

Sustainable Life Labs for the 21st Century

Saffa B. RIFFAT

School of the Built Environment, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

Abstract: The School of the Built Environment has a worldwide reputation for its innovative research into sustainable technologies including absorption/adsorption heat pumps, ejector refrigeration systems, desiccant technology, hybrid/solar driven CHP systems, solar/thermal systems and ground-source heat pumps. The School has obtained grants from the Engineering, Physical Sciences Research Council (EPSRC), the European Commission and industry to develop several new technologies, which have been licensed to industry. The School has also established new research facilities including the Marmont Centre for Renewable Energy, the David Wilson Eco-House, Sustainable Research Building and Jubilee Campus. This paper reviews some of the School's recently funded research projects and facilities.

Keywords: sustainable energy; heat pumps; heat recovery; refrigeration; desiccant technology

1. Introduction

Global warming and green issues such as worldwide energy wastage are issues of serious environmental concern. Development of sustainable energy systems offers a way to provide energy to the domestic and industrial sectors without the penalty of large pollution emissions. The UK Government is committed to reducing carbon dioxide (CO₂) emissions by 20% by the year 2010. It is estimated that up to 50% of all energy consumption is associated with buildings and it is therefore important to develop sustainable energy systems and building components to meet the CO₂ emission target.

The School has developed a number of novel renewable/sustainable technologies for heating, cooling, natural ventilation, power generation, refrigeration, lighting, indoor air quality, traffic pollution and heat recovery, as well as insulation materials for use in buildings. These would help to reduce CO₂ emissions by reducing reliance on fossil-fuel derived energy. Much of this research has been carried out with the assistance of major grants. Strong links have been formed with leading international research groups, industrial companies and SMEs in the sector of renewable and sustainable energy technologies and many novel systems have been patented (e.g., Patents Nos., GB9522930.8, GB9413496.2, PCT-GB9501584, EP92923197.5, EP16287, GB9315569, PCT-WO97/17585).

In the area of sustainable building services, the Institute of Building Technology has obtained a series

of major grants from public and private sources in the UK, EU, USA and Far East. One project has been funded under the EU THERMIE Programme for demonstration of sustainable energy technologies on the University of Nottingham's New Jubilee Campus. A major UK construction company has funded an Eco-Energy House, purpose built for investigating integration of sustainable energy technologies in buildings. The School has conducted research into sustainable technologies for heating and cooling including chilled ceilings powered by cooling towers, desiccant cooling systems, a continuous absorption-recompression system, rotary heat pumps, chemical storage heat pumps, a night-time cooling system utilising phase change materials (PCM) and heat pipe, and ejector powered absorption-recompression cooling systems. Sustainable technology developed at the School includes a novel ventilation/heat recovery system based on a fibre impeller fan system, tracer-gas techniques for accurate airflow measurement in ventilation systems, and new methods for determination of k-factors for energy efficient operation of HVAC systems. The School has also investigated refrigeration and air conditioning systems using waste heat (EPSRC and Pektron Ltd).

2. The jubilee campus

The University of Nottingham has invested £50 million in its new Jubilee Campus. The new campus is built on a 20 acre former industrial site one mile away from the main campus. This is the most "environmentally-friendly" higher education development in the

UK. Professor Riffat from the School of the Built Environment and Professor Marmont from Beacon Energy Ltd were the driving force behind the use of renewable energy in the Jubilee Campus. The entire campus has been designed and constructed to be sensitive to the environment. Construction materials were carefully selected in order to avoid the use of materials known to be of high embodied energy or harmful to the environment. Buildings at the Jubilee Campus have been designed to be extremely energy efficient. A grant from the European Community's Thermie fund has allowed the installation of additional equipment to help achieve this efficiency. Some of the features incorporated into the buildings to achieve low energy consumption include :

- 1) Mixed mode ultra low pressure ventilation.
- 2) Use of the building structure to provide air flow ducts (floor voids, corridors and staircases) and air tempering (mass concrete structure).
- 3) Thermal wheels to provide the most efficient heat exchange and thus retain heat within the buildings.
- 4) Photovoltaic cells within the atrium glazing.
- 5) Rotating wind catchers, which position the air exhaust such that it is always under natural suction.

PV panels at the Jubilee Campus were installed on the ceiling of the Atrium entrance hall. Since completion and habitation of the Jubilee Campus, the School has launched a major scientific investigation monitoring the performance of energy efficient systems within the campus.

