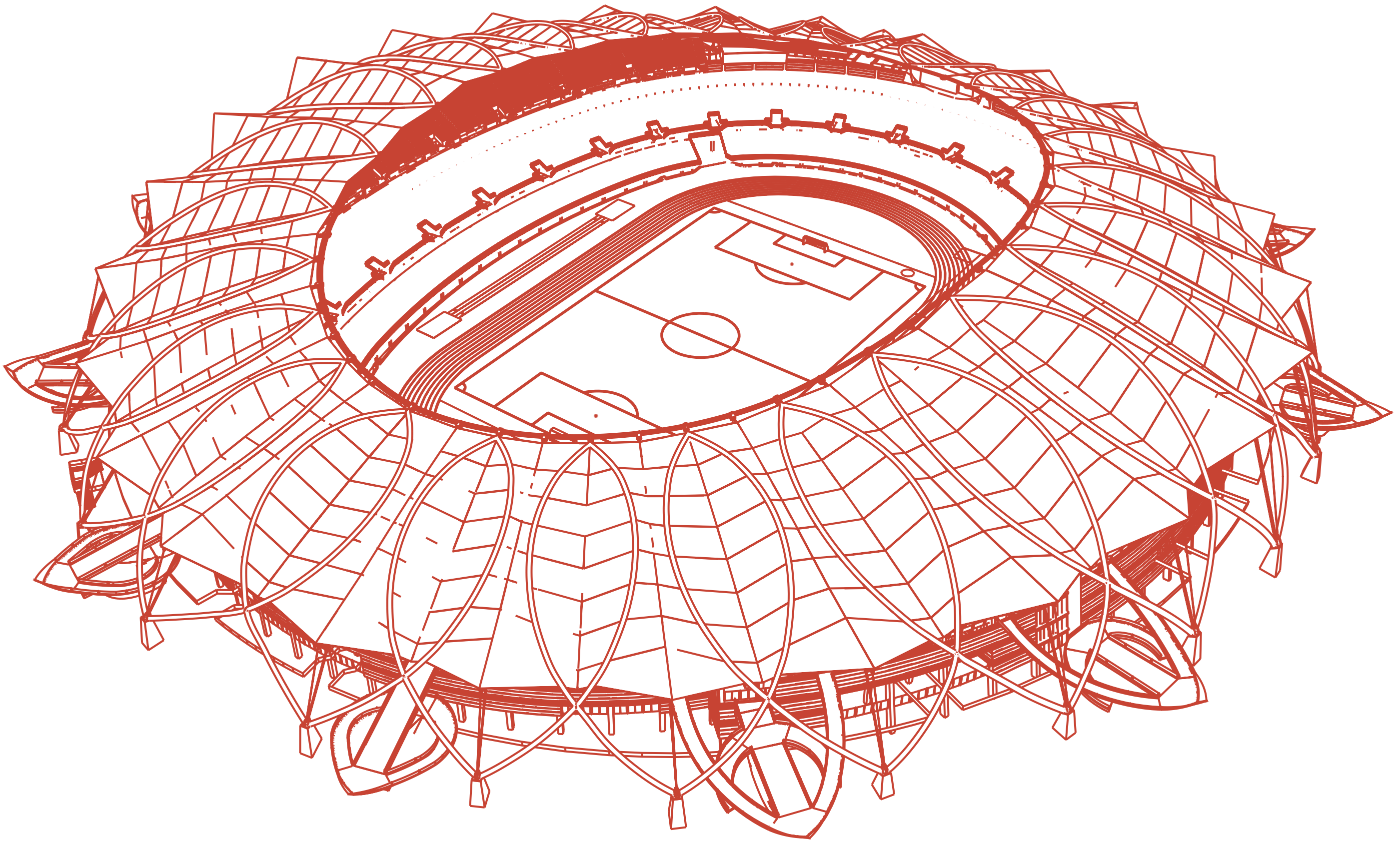
DEVELOP A NEW SPORTS VENUE



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DEVELOP A NEW SPORTS VENUE

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CHALLENGE BRIEF

YOUR CHALLENGE

There are many stages and people involved in the development of a new building.

All structures, however large or small, start as an idea. Someone has a vision of what they would like. They enlist the help of experts – such as architects, engineers and construction workers. A project manager then liaises with all the people involved and co-ordinates the process.

Your challenge is to produce a presentation for the development of a new sports venue in your local area. The venue could be indoors, outdoors, a stadium, arena or centre. You must be able to explain how it will benefit the students at your school and/or the people in your local community.

There are many parts to this Challenge. You should start by completing The Plan, then choose one or more areas to focus on: The Site, The Structure, The Court and/or The Environment.

THE PLAN

Produce a scale drawing of the floor plan. Include suggestions for spectator seating arrangements. Think about:

- What sport or sports will the venue house?
- How many spectators must the venue cater for?
- What spectator facilities are required? (refreshments, toilets, etc.)
- What player facilities are required? (changing rooms, showers, medical/physio room, etc.)
- What other facilities may be required by venue staff or any organisations/associations that may use the venue as a headquarters? (boardroom, offices, restaurant, etc.)

THE SITE

Suggest a suitable location local to you – or in the surrounding area – to site the new sports venue. You should also suggest a design for the exterior of the venue. Think about:

- **Accessibility:** How will people travel to and from the venue? How will this affect the location and site size?
- **Land:** Can you build on the site? Why? What are the pros and cons of building on different types of land?
- **Services:** Can services such as water, electricity, waste and emergency services reach the site?
- **Surroundings:** What are the surroundings and landscape of the site? Will your design be in keeping with this, or will it make a statement and create an eye-catching attraction? What may determine this decision?
- **Pollution:** How might the venue affect noise levels, traffic volumes and local streams, rivers and ecosystems?
- **Materials:** What materials could be used to achieve the aesthetics of your design? What materials will meet necessary requirements such as durability and waterproof properties? Are there any other considerations with regards to choice of materials such as the existing landscape, local producers/suppliers, sustainability, availability, etc.?

THE STRUCTURE

Suggest a structure for the new sports venue, including the materials to be used. Think about:

- **Size:** How big does the venue need to be?
- **Shape:** What shape would you like the venue to be? Is it functional and architecturally successful?
- **Function:** What is the purpose of the venue? What loads will the venue have to be able to take?
- **Scale:** Any building or modelling of structures should take scale into account.

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CHALLENGE BRIEF

- **Modelling materials:** What materials could you make your model from? How will you join materials?
- **Real materials:** What materials could be used to build the structure of the venue? What properties do they need and how do possible materials differ? What are the availability and costs of different materials?

THE COURT

Suggest efficient and effective ways to light the playing area at your venue. Think about ...

- **Insulation:** How does the design of natural light providers in the ceiling affect insulation?
- **Visibility:** Natural versus artificial lighting. Glare and reflection.
- **Spectators (and TV):** How do these factors affect lighting requirements?
- **Energy waste:** Are some forms of lighting more efficient than others? Are they still fit for purpose?
- **Flooring material:** What are the requirements of the floor? What materials have the suitable properties to meet these requirements?
- **Interior design:** How does colour affect performance and lighting?

THE ENVIRONMENT

Suggest efficient and effective power generation and storage solutions for the venue. Focus on providing hot water and suggesting how to reduce water use. Think about:

- **Insulation:** How well do different materials insulate?
- **Energy generation:** What are the possible sources of sustainable energy?
- **Energy storage:** How can energy be stored? Does the way it's stored depend on the way it will be used?
- **Materials:** Linked to insulation. Do different materials affect the storage of energy? Do some materials retain heat longer than others? How can this property be put to good use?
- **Water:** How do the points above relate to heating water? What are the requirements for the quality of water? Can water be reused? How can rainwater be harvested? Does recycled water need to be treated before use? If so, what are the treatment methods and how does this affect sustainability?

Some helpful information and ways for making fair tests can be found on the Factsheets and Test Procedures.

For all parts of this Challenge, you may think of more considerations and decide to carry out some further research yourself.

PRESENTATION ADVICE

Teams must present proposals for design and development criteria within the chosen area of focus. However, it is important that the presentation communicates effectively how the project team arrived at their final decisions and choices. All proposals and recommendations must be justified – it is these justifications that should form the main of the presentation.

SOME HINTS AND TIPS

- Before starting the challenge, think about how to record and log work as it is carried out
- Think about how to present useful information – remember the process is just as important as the final proposal
- Use a mixture of verbal, written and visual communication
- Present scientific information, rather than emotive arguments
- Use scientific language and terminology correctly
- Be able to talk knowledgeably about every aspect of your challenge

Consider

- Video recordings
- Photographs
- Diagrams and sketches – originals as well as 'worked up' final copies
- Charts and graphs
- Posters, leaflets, handouts
- Models
- Live demonstrations

These are just some things to think about – you may think of more!

{FACTSHEET} ACCESS AND PARKING

ACCESS TO THE VENUE

Key things to think about:

TEAMS

- Teams are likely to arrive by coach
- People from other parts of the country need to find their way easily
- Coaches have to turn round and be able to park

SPECTATORS

- Public transport is an important aspect of sustainability
- Some car parking might be necessary
- People on bikes may find a hilltop site difficult to reach and they need secure parking
- Disabled people need to get close to the entrance
- The system will have to cope with hundreds of people all arriving (or leaving) at the same time

SERVICES

- If water supply, electricity, gas, sewers or telephone lines are not nearby, they can be expensive to put in place
- Buildings have many service vehicles arriving: refuse lorries, catering supplies, maintenance contractors and so on

EMERGENCIES

- Ambulances and the Fire Brigade must be able to reach the venue quickly.

CONSTRUCTION

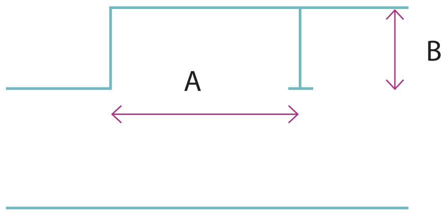
- Construction plant such as cranes, excavators and piling rigs are very heavy and arrive by road
- A large quantity of materials are used in a building such as a sport venue
- If it is not possible to store very much on a building site, materials arrive as and when needed
- Some items, such as long steel beams, arrive on special transporters
- If soil has to be taken away from the site, that can involve many lorry trips

ALSO

- Low bridges or overhead wires can restrict access
- Putting a bridge over (or tunnel under) a stream or railway, is very expensive

PARKING

Access roads should be 6.1 – 6.7 metres wide.
Any ramps must not be more than 1 in 10.



PARKING BAY DIMENSIONS

Parallel parking

space length A (metres)	space width B (metres)	notes
standard car or van		
5.4 – 6.0	2.5	Spaces next to walls should be 300 mm wider.
disabled parking		
6.0	3.6	Parking for disabled users cannot have the parallel marking more than 3 m from the roadway edge. Allow an additional 1.5 m for turning.
bus or coach		
12.0	2.5	For bus bay length, use (n x L) where n = number of buses using the bay simultaneously and L = length of vehicle. Consider taper lengths of 15 m on approach and 15 – 30 m on departure.
small truck		
6.4	3.5	
large rigid truck		
13.5	3.5	
large articulated truck		
20	3.5	
bicycle		
2.0	1.2	Stands should be placed 1 m apart so that two cycles can be attached to the stand (one on either side) and that access to the cycle is still maintained. Leave space at each end of the stand for safe and easy access.
motorcycle		
2.5	1.2	

SOME THINGS TO THINK ABOUT

- How many parking spaces should there be?
- Should you allow for any car parking, such as for match officials and people who work at the venue?
- Instead of parallel parking, cars and coaches can park in chevron fashion and what other patterns?
- How many coaches will arrive/depart all at the same time?
- For bicycles, allow eight covered cycle spaces plus four racks per each 1000 m^2 total floor area.

{FACTSHEET} BUILDING ON SLOPING LAND

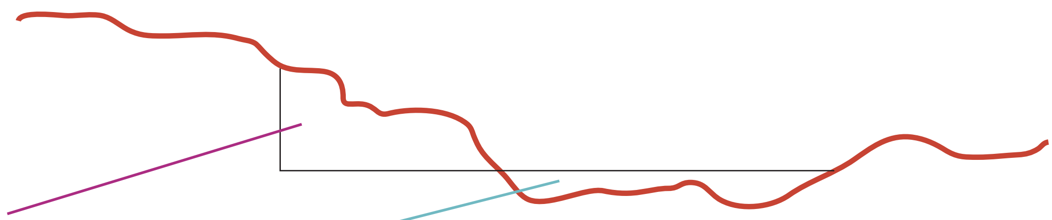
Some venues are built on fairly flat land. Others are built on hillsides. For the Braga Municipal Stadium, in Portugal, one million cubic metres of granite were removed, so that the west side is literally dug into the hillside.

ECONOMICAL EXCAVATION

Excavating is costly: it takes up a lot of time and the material has to be put somewhere afterwards. Ideally, as little as possible is done.

Whenever possible, the material that has been dug out is reused, preferably on the same site. Even so, it will need to be stored, crushed and transported.

CUT AND FILL



Is this volume of cut the same as this volume of fill?

The areas can be worked out using graph paper. Then multiply the area by the length of the site, to give the volume. Work it out in sections, as the shape of the terrain can vary along the length of a site.

If the cut does not equal the fill, try moving the horizontal line up or down, until cut = fill

USING THE HILLSIDE

Can the design be altered, so that different parts can be built on different levels of the hillside?

GATHERING INFORMATION

Aerial photography, such as on Google Earth, can give clues about the shape of the land, but something more detailed is needed to make calculations.

Ordnance Survey maps have contours marked on them. Using these contour lines, a cross-section can be drawn, showing the slope of the land.

Draw a line across the map. On a piece of graph paper, label the y-axis with the elevations shown along the line. Place the x-axis edge of the graph paper along the line drawn on the map. Where each contour line touches the graph paper, make a point at the corresponding elevation on the graph. Connect these points to give a cross section of the land.

{FACTSHEET} ENERGY GENERATION AND STORAGE

ENERGY SAVING

Methods for reducing energy use include:

- Cavity Wall Insulation
- Floor Insulation
- Low Energy Lighting
- Thermal Glass, Glass Coatings and Sunpipes
- Loft and Roof Insulation
- Draught Proofing
- Double Glazing
- Underfloor Heating

SUSTAINABLE ENERGY SOURCES

Fossil fuels such as coal, gas and oil are finite and supplies are rapidly diminishing. Sustainable alternatives that will not run out include:

- solar heating
- ground and air source heating
- hydroelectric power
- wave and tidal power
- photovoltaics (electrical energy)
- wind power
- biomass and biofuel
- combined heat and power (CHP)

Currently, solar water heating offers a fairly quick payback. Solar water heating should not be confused with photovoltaics (PV), which involves generating electricity directly from the sun. This can be used or fed into the National Grid. Some suppliers are now offering to site a PV panel next to a solar panel to generate electricity that can be used to power the solar heating pump.

A problem with solar energy for heating is that it is most available when it is least needed. Methods for storing solar heat energy, collected in the summer so that it can be used for space and water heating in the winter, include heating sand, soil or rock underneath buildings. In building design, other sustainable considerations include rainwater harvesting, waste water recycling and sewage treatment.

USEFUL SOURCES OF INFORMATION:

- The Renewable Energy Centre website (www.therenewableenergycentre.co.uk)
- Solar Trade Association (http://www.solar-trade.org.uk/)
- PV case study (http://www.alternative-energy.co.uk/index.html)
- Green building products and materials (http://www.greenspec.co.uk/)
- Sustainable construction (http://www.bre.co.uk/filelibrary/rpts/sustainable_construction_simpleways_to_make_it_happen.pdf)
- Heat storage in sand (http://www.arthaonline.com/Word%20Files/Ramlow_SolarToday_ND07.pdf)
- Seasonal hot water storage (http://www.itw.uni-stuttgart.de/abteilungen/rationelleEnergie/pdfdateien/07-08.pdf)
- German solar assisted district heating system (http://www.itw.uni-stuttgart.de/abteilungen/rationelleEnergie/pdfdateien/03-11.pdf)

{FACTSHEET} ENERGY USE AND SHOWERS

SOME FACTS

- the less water we use, the more energy we save
- all water usage demands energy, because the water has to be purified and pumped through the mains
- hot water uses the most energy of all
- in new houses, showers and baths account for around 45% of the water used
- each person in the UK currently uses about 150 dm^3 of water every day
- UK water use has been rising by 1% a year since 1930
- a typical bath uses twice as much hot water as a 5 minute shower – that's 13 000 dm^3 more hot water per year
- shower flow rates have no upper limit in the UK, in the USA the maximum flow rate is 9.5 dm^3 per minute
- swapping a bath for a shower once a week would save about 30 kg of CO_2 emissions
- cutting a minute off your shower time saves about 3300 dm^3 of water and 200 kWh of energy per year
- fitting a low-flow shower head could cut hot water use and your CO_2 emissions by about a third (Waterwise)
- switching from a power shower to a low-power shower head could can save as much as 12 000 dm^3 of hot water per year – equivalent to 150 kg of CO_2

{FACTSHEET} FACILITIES AND SPECTATORS

ORDER OF DESIGN

When planning and designing a stadium, arena or venue, factors should be considered in this order:

1. The playing area
2. The spectator capacity and seating
3. Other facilities and requirements

PLAYING AREA

The shape and dimensions of the playing area should be the starting point of any design.

SPECTATOR CAPACITY

Often, designers and clients are very optimistic which can cause them to over-estimate this number.

At the 2007 Men's World Championships in Germany, the venues ranged in size from a seating capacity of 5000 to a capacity of 19 000.

The Championships two years later in Croatia, used venues ranging in capacity from just over 2000 people to 15 000 people. The actual number of spectators at the matches ranged from attendances between 200 and 3000 for the early rounds, to between 8000 and 15 000 for the semi finals and finals.

WHEELCHAIR ACCESS

This is a guide to the number of wheelchair spaces that should be provided:

Spectator capacity	Wheelchair spaces
Up to 10 000 Example: 400 capacity… Example: 5000 capacity…	1 in 100 – but at least 6 in total …6 spaces …50 spaces
Between 10 000 and 20 000 Example: 10 000 capacity… Example: 17 000 capacity…	As above + 5 in every 1000 over 10 000 …100 spaces …135 spaces
Between 20 000 and 40 000 Example: 20 000 capacity… Example: 31 000 capacity…	150 + 3 in every 1000 over 20 000 …150 spaces …183 spaces

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{FACTSHEET} FACILITIES AND SPECTATORS

THE SEATING

Once a decision has been made on the total number of seats to be provided, the arrangement of the seats must be designed. The objective is to give the spectators the best view of the playing area as possible.

Points to consider:

- Spectators should be as close to the playing area as possible. Think about safety.
- Will the seating be along the sides of the playing area with open corners, or completely surround the playing area? Think about costs versus benefits.
- There should be no obstructions to the spectators' viewing. This includes spectators' heads! See table below.
- Each spectator should be provided with adequate seating space to be comfortable. See table below.
- Individual seats or benches? Fixed seating or flip-up seats? Think about how this affects foot space.
- Tiered seating should not be too steep. Think about safety. See table below.

Some guidance:

Seating space	Approx. 50 cm by 50 cm
Foot space	Approx. 40 cm
Gradient	1:2 (34°) Less and the person in front may obstruct view More and safety provisions must be considered
Typical arrangement (up to 10 000 capacity)	Single tier (10 – 15 rows)

FACILITIES

Outside of the main playing area (which includes the spectator seating), space must be provided for a number of other rooms and facilities. Below are some areas that might be included with suggestions for the amount of space required to house them:

Entrance/Reception	15 to 25 m^2
Players changing rooms (4 in total)	30 to 40 m^2 each
Officials changing rooms (2 in total)	10 to 20 m^2 each
Changing rooms to include:	
showers	1.5 m^2 for each shower (1 per 2 players)
toilets	90 to 100 cm^2 for each urinal (1 per 3 players) 150 to 200 cm^2 for each WC cubicle (1 per 3 players) 70 to 80 cm^2 for each washbasin
	table continued overleaf ...

