Advancing with Renewable Energy

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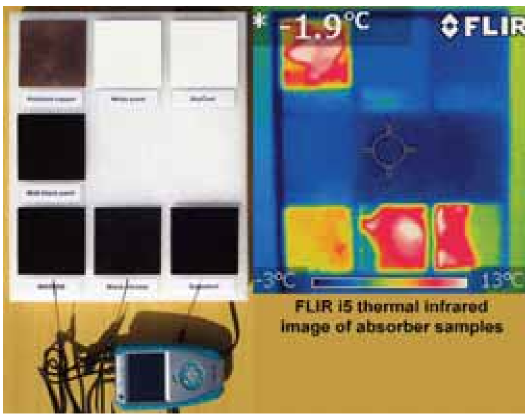
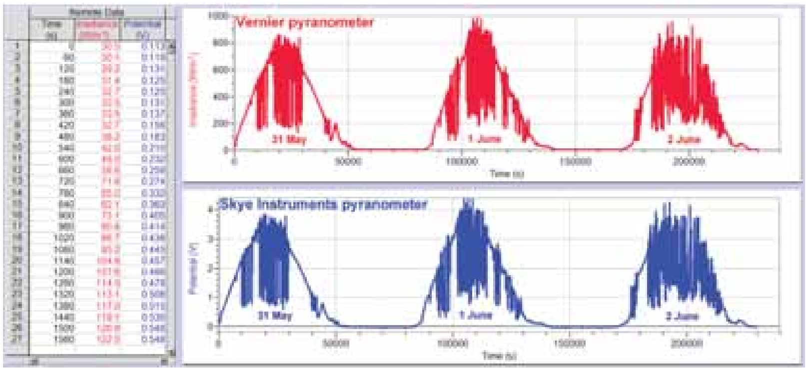
Having covered the basics of renewable energy (D&T Practice 06.2010, 01.2011, 02.2012 and 03.2012), we can now advance onwards and upwards. Topics covered in this article include infrared thermography, solar radiation instrumentation and miniature turbine testing.

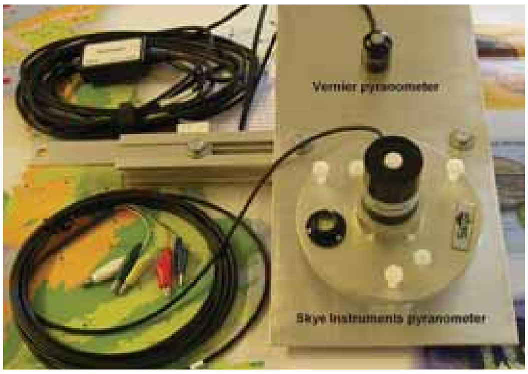
Infrared thermography

In 'Exploring the properties of Solar Energy' (D&T Practice 02.2012), a modified Leslie Cube was used to demonstrate that the optical properties of surfaces can be quite different for solar and longwave (thermal infrared) radiation. For instance, a spectrally selective solar absorber is a very poor reflector of solar radiation but a good reflector (and hence poor emitter) of longwave radiation. Conversely, a white painted surface is a good reflector of sunlight but a very poor reflector (and hence good emitter) of longwave radiation. This can be revealed by infrared thermography. The accompanying composite image of an array of solar absorber samples shows a photograph on the left (previously shown on page 28 of D&T Practice 03.2012) and a thermograph on the right. The thermographer's body heat shows clearly in reflection from the polished copper sample at top left of the FLIR i5 thermograph, but also in reflection from the three spectrally selective absorber samples in the bottom row (owing to the high reflectance of their metal substrates). The spectrally selective coatings on all three samples look black in the visible but are transparent in the thermal infrared. Conversely, the two white coatings shown at the top of the thermograph look as dark (non-reflective) as the matt black paint at middle left of the thermograph.



