Institution: University of Hull

Unit of Assessment: 12 - Engineering

Title of case study: Improved energy efficiency and reduced environmental impact of space heating and cooling in buildings

Period when the underpinning research was undertaken: 2012 - present

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:
Professor Xudong Zhao	Professor of Engineering	2012 - present
Dr Kevin Fancey	Senior Lecturer	1999 - present
Dr Xiaoli Ma	Senior Research Fellow	2016 - present

Period when the claimed impact occurred: 2014 - present

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

1. Summary of the impact

Our research has delivered two new, patented, environment control technologies for buildings in various climate settings that reduce capital and operating costs along with CO2 emissions in a critical sector for climate change mitigation. A new solar photovoltaic-thermal heating system delivers a 30% improvement in solar efficiency and 20% reduction in capital costs. It has been installed in over 300 homes in rural China, replacing coal-based heating, with an 80% reduction in operating costs, reduced CO2 emissions (330 tonnes pa/100 houses) and improved air quality. It is also installed in the University's Applied Science Building and City's Library with plans for the Council's social housing portfolio.

Our novel super performance dew point air cooler has a Coefficient of Performance 2.5 times that of existing coolers and has been installed in commercial property in China with an 88% reduction in operating cost. Two units are in the University's data centre and twenty in the City Council's data centre. Installations are planned in data centres across Europe and negotiations ongoing for commercialisation of the technology in China and the UK.

2. Underpinning research

Approximately 50% of the global energy demand is used for heating purposes and is currently largely met by oil, gas and coal. The impact of renewables on heating of internal spaces is important and growing, but the technologies are still relatively expensive and inefficient, especially for small-scale installations. In parallel, and probably less well-known, 20% of all energy used in buildings is for cooling, with the global use of air conditioning (AC) units expected to triple over the next 30 years – equivalent to three new units sold every second for the next 30 years. (The Future of Cooling: opportunities for energy-efficient air conditioning, IEA, Paris, 2018).

Our research aims to deliver solutions to the problems posed by the vast energy demand required for heating and cooling buildings, with a particular focus on the integration and optimization of renewable solar energy sources, and development of improved building climate control technologies. The scale of the energy-vs-environment crisis means that it will take years and huge investments for these new technologies to be rolled out and produce a measureable impact on this global problem. Existing, less-efficient heating and cooling systems must be replaced and new designs must be installed in new buildings, hence the full impact of this work will unfold over many decades. This impact case study describes the early stages of this journey.

Research theme 1: renewable energy for space heating of buildings

Solar PV-T (photovoltaic-thermal) heat pump systems can be used for space heating of buildings, but such systems have high set-up costs and are expensive to run due to the continuous operation of the heat pump and large PV area required. **REF1** describes a novel hybrid PV-T heat pump space heating system which consists of a large number of micro-channel thermal panels and small number of PV-T panels that are connected in a complex multi-directional flow pattern and a stand-by heat pump that only operates 2-3 hours a day. The new system saves typically one fifth of the initial set-up cost, and has a solar efficiency 30% more than existing equivalent PV systems. Its application in rural areas in northern China has resulted in near-to-zero bills for space heating and hot water supplies for these rural houses [**REF2, 3**].

Research theme 2: indoor climate control

Indirect evaporative air conditioners are attractive because they prevent the release of moisture into the air. Dew point air conditioners in particular have great potential, but their efficiency is still limited, resulting in larger sized systems which require greater air flow rates and higher running costs than traditional units. **REFs 4&5** describe a novel complex heat exchanger design which has been developed to increase the heat transfer area by typically 40% when compared to a conventional dew point air conditioner. This leads to a similar increase in heat transfer rate and an associated decrease in air flow resistance of over 50%. Together these innovations allow the development of a low cost, high efficiency and durable heat exchanger with up to 38% higher wet-bulb cooling effectiveness compared to conventional flat-plate heat exchangers [**REF 4**]. Compared to existing dew point air conditioners and traditional mechanical vapour compression technologies, the new unit achieves 120-180% and 1,200-1,600% higher energy efficiencies respectively, leading to a reduction in electrical power consumption of typically 50-70% and 90-95% respectively [**REF 6**]. The new dew point air conditioner can also achieve a Coefficient of Performance of 52.5, compared to 20 for existing dew point coolers, which enables a near-to-zero carbon air conditioning operation.

3. References to the research

The names of Hull researchers are shown in bold.