{FACTSHEET} FACILITIES AND SPECTATORS

Spectator toilets (same dimensions as changing room toilets):	
men	2 urinals per 100 spectators + 1 for every additional 80 spectators 1 WC per 250 spectators + 1 for every additional 500 spectators 1 washbasin per WC + 1 per 5 urinals
women	2 WCs per 50 spectators + 1 for every additional 40 spectators 1 washbasin per 2 WCs
Boardroom (including bar)	25 to 50 m^2
Offices:	
Chairman/Director	15 to 20 m^2
Team manager	15 to 20 m^2
Secretary	10 to 15 m^2
Others	10 to 15 m^2 each
Restaurant/Bar	
Medical room	20 to 25 m^2
Storage	Rooms could range from 1 m^2 to 80 m^2 depending on number and use

Please remember that all the information given here is no more than suggestions. It does not state how things must be or what you must do.

SOURCES

Much of this information can be found, and elaborated on, in John, Sheard and Vickery (2007) Stadia: A Design and Development Guide (Fourth Edition), available to view online at www.scribd.com

{FACTSHEET} FINDING A SITE

LOCATION

A sporting venue will have to be somewhere that suits teams, officials, all the people who work in there, people delivering goods, and many others, as well as spectators.

Where is the best place for a specialist sports facility?

where people live? town centre? in the country? industrial estate? outskirts of a town? where else?

GREENFIELD OR BROWNFIELD

Reusing land can be expensive:

- there might be dangerous chemicals left
- there can be old foundations and cellars that no one knows about
- the nearby roads could be old and too narrow for coaches.

Building on land used for open space or agriculture can be expensive:

- open space is important for ecology so using it is a cost to the environment
- agricultural land is important for food production; if we build on too much of it, food will become expensive
- open land may not have any water or electricity supply nearby
- reaching the site could be awkward and costly for the builders.

FIRM FOUNDATIONS

A sports venue (building) can be a heavy load on the land that it is built on. The land must support the building evenly so that it does not move.

Whenever a building is constructed, the topsoil is removed (and then usually kept for when the site is landscaped at the end of the project). The *soil* (or bedrock) underneath is what the foundations are built on. This *soil* can be anything from solid rock through to peat bog.

INFORMATION

Ordnance Survey 1:25000 scale maps give some details of land use, watercourses and contours.

On the British Geological Survey website, there are downloads of the geological maps for the whole of the UK. These show the type of soil (bedrock) in an area.

The school geography department or the local library will have detailed maps of the area.

Older relations may remember buildings that used to exist on a site.

Public libraries often have books with old photographs of towns and cities.

{FACTSHEET} FITTING IN WITH THE LOCAL AREA

DOES A PROPOSAL FIT WITH LOCAL PLANS FOR THE AREA?

A local authority (the local Council) has to control the way that land is used, because they must think about the interests of everyone who works and lives in their area. The local planning department will also think about the way a building looks, so that it fits in with its surroundings. Thirdly, the council will want to know that a development is designed and built properly: it should not waste energy and must be safe and convenient for people to use.

IS THE LAND SPECIAL?

The land may have planning restrictions because it's a protected open space, has ecological or archaeological importance, is in a conservation area or near an historic building, or some other environmental reason.

ARE THERE OTHER RESTRICTIONS?

Most local authorities have similar policies:

- developments to be sustainable
- people to be able to use public transport
- support for sport and recreation
- support for development that gives new employment
- prefer building on land that was previously used for something else (brownfield), rather than open space
- not to build anything else on land earmarked for housing
- not to build on land liable to flooding.

HOW CAN A DEVELOPER FIND OUT ABOUT PLANNING POLICIES?

Local authorities have local development plans. As a part of these substantial documents, there will be area maps showing the planning policies for the land in the area. These will be shown in different colours with a key at the side.

The sort of policies that might affect this Challenge:

- conservation
- countryside
- natural environment
- historic monuments
- parks and gardens
- housing
- flooding

WHERE ARE THESE MAPS KEPT?

Every library will have a copy, but they are usually online, as well:

- go to your local authority website
- select planning (the main area and not just the planning applications area)
- look for a link such as local plan or development plan and click
- select the maps link

In some instances, the local plan link will take you to the planning portal, which can be accessed directly (www.planningportal.gov.uk), if preferred. Select professional user, then local information from the menus. From here, you may again need to look for local plan or development plan. As before, select the maps link.

FITTING IN WITH THE LOCAL ENVIRONMENT

New development should respect the built and natural environment of the area. Excellence, innovation and creativity in design are ideal, poor and mediocre proposals are not. Key features to consider include:

- protecting the environment
- use of natural resources
- contaminated land
- good design

GOOD DESIGN

Good design is subjective and depends on your taste. It is not just the actual design of the building but also about local character. The aim is to create buildings and spaces which will make a place attractive.

The Government defines urban design as: *"the relationships between different buildings; the relationship between buildings and the streets, squares, parks, waterways and other open spaces which make up the public domain; the nature and quality of the public domain itself; the relationship of one part of the village, town or city with other parts; and the patterns of movement and activity which are thereby established; in short, the complex relationships between all elements of built and unbuilt space."*

THE BUILDING

- Its size needs to fit with surrounding buildings unless there is a good reason to make it different.
- It should respect the character of its locality.
- High quality modern design can enhance the surroundings by, for example creating a new point of interest.
- The skyline provides an identifiable image of a place. Traditionally, landmark buildings are of communal or civic importance, or link with political power.
- The new development should contribute to the local scene.
- It should be interesting at eye level and have a pedestrian friendly frontage. Physical and visual links between the building and the outside space is good design.
- It should be accessible for everyone, including those with disabilities and parents with young children.

LANDSCAPE

- The size and shape of the building should make it fit attractively into the contours of the land.
- Space around the building should link with surrounding spaces.
- Existing, important features should be safeguarded, for example hedges, trees and walls.
- Incorporate landscaping to enhance the appearance of the building.
- Landscaping should create an attractive and welcoming area.

Townscape is the urban equivalent of landscape.

It is the art of weaving the street pattern, spaces, size of buildings, building character, skylines and views of a town or city together.

ALSO

Good design includes continuity through paving materials, street furniture, special street lighting or floodlighting the building.

{FACTSHEET} FLOOR CONSTRUCTION (INDOOR VENUES)

FLOOR CONSTRUCTION

Ordinarily, floors in large buildings, such as leisure centres, will have a base of concrete. Underneath there will be a sheet of waterproofing, to stop any damp coming up through from the ground.

The floor must be as flat as possible, to give a good surface for laying the final covering.

FLOOR FINISHES FOR GENERAL AREAS

all areas	no trip hazards
circulation areas	hard wearing
food and changing areas	easy to clean
showers and toilets	waterproof
stairs	non-slip
upper floors	sound proof

THE PLAYING AREA

If the venue will be used for only one sport, then the floor surface can be selected with the specific requirements for that sport. However, the selection of a suitable floor surface is more difficult if it is for a range of sports. Some compromise has to be found as, although some surfaces are acceptable for multi-sports, no one surface will suit them all.

PROPERTIES

- Load bearing (players and equipment)
- Resistance to wear (durability)
- Friction (amount of sliding)
- Stiffness – point and area elasticity
- Shock absorption
- Colour and reflectance
- Bounce
- Easy to clean

TYPES OF SURFACE

- Timber
- Sheet (vinyl, linoleum, rubber and composites)
- Textile (for example: felt or carpet)

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{FACTSHEET} FOUNDATIONS

FIRM FOUNDATIONS

A sports venue is a heavy load on the land it's built on. The land must support the building evenly so it doesn't move. Whenever a building is constructed, the topsoil is removed (and then usually kept for when the site is landscaped at the end of the project). The soil (or bedrock) underneath is what the foundations are built on. This soil can be anything from rock through to peat bog.

GEOLOGY

Foundations on rock: Some rocks can support loads well, others are not so good. If the site slopes, it can be expensive to dig out the rock to make the site flat, but the rock could be crushed and then reused

Foundations on clay: Clay does not give a firm base for a building: foundations have to be deep. It is quite expensive to dig out; it has to be taken away from the site and cannot be reused

Foundations on gravel and soft materials: lightweight buildings can 'float' on these, on a raft foundation. Heavier buildings may need deep foundations such as piles

Foundations on previously used land: Foundations can be expensive to dig as you never know what you might find under the ground. Piles are often needed, to give the building a firm foundation

TYPES OF FOUNDATION

CONTINUOUS STRIP

If the bedrock is sound, a continuous strip of concrete can be laid all around underneath the walls. Its thickness will depend on the weight from the walls and columns that support the roof.

If the bedrock is clay, the concrete will have to go deep into the ground.

RAFT

If the ground is poor and the building light, a slab of concrete, reinforced with steel, can be put under the whole building. Then, if one side moves slightly, the whole building will move together and no cracks will appear.

If there is any uncertainty about the ground, piles are driven until there is a sure footing. These long thin, usually concrete, columns are then linked together with a thin strip of concrete, just below ground level.

Displacement: a steel cutting edge, on the end of a narrow cylinder, is pushed deep into the ground. The long, thin space above is filled with concrete and steel reinforcement. Because no bad material is brought to the surface, they are good to use in old industrial areas.

Continuous flight augur: a massive Archimedes screw twists down into the ground. The soil is brought to the surface and taken away. The large diameter hole is filled with concrete. As these are large, not so many are needed as when displacement piles are used.

PAD

Often, for sports venues, the structure is a series of columns holding up the roof, and the walls do not carry any load. The columns can be bolted to individual square slabs of concrete (strengthened with steel). If the ground is good, that is all that is needed. If not, some piles might be inserted below the pad.

DEVELOP A NEW SPORTS VENUE

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{FACTSHEET} HEAT OUTPUT OF LIGHTS

Electric lights can give out a significant amount of heat. This has to be taken into account when choosing one type of lamp over another, especially if illumination levels need to be high.

MEASURING UNITS FOR LIGHT LEVEL

Light level is measured in lux in the SI system. One lux is one lumen per square metre. A light source giving 1000 lumens to a square metre is giving 1000 lux. Spread over 10 square metres, the light level is only a dim 100 lux.

LIGHT LEVEL

Light level or intensity in an area is the total luminous flux falling on a surface per unit area. The type of activity determines the level that is needed. A typical office needs 500 - 1000 lux.

APPROXIMATE LIGHT LEVELS OUTDOORS

Condition	Illuminance (lux)
Sunlight	100000
Full Daylight	10000
Overcast Day	1000
Very Dark Day	100
Twilight	10
Full Moon	0.1
Overcast Night	0.0001

COMMON AND RECOMMENDED LIGHT LEVELS INDOORS

The outdoor light level of 10,000 lux on a clear day can be reduced inside a building close to the windows to about 1,000 lux, falling to as little as 25 - 50 lux in the middle. Modern light levels with additional lighting are usually in the range 500 - 1000 lux, increasing to 1500 - 2000 lux for precision and detail work.

RECOMMENDED LIGHT LEVELS IN DIFFERENT WORK SPACES

Activity	Illumination (lux, lumen/m^2)
Public areas with dark surroundings	20 - 50
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, Homes, Theatres	150
Easy Office Work, Classes	250

{FACTSHEET} HEAT OUTPUT OF LIGHTS

RECOMMENDED LIGHT LEVELS IN DIFFERENT WORK SPACES (CONT ...)

Activity	Illumination (lux, lumen/m²)
Normal Office Work, PC Work, Library, Groceries, Show Rooms, Laboratories	500
Supermarkets, Mechanical Workshops	750
Normal Drawing Work, Detailed Mechanical Workshops, Operating Theatres	1,000
Detailed Drawing Work, Very Detailed Mechanical Work	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

ELECTRIC POWER FOR LIGHTS

The electric power of lights and the light level are related in the equation:

$P = I / (e\ r\ s)$

where

P = installed electric power (watts per square metre of floor area, W/m^2)

I = light level of the room (lux)

e = light equipment efficiency

r = room lighting efficiency

s = light emitted from the source (lumen/W)

LIGHT EMITTED FROM A SOURCE

Electric lights convert electrical power (Watts) into light (lumens). They vary in efficiency according to type. Typical efficiency of different lamp types:

Lamp Type	Emitted Light from The Source (lumen/Watt)	Lifetime (hours)
Incandescent bulbs	10 - 15	1,000
Low Voltage Halogen	20	2,000 - 5,000
Mercury Vapor	40 - 60	22,000
Fluorescent	50 - 90	more than 7,000
Metal Halide	70 - 90	more than 12,000
High Pressure Sodium	90 - 125	25,000
Low Pressure Sodium	120 - 200	20,000

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{FACTSHEET} HEAT OUTPUT OF LIGHTS

LIGHT EQUIPMENT EFFICIENCY (E) AND ROOM LIGHTING EFFICIENCY (R)

Light equipment efficiency is how much of the light is actually emitted from the light. The room lighting efficiency express how much of the light is absorbed by the room before entering the activity area. Actual lighting is affected by both, typically values of the two combined (e x r) fall between 0.3 - 0.6.

HEAT LOAD FROM LIGHTS

If a room needs to be lit to 1,000 lux, if room and lighting equipment efficiency are set at 0.5, using incandescent bulbs giving 10 lumen/W, the electric power for the lightning can be calculated:

$P = (1{,}000 \text{ lux}) / (0.5 (10 \text{ lumen/W})) = 200 \text{ W/m}^2$

Using standard fluorescent tubes giving 60 lumen/W, the electric power for lighting can be calculated:

$P = (1{,}000 \text{ lumen/m}^2) / (0.5 (60 \text{ lumen/W}))$

$= 33.3 \text{ W/m}^2$

Incandescent bulbs use high energy consumption and generate a large amount of heat compared to the light they supply.

	Illumination - Light Level (lux)				
	200	**400**	**600**	**800**	**1000**
Wattage of incandescent bulb lamps	40	80	120	160	200
Wattage of fluorescent tubes	6.7	13.3	20	26.7	33.3

{FACTSHEET} INDOOR ARENAS

There are many stadiums, arenas and sporting venues around the world. Some are little more than an average sportshall. Others are incredible pieces of architecture. Below are some examples of the different shapes and designs that can be found, from the Ancient Colliseum in Rome to London's O2 Arena.

ARENAS IN THE UK

The following are just a few of the indoor arenas used for sport and other events in the United Kingdom (images can be found by putting the names into a Google Search):

- The Plymouth Pavilions (http://www.plymouthpavilions.com/)
- The O2 Arena, London (http://www.theo2.co.uk/)
- Motorpoint Arena Cardiff (http://www.livenation.co.uk/cardiff)
- Manchester Central (http://www.manchestercentral.co.uk/)
- The Odyssey Arena, Belfast (http://www.odysseyarena.com/)

{FACTSHEET} LIGHT PIPES

USING SUNLIGHT

Reflective light pipes have been used since the time of the ancient Egyptians to reflect and direct natural sunlight into darkened areas. The US Green Building Council's Sustainable Building Technical Manual estimates that well-designed daylighting can reduce lighting energy use by 50-80%. In 'well-designed' modern buildings, this often involves the use of light pipes.

Although light pipes can be made from a variety of materials, those made from reflective material are the most popular.

LIGHT PIPE OR SKYLIGHT?

Solar light pipes are now a viable alternative to traditional skylights. They are able to send more sunlight (or moonlight) into a space when compared with skylights and, therefore, take more heat into a space. As they occupy a smaller area, have better U-values and can allow more insulation to be used, they can significantly reduce heat losses from a building by replacing windows and skylights. They can also transmit daylight into areas such as basements where windows and skylights cannot be used.

Since light pipes are narrow, they can be used in high security areas. Prisons throughout the world install light pipes to add natural light to an area without creating a security risk. The light collecting domes can also be used as architectural features.

HOW MUCH LIGHT?

Although light pipes allow the transmission of free sunlight into covered areas, the amount of light transmitted is variable as it depends on whether it is cloudy or sunny, the time of day, the time of year, the length of the pipe, and whether there are trees or higher surrounding buildings. If the amount of light is measured, it will vary depending whether it is measured immediately below the end of the pipe, or at different points between floor level and the pipe.

Monolux Ltd manufacture 'SunPipes' ranging from 230 to 1500 mm in diameter. The 750 mm Diamond Dome SunPipe is used in Supermarkets, Sports Halls, Leisure Centres and Warehousing. It produces approximately twice as much light as the 530 mm diameter system, and is suited to buildings of more than 7m in height. In general terms, they state that:

- 450 mm diameter SunPipe will light up an area of 22 m^2
- 530 mm diameter will light up an area of 40 m^2
- 750 mm diameter will light up areas up to 50 m^2
- 1000 mm diameter will light up areas up to 70 m^2
- 1500 mm diameter will light up areas up to 90 m^2

They provide tables to show the light obtained from SunPipes in different sunlight conditions, for 105 klux (kilolux) on a sunny summer day, 45 klux on an overcast summer day and 20 klux on an overcast winter day.

- http://www.monodraught.com/technical/lux.php

{FACTSHEET} LIGHT PIPES

Other factors should also need to be considered, for example the colour scheme of interior and on which elevation the light collector of the light pipe is to be positioned; south, east or west. For SunPipes made by Monolux, there is an 12% reduction of light for each 45° bend used and a 6% reduction in light transmission for every metre of SunPipe.

There are a variety of companies offering different kinds of light pipes. Solartube claim that their light pipes outperform those of Monolux.

- http://www.lightupmyroom.co.uk/Cobsen_Davies_solatube_news.htm?newsid=29

LIGHT PIPE RESEARCH

The Monolux website (http://www.monodraught.com/) also provides much more information on light pipes, especially in the 'technical' section. They have scientists working at Nottingham University on the development of better light pipes, including Professor Mike Wilson. He is developing a number of systems involving the Monodraught heating and ventilation systems. These include a composite lighting unit using a SunPipe with LEDs embedded into the surround using a solar panel at roof level which are connected to a solar battery to provide 24 hour lighting.

Since modern light pipes were devised about 30 years ago, they have become more popular and several thousand are installed around the world each month. Dr David Carter of Liverpool University is a building technologist who has worked to provide the same kind of wealth of reference data, established methods, protocols and standards which designers can draw on when devising electric lighting installations.

- http://www.liv.ac.uk/researchintelligence/issue25/lightpipes.html

{FACTSHEET} MAKING A WIND TURBINE

CENTRE FOR ALTERNATIVE TECHNOLOGY

At the Centre for Alternative Technology (CAT) in North Wales, scientists have been experimenting with wind turbine designs for years. They offer advice to people who want their own wind turbines. If you visit their website (www.cat.org.uk) you can see pictures of different types of wind turbine that they have investigated.

THE PROCEDURE

This procedure uses materials similar to a kit sold in the shop at CAT. It allows different aspects of wind turbine design to be investigated. Your wind turbine should have a hub that holds the blades and connects to a shaft. The shaft must be supported in a frame so that it spins freely.

A risk assessment must be carried out before you start. When you use the craft knife, cut away from your hands and body. Take care using a drill – your teacher may need to help you with this.

EQUIPMENT

- 4 mm *Corriflute* (corrugated plastic sheet)
- 5 mm diameter dowel (about 30 cm)
- rubber and steel washers to fit the dowel
- solid wooden, MDF or thick cardboard wheel for a hub (about 50 mm diameter)
- craft knife
- saw
- wood for a frame (4 x 150 mm lengths of 30 mm x 20 mm)
- drill and bits to make 5 mm and 6 mm holes in wood
- glue

METHOD

Planning ahead: Think about how you will construct the wind turbine – you will probably want to modify things to see if you can make it work better. For example, you may want to vary the size, shape and numbers of blades, so you could build flexibility into the design.

1. MAKING THE BLADES

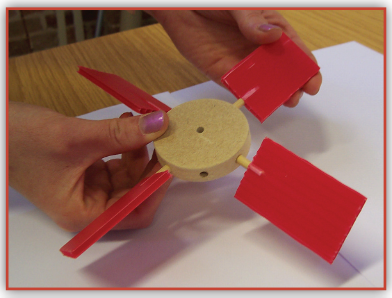
Use a craft knife [CARE] to cut the blades from *Corriflute*. Number, size and shape can be varied, but a simple starting point is to make four blades, each about 4 cm (seven corrugations – always use an odd number) wide by 6 cm long (the holes should run through the longest side).

