Modernisation Programme in 2015-2018.

Additionally, the team uncovered a major humidity issue in some subway stations, reaching up to 85% in peak summertime. Our approach solved the resulting thermal discomfort by removing part of the air moisture in the concourse level of the six stations, leading to improved thermal comfort and better customer experience.

There are some sites already modernised that do not have our systems at present and a retrofit may not be cost-beneficial at this time. These sites could be retrofitted at a later stage, as part of a mid-life capex replacement of the installed system.

3. References to the research

- [R1] Hytiris N., Emmanuel R., Ăaen B., Church E.S., Ninikas K., Campbell D.S., Robertson A., 2015. Heat recovery from mineworkings: opportunities in the Glasgow area, Proc Inst Civil Engineering, Env. Geotechnics, 4(EG6), pp. 395-401, https://doi.org/10.1680/envgeo.15.00007

- [R2] Ninikas K., Hytiris N., Emmanuel R., Ăaen B., Younger P.L., 2016. Heat recovery from air in underground transport tunnels, Renewable Energy, 96, pp. 843-849, https://doi.org/10.1016/j.renene.2016.05.015

- [R3] Hytiris N., Ninikas K., Emmanuel R., Ăaen B., Younger P.L., 2016. A heat energy recovery system from tunnel waste water, Proc Inst Civil Engineering, Env Geotechnics, 5, pp. 300-308, https://doi.org/10.1680/jenge.15.00087

- [R4] Ninikas K., Hytiris N., Emmanuel R., Ăaen B., 2019. The performance of an ASHP system using waste air to recover heat energy in a subway system, Clean Technologies, 1, pp. 154-163, https://doi.org/10.3390/cleantechnol1010011

- [R5] Ninikas K., Hytiris N., Emmanuel R., Ăaen B., 2020. Heat energy output from shallow geothermal in Glasgow: performance evaluation design, Environmental Geotechnics, 7, pp. 274-281, https://doi.org/10.1680/jenge.17.00033

- [R6] Ninikas K., Hytiris N., Emmanuel R., Ăaen B., 2019. Recovery and valorisation of energy from wastewater using a water source heat pump at the Glasgow subway: potentials for similar underground environments, Resources, 8, 169; https://doi.org/10.3390/resources8040169

Research underpinning the impact were funded by Innovate UK as well as several industry partners. These include:

- [G1] "Ground source renewable energy map for Glasgow" 2012-2015, SP Energy Networks (SPEN), N. Hytiris, PI, & R. Emmanuel, £22,500
- [G2] "Innovative solutions for managing the sub-surface water in SPT's subway's tunnel system" Knowledge Transfer Partnership (KTP) Project funded by the Technology Strategy Board (TSB) (Now Innovate UK), 2013-2015, N. Hytiris, PI, R. Emmanuel & B. Ăaen, £128,231
- [G3] Energy Technology Partnership (ETP) PEER Award, 2016-2017, N. Hytiris, £20,871

4. Details of the impact

Energy harvesting from mine workings in Glasgow has been a longstanding activity of the Team [R1, R2]. This research created media interest from the BBC, ITV, The Herald and Digital Journal [C1, C2, C3]. These led SPT (owner operator of Glasgow's subway system that carried 13.15 million passenger journeys in 2018/19) to approach the team for advice on water ingress issues in Glasgow's subway during 2013.

Our demonstration of cost and carbon savings for SPT won the 2016 Scottish Transport Awards, under the category of 'Contribution to Sustainable Transport' [C4].

The SPT Chief Executive said: "SPT manages large volumes of water within the subway tunnel network causing condensation, corrosion and defects making it a major contributor to on-going expensive infrastructure maintenance for us… Working with the University through the Knowledge Transfer Partnership we have found the best solution, turning what was one of our biggest problems into a viable energy source in our stations… At the same time, our work to recycle air from the tunnels has created another source of heat for stations. We were delighted to win a Scottish Transport Award for this project earlier in the year but to now have this work recognised by an international audience is further proof that we have achieved something quite unique and outstanding in terms of recycling energy power."