1. Zhang X, **Zhao X**, Xu J, Yu X. 2013. Characterization of a solar photovoltaic/loop-heat-pipe heat pump water heating system. Applied Energy 102, 1229-1245.
2. **Fan Y**, **Zhao X**, **Li G**, Chen Y, **Zhou J**, **Yu M**, Du Z, Ji J, **Zhu Z**, **Diallo T**, **Ma X**. 2019. Analytical and experimental study of an innovative multiple-throughout-flowing micro-channel-panels-array for a solar-powered rural house space heating system. Energy 171, 566-580.
3. **Diallo T**, **Yu M**, **Zhao X**, **Zhou J**, Ji J, **Li G**, **Hardy D**. 2019. Energy performance analysis of a novel solar PVT loop heat pipe employing a microchannel heat pipe evaporator and a PCM triple heat exchanger. Energy 167, 866-888.
4. **Xu P**, **Ma X**, **Zhao X**, **Fancey KS**. 2017. Experimental investigation of a super performance dew point air cooler. Applied Energy 203, 761-777.
5. **Xu P**, **Ma X**, **Thierno D**, **Zhao X**, **Fancey KS**, Li D, Chen H. 2016. Numerical investigation of the energy performance of a guideless irregular heat and mass exchanger with corrugated heat transfer surface for dew point cooling. Energy 109, 803-817.
6. **Xu P**, **Ma X**, **Zhao X**, **Fancey KS**. 2016. Experimental investigation on performance of fabrics for indirect evaporative cooling applications. Building and Environment 110, 104-114.

Grants

- EPSRC/Innovate-UK/MOST. A high efficiency, low cost and building integratable solar photovoltaic/thermal system for space heating, hot water and power supply. EP/R004684/1. £387k. Apr 2017 - June 2019.
- EPSRC/Innovate-UK/MOST. Key Technologies for Enhancing Energy Efficiency of the Dew Point Air Cooler and its Manufacturing. EP/M507830/1. £381k. May 2015 - Jul7 2017.

4. Details of the impact

With the rapid economic growth and massive building projects currently underway in both the developing and developed world, the demand for energy (for space heating, cooling, hot water and power) is growing exponentially. As a result, and because of a looming fossil fuel energy shortage and potential for further huge environmental damage from this expansion of urban areas, the development of renewable solar heating systems for buildings has been listed as a top priority in both China and the UK. Our research impact has been realised through a number of projects that have focussed on the development of new technologies to improve energy efficiency and support the transition to low carbon energy. Two impact dimensions are outlined in this impact case study.

Impact dimension 1: very significant reduction in running-costs and CO2 emissions in the heating of buildings through more efficient use of solar energy

A novel solar photovoltaic-thermal (PV-T) space heating system [**PATENT1**] embodying the principles described in **REF1**, and outlined in Research Theme 1, was shown to have a 30% higher solar efficiency and 20% lower capital cost compared to existing systems. The system was trialled in 100 rural houses in China in 2017, which previously used a coal-based heating system. This confirmed the substantial technical and economic advantages of the new technology, and demonstrated an 80% reduction in energy costs (typically £2,500/house reduced to £500/house). In addition, replacement of the fossil-fuel system with PV-T heating, led to CO2 emissions being reduced to zero (saving 337 tonnes CO2/annum) and improvements in air quality (through no longer using 132 tonnes coal/annum) in just this one village [**EVID1**]. Following this successful trial, the system was installed in another 100 houses in two further villages, and in a large data centre and a local business centre [**EVID2**]. In total, these installations alone are now estimated to be saving over 1000 tonnes CO2/annum and burning 400 tonnes/annum less coal.

More recently, the system has been installed in the Applied Sciences Building at the University of Hull and in Hull's City Library (funded by a £2M Low Carbon Heating Technology Innovation grant from BEIS). In addition, a demonstration house is being built by Hull City Council to examine how this system can be rolled out across the authority's council houses [**EVID3, CONTACT1**]. Sample data from the first of these installations confirms the expected efficiency of the unit, but it is too early to provide long-term quantifiable evidence of its impact. Nevertheless, CNBC (NBC business news channel) reports that:

> *"*[Hull] *city's council says it has "committed to innovative design principles" for the scheme and has described it as the "largest zero carbon house building programme in the country.* […] *authorities are also looking to the future with a plan to develop 600 new homes through its Housing Delivery Programme."* [**EVID 4**].

To exploit this technology, Shanxi Jingxu Renewable Energy Technologies Ltd (SJRETL) was established in 2014 (to manufacture and install the PV-T system in China) with the University of Hull providing technical support to the organisation. The business has achieved sales of 21.5M RMB (£2.5M) to date [**EVID2**]. A collaboration between the University of Hull and Phase Change Material (PCM) Products Ltd (a UK manufacturer and installer of heating and cooling systems) was also established in the UK in 2014, as a result of which the companies turnover has increased by 250% (£0.6M to £1.5m) [**EVID5**]. The two companies (SJRETL and PCM) are aiming to capture a 10% share of the heating market in China and the UK, equivalent to annual sales of around £2 billion in China and £200 million in the UK. As illustrated above, even this relatively modest share of the market has the potential to produce a significant reduction in coal use and CO2 emissions.