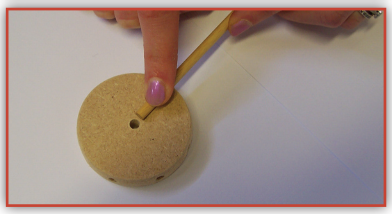
{FACTSHEET} MAKING A WIND TURBINE

2. MAKING THE HUB

Make this from a 5 cm wheel. Drill [CARE] a 5 mm hole exactly in the centre of the wheel to give a tight fit for the shaft. Fit the blades to the hub using short pieces of dowel pushed into the centre corrugation.

- If the wheel is thick enough, drill equally spaced 5 mm holes 1 cm deep in the rim of the wheel, so that the 5 mm dowel is a tight fit. Use a separate hole for each blade. The holes must be very accurately spaced, point precisely to the centre of the hub and be parallel to the edges. If they are out of position in any direction the blades will not fit symmetrically to the hub. Drill extra holes if you want to try the effect of increasing the number of blades in your wind turbine.
- If the wheel is thin, use a 5 cm length of the 5 mm dowel for each blade and glue them symmetrically to the face of the wheel.





3. ADJUSTING THE PITCH

The angle (pitch) of the blades can be adjusted by twisting them on the dowel. Adjust your blades so that they all have the same pitch.

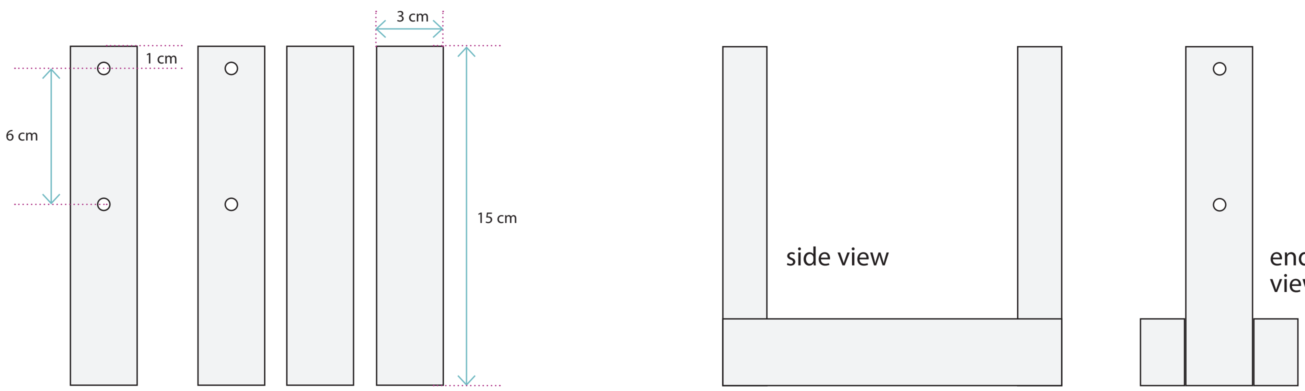
4. MAKING THE SHAFT

Cut a piece of 5 mm dowel 20 cm long and glue one end into the hub.

5. MAKING THE SUPPORT FRAME

Glue together four 15 cm lengths of 3 cm x 2 cm wood (or similar). If necessary, cut the wood to size and, if not predrilled, make a 6 mm hole centrally 1 cm from one end in two of these to use as uprights. The other two pieces form a horizontal base: sandwich the drilled pieces of wood vertically so that the holes are aligned at the top, at opposite ends. Note: The shaft should be able to spin freely when passed through these holes. Make sure all the pieces are carefully fixed at right angles to each other.

You may wish to construct a different type of support frame, depending on the materials that you have available.



6. ASSEMBLING THE WIND TURBINE

Use the rubber washers to hold the shaft in place, by putting one on each side of the two uprights. First insert a steel washer between each rubber washer and the uprights.

This simple frame may be held in position by a clamp and stand. Additional support may be needed if a powerful fan is used as the wind source.

The wind turbine shaft can now be connected to turn other devices, for example, to lift loads or generate electricity. The test procedure, Testing a wind turbine, can be used to compare different wind turbine designs.

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{FACTSHEET} MATERIALS USED IN BUILDINGS

Materials in different places, inside and outside a building, have to cope with all sorts of problems. Not all materials have to do the same thing. Glass in a window has to be clear, be tough, but doesn't need to be strong. Steel in a roof beam doesn't need to be a good insulator. Tiles in a shower have to be waterproof, but don't need to be fireproof. It's a question of choosing the right material for the right job.

Materials for buildings need to meet these aims …

strength	withstand the loads it has to carry
stiffness	does not bend too much
toughness	not break easily: resists impact such as feet on a floor or hailstones on glass
resilience	how elastic the material is, such as the bounciness of a floor
creep	after being constantly bent and stretched the material should stay the same size
fatigue	after being constantly bent and stretched the material should not break
hardness	resist dents
resist wear	not spoil after constant friction
moisture resistant	not spoil when subjected to rain or water, as in a bathroom
resist chemicals	acid rain, outside, foodstuffs and cleaning liquids indoors
insulation - thermal	keep the heat in, in winter and the heat out, in the summer
insulation - acoustic	stop noise disturbing the neighbours, and stop outside noise getting in
fire resistant	very important for the main structure
sustainable source	• recycled materials, such as insulation from plastic bottles • reusing materials, such as old bricks • renewable, such as softwood rather than tropical hardwood
sustainable manufacture	• less carbon making the material • less material to make the item
aesthetics	• looks good • still looks good after several years use
light weight	• less load (smaller forces) to carry • less pressure on the foundations • easier to build with
economical	Is a lot of a cheap material better value than a little of a costly material?

{FACTSHEET} MODELLING STRUCTURES

Shapes and forms can be as inventive as your imagination will allow. Your only limit is available materials.

Some ideas to start with ...

... draw some ideas on paper

... read *factsheet: structural form*

... look for shapes and forms on the internet

www.cabe.org.uk/case-studies

www.bdonline.co.uk (see *structure* or *building studies*)

... look at bridge or tower building competitions on the internet

Try out different frameworks.

See what happens when you add covering materials.

Refine your design ...

... can you reduce the thickness of the materials?

... can you take away any of the parts?

... what happens if you change the joints from pin to rigid, or vice versa?

... have you checked for all types of loads?

HEALTH AND SAFETY

Before you try out anything, make sure that your teacher agrees with your plan. Think about which way your structure might topple over and avoid standing there. When you put the loads on, keep your feet out of the way. Can you arrange a soft landing for anything that falls?

MATERIALS

All sorts of materials can be used to make and test a model:

- lengths of wood, cane, lollipop sticks
- plastic drinking straws, rigid plastic tube
- K'nex, Meccano
- Corriflute
- thin card folded to form triangular or square section tubes
- rods from rolled newspaper
- rigid plastic sheet, card
- fabric such as pvc coated cotton, nylon, starched cotton
- string, wire

Note: You will need tools to cut some of these materials. Make sure that you have your teacher's permission. When using craft knives or saws, cut away from your hands and body.

{FACTSHEET} MODELLING STRUCTURES

JOINTS

Structures are connected together in different ways. Many structures are slightly flexible, so that they can bend and stretch when the temperature changes or when they have to carry different loads at different times (such as snow or spectators). For this, they may have pin joints. In other parts of the structure, the connections must be very firm (you do not want gaps opening up around windows, for example). These rigid joints are welded, bolted firmly together, glued or concreted up.

To model both these situations, try using:

- pins (preferably safety pins), split pins
- plain bolts, either left slightly loose, for a pin joint or firmly fixed
- glue
- string

WEIGHT

Part of the load that any structure has to carry is its own weight. Avoid making your structure too heavy.

SIZE

A good model should be to scale. Decide on the scale that you will use.

When you try out different structural forms, make sure that you are comparing like with like (fair tests).

LOADS

What size loads will you use? You may need:

- masses
- wood blocks
- fan or hairdryer
- wood or metal sheets
- access to a balance

TESTS

There are two types of load to think about:

- point loads, like a stiletto heel or the force where a beam presses down on a column
- distributed loads, like the caterpillar treads on a tank or the spread out force of snow on a roof.

You might also think about overturning forces:

- Is the building self-supporting in all directions?
- Could gusts of wind push the building over, or lift off the roof?

RECORDS

Keep records of your tests so that you can justify your design. Make drawings of your design, showing the sizes and details. Show how your design will scale up to full size: what will be the actual size of the structure?

{FACTSHEET} RAINWATER TREATMENT

REGULATIONS

United Kingdom Building Regulations stipulate that rainwater is not suitable for drinking (non-potable). Therefore, unless it is properly treated, it cannot be used for drinking, or in kitchens for catering purposes, nor can it be used for bathing or showering. It can be used for washing clothes, flushing toilets and in bidets.

UK Government requirements can be found at:

http://www.opsi.gov.uk/SI/si2000/20003184.htm and World Health Organisation (WHO)

Recommendations are at:

http://www.who.int/water_sanitation_health/dwq/en/

POLLUTANTS

The most common pollutants of rainwater are:

- bacteria
- insecticides
- heavy metals, nitrates and nitrites.

WATER TREATMENT

1. REMOVAL OF BACTERIA

Bird droppings and the bacteria in them are the most common pollutant for rainwater that is being collected from a roof. **Disinfection** methods can be used to kill micro-organisms present in water. **Ultra-violet filtration** is an effective method for killing bacteria. Precautions are essential to ensure that the sterilisation process does not fail. Filters with alarms and double bulb UV filters are available. Filters are usually used to remove particles before the UV treatment, to prevent bacteria from being shielded. **Chemical disinfectants** (biocides) such as chlorine, may also be used.

2. REMOVAL OF INSECTICIDES

Rainwater collected near fields that have been sprayed may contain insecticides. Other substances from industrial sites may also be washed down in rainwater. **Carbon filters** can be used to absorb such chemical compounds, which can travel in the atmosphere long distances downwind of their origin.

3. REMOVAL OF HEAVY METALS, NITRATES AND NITRITES

Redox alloy cartridges containing very fine copper and zinc alloy particles can be used to convert many dissolved pollutants by oxidation, removing most water soluble cations of harmful contaminates like lead, mercury, copper, nickel, chromium, cadmium, arsenic, antimony and cobalt. Soluble metals are reduced into insoluble metal ions and metallic contaminants are bonded to the redox alloy.

4. REMOVAL OF EVERYTHING

For high quality, very pure water, **reverse osmosis** can be used to remove everything. Water (solute) is forced through a dense semipermeable membrane by applying a high pressure. This method can be used for desalination, as the membrane can be designed to allow only water to pass through, which prevents the passage of solutes such as salt ions.

WATER PURIFICATION WEBSITES

Pozzani http://www.pozzani.co.uk/

Rainwater Harvesting http://www.rainwaterharvesting.co.uk/

Katadyn http://www.katadyn.com/brands-products/katadyn/tab/product-categories.html

Aquamira http://www.aquamira.com/

MSR http://www.msrgear.com/watertreatment/

Hydropal http://www.hydropal.co.nz/index.pasp

{FACTSHEET} SPORTS ARENA LIGHTING

Lighting is needed for:

- the play area – players and spectators must be able to see the action clearly without strain
- passageways and escape routes – spectators must be able to go in and out of the stadium safely
- alarm call points and fire-fighting equipment so that they can be easily located
- television cameras – this has greater lighting requirements.

Illumination levels will depend on the particular sport because of:

- different speeds of action
- different playing object sizes
- the variety of colour contrasts involved
- the range of viewing distances.

Higher illumination is needed for:

- faster moving objects
- higher standards of play.

REQUIREMENTS OF ARENA LIGHTING SYSTEMS

Arena lighting systems have to deliver a minimum horizontal and vertical illumination, taking into account all the numerous viewing angles of players and spectators, the requirements of television broadcasts, while providing uniformity of light levels and minimizing glare.

Players must see the ball in play and be able to view the field without shadows or blinding glare in their eyes. Horizontal and vertical illumination and uniformity criteria determine the ability of the lighting system to reveal the three dimensional image of an object, such as a ball or a player. Lighting levels will also depend on the size of the venue. Those sitting furthest from the action require the greatest level of illumination to be able to see clearly.

Spectators must be able to look down and see an evenly-lit play area where the colours are clearly visible and the movement of the ball can be followed smoothly and continuously with the eye. If too few lights are installed to evenly light the stadium, the ball will appear to "hop" from point to point in mid-air, making the game very difficult to follow.

If different events are to be illuminated, the venue lighting must be flexible enough for all of them. The event occupying the largest playing area (width/length/height) and/or the highest illumination level will determine the maximum extent of the system.

FLOODLIGHTING

Modern systems typically consist of 150 to 250 special purpose floodlight lighting fixtures rated at 1000 W each. Metal halide (M-H) lamps are more efficient than incandescent sources.

They render colours more truly than high pressure sodium (HPS) sources and have a flicker factor of less than 0.1, reducing the stroboscopic effect that is noticeable during slow motion television replays.

Floodlights are increasing in efficiency, making it both cheaper and easier to provide the quantity and quality of light that is required by colour television cameras. This has been made possible by technological advances in lamp design. Light sources have evolved from enormous tubular and elliptical lamps with poor alignment, into small unjacketed double-ended lamps designed for long life and high performance within sophisticated, compact, and stable optical systems.

Dimming systems are generally not used for event lighting systems, they are designed to meet each event's illumination criteria with all lamps at full brightness. Dimming M-H lamps produces an undesirable colour shift that affects the colour rendering of the viewed objects.

It should also be noted that human vision deteriorates with age. We need more light to achieve the same level of visibility when we are older. The illumination levels required by a 60-year-old person can be as much as four times that required by a 20-year-old.

In Europe, lighting standards are specified by BS EN 12193. The illuminance levels stated are the minimum 'Maintained Average Illuminance' (Em). Up-to-date guidance can be obtained from the relevant governing bodies of the individual sports and from the professional lighting institutions in various countries. In the UK the CIBSE Lighting Guide: Sport LG4 (Chartered Institution of Building Services Engineers, 1990), plus addenda, is the essential reference.

All design calculations have to take into account light loss due to the accumulation of dirt on light-emitting surfaces, and lamp deterioration with use. Cleaning characteristics have a significant effect on performance and cleaning interval. Floodlights need to be protected against dust and water to ensure maximum performance over long periods between cleaning and replacing bulbs.

GLARE CONTROL

Glare is a major factor to eliminate when designing a lighting system. It can affect the players and the spectators and may be regarded as environmental pollution. Control of the levels of brightness of the light sources and the background help to reduce its effect. Players and spectators are likely to be affected by glare when the light reaches them at angles near the horizontal. So if possible, the floodlights should be outside the observers' line of sight. This is sometimes difficult to avoid if the floodlighting is mounted around the edge of the roof.

Glare can be calculated using the Glare Rating (GR) value. A grid of GR values can be calculated over the whole playing surface and the maximum value achieved is the Glare Rating. A GR value of less than 50 is normally considered the highest acceptable level for all levels of competition and TV coverage.

Floodlights located in small stadia using a side-lighting system should be mounted at a height of not less than 12 m. The angle between the fitting and the pitch centre should be between 20° and 30° to reduce glare, and the angle between the fitting and the side line between 45° and 75° to ensure adequate lighting on players at the touchlines. No floodlighting is permitted within an approximately 15 m zone on either side of a line projected along goal axes, to prevent direct glare to goalkeepers in some ball sports, including football and hockey.

Floodlight systems can produce a large roof loading. It must be considered at the outset of the stadium design. Larger stadia often use corner columns or masts, and may have a number of fittings along the side(s) to allow optimum illumination for each type of event.

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{FACTSHEET} SPORTS ARENA LIGHTING

Corner masts should be offset at least 5° from the side, and 15° from the end of the field of play, taken from the centre of the respective side or end to ensure that they are outside the principal viewing directions of spectators and players. Typically, mast height should be at least 0.4 times the distance on plan between the mast and the centre of the field, and mounting angles should be as above to restrict glare. Final design is greatly influenced by the requirements to achieve recommended Glare Rating limits over the playing surface.

LIGHT LEVELS (ILLUMINANCE)

Light levels vary according to the sport and the level of play. For example, archery requires 750 lux at recreational to international levels. Soccer, rugby and basketball can be played in as little as 75 lux but need at least 500 lux at international level. Hockey needs a minimum of 200 lux. A handball player can do with as little as 50 lux, measured horizontally. This luminous intensity is normally reached with 200 lux, measured vertically. However, spectators need more light because they are not in the centre of the action and the recomended levels do not include lighting for television broadcasting which needs even higher light levels.

TELEVISION LIGHTING

Television lighting needs more light than the best spectator standards, because the camera cannot adapt as quickly as the human eye to the variations in lighting on a playing surface. For television coverage, lighting must be based on television standards rather than visual ones. These must take into account:

- distance of the action from the camera – zoomed pictures taken from a greater distance require more light
- type of camera and camera lens being used
- speed of play
- quality of the artificial light source

A vertical average luminous intensity of 500 lux to give a horizontal average luminous intensity of 250 lux is considered the minimum for a spectator number up to 4000. In a big hall, e.g. 10 000 spectators, the luminous intensity must be at least 800 lux, measured vertically, in order to guarantee that the TV companies will not face difficulties. Standard definition television lighting requirements (SDTV) to CIE 83 are given in the table:

	Camera distance		
Speed of action	25 m	75 m	150 m
Slow	500	700	1000
Medium	700	1000	1400
Fast	1000	1400	

{FACTSHEET} STRUCTURAL FORM

HOLDING UP THE ROOF (UNLESS IT HAS NO ROOF!)

WHAT'S NEEDED

For a sports venue, the structure must create

- a large open space (room for the playing area; unrestricted view for spectators)
- high space (room for balls in the air; height for tiered seating; space for lights, air conditioning and other services)
- small spaces alongside for offices, changing rooms, spectator facilities, plant and store rooms etc.

The structure has to do two things: hold up the roof and keep out the weather. Ideally, it should also help with keeping the inside warm (cool in summer). The roof has to:

- keep out the weather
- be strong enough to support a heavy snowfall
- provide heat and sound insulation
- slope, so rainwater can drain away
- be securely fixed so that wind cannot lift it off.

HOW IT CAN BE DONE

Some buildings have a framework of columns (vertical), beams (horizontal), arches and lattices that create the space. The framework is then covered with lighter materials that keep out the weather and provide insulation.

Some buildings have solid walls (giving support, weather protection and insulation), which support a framework roof. Houses are usually built like this.

There are a few buildings where the framework and cladding is all in one. Igloos and church domes are examples.

Not surprisingly, architects and engineers have devised many structures that are a mixture of these.

EXAMPLES

POST AND BEAM

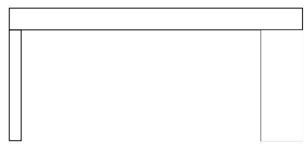
This system uses a row of columns parallel to the court, supporting the beams or trusses which carry the roof.

GOAL POST

This is like a post and beam but with posts only at the two ends, and none between. The length of the roof is spanned by a single girder on each side. A variation is to have arches instead of the beams. (See how the stands are covered at the John Smith's Stadium, Huddersfield, or Ibrox Park, Glasgow.)

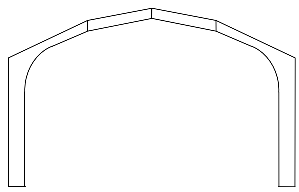
{FACTSHEET} STRUCTURAL FORM

CANTILEVER



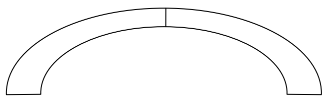
A cantilevered roof is securely supported at one end. The other end almost hangs free: it just needs to be lightly propped at the free end. Bridges are often built like this: one side props up the other where they meet in the middle. Tiered seating and staircases are often cantilevered.

PORTAL FRAME



Portal frames are part column and beam, part arch. The frames have to be linked together, with beams, along the length of the building, so that they stand up. They are often steel, but timber can be used to good aesthetic effect.