In addition to the energy savings impact of the team's efforts, our involvement with the SPT further enhanced a cultural shift in the organisation to encourage greater and innovative use of renewable resources. This can be seen from the SPT statement: "Without the input from Glasgow Caledonian University, and their significant knowhow and expertise, as well as their ability to spot potential, none of this would have happened. Working through the Knowledge Transfer Partnership has proved very beneficial. The strong connections developed with colleagues at GCU have made us more environmentally progressive as an organisation, keen to further develop and exploit new opportunities in this area…The KTP experience was extremely worthwhile and was a positive opportunity to work together and help achieve SPT's goals to reduce its carbon footprint by minimising emissions and consumption of resources and energy in our day-to-day operations." [C5]

The research project has received international recognition for its work to find a cost-effective solution to water management in the subway and transform it into a form of energy power. For example, Hytiris presented the project work at the first International Conference on Energy Geotechnics, in Germany [C6].

Policy and practice impact

The successful demonstration led to a total of five subway stations heated with ASHPs and one with a WSHP, leading to approx. £20,000 per year savings in heating costs and a reduction of

67 tonnes of CO2 per year at the six installed stations. This further led to an advisory role for Hytiris and Aaen on Clyde Gateway's Geothermal Energy project where a number of low carbon energy solutions were evaluated at an early feasibility stage. Additionally, Hytiris was appointed member of the Scottish Government's short-life Geothermal Energy Expert Group [C7]. This role, together with the support received from the Energy Technology Partnership (ETP) [G3] helped develop a 'Scottish Learning Journey' for stakeholders in the public, private and academic sectors to explore the potential of geothermal energy from stored water in abandoned coalmines [C8].

Internationally, at the invitation of Dept. of Science Technology (DST), Govt. of India and in collaboration with Institute Chair (IIT Mumbai), Hytiris and Ninikas helped set up a programme of work on energy geotechnics relevant to contemporary Indian conditions in 2017 [C9].

Commercial impact

The Group's successful exploitation of renewable heat from shallow geothermal sources had led to several commercial benefits. As an example, Hytiris and Aaen contributed to the development of a digital conceptual model of an enhanced closed-loop GSHP system at Wishaw to estimate locally generated heat on the basis of their expert knowledge on ground conditions and thermal conductivity. This helped enhance the reliability and predictive power of a commercially available renewable heat estimation model that could assist commercial developers make informed choices about renewable heat potential of shallow geothermal sources.

Furthermore, the impact of the work can be seen in its major attribution to raising awareness of this renewable heat resource and build confidence in the technology. Towards this end, the team has undertaken wider dissemination activities (such as [C10]) to embed shallow geothermal sources of heat as part of Scotland's ambitious renewable heat targets.

5. Sources to corroborate the impact

- [C1] BBC Interview – https://www.bbc.co.uk/news/uk-scotland-glasgow-west-21431763
- [C2] Glasgow Herald news item – https://www.heraldscotland.com/news/13091976.glasgow-looks-to-turn-underground-hot-water-into-power
- [C3] Digital Journal News item, 14 Feb 2013 – http://www.digitaljournal.com/article/343484
- [C4] Scottish Transport Award, 2016, Contribution to Sustainable Transport – https://www.transporttimes.co.uk/news.php/THE-SCOTTISH-TRANSPORT-AWARDS-2016-WINNERS-ANNOUNCED-130
- [C5] Testimonial from Strathclyde Partnership for Transport
- [C6] Deutschlandradio, 2016 – https://www.deutschlandfunk.de/abgepumpt-energie-aus-u-bahn-abwaessern.676.de.html?dram:article_id=364613
- [C7] Letter confirming N. Hytiris's role in Scottish Government's Geothermal Energy Expert Group
- [C8] Scottish Learning Journey to Heerlen Minewater District Heating System, Scottish Development International, March 2016
- [C9] Letter of invitation, Institute Chair, Indian Institute of Technology, Bombay

- [C10] Hytiris N., Aaen B., Emmanuel R., Church E.. 2013. Underground water heat will aid bid to hit renewable targets, The Conversation, 22 Oct 2013 – https://theconversation.com/underground-water-heat-will-aid-bid-to-hit-renewable-targets-19317