Thermal infrared cameras are fairly expensive 'hand tools' beyond the equipment budgets of many schools, but they are commonly used in Urban Search and Rescue (USAR) and by Domestic Energy Assessors (DEAs), so it's worth contacting your local fire brigade and/or DEAs to see if they'd be able and willing to demonstrate one in your school.





Pyranometers

In a previous article 'Resources for Renewable Energy Education' (see page 9 of D&T Practice 06.2010), I stated that "Accurately calibrated solar irradiance instruments (pyranometers/solarimeters and PV reference cells) are inherently expensive; there is a need for low-cost models or alternatives for school use." That article was brought to the attention of Vernier in the US and they have recently introduced their pyranometer PYR-BTA for use with their LabQuest data loggers (and also in LEGO® MINDSTORMS® NXT or EV3 projects – see page 38 of D&T Practice 05.2011).

I am currently evaluating the new Vernier Pyranometer together with a Skye Instruments High Output Pyranometer Sensor mounted in the plane of a photovoltaic (PV) array on the roof of my home in Shrewsbury. Both are connected to a Vernier LabQuest data logger (the Skye Instruments pyranometer is connected via a Vernier Differential Voltage Sensor). After a month of testing, the outputs of both pyranometers show excellent agreement, but there have been some issues with their calibrations. In order to resolve the discrepancies between their readings, I invested in a Metrel TEK1307 Solar Power Irradiance Meter (commonly used by solar PV system installers). The accompanying illustration shows plots of data from both pyranometers logged over three consecutive days by a LabQuest and imported into Logger Lite. These compare well with data obtained using much more expensive pyranometers (from Kipp & Zonen in the Netherlands and Eppley in the US) used by meteorologists. Costing less than £100, the Metrel TEK1307 Solar Power Irradiance Meter is an even lower-cost option which could be used in outdoor school demonstrations and experiments like those described in my article 'Solar Collectors' in D&T Practice 03:2012.

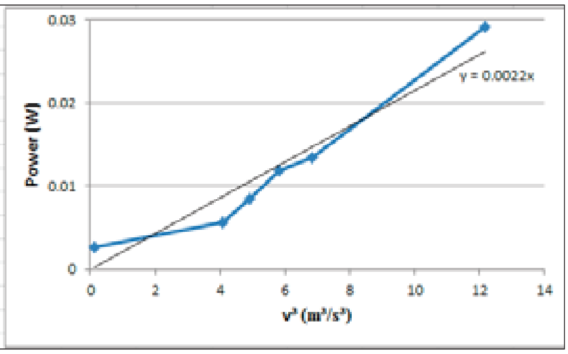
It should be noted that pyranometers are notoriously difficult to calibrate accurately. Even the so-called 'solar constant' (the irradiance above Earth's atmosphere) varies from 1412 W/m2 in early January to 1321 W/m2 in early July, owing to the ellipticity of Earth's orbit around the Sun. On rare occasions, the measured irradiance under a partially overcast sky will exceed the solar constant. This can occur only when an additional light source is present, such as a tall thunderstorm cloud reflecting sunlight onto the sensor.

Miniature wind turbine testing

In 'Resources for Renewable Energy Education' (D&T Practice 06.2010), I described LEGO Education's 9688 Renewable Energy Add-on Set for use either with its 9686 Simple & Powered Machines Set or in MINDSTORMS NXT (or EV3) projects. The 9688 Set includes a solar PV panel, motor/generator, turbine blades, LED lights and energy meter. The meter displays the following data: input and output in volts, amps and watts, and energy storage level in joules. Data can be logged by an NXT brick connected to the meter, and used for programming or viewed in the MINDSTORMS Education NXT Software v.2.0 (or later) data logging window on a PC, laptop or notebook.