ARCH



A series of structural arches are used instead of column and beam or portal frame. The arch can be circular or oval. The arch may have a join at the top.

CONCRETE SHELL

Shells are thin surface structures, curved in one or two directions. It's their shape, rather than the material they're made from that makes them strong. (See Smithfield poultry market, London, or Sydney Opera House.)

SPACE FRAME

Space frames are grids of, usually steel, pieces. They are three-dimensional, normally made up of a series of triangles. They are stable in three dimensions, unlike, for instance, a roof truss. (See Beijing airport, or the Beijing National Aquatics Centre.)

GEODESIC DOMES

These are a variation of a space frame; it is a lattice shell. (See the Eden Project, Cornwall.)

TENSION STRUCTURE

This is a roof that is supported by steel cables hanging from steel masts. Tension structures are very economical in the amount of material used. The roof is often a polyester-type fabric, but concrete and other materials can be used. (See the O2 Arena, London, or the Dynamic Earth Project, Edinburgh.)

AIR SUPPORTED

A plastic membrane, with cable reinforcement, forms the enclosure. It is supported by positive internal pressure provided by fans. (See the baseball park, Tropicana Field, Florida.)

RING BEAM

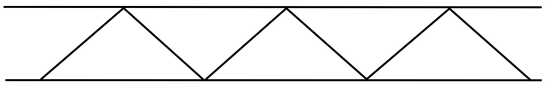
Steel rings are used to make a doughnut-shaped structure that carries the roof covering. From an outer ring, on the top of a wall, supports extend to an inner ring. This system can be used to create an oval shaped building. (See the Camp Nou Stadium, Barcelona.)

SOME DETAILS

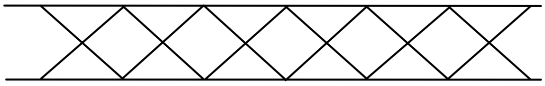
The main structure of a large building (the part that carries the loads) can be made from solid materials such as concrete, steel or timber.

Often, the main structure is steel as it is stronger and lighter than concrete. For medium-sized buildings, timber is a sustainable alternative.

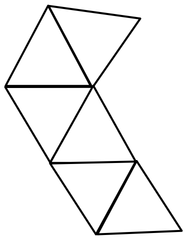
To reduce the amount of material needed, steel and timber are made into lattices:



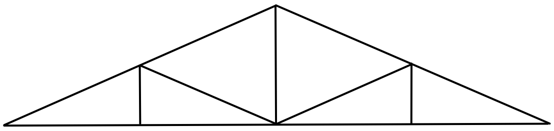
Warren truss



Brown truss



Space frame



Howe girder

{TEST PROCEDURE} BUILDING FOUNDATIONS

GOOD GROUNDING

The purpose of a foundation is to transmit the weight of the building to firm ground. However, this is rarely solid rock; some rocks can support loads really well, others not. The science of this is called *soil mechanics*.

When civil engineers design foundations, they select the shape that will support the building without compressing (squashing) the ground beneath. The foundations have to spread the load to suit the underlying rock.

To find out what shape might be suitable for your local area, you should first see how the different shapes behave on a very squashy material.

THE PROCEDURE

To compare shapes, measure the amount each one compresses the material beneath, for the same load. A wood block will be used to represent the foundation.

A risk assessment must be carried out before you start any practical work. Take care when using scissors and handling masses.

EQUIPMENT

- large box, approximately 500 mm x 500 mm x 400 mm deep
- slabs of foam
- assorted wood blocks
- assorted masses
- long straight edge, such as a metre ruler
- ruler
- large scissors

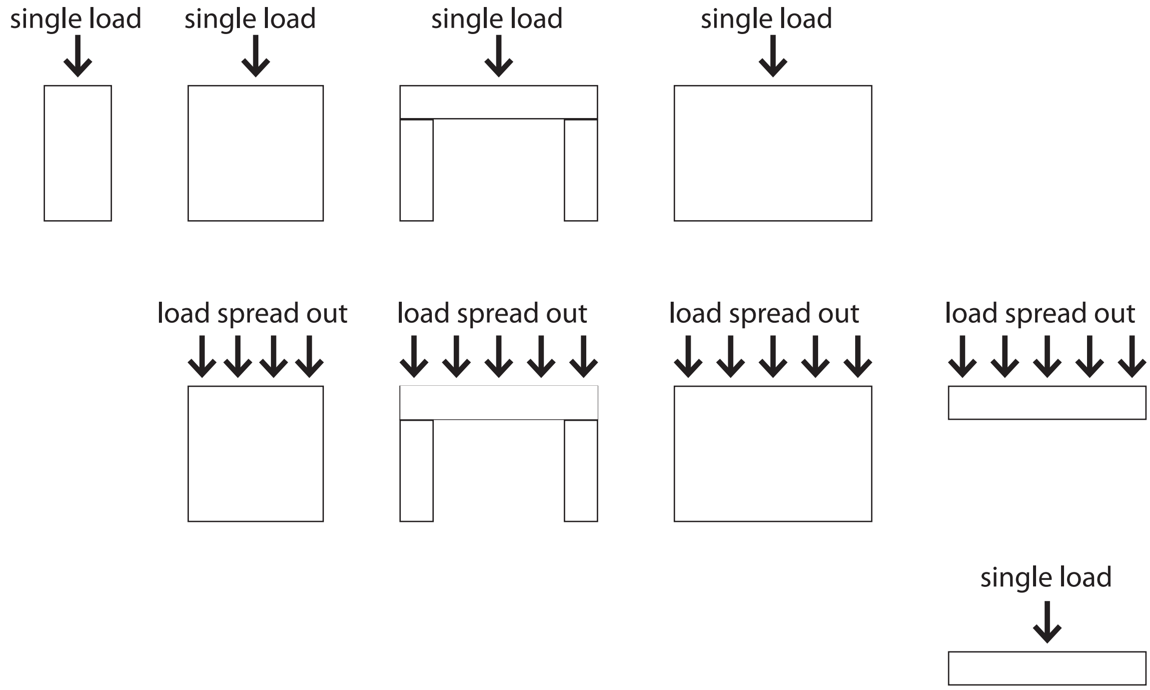
METHOD

1. Draw up a table like the one shown on the next page.
2. Fill the box with foam, in horizontal layers, to within 100 mm of the top.
3. Take a piece of foam 100 mm thick that fits the box. Cut a hole in the centre to take a block of wood that is 100 mm high and approximately 25 mm x 25 mm in cross section.
4. Weigh the wood block.
5. Lay the long straight edge across the top of the box. Measure the distance from the straight edge to the top of the block (this could be zero). Write this in the first row of the table (h_1).

{TEST PROCEDURE} BUILDING FOUNDATIONS

6. Add masses to the centre of the block. Measure the height between the straight-edge and the block. Record this in column 1.
7. Calculate the actual compression depth: subtract or add the distance h_1 (from step 5) to your measurements in columns 1.
8. Repeat step 6 twice more, recording the height in columns 3 and 4.

9. Repeat the procedure with different shaped blocks, keeping them all 100 mm high.
10. Repeat the procedure with the masses evenly spread out on the top of the block.



{TEST PROCEDURE} BUILDING FOUNDATIONS

USING YOUR RESULTS

For each shape of block, calculate and record the mean of your three readings.

For a given total mass, list the foundations in order of decreasing compression depth.

QUESTIONS

1. To make the comparisons fair, you had to use the same height block in all the tests. Why?
2. Why did you need to take into account the mass of the block? How important might this be, when designing foundations for the arena?
3. Do your results show significant differences in compression depth? If so, which foundation appears to be best to support the arena?
4. When the load was spread out across the top of the block(s), how did this affect compression?

EXTENSIONS

5. Try different depths of block.
6. Try removing a lower layer of foam. Place the box on a firm floor to see what effect this has on reducing compression.
7. Instead of foam, try using polystyrene packing pieces, to see how foundations behave on sand or gravel.

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{TEST PROCEDURE} WATER RESISTANCE

SOAKING IT UP

You may think that building materials such as bricks and cement are waterproof. If that were the case, then why do buildings have a damp proof course? This is a layer of waterproof material built into the brickwork 15 to 30 cm above ground level. Its purpose is to stop rising damp – in other words, to prevent the wall soaking up water from the ground. However, some people claim rising damp is a myth – that damp walls are caused by other building faults, not by bricks soaking up water.

QUESTION

1. Apart from the walls and roof, where will water-resistant materials be needed?

Some materials are more absorbent than others. They can absorb (soak up) water or other liquids. A sponge is very absorbent. Building materials are much less absorbent, so more water resistant.

Water soaks into porous materials through tiny holes, called pores. Sponges are very porous, and therefore absorbent, because they are full of holes. Fibrous materials like cloth and wood absorb water through the tiny gaps between the fibres.

So how 'waterproof' are various building materials? And what is suitable to use where in the arena?

THE PROCEDURE

To compare the water resistance of various materials, leave them standing in water for a week or more. Then measure how much (or how little) water they have absorbed. The less water a material absorbs, the more water resistant it is.

The tests will also show whether water affects the appearance of the materials.

A risk assessment must be carried out before you start any practical work.

EQUIPMENT

- Petri dishes and beakers
- samples of building materials (small enough to fit in the dishes or beakers)
- balance weighing to 0.01 g
- paper towels

{TEST PROCEDURE} WATER RESISTANCE

METHOD

Work as a team, with each member testing different materials. You can share the Petri dish and beaker if there is space for several samples.

1. Draw a results table like the one below. Have a double row for each material you are going to test.
2. Label a Petri dish and a beaker with your name.
3. Obtain two pieces of the same material. Record the type of material in the table.
4. Weigh one sample to 0.01 g. Record its mass against 'shallow' in the 'before' column.
5. Stand this 'shallow' sample in about 5 mm of water in the Petri dish.
6. Weigh the other sample, and record its mass against 'submerged' in the 'before' column.
7. Place this 'submerged' sample in the beaker, and cover it with water.
8. Put the dish and beaker where your teacher tells you. Leave them for at least a week.

   Note: All the samples must be left for the same length of time.
9. After a week or so, remove the sample from the Petri dish. Remove excess water from the surface of the sample by dabbing with a paper towel. Take care not to suck out any of the absorbed water.
10. Weigh the sample and record its mass against 'shallow' in the 'after' column.
11. Compare the appearance of the sample with a piece that has not been in water. Record any changes in appearance, such as colour, size, rougher surface or softness.
12. Repeat steps 9 to 11 for the sample in the beaker. Record its mass and changes in appearance in the 'submerged' row.

Material		Mass (g)				Change in appearance
		before	after	increase in mass	%age increase	
	shallow					
	submerged					
	shallow					
	submerged					
	shallow					
	submerged					
	shallow					
	submerged					

{TEST PROCEDURE} WATER RESISTANCE

USING YOUR RESULTS

For each of your group's samples calculate:

- its increase in mass (This is the mass of water it has absorbed.)
- the percentage increase in mass

$$\text{percentage increase} = \frac{\text{mass of water absorbed}}{\text{original mass of dry sample}}$$ (= *mass in the 'before' column*)

List the materials in order of percentage increase – lowest first.

QUESTIONS

1. Does this mean that materials at the top of the list are the most water resistant, or the least?
2. Why do you need to calculate the percentage increase? Why not just compare the increase in mass for various materials?
3. Is there any relationship between water-resistance and change in appearance of your samples?

Various parts of a building, such as walls, roofs and washroom floors, need to be 'waterproof'. However, they are not normally built from the same water-resistant material.

4. What else must you consider when deciding the best material for each purpose?
5. Do your results show that brick is waterproof or not?

{TEST PROCEDURE} FATIGUE TESTING

BENDING BACK AND FORTH

Some objects are designed to be slightly flexible, rather than completely stiff. For instance, when you sit in this chair, the frame bends a bit, making it slightly springy.

The problem is, repeatedly bending a material back and forth causes wear and tear. Scientists call it *fatigue*. After a while it causes a small crack, which gradually spreads. Eventually the material breaks. This is called *fatigue failure*.

It isn't just furniture that suffers in this way. Repeatedly applying and removing a load to any structure causes fatigue.

Some materials can withstand fatigue better than others. You can use the procedure below to compare how well they resist fatigue due to bending.

THE PROCEDURE

To compare fatigue resistance, bend the material back and forth many times. Count the number of bends before the material snaps. The more bends the better its fatigue resistance.

The larger the bending angle, the greater the fatigue. So you must bend all your samples in the same way. To save time, you want the materials to fail sooner rather than later. So make the test severe by bending the test pieces through 90° in each direction.

A risk assessment must be carried out before you start any practical work. Beware of sharp edges where the materials have broken.

You **must not use** materials that are likely to shatter and shoot out sharp fragments when they break, such as Perspex. Wear goggles, just in case something does so unexpectedly.

EQUIPMENT

- 2 wooden blocks
- G-clamp
- cm ruler
- marker pen
- small hacksaw
- mole wrench or pliers
- thin strips of test materials of similar size (approx 15 cm x 1.5 cm, and 0.5 mm thick)

  Samples should be fairly stiff, but flexible.

{TEST PROCEDURE} FATIGUE TESTING

METHOD

1. Draw up a results table like the one below.
2. Choose a test strip. Record the name of the material in the table.
3. Draw a line across the test strip 3 cm from one end. Sandwich this end between the two wooden blocks, so that the line is just showing.
4. Use the G-clamp to clamp the blocks firmly to each other and to the bench (**Fig 1**).
5. Grip the test strip with the mole wrench, pliers (or wear a thick glove). Carefully bend the strip upwards until vertical (**Fig 2**). Make sure it bends as close as possible to the line next to the wood blocks. This is bend number 1.
6. Now bend it back 180° until it is vertically downwards (**Fig 3**). This is bend number 2.

Fig 1

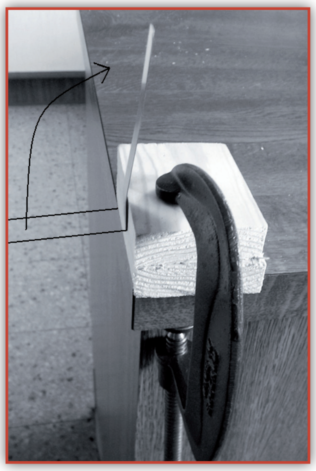

Fig 2

Fig 3

7. Continue bending the strip up and down, counting the bends, until the strip suffers fatigue failure and breaks. Record the number of bends in the table.
8. Release the clamp and dispose of the small broken piece of strip. Beware of the two sharp ends where the strip has broken.
9. Repeat the whole procedure with strips of other materials.

Material						
No. of bends needed to cause failure						

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{TEST PROCEDURE} FATIGUE TESTING

USING YOUR RESULTS

If other people or groups have tested different materials, share your results to get a complete set.

List the materials in order of increasing fatigue resistance.

QUESTIONS

1. Fatigue resistance means standing up to a stress or load repeatedly being applied and removed. Apart from armchairs, suggest where in a sports venue materials must stand up to this type of wear and tear?
2. Which material stands up to this type of wear and tear the best?
3. The most fatigue resistant material is not necessarily the most suitable for the uses you thought of in question 1. What other properties would you need to consider?
4. From your results, do metals seem to be more resistant or less resistant to fatigue than plastics? Or can't you tell? Explain how you decided.
5. Some materials, like the wood in the armchair, won't bend through 180°. Suggest how you could adapt the procedure to test less flexible materials like these.

{TEST PROCEDURE} HARDNESS

HOW HARD?

Hopefully, the arena will be well used, with lots of people in both the player and public areas. So the materials used in its construction must be hard-wearing. They must stand up to wear and tear.

Scientifically, hardness means resistance to indentation (denting), cutting and abrasion (scratching).

- Surfaces must not dent when things knock against them, or are dropped on them.
- Floors must not dent when high heels walk on them.
- Surfaces must resist scratching when things rub against them.

However, some hard materials, such as glass, are brittle. They break easily, so would be unsuitable for many purposes.

QUESTIONS

1. Revolving doors (and sometimes ordinary doors) are made of glass. What do they do to the glass so that it doesn't shatter if someone knocks it or falls against it?
2. What other difficulties with using hard materials can you think of?

THE PROCEDURE

Engineers measure the hardness of a surface using the Brinell Hardness Test. This involves pressing a round object into the surface. The softer the surface, the bigger the indentation (dent) it makes. So a smaller indentation shows that the material is harder.

You can compare hardness using a simple version of the Brinell Test. Drop a weighted ball bearing onto various surfaces, and compare the dents produced. The size of the dent also depends on the force of the impact when the ball hits the surface. So, for a fair test, you must drop the same weight from the same height each time.

A risk assessment must be carried out before you start any practical work. You **must not** test brittle materials which might shatter, such as glass or ceramic tiles. When using the resin, wear disposable gloves and a lab coat or apron. The resin will not wash off.

EQUIPMENT

- steel rod (approx 1 m)
- polyester or epoxy resin*
- disposable plastic knife*
- emery cloth*
- clamp stand
- plasticine or *BluTack*
- hand lens
- large ball bearing
- disposable mixing dish*
- disposable plastic gloves*
- plastic pipe (approx 1 m)
- marker pen
- mm ruler
- sheets of various test materials

** not needed if ball bearing is already attached to steel rod*

{TEST PROCEDURE} HARDNESS

METHOD: ATTACHING THE BALL BEARING

You need to do this at least an hour before you want to start testing hardness. If the ball bearing is already glued to the rod, go straight to *Method: testing hardness*.

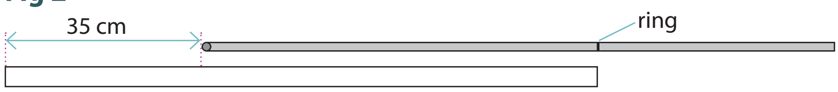
1. Clamp the steel rod vertically.
2. Clean the top end of the rod, and the ball bearing, with emery cloth.
3. Read the instructions for mixing the resin and hardener. The proportions are important.
4. Put on gloves and protective clothing. Mix a small amount of resin in the disposable dish – just enough to glue the ball onto the rod. Mix it with the knife. Spread some on the end of the rod.
5. Carefully press the ball bearing into the resin on the end of the rod. Spread more resin between the ball and the rod. Spread it all the way round, to make a smooth joint with no gaps. (See **Fig 1**.)
6. Hold the ball in position for about five minutes until the resin sets. Leave the assembly for at least an hour to let the resin harden fully.

Fig 1

METHOD: TESTING HARDNESS

1. Draw a results table like the one on the next page.
2. Place the rod alongside the tube, with the ball bearing 35 cm from the end of the tube. Mark a ring around the rod at the other end of the tube (see **Fig 2**).
3. Roll the plasticine or *BluTack* into a smooth, flat block about 1 cm thick. Place it on the clamp stand base.

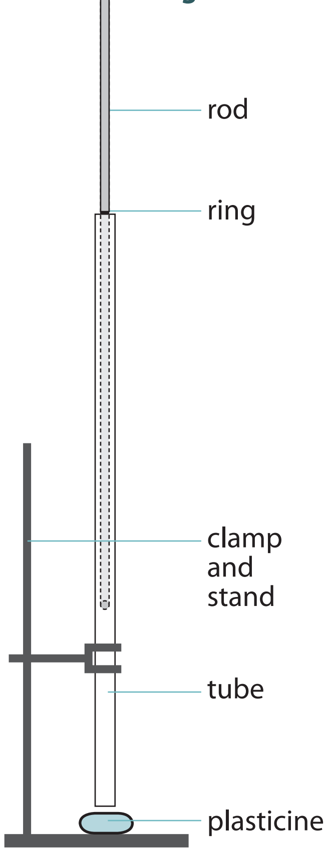
Fig 2



4. Clamp the tube vertically so the bottom is a few millimetres above the plasticine.
5. Lower the rod, ball bearing downwards, into the tube. Hold it just above the ring, so that the ring is level with the top of the tube. (See **Fig 3**.)
6. Let go, so the rod drops onto the plasticine.
7. Remove the rod and raise the tube, so you can see the indentation (dent) in the plasticine (**Fig 4**).
8. Measure the diameter of the indentation to the nearest 0.5 mm. Record this in the '1' column of the table.
9. Repeat steps 4 to 8, placing the tube over a flat part of the plasticine each time. Record the diameters in columns 2 and 3.
10. Repeat steps 4 to 9 with various other materials. If the indentation is small, use the hand lens to help you identify its edges while measuring.