Impact dimension 2: very significant decrease in energy costs through more efficient indoor climate control systems

A novel super-performance dew point air cooler [**PATENT2**] was developed in Hull with a Coefficient of Performance 2.5 times that of existing dew point air coolers, and 10-16 times that of traditional (vapour compression) designs, as described in Research Theme 2 and expanded upon in **REF4&5**.

In 2017 a 20kW-rated dew point air conditioner was installed in the workshop of Sinogreen Ltd in China. The company reports that it has reduced their energy costs by 88% (for example, typically costs of £350/unit are reduced to £43/unit) [**EVID6**]. A license to exploit the dew point cooling technology is currently being negotiated with companies AOLAN (http://www.aolan-china.com/) in China and PCM (https://www.pcmproducts.net/) in the UK. Two 5kW-rated dew point air conditioners have also been installed in Hull's new AURA Data Centre, and ten 20kW units are to be installed in Hull City Council's data centre. It is too early to provide robust quantifiable evidence of the impact of these developments in these sites but they are being trialed with the support of significant investment. Further afield, through EU funding (MSCA-RISE-2016-734340) systems are currently being designed for four further computing/data centres in Europe and China: (1) Maritime Data Centre, Hull; (2) Poznan Supercomputing and Networking Center (PSNC) Data Centre, Poland; (3) His-E Computing Centre, China; and (4) Harbin Data Centre, Harbin. As an illustration of the long-term impact of this technology, even modest use of dew point

coolers to provide just 5% of *today's* building cooling capacity would lead to a global reduction of nearly 50 million tonnes of CO2 emissions per year. A more substantial roll-out of this technology therefore offers the potential for very significant CO2 reductions.

Wider context: promoting the green economy

The impact described here is part of a larger agenda at the University of Hull to promote the green economy and to become a carbon neutral organisation by 2027 under its Project Aura initiative. That wider agenda has generated engagement events both locally (*e.g.* Hull City Council, **CONTACT1**), and with national and international policy makers (*e.g.* UKRI, **CONTACT2**; Chinese Embassy in London, **CONTACT3**). While it will take time for our technology's impact to be realised fully, our external recognition [**AWARDs 1-4**] and the interest in, and uptake of, our research findings (exemplified above) already reflect its significance and reach.

5. Sources to corroborate the impact

Evidence

1. Shanxi Jingxu Renewable Energy Technologies Ltd: letter confirming technology benefits in rural housing.
2. Shanxi Jingxu Renewable Energy Technologies Ltd: letter confirming further commercial activity and financial benefits.
3. "*Hull council house to be turned into science lab for new carbon project*" Hull Daily Mail, 21st October 2020; archived at: https://archive.is/73Ncp
4. "*A British university is testing new low-carbon tech that could cut heating costs*" CNBC, 23rd of October 2020; archived at: https://archive.is/uiaYq
5. Phase Change Material (PCM) Products Ltd: letter confirming commercial activity and financial benefits
6. Sinogreen: letter confirming technology benefits to the business.

Patents

1. A micro-channel based photovoltaic/thermal (PV/T) panel. CN 201610090634.X, Feb 2016.
2. Heat exchanger apparatus. PCT/GB1617362.7, Oct 2016. (Now converted into EF filling covering Europe, China and USA). Negotiations are being finalised to license the patent to companies AOLAN (China) and PCM (UK).

Awards

The hybrid PV-T heat pump won:

1. The 2015 European Dragon-STAR Innovation Silver Award. European Commission, Brussels 2015. (No link available).
2. A 2017 World Society of Sustainable Energy Technology Innovation Award, Bologna 2017. https://www.wsset.org/docs/newsletters/september-2017.pdf (page 4)

The dew point cooler won:

3. A 2018 World Society of Sustainable Energy Technology Innovation Award, Wuhan 2018. https://www.wsset.org/docs/newsletters/july-2018.pdf (page 3)
4. The 2019 UK Rushlight Innovation Award, London 2019. (No link available).

Contacts

1. Environment and Climate Change Strategic Advisor, Hull City Council. Confirmation of Hull City Council's activities in implementing the new PV-T system in council buildings and the authority's council houses.
2. Director of the China-UKRI office.
3. Minister Counsellor of Science and Technology Section, Chinese Embassy in London.