It has long been my ambition to use a LEGO wind turbine built using the 9686 and 9688 sets together with a desk fan and anemometer to demonstrate that the power generated by a wind turbine is proportional to the cube of the wind speed. However, I found that ordinary desk fans produce airflow which is too turbulent to enable reliable data to be obtained. Last year I learnt about the Dyson 12" bladeless desk fan and realised that it could be exactly what's needed for the experiment I had in mind, but its cost deterred me from buying one in case it proved to be little better than ordinary desk fans. Then I learnt about the James Dyson Foundation (JDF) and requested one of their JDF Engineering Boxes for short-term school use. Having established contact with JDF, I explained my need for a Dyson 12" bladeless desk fan and they sent me one so I could try out my idea. The accompanying illustrations show the experiment underway and a graph of power generated (in W) against the cube of the average air speed (in m3/s3). Both the anemometer's air speed reading and the instantaneous power generated by the turbine (as indicated on the LEGO Energy Meter) fluctuated more than I expected. I determined the average power generated by timing how long it took the LEGO Energy Storage to accumulate 20 J. I used a Kestrel 1000 pocket anemometer to measure the average air speed.

v (m/s)	v^3 (m^3/s^3)	P (W)
0.5	0.125	0.0026
1.6	4.096	0.0056
1.7	4.913	0.0085
1.8	5.832	0.0119
1.9	6.859	0.0134
2.3	12.167	0.0292



The graph shows the data points joined by straight lines, together with the best straight line fit. These are much better results than those obtained using an ordinary desk fan. The only difficulty I experienced with the Dyson bladeless desk fan is that the airflow it produces is appreciably lower along its axis than at the position of the LEGO turbine blades, so I measured the average air speed at about 9 cm from the axis. The turbine blades spun in a plane 18” (~ 45 cm) from the centre of the desk fan. As far as I'm aware, this is the first time that a table-top experiment has demonstrated that the power generated by a wind turbine is directly proportional to the cube of the air speed.

Acknowledgements

My thanks to Steve Emery for donating the Vernier pyranometer, staff at Salop Energy for mounting the pyranometers on the roof of my home, the James Dyson Foundation for loaning me a Dyson 12” bladeless desk fan, and to staff and students (and parents thereof) at Belvidere School, Shrewsbury for their co-operation in the preparation of some of the illustrations for this article.

Further Reading

Duffie, J.A. and Beckman, W.A. Solar engineering of thermal processes (4th edition). Wiley. 2013 (ISBN 978 0 470 87366 3)

Energy – Post 16. Technology Enhancement Programme. (ISBN 1 898126 90 9)

LEGO® Education Catalogue 2013 Key Stages 2-4. LEGO Education UK.

Hot Links

Alliant Energy Kids: www.alliantenergykids.com
ClearDome Solar Thermal: www.cleardomesolar.com
Dyson 12” bladeless desk fan: www.dyson.co.uk
EcoStyle kits: www.ecostyle.co.uk
Evacuated tube collectors: www.navitron.org.uk
FLIR i-Series infrared cameras: www.flir.com
Instruments Direct: www.inds.co.uk
International Solar Energy Society: www.ises.org
James Dyson Foundation: www.jamesdysonfoundation.co.uk
Kestrel 1000 Pocket Anemometer: www.r-p-r.co.uk/kestrel/
LEGO Education: www.legoeducation.co.uk
MCS PV Guide: www.microgen-database.org.uk
NREL Solar: www.nrel.gov/learning/re_solar.html
Skye Instruments pyranometer: www.skyeinstruments.com
SMA monitoring systems: www.sma.de/en.html
Solar-Active: www.new.solar-active.com
Solar Irradiance Meter: www.tester.co.uk
Solar Pathfinder: www.solarpathfinder.com
Solar Spark: www.thesolarspark.co.uk
Solar Spark STEM: www.nationalstemcentre.org.uk
UK-ISES: www.uk-ises.org
US Energy Education lesson plans: www1.eere.energy.gov/education/lessonplans/
Vernier pyranometer: www.vernier.com