Fig 4

Fig 3



{TEST PROCEDURE} HARDNESS

Material	Diameter of indentation (in mm)			
	1	2	3	Mean
Plasticine (or *BluTack*)				

USING YOUR RESULTS

To get an idea of the hardness of the various materials, compare the size of the indentations.

For each material, calculate the mean (average) diameter of the three indentations.

List the materials in increasing order of hardness – from softest to hardest.

QUESTIONS

1. Why must you stand the sample on a hard surface (such as the clamp stand base) when testing it? (Think what might happen if it stood on a soft or springy surface.)
2. Do you think the thickness of the sample makes any difference? Suggest why or why not.
3. Are 'hardwoods' harder than 'softwoods'? What do these two terms actually mean?

WHICH MATERIALS ARE AFFECTED BY ACID RAIN?

All rain is slightly acidic because of carbon dioxide dissolved in it, forming carbonic acid. This is not what we mean by 'acid rain'. Normal rain does attack some metals and certain types of stone, but only very slowly. It takes hundreds of years.

Acid rain means rain that has sulfur dioxide and/or various nitrogen oxides dissolved in it. These gases are produced when fuels such as coal and oil (including petrol) are burned. When the gases dissolve in rain, they produce sulfuric acid and nitric acid. These are much more corrosive than carbonic acid. Acid rain forms:

- in towns and cities because of vehicle exhaust fumes
- downwind from industrial areas and/or power stations that burn coal or oil.

To last a long time, the outside of the venue needs to resist the corrosive effects of acid rain. So you need to find out which materials are affected. Since you can't wait years for the results, you need to use accelerated testing. That is, you must speed up the tests to get your results more quickly.

THE PROCEDURE

To speed up the tests, use the actual acids instead of acid rain. The acids are dilute, but much less dilute than acid rain. Investigate which materials are attacked by the acids. These are the materials that are likely to be affected by acid rain over the years.

Use small pieces of test materials – preferably powdered, or thin sheets or foils. These will react more quickly than lumps.

A risk assessment must be carried out before you start any practical work. Wear protective clothing as well as goggles. Dilute acids are not particularly dangerous, but take care not to spill them on your clothes. As they dry they become more concentrated and will make holes.

EQUIPMENT

- 3 racks of test tubes per person
- marker pen and/or adhesive labels
- distilled water
- dilute sulfuric acid (H_2SO_4)
- dilute nitric acid (HNO_3)
- full range indicator
- test samples of various materials

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{TEST PROCEDURE} ACID RAIN

PROCEDURE

Work as a team, each person using different materials, to cover a wide range between you.

1. Draw up a results table like the one below (one table per person). Use a whole page, sideways, so the boxes are large enough to write in.
2. Label a rack of test tubes with your name and 'Water'. Add a few drops of universal indicator to each tube. Then half fill them with distilled water.
3. Note the indicator colour and record the pH in the six 'pH' columns of the 'at start' row.
4. Add a different test material to each tube. Use one piece, or half a spatula if powdered. Label each tube with the name of the material. Record the names in table row 2.

   These are your control samples – that is, they are tested with no acid in the water.

   Note: One team member should keep one tube with no material added to the water. Label this tube 'Glass'. The glass tube itself is the test material.
5. Record the appearance of each test material (not the solutions) in the 'at start' row. Give its colour, shiny or dull, and whether it appears to be reacting, eg forming bubbles.
6. Repeat steps 2 to 5 using sulfuric acid instead of water. Make up a third set using nitric acid. Make sure all the racks and tubes are labelled, so you know what is in each tube.
7. Put all three racks of tubes aside – somewhere they can stay for a week.
8. Examine the tubes after one day. For each tube, as before, note the pH (from the indicator colour) and the appearance of the test material. Record your results in the three 'after 1 day' rows.
9. Examine the tubes again after a week, recording your results in the 'after 1 week' rows.

		Test material											
		pH	appearance	pH	appearance	pH	appearance	pH	appearance	pH	appearance	pH	appearance
water	at start												
	after 1 day												
	after 1 week												
dilute H_2SO_4	at start												
	after 1 day												
	after 1 week												
dilute HNO_3	at start												
	after 1 day												
	after 1 week												

{TEST PROCEDURE} ACID RAIN

USING YOUR RESULTS

There are several changes that show that a material reacted.

- It gives off bubbles of gas, and part or all of it dissolves.
- The pH increases. This shows that the acid is being used up, so it must be attacking the test material.
- The test material goes dull, or changes colour. For instance iron goes brown as it rusts.

Collect together the results for all the materials your team tested. Draw up a summary table to show how quickly the materials reacted. Make enough rows for all the materials.

For each material, put a tick in the appropriate column(s). Materials that did not react at all get no ticks.

	Reacted with H_2O			Reacted with dilute H_2SO_4			Reacted with dilute HNO_3		
Material	straight away	after 1 day	after 1 week	straight away	after 1 day	after 1 week	straight away	after 1 day	after 1 week

Use this summary table to divide the test materials into four groups – those that:

(a) react with water, even without any acid in it

(b) do not react with water, but are rapidly attacked by either or both acids (straight away or after only one day)

(c) do not react with water, but are slowly attacked by acids over the course of a week

(d) do not appear to react with dilute acids, even after a week

QUESTIONS

1. Which of these groups (a to d) would be suitable for use on the outside of a venue in an area that gets only a little acid rain?
2. Which of the groups (a to d) would **not** be suitable even in areas with no acid rain?

Assume that the venue is to be built in an area that often gets acid rain.

3. If the outside walls are to be built of stone or brick, which materials appear to be suitable?
4. If the roof is to be clad (covered) with metal, which metals appear to be suitable?

Think about other outside uses, such as street furniture (seats, litter bins, lamp posts etc), flags, advertising banners, posters and so on.

5. Does the choice of material for any of these uses depend on their resistance to acid rain? Explain why or why not.
6. Acid rain can kill trees. From your tests, do you think that this is because it attacks and corrodes the wood? Explain how you decided.

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{TEST PROCEDURE} STIFFNESS

HOLDING UP THE ROOF

Have you ever thought about what holds a roof up? At the edges it's the walls, but what supports the roof in the middle? You can't have any columns or uprights in the middle of a venue

There are various solutions to this problem. One is to use beams supported at each end by the walls. The beams then support the weight of the roof. Beams are also used to support upstairs floors, and the tiered rows of seating for spectators.

These beams must support heavy weights without bending. So they must be stiff, not flexible. Some materials are stiffer than others, so what materials are suitable? You will not be testing roof beams, of course, but the procedure below shows you how to compare the stiffness of various materials. (Stiffness is the opposite of flexibility.)

Long thin shapes bend more easily than shorter, thicker pieces of the same material. So, you need to compare sample 'beams' of similar shape and size.

THE PROCEDURE

You will use the three point bend test. Support the beam at two points (the ends). Add weights at a third point (the middle). Measure how much the beam bends. Compare:

- how much load is needed to produce the same amount of bending
- how far each material bends under the same load

The heavier the load needed, or smaller the bend, the stiffer the material.

A risk assessment must be carried out before you start any practical work. Beware of falling masses, and **do not test** materials that may be dangerous if they break, such as glass.

EQUIPMENT

- end supports (e.g. wooden blocks) about 10 cm high
- mm graph paper on a board
- clamp stand
- sets of stackable masses
- marker pen
- box to catch falling masses
- test sample 'beams' about 50 cm x 3 cm x a few mm thick

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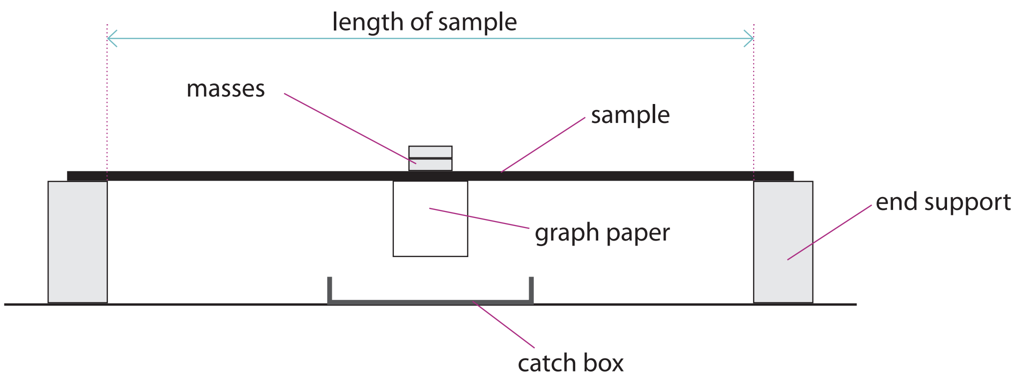
{TEST PROCEDURE} STIFFNESS

METHOD

Work as a team, with each member testing different materials.

1. Draw up results tables like the one below – one for each sample.
2. On the graph paper, draw a vertical scale with marks every 5 mm. Label the scale 0 at the top, and 5, 10, 15 mm etc working downwards to 50 mm.
3. Place the support blocks a measured distance apart. This needs to be about 10 cm shorter than the shortest sample. Record the distance in the top line of the table.

   Note: All the team should place their blocks the same distance apart. (If not, you will be comparing beams of different lengths.)
4. Measure the beam's width and thickness in millimetres. Record these in the table.
5. Lay the beam across the supports with no masses on it. Measure and mark the beam exactly half way between the supports.
6. Clamp the graph paper close behind the centre of the beam, but not quite touching it. Adjust the clamp so that the 0 mark is level with the bottom of the beam.



7. Put the box under the centre of the sample to catch falling masses.
8. Add masses at the centre mark until the bottom of the beam is deflected (pushed down) at least 1 mm, but no more then 5 mm.
9. Note the position of the point on the beam on the graph paper scale. Record the load (mass added) and deflection in the table.
10. Add more masses to produce a few more millimetres deflection. Record the total load and new deflection.
11. Continue adding masses and measuring deflections until one of the following happens:
    * the load mass reaches 3000 g (3 kg) [Note: After adding ten x 100 g, you can replace these with a 1 kg mass, so you can continue adding in steps.]
    * the deflection exceeds 50 mm
    * the beam breaks or kinks, so that it cannot return to its original shape.
12. Remove the masses. Check whether the sample returns to its original position (0 on the scale). If not, the load has caused a permanent bend. Note this deflection and record it at the bottom of the table.

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{TEST PROCEDURE} STIFFNESS

Beam material:								
Length of beam (= distance between supports) = cm								
Width = mm								
Thickness = mm								
Mass of load (g)								
Deflection (mm)								
Did the beam return to its original position when you removed the masses? Yes / No								
If not, how big was the permanent deflection? mm								

USING YOUR RESULTS

For each material your team tested, plot a graph of deflection (0-50 mm on y-axis) against mass of load (0-3000 on x-axis). Plot them on the same axes in a different colour for each. Add a colour key to show which line is for which material.

From your graphs:

- Compare the deflections produced by a given load, such as 500 g or 1000 g. List the beams in order of increasing deflection.
- Compare the loads needed to produce a given deflection, such as 10 mm or 20 mm. List the beams in order of increasing load.

{TEST PROCEDURE} TESTING LIGHT PIPES

THE PROCEDURE

The amount of light produced by different light sources can be compared by monitoring light levels in different parts of an area in which all other conditions are kept constant. The effect of using different surfaces (e.g. matt versus gloss, or different colours) may also be tested. Full scale testing is very expensive, so initial tests can be carried out using modelling techniques. A light testing rig can be made using a light-proof box which blocks out all unwanted light, together with some light sensors.

A risk assessment must be carried out before you start any practical work. No mains voltage or parts that can heat up should be used inside or in contact with the box. Take care when using tools to cut the box.

EQUIPMENT

- materials, tools and a work area to construct a light-proof box
  - rigid cardboard (e.g. strong cardboard box), MDF, hardboard, block board, wooden dowelling
  - metre rule, steel ruler, pencil
  - scissors, handsaw, Stanley knife, drill and tool for cutting circular holes
  - PVA (or other suitable) adhesive
  - range of paints (e.g. matt, gloss, black, white, various colours)
- equipment to monitor and compare light intensities such as light probes or photovoltaic (PV) cells and meters, data collection box and/or PC with appropriate software, cables and connectors
- bright low voltage light source (e.g. LED array, halogen lamp)
- clamp stand(s) (or other means to hold the lamp in a fixed position)
- dark room (or other room that can be blacked out)
- thin card, aluminium foil or mirror film, black adhesive tape

METHOD: CONSTRUCTING THE LIGHTING TEST RIG

1: DETERMINE THE DIMENSIONS OF YOUR LIGHT PROOF BOX

Length, width and height: This should be scaled to have a 'floor' the same shape as the real area which is to be illuminated. The height of the box should be made proportional to these dimensions, so that the light sources under test are at the same scaled height that they will be in the real building. If the effect of changing height is to be tested, you should incorporate this into your design at this stage.

The box should be large enough to accommodate the maximum number and dimensions of light sources that you want to test while allowing you, the box and associated equipment to fit comfortably into your work area. If possible, adapt a suitable existing box.

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{TEST PROCEDURE} TESTING LIGHT PIPES

2. DECIDE ON THE STRUCTURE OF THE 'ROOF' (LID)

Choose material which will be rigid enough to support the light sources. To be able to test light pipes, you will need to be able to cut circular holes to hold cardboard tubes.

Decide if the roof panel is to rest on top of the box or to drop in onto supports. For example, wooden dowelling could be glued to the inside edges of the box and used to support a drop-in lid.

Note: the final design of the box will depend on the tests that you wish to conduct. For example, different roof panels may be used for differing diameters, cross-sectional shapes or patterns of light pipes. Alternatively, new larger holes could be cut for each subsequent test or light pipes could be made with collars that allow them to be placed into wider holes.

3. MANUFACTURE YOUR BOX

Ensure that any joins are light proof, for example by using black tape. The surfaces of the interior of the box should be uniform, for example paint them with matt black paint. As part of your investigation, you may wish to test the effect of changing this surface finish. Optional: the front panel and or base can be made removable. This makes it easier to manipulate the light sensors and décor.

4. MODIFY THE BASE

Modify the base to allow light sensors to be fixed into position. You will need to decide which light intensity measuring devices you are going to use.

Permanent array

Depending on the number of sensors that you have available, decide how you will distribute them across the floor of the box to measure a representative sample of light intensities.

Decide on a method of fixing – the sensors must be in exactly the same position each time for comparative measurements to be made. You may need to support your box in a raised position and make holes in the base.

Small, cheap PV cells are available, which could be fixed in an array in the base of the box.

Movable sensors

If you only have a single light sensor or a small number, you will need to be able to move them around to sample your floor area. They will need to be in exactly the same positions for comparative measurements to be made, so you will need to make fixing points to ensure this.

5. FIX CABLING

Fix in place any necessary cabling to attach your light sensors to meters or data collection devices. You may need to drill holes and seal gaps.

6. CONNECT AND TEST

Connect up your light measuring equipment and test its operation.

Do you get reliable measurements? Are measurements repeatable? Do you get the same readings if you swap sensors around?

Are the measurements sensitive enough? Can you get a wide range of readings by varying the light intensity from low to high?

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{TEST PROCEDURE} TESTING LIGHT PIPES

METHOD: TESTING LIGHT PIPES

1. Fix into position a bright external light source so that it illuminates the 'roof' area of the box. This represents the effect of constant, unchanging sunlight. If you are unable to set up your rig in a permanent position, you must ensure that you can set it up in exactly the same way each time. Check this by having standardised test conditions which should give the same light readings each time.

   To test light pipes you should not illuminate directly from above. Set up your lamp above and to one side of your box at an angle of about 45°. It may take some trial and error to establish the best angle of illumination and distance of the lamp to use for your tests.
2. Manufacture model light pipes by gluing mirror foil or aluminium foil shiny side out to thin card. Avoid wrinkles and creases. The card can then be rolled with the foil on the inside and taped into tubes of varying diameters and lengths for testing.
3. Different types of light pipe may then be introduced into roof panels for the box in different numbers and patterns, ensuring gaps are sealed so that light can enter the box only through the light pipes. (See Construction of the light test rig above.) When the light pipes are in place, switch on your light source and darken the room so that no extraneous light can enter the box. For each set up obtain light intensity measurements for each sensor position, checking your results for reliability.
4. Data should be recorded in suitable tables and presented in graphical form to make analysis easier.

FOR CONSIDERATION

1. As data accumulate, you may wish to refine the design of your light testing rig, for example by altering the position of the light sensors.
2. If you wish to compare different cross sectional shapes, such as square or triangular, with the circular tubes, you should take into account that the orientation of the pipe will have an effect on the light transmitted.
3. If time is short, or you are unsure which factors to investigate, single light pipes can be constructed and tested before determining the effect of using arrays in different patterns.
4. You need to relate your findings to the design of your sports venue. Why use light pipes? What factors affect the optimum number of pipes to use? Do all parts of the arena need to be illuminated in the same way?

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{TEST PROCEDURE} THE HEATING EFFECT OF LAMPS

THE PROCEDURE

Spotlights used to light arenas may generate large quantities of heat. The rate at which metal sheeting absorbs energy can be compared by observing the rate of changes in the colour of thermocolour film. This can be used to compare the heating effect of different types of spotlight.

A risk assessment must be carried out before you start any practical work.

EQUIPMENT

- thermocolour film with self adhesive backing (or use transparent adhesive tape)
- variety of different types and wattages of spotlight
- stopclock or stopwatch
- metre rule or tape measure
- spirit in glass thermometer
- thin metal sheet (does not need to be large), for example matt black aluminum
- insulating materials (such as corrugated cardboard, mineral fibre or polystyrene)
- clamp and stand

METHOD

You will need to conduct trials to find the best standardised distance to use between the lamp and the metal sheet. You may also wish to trial different metals and surfaces. The sheet should then be kept constant for all trials, so that you can make fair comparisons between different types of sheets. Room temperature should also remain more or less constant for fair comparisons to be made.

1. Attach a piece of thermocolour film (enough to see a clear colour change) to the back of a piece of metal sheet.
2. Switch on a spotlight and allow it to heat up for a minute or two.
3. Record room temperature. If room temperature changes you may continue, but you will need to decide how this has affected your results.
4. Clamp the metal sheet at the same height as your lamp. Make sure the spotlight points directly at the metal sheet to give maximum illumination.
5. Place the metal sheet near to the heat source, with the thermocolour film on the other side and immediately start a stopwatch. Record how long it takes for the thermocolour film to completely change colour.
6. If necessary, repeat until you have found a suitable distance where the colour change takes between about 1 and 3 minutes. Make a note of this distance and use it for the rest of your measurements.
7. For each trial, record in a table the type of spotlight, its rating (wattage, W), room temperature and the time for the colour change.
8. Allow the sheet to return to room temperature and repeat.
9. Check the results for reliability and repeat again for any inconsistent results.
10. Reject any obviously anomalous values, calculate the mean times and plot a bar chart to compare the different spotlights.

{TEST PROCEDURE} COMPARING BOUNCE

WHAT MAKES A GOOD FLOOR MATERIAL?

You can test how well a ball bounces on various floor surfaces. Scientifically, the measurement is called the *Coefficient of restitution*. It depends on:

- what the floor is made of
- the type of ball (since some are designed to be more bouncy than others).

THE PROCEDURE

To compare different floor materials, drop a ball from a known height and measure how high it bounces back – the higher the better. You can use whatever type of ball you like, so long as you use the same ball with each type of floor.

A risk assessment must be carried out before you start any practical work.

EQUIPMENT

- bouncy ball, e.g. tennis ball
- tape measure (or 2 x metre rules)
- clamp stand(s)
- various floor surfaces
- video camera (optional) with tripod

METHOD

Work in a pair. The diagram on the next page should help you.