3. The marmont centre for renewable energy

Professor Marmont has provided funding to the School of the Built Environment for the establishment of a Centre for Renewable Energy, "The Marmont Centre". This facility is the test bed for existing and new technologies developed by the School. The facility also provides an excellent learning environment for students and spearheads the drive for "environmentally-friendly" constructions in industry. The Marmont Centre contains a large laboratory, a lecture theatre, an IT suite and a coffee bar/exhibition area. The objectives of the Centre are :

- 1) To carry out high quality research into the integration and performance of renewable energy technologies;
- 2) To encourage inter-disciplinary research between staff in the School and other research groups with

the aim of maximising the potential of renewable energy systems in buildings;

- 3) To encourage technology transfer between the University and industry; and
- 4) To carry out training of students and research staff.

The following renewable energy technologies have been incorporated into the Marmont Centre :

- 1) Photovoltaic (PV) solar panels generating 400kWh per annum of electricity.
- 2) Solar collector for heating and hot water supply.
- 3) Light pipes incorporating a highly reflective silvered surface for directing sunlight into occupied spaces.
- 4) Rainwater collection system which stores and filters water for utility use and washing.
- 5) A lightweight, vertical-axis wind turbine for extra power generation.
- 6) A ground source heat pump using ground-coupled loops for extracting energy from the ground. This is used to provide additional heating for the building in winter and for cooling in the summer.

Laboratory facilities within the Marmont Centre also include a state-of-the-art environmental test chamber for simulating different climatic conditions. Photovoltaics are continuously being used in renewable energy projects utilising the sun's power. Three new PV arrays have recently been installed at the School to investigate new projects involving solar energy. These large PV arrays track the sun's movement through the sky so that the maximum amount of electrical power is generated throughout the entire day.

4. The David Wilson millenium eco-house

The new Eco-Energy House at the School of the Built Environment has been constructed by David Wilson Homes plc, a major house builder in the UK. It is a four bedroom detached house of brick and block construction. The house incorporates a steel frame which allows bolting and testing of new technologies developed by the School, or other organisations. The Eco-House is occupied and monitored by researchers from the School. The researchers are offered free accommodation but act as human guinea pigs for testing and energy saving devices. The Eco-House makes use of the following energy technologies :

- 1) Photovoltaic (PV) system. Creating about 1250 kW·h per annum, the tile shaped PV panels generate electricity for lighting, cooking,

refrigeration, washing and powering other domestic electrical appliances. The surplus electricity generated is fed directly into the University's grid system.

- 2) Light pipes. These are used to provide natural daylight into the toilet and landing areas of the house. The light pipe system used in the landing area also acts as a natural ventilation system.
- 3) Rainwater recovery system. Rainwater from the roof is collected and passed through pipes on the sides of the house to an underground tank. The water is pumped back up to a filter unit inside the house when needed. The filter unit has two levels of filtering and can provide water for drinking as well as for domestic utilities and washing.
- 4) Solar heat collectors. These are installed on the south-facing side of the house, and will be used to provide hot water for the kitchen and for washing utilities.
- 5) Solar chimney. Glass blocks are integrated into all sides of the chimney to allow as much sunlight as possible to enter. This allows the chimney to provide ventilation in the summer and passive heating in the winter.

PV panels were installed as roof tiles built into the Eco-House. The School has been successful in attracting £250,000 from the EPSRC and DTI for research and monitoring equipment installed within the Eco-House. This major investigation will be carried out by researchers under realistic conditions. The results of the monitoring phase should provide valuable information which will help to improve the design and implementation of energy-efficient houses [1].

5. Environmental impact of heat pumps

For every building, a heat pump system offers an excellent way to meet comfort needs and save energy. In homes, heat pumps have a reputation for reliable operation and high performance; nearly 25% of new homes built in the USA and 40% of those in Sweden have a heat pump system. The occupants benefit from low energy bills for heating, and when appropriate, they can use the same system for cooling. The heat pump's high efficiency means that it consumes much less fuel than conventional systems for heating systems. The advantages of heat pump technology are being exploited through various areas of building technology such as heat recovery and cooling.

The School of the Built Environment has developed an extensive portfolio of heat pump/heat pipe/heat recovery systems worked with several different funders from research and industry [2,3].

6. A novel heat pump/heat recovery system

This work is concerned with the research into a novel ventilation/heat recovery heat pump. Several prototypes have been built to provide heat recovery and heat pumping. The systems are based on revolving heat pipes which simultaneously transfer heat and impel air. The devices therefore act as fans as well as a heat exchangers. Heat pumping is achieved by utilising a reciprocating compressor or a fixed nozzle ejector compressor. The systems are compact, energy efficient and use an environmentally-friendly refrigerant with no ozone depletion potential and very small global warming potential. The work involves computer modelling, components investigation and prototype construction and testing.