1. Draw up a table like the one on the next page.
2. Choose a floor surface to use. Record the type of floor in the table.
3. Clamp a tape measure (or two metre rules) vertically, with 0 at floor level.
4. Hold the ball in front of the tape. Carefully drop the ball and watch how it bounces. You will probably need some practice to make sure the ball bounces back up in front of the tape, rather than bouncing away sideways.
5. When you're sure you can do this, hold the ball still, so your partner can read the height at the bottom of the ball. Their eye must be level with the bottom of the ball.
6. Record this drop height, h_1, in the table.
7. When you drop the ball, your partner needs to watch how high it bounces – again, reading the bottom of the ball, with their eye at that level.
8. Record this bounce height, h_2.
9. Drop the ball three more times from the same height, recording the bounce heights.
10. Calculate the mean value of h_2 (the average of the four heights). Record it in the table.

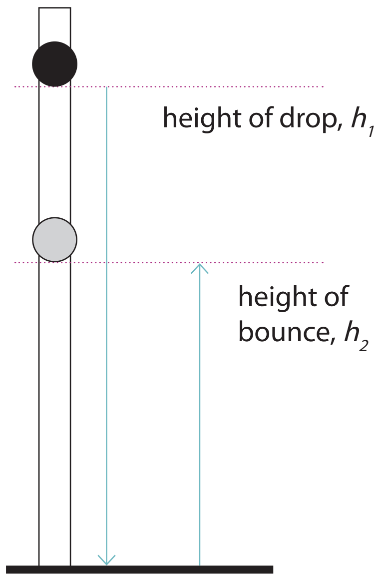
{TEST PROCEDURE} COMPARING BOUNCE

Floor type							
Drop height, h_1 (cm)							
Bounce height, h_2 (cm)	1						
	2						
	3						
	4						
Mean value of h_2 (cm)							
Coefficient of restitution, *c*	$\sqrt{\frac{h_2}{h_1}}$						

USING YOUR RESULTS

Use the method below to calculate the *coefficient of restitution* for each type of floor.

$$\textit{Coefficient of restitution, } c = \sqrt{\frac{\textit{bounce height}}{\textit{drop height}}} = \sqrt{\frac{h_2}{h_1}}$$



So:

- use the drop height h_1 and the mean value of h_2 to calculate $\frac{h_2}{h_1}$
- use a calculator to find the square root of $\frac{h_2}{h_1}$
- ... this is *c*, the coefficient of restitution; record your value in the table.

Note: The value of *c* is always between 0 and 1. If your value is greater than 1, your calculation has gone wrong! Try again.

QUESTIONS

1. Why can *c* never be more than 1?
2. Do soft surfaces have a higher or lower coefficient of restitution than hard surfaces?
3. The higher the value of *c*, the better the ball bounces on that surface. In your tests, on which floor type did the ball bounce best?

{TEST PROCEDURE} FRICTION

GETTING A GOOD GRIP

Friction is the force that resists one object sliding over another. Slippery surfaces like ice produce very little friction. Because there's very little resistance, things slide over them very easily. Sports players need surfaces with high friction, so their feet stay where they put them, and not slide away.

Friction depends on both surfaces – in this case:

- the playing area surface
- the player's footwear (sole material and tread pattern).

THE PROCEDURE

To compare floor materials, measure the force needed to drag a trainer across different types of floor surface. The larger the force needed, the higher the friction.

A risk assessment must be carried out before you start any practical work.

EQUIPMENT

- sports trainer shoe
- various newton meters (or tension forcemeters)
- 1 kg mass
- various types of floor surface

METHOD

Use the same trainer with each floor surface.

Two people may use a pair of trainers, but do not use different types.

1. Draw up a table like the one shown on the next page.
2. Choose a floor surface to use. Record the type of floor in the table. Give some detail, such as 'bare wood planks' or 'polished wood blocks' rather than just 'wood'.
3. Place the trainer on the floor. To avoid the trainer tipping up instead of being pulled along, place a 1 kg mass inside at the toe end.
4. Hook a newtonmeter onto the back of the trainer.
5. Pull the meter horizontally – gently at first, increasing the force until it drags the trainer across the surface. Note: If the trainer moves with only a little force, use a meter with a lower range. If it doesn't move before the meter reads maximum force, use a stronger meter.
6. In table column 1, record the force when the trainer just starts to move.
7. Repeat step 5 twice more, recording the force in columns 2 and 3.
8. Repeat steps 2 to 6 with other floor surfaces around the school. You can also test materials in the laboratory, such as ceramic floor tiles or samples of carpet and floor coverings.

{TEST PROCEDURE} FRICTION

Type of floor	Force needed (N)			
	1	2	3	Mean

USING YOUR RESULTS

For each type of floor, calculate and record the mean of your three readings.

List the floors in order of increasing friction.

QUESTIONS

1. To make the comparisons fair, you had to use the same trainer in all the tests. Suggest why the tread patterns of different trainers might affect the friction.
2. Do your results show significant differences in floor surface friction.
3. If there is no great difference in friction, what other properties of the floor should you consider when deciding what material to choose?

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{TEST PROCEDURE} COLOUR IN SPORTS HALLS

THE PROCEDURE

To see the effect of different coloured backgrounds, use a series of coloured cards. Each card has a set of letters: the middle letter, at 6 metres distance, corresponds to 6/6 vision (called 20/20 in the US, where they use feet and inches), which is about normal eyesight. View the cards in different types of light.

Observe usual safety practices for working outdoors. A risk assessment must be carried out by your teacher before you start work.

EQUIPMENT

- tape measure
- target cards – print the final page of this document onto A4 white card and coloured cards including red, yellow, blue and green (make sure each card is printed at the same size).

METHOD

1. Using the instructions for the target, print out versions onto card.
2. Measure out a distance of 6 metres between the person holding the targets and the observer. Take it in turns to be the observer.
3. Use the black and white target first. When you are the observer, make an honest assessment of the smallest letter you can see clearly. (If you normally wear distance spectacles, keep them on.)
4. Hint: To help you decide what you can see, the student holding the card can hold it on its side or upside down – you have to say which way round it is.
5. Repeat this assessment for each coloured card.
6. Record the results in a table like the one on the next page.
7. Repeat the procedure under different lighting conditions and types of light.

For each type of lighting, which colour background gave the best results?

	outdoors			floodlighting			fluorescent		
observer	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
target colour									
white									
red									
yellow									
etc.									

EXTENSIONS

What happens if the surface of the background is rough, rather than smooth card?

{TEST PROCEDURE} TESTING A WIND TURBINE

THE PROCEDURE

Wind energy can be used to carry out useful work, for example to generate electricity or lift water. Wind turbines can be tested by measuring their capacity to do work for a given wind speed. In a modelling situation, a constant air flow can be provided by an electric fan. Wind turbines may be compared by finding the maximum load that they can lift or by finding their efficiency. The efficiency of wind turbines can be calculated if the energy from the moving air is compared to the energy used to do useful work. To do this, it is necessary to find the speed and power of the wind and the useful energy output of the wind turbines.

A risk assessment must be carried out before you start. Tie back hair, ties and scarves, so that you do not get entangled with the fan. Take care with mains electricity.

EQUIPMENT

- model wind turbine (e.g. from *Factsheet: Making a wind turbine*)
- electric fan
- clamp and stand
- thin string or thread and adhesive tape
- slotted masses and hanger (10 x 10 g)
- box of crumpled paper
- stopwatch
- measuring tape or metre rule
- an anemometer or clamp and stand, table tennis ball attached to light nylon thread and a protractor

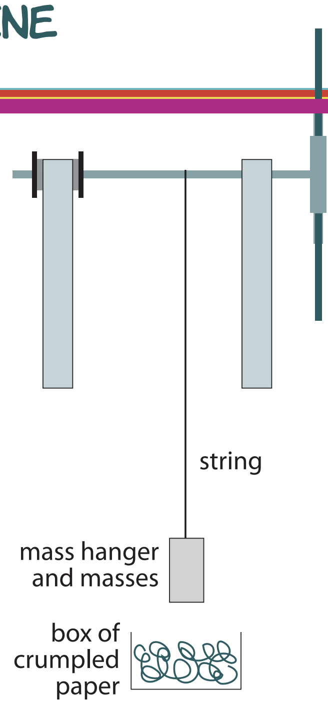
METHOD: MAXIMUM LOAD

Find the maximum load that can be raised by the wind turbine.

1. Set up the wind turbine, using a clamp stand. Position it so that it will be able to lift a load about 1 m vertically. Make sure you have space to move the fan backwards and forwards in front of the wind turbine.
2. Using trial and error, find out where to put the fan so that the wind turbine's blades spin fast, but do not shake or vibrate. Start with the fan some distance away from the wind turbine and gradually bring it closer (switch off the fan before moving it). You may need to support the base of the clamp stand to hold the wind turbine steady. If the speed of the electric fan is adjustable, you may wish to experiment with this too.

{TEST PROCEDURE} TESTING A WIND TURBINE

3. Tape the string firmly to the shaft so it won't slip when the mass is lifted, but do not attach the mass yet. The string should be long enough to reach the floor. You can either attach the string to the centre of the shaft between the uprights or to the end farthest from the blades outside the uprights. If you fix it at the end of the shaft, use a washer to stop the string from coming off the free end as it winds on.
4. Record the final position of the wind turbine and fan so that you can keep conditions the same for every trial.
5. The box of crumpled paper should be placed on the floor and positioned to catch the mass if it falls.
6. Attach the mass hanger to the string. It should be free to move up through about 1 m.
7. Add masses 10 g at a time until the wind turbine cannot lift the mass to the bench. Record the maximum mass that could be lifted.



METHOD: ENERGY OUTPUT OF THE WIND TURBINE

Find the time for a known mass to be raised through a given distance.

1. Mark out convenient upper and lower limits and measure the distance (metres, m) between them. You could clamp a metre rule parallel to the string.
2. Try out different masses. Choose a total mass that can be pulled up steadily through the marked out vertical distance, in a time you can measure using a stopwatch.
3. With the fan switched off, wind up the string to raise your chosen mass to the lower position. Hold the shaft to prevent it from moving and turn on the fan. When ready, let go of the shaft and start the stopwatch. Record the time (seconds) for the mass to be raised to the upper mark. Stop the shaft from rotating before the mass reaches the top and switch off the fan. Let the shaft rotate slowly to let the mass descend into the box.
4. Obtain two more results. Calculate the mean value. If one of your values seems different from the other two, do not include it in your calculation. Record your results in your table. If you do not get at least two consistent values you may need to try again.
5. Find the energy output of the wind turbine:
   * calculate the force used to raise the mass from:

     force (newtons,N) = mass (kg) x gravity (10 m s^{-2})
   * calculate the energy output of the wind turbine from:

     useful energy output (joules, J) = force (newtons, N) x distance moved (metres, m)
6. Record your results in a table:

mass raised by wind turbine / kg	time taken to lift load / s	force used to raise load / N	distance load is raised / m	energy output of wind turbine / J

DEVELOP A NEW SPORTS VENUE

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{TEST PROCEDURE} TESTING A WIND TURBINE

METHOD: POWER OF THE WIND AND ENERGY INPUT

The power of a wind turbine depends on:

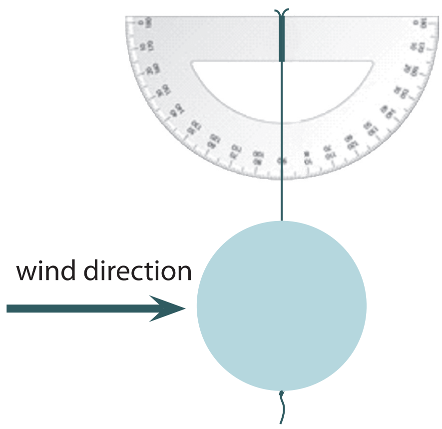
- the cube of the speed of the wind (speed x speed x speed = speed^3)
- the area swept by the blades
- the density of the air.

To be able to calculate the energy input you need to find the speed of the wind from the fan.

1. MEASURE THE AIR SPEED

If you have an anemometer, use it to measure the wind speed exactly at the position used for the centre of the blades of your wind turbine. You will need to position the anemometer as you move the wind turbine out of the way.

If you do not have an anemometer, set up and use a protractor as follows:



- Tie the thread around the centre of the protractor (as shown in the diagram).
- Out of any breeze, clamp the protractor so that the thread hangs down the 90° line. The ball must be able to swing freely.
- Place the ball immediately in front of the centre of the wind turbine blades and remove the wind turbine.
- Start the electric fan. It should be in the same position as when it was used to raise the mass. Measure the angle of the nylon thread when the ball is blown in the wind and record your result in your table.
- Confirm your value by switching off the fan and repeating the measurement of the angle twice.
- Calculate the mean angle. If one of your values seems different from the other two, do not include it in your calculation. If you do not get at least two consistent values you may need to try again.
- Obtain an estimate of wind speed using the table:

Angle (°)	90	80	70	60	50	40	30	20
Speed (metres per second, ms^{-1})	0	3.6	5.3	6.7	8.1	9.5	11.4	14.4

You can plot a calibration graph (speed against angle) to find intermediate values.

2. FIND THE AREA SWEPT BY THE BLADES.

This is the biggest circle that the blades cover as they rotate. The number and shape of the blades does not matter.

- measure the radius (in metres, m) of the area swept by finding the maximum distance from the centre of the shaft to the tip of a blade.
- calculate the area swept using area (m^2) = π radius^2 (m^2) [π = 3.14]

{TEST PROCEDURE} TESTING A WIND TURBINE

3. CALCULATE THE POWER

Assume that the density of air is 1.2 kg m^{-3} (kilograms per cubic metre) and calculate the power of the wind that is available to the wind turbine:

power (watts, W) = ½ x area swept by blades (m^2) x density of air (kg m^{-3}) x wind speed^3 (m^3 s^{-3})

4. CALCULATE THE ENERGY

Using the time taken to lift the load, calculate the energy input from the wind using:

energy input (J) = power (W) x time (s)

Record the values from your calculations in a table:

radius of area swept by blades / m	area swept by blades / m^2	estimated wind speed / m s^{-1}	power of wind turbine / W	time taken to lift load / s	energy input / J

5. CALCULATE THE EFFICIENCY

You can now calculate the efficiency of your wind turbine using:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%$$

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{TEST PROCEDURE} HEAT ABSORPTION OF METAL SHEETS

SOLAR HEATING

The first solar heating panels were just central heating radiators put in the sunshine. Water was pumped through them and warmed up. These panels are usually made of painted steel. However, they absorb only a small amount of the available energy. How could you make the heat transfer into the water more efficient?

THE PROCEDURE

The rate at which metal sheeting absorbs energy can be compared using a standardised heating method and observing the rate of changes in the colour of thermocolour film. A risk assessment must be carried out before you start any practical work.

EQUIPMENT

- thermocolour film with self adhesive backing (or use transparent adhesive tape)
- 100 W spotlight or 150 W lamp (or similar, to act as a source of radiant heat)
- stopclock or stopwatch
- metre rule or tape measure
- spirit-in-glass thermometer
- standard size metal sheets (not too large)
- insulating materials (such as corrugated cardboard, mineral fibre or polystyrene)
- shallow box with transparent lid for the metal sheets
- clamp and stand

METHOD

Conduct trials to find the best distance between the heat source and metal sheets. Keep room temperature constant.

1. Attach a piece of thermocolour film (enough to see a clear colour change) to the back of a piece of metal sheet.
2. Switch on your heat source and allow it to heat up for a minute or two.
3. Record room temperature. If room temperature changes you may continue, but you will need to decide how this has affected your results.
4. Clamp the metal sheet at the same height as your heat source.
5. Place the metal sheet near to the heat source, with the thermocolour film on the other side and immediately start a stopwatch. Record how long it takes for the thermocolour film to completely change colour.
6. If necessary, repeat until you have found a suitable distance where the colour change takes between about 1 and 3 minutes. Make a note of this distance and use it for the rest of your measurements.
7. The ability of different metal sheets to absorb energy can be compared, for example by altering the metal used, the thickness of the sheets, the surface finish and the effect of insulating the side away from the heat source (cut a small hole to make the thermocolour film visible). For each trial, record in a table the type of sheet, room temperature and the time for the colour change.
8. Allow the sheets to return to room temperature and repeat.
9. Check the results for reliability and repeat again for any sheets that show inconsistent results.
10. Reject any obviously anomalous values, calculate the mean times and plot a bar chart to compare the different metal sheets.

{TEST PROCEDURE} HEAT INSULATION

KEEPING HEAT IN OR OUT

Modern buildings have insulated walls and roofs, to limit the amount of heat flowing in and out. The insulation serves two purposes.

- In winter, when it's cold outside, insulation keeps heat in, reducing heating costs.
- In summer, when sunshine warms the walls and roof, insulation keeps heat out, helping to keep the inside cooler.

Scientists and engineers talk about thermal conductivity and thermal transmittance (or U-value). These measure how easily heat passes through a material. The higher the value, the more heat passes per minute. So insulation materials need **low** values.

Measuring these values is rather complicated. However, the simpler procedure below will help you compare how well various materials keep heat in or out.

THE PROCEDURE

Heat flows from a warm area to a cooler one. It makes no difference whether the heat is flowing in or out. To compare different insulation materials, pack them around some hot water and measure how quickly the water cools – the more slowly, the better the insulation.

The hotter something is, the faster it loses heat, so for fair comparisons you need to start measuring from the **same temperature** in each test.

A risk assessment must be carried out before you start any practical work.

EQUIPMENT

- boiling tube
- beaker
- cork or bung (large enough to support bottom of boiling tube)
- clamp stand
- various insulation materials
- 50 or 100 cm^3 measuring cylinder
- long 110 °C thermometer
- stopclock (or watch showing seconds)

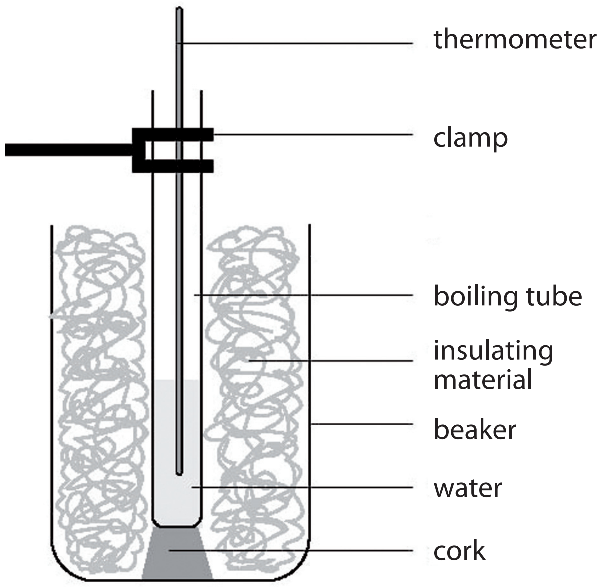
  (long 110 °C thermometer and stopclock: or digital thermometer and datalogger)
- source of hot water (at about 75 °C)

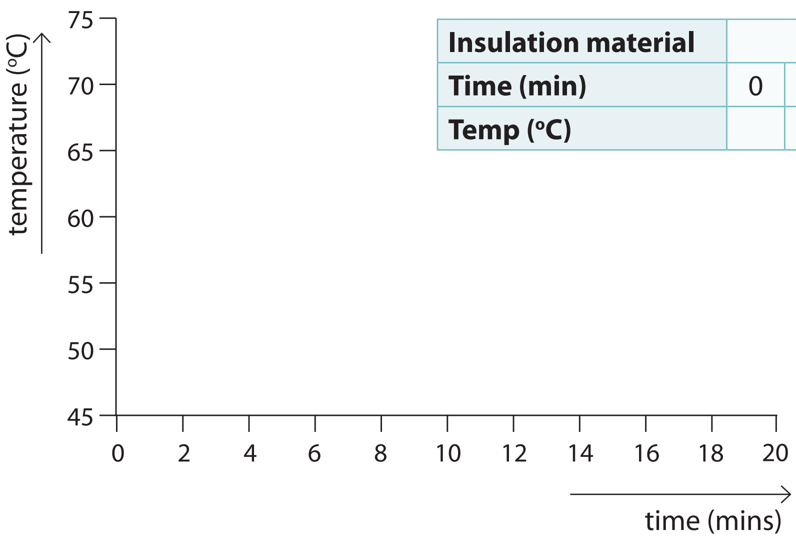
{TEST PROCEDURE} HEAT ABSORPTION OF METAL SHEETS

METHOD

Take particular care with hot water.

1. Draw a results table and graph axes like the ones below. Write the insulation material in the table.
2. Set up the apparatus as shown in the diagram.
   - If the insulation is in sheets, wrap it around the boiling tube. Use enough layers to make the wrapped tube fit snugly in the beaker.
   - For loose insulation, clamp the tube in place. Then pack the material between the tube and beaker. Tap the beaker gently to help the insulation settle.
3. Measure 40 cm³ of hot water (at about 75 °C) into the tube. Put the thermometer in the water and stir gently.
4. Record the water temperature in the table and immediately start the stopclock.
5. Every two minutes, stir gently and record the temperature.
6. To save time later, plot these temperatures on the graph as you go along – but keep an eye on the time, so you don't miss a reading.
7. Continue for 20 minutes, or until the temperature falls below 50 °C, whichever happens first.
8. Draw a smooth best-fit curve through your set of points. (See example on next page.)
9. Repeat the procedure with at least two other insulation materials. Use a new results table for each.
10. Use different colours to plot each new set of results on the graph.





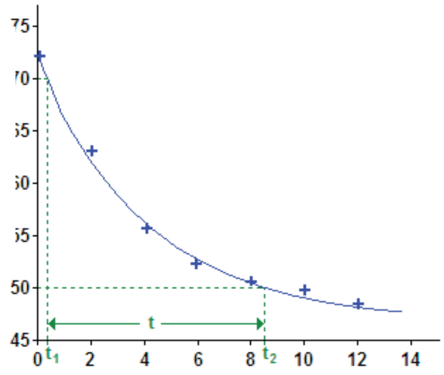
Insulation material											
Time (min)	0	2	4	6	8	10	12	14	16	18	20
Temp (°C)											

{TEST PROCEDURE} HEAT ABSORPTION OF METAL SHEETS

USING YOUR RESULTS

You need to compare how well the materials keep the water hot. To do this you must work out how long it takes the water to cool by the same amount – for example, from 70 °C to 50 °C.

Note: For fair comparison, you must use the same temperatures for each material.



QUESTIONS

1. Why would using different temperatures (such as 60 °C to 40 °C) not be a fair comparison?

   From your graph curve for one material:
   - Read off the time, t_1, when the temperature was 70 °C.
   - Read off t_2, when the temperature was 50 °C.
   - Calculate the time it took to cool, t .

     $t = t_2 - t_1$ min
   - Repeat for each material.

2. Which material is the most effective insulation material? How did you decide?
3. The most effective material is not necessarily the **best** insulation for your venue. What other factors should you consider in order to decide what is the best to use?

{TEST PROCEDURE} USING PVs TO HEAT WATER

PHOTOVOLTAIC CELLS

Thermal solar panels used to heat water directly are heavy, bulky and require complex plumbing and insulation to transfer the heat to a hot water tank. Could PVs (photovoltaic cells) be used to supply electricity to an immersion heater instead?

THE PROCEDURE

PVs can be used to generate electricity for a water heater, and the rate of rise in temperature of a known volume of water can be measured. Measurement of the voltage and current obtained can also be used to calculate the expected rise in temperature.

You must carry out a risk assessment before you start any practical work.

EQUIPMENT

For measuring the heating effect of the electricity produced by a PV panel:

- PV panel, clamp and stand
- temperature probe and meter or thermometer
- multimeters or voltmeter and ammeter (if available, datalogging equipment could be used to continuously monitor changes)
- low voltage immersion heater or 25 cm of thin nichrome wire
- lagged beaker
- magnetic stirrer or low heat capacity stirrer such as a glass rod
- switch, cables and connectors
- direct sunlight or lamp
- ruler or tape measure
- balance
- timer

For comparison with solar thermal heating (heating water directly with sunlight):

- 1.5 dm^3 plastic bottle (empty mineral water or soft drink bottle)
- temperature probe and meter or thermometer
- clamp and stand
- sleeve from an old black sweatshirt
- thin wooden dowel to use as a stirrer

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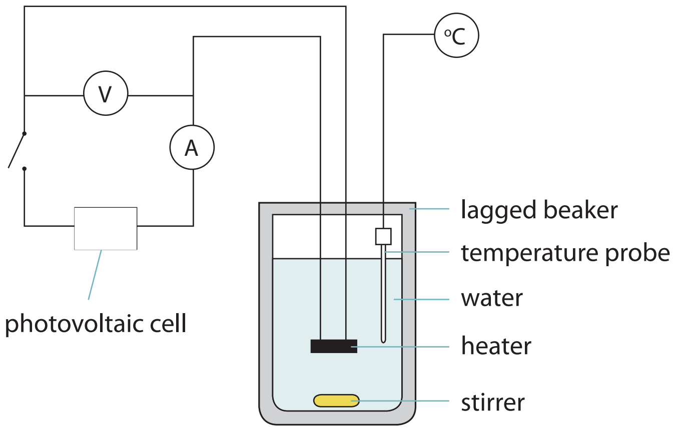
{TEST PROCEDURE} USING PVS TO HEAT WATER

METHOD

1. Measure your PV panel and record the area.
2. Set up the photovoltaic panel so that it is directly facing the sun (or other light source).
3. Connect an ammeter (A) in series and a voltmeter (V) in parallel to the PV panel, as shown in the diagram.
4. Connect up the heater with the switch open. If a suitable low voltage immersion heater is not available, make a heating coil by winding about 25 cm of thin nichrome wire around a pencil. Leave ends long enough to attach to crocodile clips. Slide the coil off the pencil before use.
5. Weigh or tare the beaker and three quarters fill with water. Weigh again and record the mass of the water.



6. Assemble the rest of the apparatus, making sure that the PV panel is receiving maximum illumination.

Optional: To make a comparison with the direct heating effect of the sunlight, also set up the apparatus described on the next page.

7. Start the magnetic stirrer. If a manual stirrer is used, stir the water in the beaker well before each temperature reading is taken.
8. Record the starting temperature (°C) of the water.
9. Switch on the circuit and timer at the same time. Check that the voltmeter and ammeter are measuring the voltage and current.
10. Record the voltage, current and temperature at one minute intervals. Plot the temperature readings against time on a graph as you take them. If the temperature rises slowly or steadily, you can increase the time interval between readings.
11. Continue for 30 minutes, or until a 10 °C temperature rise has been obtained.
12. Find the average rate of heating of the water by your PV panel. Express this as the temperature rise per gram (or cm^3) of water per minute. Convert this to the temperature rise per kilogram (or dm^3) of water per hour.
13. If a typical shower uses 100 kg or dm^3 of water which has been raised from 20 °C (cold water tank) to 42 °C (shower temperature), how long would it take your PV panel to heat the water for one shower?
14. If you were able to use 20 m^2 of PV panel of the same specification as your test panel, how long would it take to heat the water for one shower?

{TEST PROCEDURE} USING PVS TO HEAT WATER

USING YOUR RESULTS

Using an electrical immersion heater to heat water is 100% efficient. As long as the heater is totally immersed, all of the electrical energy will be converted to heat in the water. Using your measurements of voltage and current, calculate the rate at which electrical energy is being converted to heat. If it takes 4.186 joules to raise one gram of water by 1 °C (thermal heat capacity of water), how do your measurements of the average rate of change in temperature of the water compare to the expected value? Can you explain any discrepancy?

OPTIONAL METHOD

To compare the efficiency of the PV panel with direct solar heating of water:

1. Draw around a plastic bottle to obtain a profile on graph paper. Use this to estimate the area of sunlight radiation that will strike the bottle.
2. Wrap a plastic bottle in the sleeve of an old black sweatshirt, cutting away the excess (or use another method to blacken the bottle).
3. Fill the bottle with water.
4. Clamp or support it at an angle, to receive maximum illumination, alongside the PV panel.
5. Insert a piece of wooden dowel as a stirrer.
6. Insert a temperature probe or thermometer (you may need a clamp to support it).
7. To make this apparatus more efficient, support the bottle in an open box lined with aluminium foil behind the bottle.
8. Begin temperature readings at the same time as those for the PV panel, stirring before each reading.
9. Plot your results in a graph as you go along, so you can decide how frequently you need to take readings.
10. Compare the efficiency of the direct heating method with that of heating water using electricity from a PV panel. You will need to compare the temperature rise per unit mass of water per unit time with the equivalent data for the PV panel.

USING YOUR RESULTS

Do you think that PV panels should be used for water heating?

Use your results to explain your conclusions.

{TEST PROCEDURE} BACTERIA IN WATER

THE PROCEDURE

Although bacteria are invisible to the naked eye, in the right conditions (warmth and food) they grow rapidly to form visible colonies. This can be used to compare the bacterial content of water samples that have been treated in different ways. If a known volume of sample is used and it is assumed that each original bacterium gives rise to a separate colony, the bacterial concentration of the original sample can be calculated.

A risk assessment must be carried out before you start any work. Do not open bacterial cultures.

EQUIPMENT

- water samples in sterile containers
- self adhesive labels, wax pencil or spirit marker pen
- sterile Petri dishes
- McCartney bottles or capped test tubes containing molten sterile nutrient agar, stored in a water bath
- discard pot containing disinfectant
- incubator at 25-30 °C
- Bunsen burner
- transparent adhesive tape to tape the lid on Petri dishes
- sterile Pasteur pipettes

A separate test plate will be needed for each water sample being tested.

METHOD

1. Arrange a clean workspace so you have, within reach:
    - Bunsen burner with a yellow flame
    - water samples

    for each sample

    - sterile Pasteur pipette
    - Petri dish

    (don't take any lids off yet).
2. Label the bottom of the plates. Write your name, date and the name of the water sample. Keep the labelling clear but small and near the edge so that you will be able to see what grows on the plate.
3. Open the air hole of the Bunsen burner to obtain a blue flame.
4. Using aseptic technique, loosen and then remove the cap of a water sample bottle. Immediately pass the neck of the bottle briefly through the hot part of the Bunsen flame. Using a sterile pipette, withdraw a little of the water sample.
5. Lift the lid of the Petri dish and carefully drip one drop of sample onto the centre of the agar plate. Immediately replace the lid of the Petri dish and the cap of the water bottle.
6. Put the pipette into the waste beaker of disinfectant.

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{TEST PROCEDURE} BACTERIA IN WATER

7. Close the air hole of the Bunsen burner to give a yellow flame.
8. Collect a container of molten sterile nutrient agar from the water bath. Allow it to cool until it is 'hand hot', that is quite warm to the touch but can be held. Do not allow it too cool to much, or it will set.
9. Using aseptic technique, loosen the lid of a container of sterile nutrient agar. Using aseptic technique, loosen and then remove the cap and immediately pass the neck of the container briefly through the hot part of the Bunsen flame.
10. Lift the lid of the Petri dish and carefully pour the nutrient agar into the dish. Immediately replace the lid of the dish and put the empty agar container to one side.
11. Gently swirl the Petri dish so that the agar spreads across the whole of the bottom of the dish and mixes with the water sample. Allow to cool, so that the agar becomes solid.
12. Now repeat steps 3-11 to inoculate the plates with other water samples.
13. Once the plates have set, use two short pieces of tape to tape the lids onto the Petri dishes, making sure a complete seal is avoided. Check with your teacher if you are not sure how to do this.
14. Turn the Petri dishes over (this prevents condensation dripping onto the agar surface during incubation).
15. Incubate the plates at 25 to 30 °C for 48 hours. Your teacher or technician will probably fix (stop) the growth of the cultures before giving the plates back to you.
16. Without opening your plates, examine them and record:
    - the water sample used
    - the number of colonies
    - the appearance of the colonies (shape, colour, texture).
17. After examination, dispose of your agar plates safely. Your teacher will tell you how.
18. To calculate the concentration of the bacteria in the original water samples, you will need to know the volume of one drop of water from a Pasteur pipette.
    - Find the weight of one drop of water by weighing a known number of water drops. For example, drip 100 drops of water from a Pasteur pipette into a suitable container which you have tared or weighed on an accurate balance.
    - Assuming 1.00 cm^3 of water weighs 1.00 g and each visible colony came from one original bacterium, calculate the number of bacteria per cm^3 of water for each water sample tested. Record your results in a table.

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{TEACHER NOTES} INTRODUCTION

Designing and developing any building is a complex and time-consuming process. It involves many stages and even more people!

To make this Challenge more manageable, it has been divided into four separate challenges:

The Site | The Structure | The Court | The Environment

Students should work in project teams of 4-6 people. All teams must complete an Initial Challenge, then choose one of the challenges above to focus on.

Even organised in this way, the workload may be daunting. Teams will need to think about what work to do within their area of focus – enough to meet the challenge brief, but no more than can be realistically completed in the time available. Smart thinking and careful planning is required.

As well as researching and developing ideas, the Challenge is an opportunity for students to **explore**, **experiment** and **innovate**.

The *Challenge Brief* does not state precisely what work the project teams should carry out. Rather, it provides some points for teams to think about. The teams do not need to consider all of these; neither do the points cover all considerations. Flexibility and ownership are key. Teams are encouraged to choose what they want to do, using the brief for guidance, but also incorporating their own thoughts and ideas.

For each challenge, a selection of relevant test procedures and factsheets are available. Project teams may use some, or all, of the procedures, but may decide on alternative tests to carry out. The factsheets provide some information and guidance, but teams may wish to undertake further research of their own.

Note: Where possible, encourage students to look at the resources online. Only print sheets that are strictly necessary.

PRESENTATION

The *Challenge Brief* provides some guidance for the students on what they need to do and how to present their work. There is no set way of presenting the design proposals.

When developing presentations, students should be reminded about features of good communication:

- using a mixture of verbal, written and visual communication
- presenting mathematical and scientific information, rather than emotive arguments
- using mathematic and scientific language and terminology correctly
- being able to talk knowledgeably about every aspect of the Challenge

HEALTH AND SAFETY

By the nature of these challenges, students will want to carry out unorthodox procedures when building and testing models, materials and ideas. It is important for teachers to talk through proposals with the students and ensure that risks are avoided/minimised. Where test procedures pose a significant hazard, this is noted in the Teacher Notes. Notwithstanding this, teachers must make a risk assessment for their particular circumstances and student group.

{TEACHER NOTES} CURRICULUM LINKS (ENGLAND)

PROGRAMME OF STUDY FOR KEY STAGE 3

DESIGN AND TECHNOLOGY

KEY CONCEPTS

Designing and making

a. Understanding that designing and making has aesthetic, environmental, technical, economic, ethical and social dimensions and impacts on the world.

b. Applying knowledge of materials and production processes to design products and produce practical solutions that are relevant and fit for purpose.

Creativity

a. Making links between principles of good design, existing solutions and technological knowledge to develop innovative products and processes.

c. Exploring and experimenting with ideas, materials, technologies and techniques.

Critical evaluation

a. Analysing existing products and solutions to inform designing and making.

b. Evaluating the needs of users and the context in which products are used to inform designing and making.

KEY PROCESSES

a. Generate, develop, model and communicate ideas in a range of ways, using appropriate strategies.

b. Respond creatively to briefs, developing their own proposals and producing specifications for products.

c. Apply their knowledge and understanding of a range of materials, ingredients and technologies to design and make their products.

d. Use their understanding of others' designing to inform their own.

e. Plan and organise activities and then shape, form, mix, assemble and finish materials, components or ingredients.

h. Reflect critically when evaluating and modifying their ideas and proposals to improve products throughout their development and manufacture.

RANGE AND CONTENT

b. Users' needs and the problems arising from them.

c. The criteria used to judge the quality of products, including fitness for purpose, the extent to which they meet a clear need and whether resources have been used appropriately.

e. Aesthetic, technical, constructional and relevant wider issues that may influence designing, selection of materials, making and product development.

j. How to use materials, smart materials, technology and aesthetic qualities to design and make products

SCIENCE

KEY CONCEPTS

Scientific thinking

b. Critically analysing and evaluating evidence from observations and experiments.

KEY PROCESSES

Practical and enquiry skills

a. Use a range of scientific methods and techniques to develop and test ideas and explanations.

b. Assess risk and work safely in the laboratory, field and workplace.

c. Plan and carry out practical and investigative activities, both individually and in groups.

Critical understanding of evidence

a. Obtain, record and analyse data from a wide range of primary and secondary sources, including ICT sources, and use their findings to provide evidence for scientific explanations.

b. Evaluate scientific evidence and working methods.

Communication

a. Use appropriate methods, including ICT, to communicate scientific information and contribute to presentations and discussions about scientific issues.

RANGE AND CONTENT

Energy, electricity and forces

b. Forces are interactions between objects and can affect their shape and motion.

KEY STAGE 3 AREAS OF LEARNING

TECHNOLOGY AND DESIGN

LEARN ABOUT

- Design
- Communication
- Manufacturing

LEARNING OUTCOMES

- Demonstrate practical skills in the safe use of a range of tools, machines and equipment.
- Research and manage information effectively to investigate design issues, using Mathematics and ICT where appropriate.
- Show deeper understanding by thinking critically and flexibly, solving problems and making informed decisions, using Mathematics and ICT where appropriate.
- Demonstrate creativity and initiative when developing ideas and following them through.
- Work effectively with others.
- Demonstrate self management by working systematically, persisting with tasks, evaluating and improving own performance.
- Communicate effectively in oral, visual (including graphic), written, mathematical and ICT formats showing clear awareness of audience and purpose.

SCIENCE

LEARN ABOUT

Chemical and material behaviour

- Structures, properties, uses of materials

Forces and energy

- Forces and energy transfer

LEARNING OUTCOMES

- Demonstrate a range of practical skills in undertaking experiments, including the safe use of scientific equipment and appropriate mathematical calculations.
- Use investigative skills to explore scientific issues, solve problems and make informed decisions.
- Research and manage information effectively, using Mathematics and ICT where appropriate.
- Show deeper scientific understanding by thinking critically and flexibly, solving problems and making informed decisions, using Mathematics and ICT where appropriate.
- Demonstrate creativity and initiative when developing ideas and following them through.
- Work effectively with others.
- Demonstrate self management by working systematically, persisting with tasks, evaluating and improving own performance.
- Communicate effectively in oral, visual, written, mathematical and ICT formats, showing clear awareness of audience and purpose.

{TEACHER NOTES} CURRICULUM LINKS (SCOTLAND)

CURRICULUM FOR EXCELLENCE

TECHNOLOGIES

Technological developments in society

- When exploring technologies in the world around me, I can use what I learn to help to design or improve my ideas or products. TCH 2-01a
- From my studies of technologies in the world around me, I can begin to understand the relationship between key scientific principles and technological developments. TCH 3-01a
- Craft, design, engineering and graphics contexts for developing technological skills and knowledge
- By using problem-solving strategies and showing creativity in a design challenge, I can plan, develop, organise and evaluate the production of items which meet needs at home or in the world of work. TCH 3-14a
- Having explored graphical techniques and their application, I can select, organise and represent information and ideas graphically. TCH 3-15a

SCIENCES

- **Forces**, electricity and waves: Forces
- **Materials**: Properties and uses of substances

PROGRAMME OF STUDY FOR KEY STAGE 3

DESIGN AND TECHNOLOGY

- Use given design briefs, and where appropriate, develop their own to clarify their ideas for products.
- Identify and use appropriate sources of information to help generate and develop their ideas for products.
- Be creative and innovative in their thinking when generating ideas for their products.
- Identify and apply knowledge and understanding about technological, sustainability and health and safety issues to develop ideas for products that are achievable and practical.
- Develop a specification for their product.
- Explore, develop and communicate design ideas in a range of ways, including annotation, drawings and CAD.
- Evaluate, refine and modify their design ideas.
- Evaluate their final design ideas against their initial specification.
- Learn about the properties and characteristics of materials and apply this knowledge and understanding when designing and making products.
- Undertake materials testing, to determine suitability for intended use.
- Combine and process materials in order to create enhanced properties and desired aesthetic characteristics.