Several prototype rigs have been designed, built and tested. An annular array of revolving heat pipes spanning two adjacent centrifugal fan casings are used to both expel air and transfer heat. A hybrid system incorporates a compressor to provide heat pumping. The prototype systems use environmentally friendly refrigerants. The prototype system has a coefficient of performance (COP) of up to 4.6 and an average COP of 2.5 over a range of conditions. The system typically provides 2.3kW of heating for air supplied at 260m³/hr. The heat pump's high performance means it consumes much less fuel than conventional heating boilers and so emits a much less quantity of CO₂, the principle contributor to the greenhouse effect. The system can also be used for cooling by switching the air flows over the evaporator and condenser. The prototype system requires very little maintenance and is compact and energy efficient [4].

7. Desiccant cooling system

In this research work, a flexible fibre 'mop' fan was constructed as an 'air moving' device. This fan, originally a chimney sweep brush, was mounted on a shaft within a centrifugal fan casing. The mop fan is a novel air-cleaning device that fulfils the functions of; i) de-dusting of gas streams, ii) removal of gaseous contaminants from gas streams, and iii) gas circulation.

The mop fan is very similar to a conventional,

centrifugal ventilation fan except that it utilises a brush disk instead of the blade disk of the latter. The brush is thinly coated with water to trap colliding particles and absorb gases. It is made from a commercial corrosion-resistant flexible fibre and is cleaned by a slow continuous supply of water to its surfaces. As the fibres are in a state of constant oscillation, scale deposits are unable to adhere and the device is very resistant to fouling and blockage. The trapped dust flows out of the fan case as dilute slurry. A dust removal efficiency of 97% has been achieved and this efficiency decreases only slightly with decreasing particle size. The results indicate that a removal ratio approaching 100% would be possible with optimised fan speed, water flow rate and number of fibres.

Experimental investigations were carried out using the mop fan to humidify and cool air. The results showed that the cooling achieved across the mop impeller was an adiabatic process. The efficiency of the mop in saturating a passing air stream was as good as commercial air washers, and a comparison with the mop fan has been summarised.

Further tests on the mop to dehumidify air were undertaken. The mop fan showed potential by using liquid absorbent sprays to absorb moisture from passing air streams. The absorbents used were lithium bromide, and a less corrosive potassium formate. A system combining the cooling and absorbing effect of the mops was designed. The system, known as a desiccant system, and named DesicAir, was constructed and tested. The mop fan is cost-effective, robust, efficient and fouling-resistant and seems suitable for application in industrial, agricultural, and commercial buildings, either as a unit, or part of a system [5].

8. A thermal diode wall system

This project involves the investigation into a low cost sheet material which acts as a thermal diode, permitting heat transfer in one direction while acting as an insulating material in the opposite direction. The sheets are designed so that they may be used as cladding on new or existing buildings. The objectives of this project are to :

- 1) To investigate a thermal diode suitable for fabrication in sheet form.
- 2) To investigate manufacturing methods for the diode which would be amenable to low cost mass

production.

- 3) To devise appropriate modelling techniques to permit prediction of the performance of various structures incorporating the thermal diode.
- 4) To determine the energy saving potential of the thermal diode under different climatic conditions.

The cladding material would have a potential worldwide market and its widespread use would result in a substantial reduction in the energy consumed to maintain comfortable conditions within buildings. Other partners in this project are Heriot Watt University, Sulzer Ltd from Switzerland, University of Porto from Portugal and Isoterix Ltd. Further development of the research will include the investigation of super insulation cladding in collaboration with Sulzer Ltd.

The solar simulator provides the controlled radiation of up to 800W/m^2 onto the test sample. Metal halide sources give a spectral distribution approximating sunlight fit for test purposes. An insulated enclosure closes off one side of the diode wall test piece. This temperature controlled by a heater circuit, and simulates the room-side conditions of a building. The environmental chamber installed in the Marmont Energy Centre provides the facility to control key environmental parameters; temperature and humidity. The South-East façade has removable glazing. Components may have one side inside the chamber, and the other subject to exterior ambient conditions. The environmental chamber was set to simulate external climatic conditions. A variety of temperature, heat flow, and global radiation sensors were used to record the key parameters during the test.

A simulation of one complete year using climatic data for the Nottingham area was done and the promise of the diode wall system was apparent when compared with a normal insulated wall and a non-insulated bare wall. The thermal diode wall had a positive influx of heat into the building.

9. Ground source heat pump system

The term “ground source” is applied to a variety of heat pump systems that use ground soil, ground water or ground surface water as a heat source or heat sink [6]. This system is a ground source heat pump system (GSHP) for space heating and cooling in buildings. The GSHP system utilises the free, low-grade heat energy stored in the earth by upgrading it to a useful energy at

a higher temperature. The main benefit of using the GSHP system is that the temperature of the subsurface is not subject to the large variations experienced by air, currently the most common energy source for heat pumps, and therefore more efficient and reliable systems are possible. A closed loop GSHP system has been installed at the Marmont Renewable Energy Research Centre of the School of the Built Environment [7]. The system consists of a reverse cycle water-to-air heat pump coupled to three vertical ground- loops (one U-tube and two concentric tubes). Investigations of the thermal performance of this system have been carried out for different ground heat exchanger designs in order to examine their effect on the overall thermal performance of the system. This would help develop more energy efficient and cost competitive ground source heat pump systems.

The GSHP system installed at the Marmont Renewable Energy Research Centre incorporates a water-to-air, vapour compression, reverse cycle heat pump unit. The heat pump uses R-407C as the working fluid. It also has low global warming potential. The heat pump unit is coupled to the ground via three vertical closed loops. These loops, which are normally called ground couplings or ground heat exchangers, are made from virtually indestructible fusion welded, high-density polyethylene pipes. The loops have a total ground-coupling length of 80 metres. They are filled with a mixture of water and antifreeze (mono propylene glycol) and connected in parallel to the heat pump unit. The heat pump has been tested under various operating conditions. The coefficient of performance (COP) was a maximum of 4.0 for heating and 2.6 for cooling.

10. Cool-Gen

Cool-Gen is an integrated hybrid solar/gas system for power generation, heating and cooling of buildings. The purpose of the Coolgen project, was to develop a combined cooling, electricity generation and heating system run by solar energy, with gas backup, or by waste heat. The project involved a number of partners including the School of the Built Environment, the University of Porto, Thermomax Ltd (manufacturers of evacuated tube solar collectors), All Venturi Equipment (manufacturers of ejectors) and Beacon Energy (a renewable energy consultancy). The School had previously been involved in projects to develop a

Rankine cycle turbine and a number of ejector cooling systems driven by solar energy. This experience evolved into the Coolgen project which combines both cycles.

The refrigerant in the boiler is supplied with heat from a waste heat system or by solar energy. The vapour generated in the boiler is then channelled through either the turbine or the ejector. The vapour expanding through the turbine generates electricity and the vapour going through the generator causes the evaporation and entraining of vapour from the evaporator that causes the evaporator to cool. The cooling from the evaporator can then be mixed with ventilation air to produce cooling. The vapour after the turbine and the ejector is then condensed in the condenser. The heat extracted from the condenser can be used for space heating or preheating of water. Using boiler temperatures of 100°C, turbine efficiencies of 5% and cooling coefficients of performance (COP) of 0.3 to 0.35 were achieved.

The main benefits of the system are:

- 1) Low emissions from the system (Zero if solar energy or waste heat alone is used, however it is usually necessary to use a gas supplement.)
- 2) Provision of all building needs (Heating, cooling and electricity) from one compact system

Although the system has been demonstrated and installed at the offices of Beacon Energy, further development work needs to be carried out to achieve better turbine efficiency and cooling COP's. A number of ideas are being explored including running the system using concentrating collectors to achieve higher temperatures and the use of electrogasdynamics [8].

11. Desert cooler

The cooler is a very simple device that utilises a very safe raw material, water, as its cooling element. The cooler does not need complicated monitoring or operation, and it also filters airborne particles, making the air cool and clean. This cooler requires no filters, neither permanent nor replaceable, simply because the fan is a bi-purpose device. Reduction on power consumption as well as maintenance is guaranteed. Evaporative cooling works on the principle of heat absorption by moisture evaporation. When a swimmer leaves the water on a windy day, he feels cool because the moisture on his body is evaporating and absorbing heat. Your evaporative cooler draws outside air by the

use of a polyester fibre impeller that operates as a fan. Water is supplied to the impeller through a hose connected to a pump. The water leaves the hose through a nozzle to spray and wet the fibres. Impact on the fibres disperses the flow into a fine mist, thus increasing the water's surface area making it easier for the droplets to evaporate. The air entering the cooler is therefore humidified, and cooled.

12. Conclusions

This paper has presented a summary of the main research themes of the School of the Built Environment. Sophisticated facilities have allowed comprehensive investigation of new heat systems in real situations. Novel technologies in air conditioning and refrigeration have been developed successfully at the School and these have been successfully integrated with sustainable sources of energy. The School intends to further develop its already proven track record in the field of sustainable technologies. Strong relationships between the School and other research establishments have been established and new links are continuously being sought. The School is involved with all major developments in sustainable energy and welcomes the interest of offers in renewable issues.

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