SCIENCE

SKILLS

- Opportunities to carry out different types of enquiry (planning, developing, reflecting).

RANGE

- How things work

{TEACHER NOTES} BUILDING FOUNDATIONS

This procedure investigates how differently-shaped foundations behave on a soft material. Together with data from geological maps, students can decide on a suitable configuration for the foundations. If another group is working on the Structure Challenge, students may wish to find out what sort of structure their colleagues are proposing, and factor this into their decision.

This is a simplified version of one of many tests carried out during a geotechnical survey, prior to designing foundations. It shows students a little about the bearing capacity of the ground below the topsoil.

EQUIPMENT

- large box, approximately 500 mm x 500 mm x 400 mm deep. The box should be as rigid as possible. The dimensions are not critical and any reasonably sized box can be used.
- slabs of foam. A soft foam will be easier for students to cut with scissors and will only require smaller masses to compress.
- assorted wood blocks, a set at 100 mm high, then other dimensions selected by the students. Lower density softwood is ideal.
- assorted masses
- long straight edge, such as a metre rule
- ruler
- large scissors
- polystyrene packing pieces or similar, for the extension activity

HEALTH AND SAFETY

A risk assessment is required before any practical work. The only significant hazard is in the use of scissors to cut the foam. The masses pose a small hazard during handling but are used within the confines of a foam filled box.

METHOD

Students may work in pairs or groups. The limiting factor may be the amount of foam available. There are many variants that students might try and their conclusions can be combined. Although numerical data is collected, this is rather more a qualitative exercise.

It is suggested that pre-testing is carried out to determine the range of masses likely to be needed. It is very dependent on the softness of the foam being used.

Students may need help deciding if they should add or subtract the value of h, when completing the results table. The purpose of this is to use the actual amount of compression, whether or not the block is slightly above or below the rim of the box.

Students should select the size and shape of their subsequent sets of test blocks.

EXTENSIONS

If the materials are available, students could extend their investigation by using sand, gravel and a sand/gravel mix in a large bucket. They should use the sand and/or gravel dry and then experiment again, adding water to different degrees of saturation. The percentage water content can be assessed by calculating the ratio *mass of water : total mass of sample*. Students may need help to calculate this ratio.

[mass (container + wet sample) – mass (container + dry sample)] ÷ [mass (container + wet sample) – mass container]

The moisture content of certain types of soil is an important factor in its bearing capacity. Depending on the soil, a certain amount of water can increase bearing capacity; too much and it will reduce.

{TEACHER NOTES} WATER RESISTANCE

Students may use this procedure to investigate how 'waterproof' various materials are, and how soaking with water effects their appearance, and possibly their function.

Apart from exterior walls and roofs, areas that need water resistance include floors in entrance areas; washrooms, toilets and showers; and restaurant/kitchen work surfaces.

The test is necessarily simplistic, since the conditions under which building materials must be waterproof depend on circumstances. However, it provides comparisons of water absorbance, and thus water-resistance, when exposed on one side and when submerged.

Weighed samples are left in contact with water for a week or more. Water uptake is measured and calculated as a percentage to allow for differences in sample size. Students also note any changes in appearance.

EQUIPMENT

- Petri dishes and beakers (Quantities depend on the number and size of samples.)
- fragments of building materials (small enough to fit in the dishes or beakers)
- balance weighing to 0.01 g
- paper towels

A selection of materials with varying absorbencies should be used, to give a range of results.

HEALTH AND SAFETY

A risk assessment is required before any practical work, though neither the procedure nor materials present any significant hazards.

METHOD

Students should work in teams, with each member setting up the tests with different materials, which should be labelled with the names of the materials and the student. All the samples should be left for the same period. The Petri dishes should be checked daily and topped up as necessary to maintain the water level at about 5mm.

Before reweighing the samples, excess surface water should be removed by briefly dabbing with a paper towel, trying to avoid sucking out the absorbed water.

From their results, students arrange the materials in order of water-resistance. To select suitable materials for the arena, they must also consider what other factors govern the choice for each particular purpose.

EXTENSIONS

Students could extend their investigation by:

- extending water-contact times, weighing at intervals to see whether water absorption continues to increase over time
- testing samples in different orientations – for example, wood laid sideways in shallow water and stood up on its end grain
- testing the effectiveness of 'waterproofing' treatments
- trying to find out how and why water travels upwards (against gravity) into porous materials – and whether there is a limit to how high it will rise.

{TEACHER NOTES} FATIGUE TESTING

The required properties of construction materials, such as rigidity or tensile strength, are usually fairly obvious – though students may not know the technical terms. However, students are unlikely to think of testing fatigue resistance. Yet it is a vital consideration for many applications, and should be brought to their attention.

With suitable prompting, students should be able to think of items that work well for months or years, but then suddenly fail. Light bulbs 'blow', railway lines crack, and flexible plastic parts snap. The cause is often fatigue failure due to stress cycling.

Repeatedly applying and removing a stress causes changes in shape, and thus movement within the structure of the material. Microscopic imperfections, such as dislocations in the crystal structure, multiply. A tiny crack forms and gradually propagates, eventually leading to catastrophic failure.

Causes of stress cycling in the context of the sports venue include:

- people coming and going
- running and jumping on floor support joists
- varying tension in lift cables as passengers step in and out
- flexing of lift cables over pulleys and/or around winding drums
- expansion and contraction of building materials due to fluctuations in solar radiation and ambient temperature
- expansion and contraction in heating and hot water systems.

Some materials are more prone to fatigue than others. Students may use this procedure to compare fatigue resistance of various firm but flexible materials. Since it involves flexing the test sample through 180°, the procedure is unsuitable for more rigid materials.

EQUIPMENT

- 2 wooden blocks (approx 10 x 10 x 3 cm)
- G-clamp (suitable size to clamp both blocks to the bench top)
- cm ruler
- marker pen
- small hacksaw
- mole wrench or pliers (to grip sample strips)
- strips of test materials of similar size (approx 150 mm x 15mm x 0.5 mm) such as metal sheets, firm but flexible plastics (eg ice cream boxes), cardboard

Samples must be able to flex through 90° in each direction when bent by hand. Materials that are likely to splinter must not be used.

HEALTH AND SAFETY

A risk assessment is required before any practical work. Hazards include sharp edges on metal strips or broken samples, and flying splinters from inappropriately chosen plastics.

{TEACHER NOTES} FATIGUE TESTING

METHOD

Depending on availability of equipment, students could work individually, in small groups or in teams, distributing the test materials between them and pooling their results.

The procedure is straightforward, but requires care to ensure that test strips bend along the line and against the wooden blocks. It must be clamped tightly enough to prevent the strip being pulled sideways during bending.

Provided the rest of the strip remains straight, so subject to minimal fatigue, it can be re-used – by another student, or to check results as below.

EXTENSIONS

Students could extend their investigation by:

- repeating the tests with the same samples, to check for consistency and reliability of the results
- comparing results of several individuals or groups for the same material. Pre-existing microscopic flaws in the structure may cause premature failure and anomalous results.
- repeating tests on the same material, bending it more quickly and more slowly, to see whether the frequency of stress cycling affects the results
- testing wires (single and multi-strand of similar diameters – with insulation removed) [relevant to applications such as portable appliance flexes or lift cables].

Question 5 asks students to suggest how to adapt the procedure to test less flexible materials, which cannot be bent through 180°. They are likely to suggest bending through a smaller angle, but should appreciate that this will cause much less fatigue per bend, so will take many more bends, and thus much more time, to reach failure point.

Examples of such stress-cycling tests can be seen in Ikea stores, where items such as the chair are subjected to repeated flexing by an oscillating piston. However, the force is limited so that the test demonstrates durability, rather than fatigue failure.

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{TEACHER NOTES} HARDNESS

Students may use this simplified version of the Brinell Test to compare the hardness of materials. The procedure is semi-quantitative, but does not give recognised hardness values.

The test involves dropping a weighted ball bearing onto the test samples from a set height. The impact force is thus reasonably constant. The diameter of the resulting indentation gives a comparative measure of the hardness of the surface.

The weight is provided by a length of steel rod. Students could attach the ball bearing to the rod themselves, or be provided with a ready-made assembly.

EQUIPMENT

- steel rod (approx 1 m x 12 mm diameter)*
- large ball bearing (approx 15 mm diameter)*
- plastic pipe (20-25 mm diameter, 2-3 cm shorter than the steel rod)*

* *Dimensions are not critical, but must be compatible. That is mass of rod is 0.8 - 1 kg (to provide suitable impact force); ball bearing is a few mm wider than the rod; pipe is a few mm wider than the ball bearing, and a few cm shorter than the rod.*

- polyester or epoxy resin (eg *Chemical Metal* or *Araldite Rapid*)
- small disposable mixing container (eg aluminium foil dish or paper plate)*
- disposable plastic knife*
- disposable plastic gloves*
- emery cloth (approx 5x3 cm)*
- clamp stand*

* *not required by students if pre-assembled*

- marker pen
- mm ruler
- hand lens
- plasticine, *BluTack* or similar (about 10 cm3)
- labelled flat sheets of various test materials, such as softwoods (eg pine, spruce) and hardwoods (eg ash, balsa, beech, iroko, oak); common metals (eg aluminium, brass, copper, lead, mild steel, stainless steel); kitchen worktop; plastic floor tiles and/or cushionfloor

Each sample should have sufficient surface area for several dents.

Thin metal sheets should be avoided, since they are more easily distorted than thicker sheets or blocks, so liable to give misleading results.

HEALTH AND SAFETY

A risk assessment is required before any practical work. Brittle materials, such as glass or ceramic tiles, which might shatter, must **not** be used.

When using resin, protective clothing and disposable gloves should be worn. It is important to follow the maker's instructions, use the correct proportions of resin and hardener, and allow sufficient setting time.

METHOD

Students may work individually, or in small groups sharing the testing. Given sufficient sets of equipment, they could work in teams, dividing the test samples between them.

{TEACHER NOTES} HARDNESS

The specified drop height (35 cm) may be adjusted if it proves unsuitable for the weight of the ball-and-rod assembly and the sample materials used. However, to obtain comparable results, the same height must be used for all samples.

More precise measurements of the indentations can be obtained using vernier callipers. However, this is probably inappropriate for students at this level.

EXTENSIONS

Students could extend their investigation by:

- testing the same material as a foil, thin sheet and thicker sheet, to check whether thickness affects the results
- adapting the procedure to test whether wood is harder along or across the grain – and thus whether orientation of the grain is important in wooden surfaces (apart from visual aesthetics).

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{TEACHER NOTES} ACID RAIN

If the sports venue is to be long-lasting, the exterior and any items such as street furniture, must resist acid rain.

Students may use this procedure to investigate the effects of acid rain on a range of materials. Since these effects are long-term, they must use accelerated testing to obtain results within a reasonable time scale. They therefore submerge materials for a week in 0.1 mol dm^{-3} sulfuric and nitric acids, and also in distilled water as a control.

Students need to appreciate that these dilute acid solutions are mainly water, with only a little acid dissolved in it – but still significantly more than in acid rain, so they affect the test samples more quickly.

Note: To avoid reinforcing the common misconception that 'strong' = 'concentrated' and 'weak' = 'dilute', it is best to avoid 'strong/weak' in relation to acids at this level.

The tests involve observing the reactions between the acids and test samples. This includes noting any change in pH. Therefore, students need to be familiar with interpreting the colours of Full Range Indicator, using the manufacturer's colour chart. Be careful not to confuse 'Full Range' (pH 1-14) with 'Universal Indicator' (pH 4-11)

EQUIPMENT

- 3 racks of test tubes per person
- marker pen and/or adhesive labels
- distilled water squeeze bottle
- approx 0.1 mol dm^{-3} sulfuric acid (low hazard)
- approx 0.1 mol dm^{-3} nitric acid (low hazard)
- full range indicator (pH 1-14)
- powdered or small pieces of test materials, such as various types of 'stone' (e.g. limestone, marble, granite, sandstone, concrete, brick, mortar); metals (e.g. mild steel, stainless steel, copper, lead, magnesium, aluminium, zinc); ceramics (e.g. glazed and unglazed tiles, earthenware, terracotta flower pot); rubber and plastics; hardwoods and softwoods; painted surfaces; fabrics, paper and card (used for flags, banners, posters etc). Notes: Include reactive metals to show that some are unsuitable as building materials. A test tube itself acts as the test piece for glass.

HEALTH AND SAFETY

A risk assessment is required before any practical work. The 0.1 mol dm^{-3} acids are well below the concentrations ASE classify as hazardous or corrosive. However, protective clothing should still be worn, since any splashes on clothing will concentrate as they dry out.

METHOD

Students should work in teams, with each person testing a different set of materials. They should be encouraged to suggest test materials for themselves, with prompting to widen the range, which should include some thought likely to be unsuitable, to show why.

A large number of test tubes will be needed – three per test sample. Also somewhere to put them aside for a week.

When considering results, reinforce that if the acid is made less acidic by a material, that must also mean the material has reacted and dissolved – and therefore would gradually dissolve away in acid rain.

EXTENSIONS

Students could extend their investigation by:

- adding a fourth rack of test tubes containing carbonic acid, and comparing results with the water, sulfuric and nitric acids. They can make carbonic acid simply by using a straw to gently breathe out through distilled water – a few lungs-full will suffice.
- using a mixture of sulfuric and nitric acids, to check whether this is any more corrosive than the individual acids. This is a better simulation of acid rain, which normally contains both, but it will not show whether the problem is caused by one or both acids.

  Note: The above require more extensive, or additional, results tables. To avoid taking even more test tubes out of circulation for a week, some students could do these instead of the main tests.
- leaving unreacted test materials for a longer period, to see whether extended immersion has any effect. Explain that attack by acid rain is a very slow process, so it is possible that there is a reaction, but it is too slow to notice after only one week.
- investigating the formation of acid rain by dissolving sulfur dioxide and nitrogen dioxide in distilled water containing indicator. (Teacher demonstration, performed in a fume cupboard.)

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{TEACHER NOTES} STIFFNESS

This procedure is set in the context of beams used to support the roof, upper floors and tiered seating in the arena. Students compare the stiffness of long, thin samples of materials by measuring the deflection of these 'beams' under increasing load in the 3-point test.

Unless identical sized samples are available, the results will be only semi-quantitative. The terms stress, strain and elasticity are avoided, and students are not expected to calculate the Young Modulus.

EQUIPMENT

- end supports (eg wooden blocks) about 10 cm high
- mm graph paper mounted on a flat board
- clamp stand (to support graph board)
- 3 kg of stackable masses (eg 10 x 100 g on hangers + 2 x 1 kg)
- marker pen
- box to catch falling masses (eg lid from box of duplicating paper)
- test 'beams' of various materials, about 50 cm x 3 cm x a few mm thick

Note: For meaningful comparisons, beam dimensions, particularly thickness, should be as similar as possible. The CDT department may be able to provide suitable offcuts.

HEALTH AND SAFETY

A risk assessment is required before any practical work. Do not use materials, such as glass, that may be dangerous if shattered.

METHOD

Students may work in teams, dividing the samples between them. Members of a team should all use support blocks the same distance apart, giving the same effective beam length to eliminate one variable.

They use a graph paper scale as a wide ruler to measure deflection of the beam at its lowest point. They compare their results graphically, since beam A may show a larger deflection than B, but may have required a much greater load to cause this.

They are intended to deduce relative stiffness by comparing loads required to produce a given deflection, and deflections produced by a given load.

They also check whether being under load has caused any permanent distortion of the beam.

Comparative stiffness is also indicated by the gradient of the graph lines. The shallower the gradient, the less the beam deforms under load, so the stiffer it is. A steeper gradient indicates greater flexibility.

The graphs should initially be straight lines, as the materials obey Hooke's Law (distortion proportional to load). They may deviate at higher loads if the stress exceeds the material's elastic limit.

Note: These results show the comparative stiffness of the beams, not stiffness of the materials. To compare materials, the beams must have the same dimensions, or their actual dimensions must be used in a complex formula to give a standard value, such as the Young Modulus.

EXTENSIONS

Students could extend their investigation by testing different sized samples of the same material, to see how stiffness depends on the length, width and thickness of the beam. (Length is easily adjusted by moving the end supports.)

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{TEACHER NOTES} TESTING LIGHT PIPES

Students may use this procedure to investigate the use of light pipes. They are able to model the use of light pipes of different lengths and diameters used in different configurations. While the shiny side of aluminium foil can be used to line the tubes, better reflectivity can be obtained by using mirror foil, obtainable from MindSets £3.49 for 410 mm x 1 m). Direct comparisons may be made by monitoring changes in the light intensity at fixed points inside a lightproof box. The method may need to be adapted to suit the light monitoring equipment available, for example if data logging equipment is available. A fixed array of PV cells for the floor of the box can be constructed relatively cheaply and can provide a convenient method for obtaining large numbers of results for comparison. For example, Phillip Harris 0.45 V solar cells (55 x 35 mm) giving up to 200 mA cost just over £1 each (for ideas, see instructables.com)

Students may need help with the concept of scaling, in order to be able to build a test rig that models the dimensions of the proposed venue.

Light pipes allow in natural daylight for day to day purposes, but will be blacked out for high level sporting events for which no natural light must enter. They allow a greater area for insulation, which helps the building to remain warm in the winter but also cool in the summer.

Commercial suppliers of light pipes provide much useful information on their websites, e.g. Monodraught.

EQUIPMENT

- materials, tools and a work area to construct a light-proof box – rigid cardboard (e.g. strong cardboard box), MDF, hardboard, block board, dowelling; metre rule, steel ruler, pencil; scissors, handsaw, craft knife, drill and tool for cutting circular holes; PVA (or other suitable) adhesive; range of paints (e.g. matt, gloss, black, white, various colours)
- equipment to monitor and compare light intensities such as light probes or PV cells and meters, data collection box and/or PC with appropriate software, cables and connectors
- bright low voltage light source (e.g. LED array, halogen lamp)
- clamp stand(s) (or other means to hold the lamp in a fixed position)
- dark room (or other room that can be blacked out)
- thin card, aluminium foil or mirror foil (from MindSets), black adhesive tape

HEALTH AND SAFETY

A risk assessment is required before any practical work, but the specified method involves no serious hazards. Students should take extra care when using scissors, handsaws, craft knives and drills.

METHOD

Students may choose any aspect of light pipe design to investigate that can be modelled, including diameter, length, internal surface, addition of a bend, location/patter or number. They can also investigate the effect of different surface finishes inside the box, such as using matt or gloss finish and different colours. Evenness of illumination may be considered as well as light intensity levels. However, they should limit their investigations to fit the time available. If the interior of the box is to be altered, or the arrangement of the light sensors needs to be altered, a box with a removable front is desirable.

{TEACHER NOTES} THE HEATING EFFECT OF LAMPS

Thermocolour film and A4 size metal sheets are obtainable from MindSets.

EQUIPMENT

- thermocolour film with self adhesive backing (or use transparent adhesive tape)
- variety of different types and wattages of spotlight
- stopclock or stopwatch
- metre rule or tape measure
- spirit in glass thermometer
- thin metal sheet (does not need to be large), for example matt black aluminum
- insulating materials (such as corrugated cardboard, mineral fibre or polystyrene)
- clamp and stand

HEALTH AND SAFETY

A risk assessment is required before any practical work. Particular care should be taken if using mains electricity for the lamps under test.

METHOD

Spotlights used to light arenas may generate large quantities of heat. Students compare the times taken for a metal sheet to absorb heat from different lamps by observing the rate of changes in the colour of thermocolour film. If the heating effect is rapid, the distance of the lamp may be increased, or a double colour change in the thermocolour film could be timed.

Thermocolour film is black below 25 °C, changes to brown at about 26 °C, to green at around 29 °C and to blue above 30 °C.

EXTENSION

Students could investigate the effect of increasing distance on the heating effect of the lamps.

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{TEACHER NOTES} COMPARING BOUNCE

Students may use this procedure to investigate suitable materials for the venue flooring. This involves comparing the coefficient of restitution for bouncing off various floor materials.

The coefficient of restitution, c, is a measure of what proportion of its kinetic energy the ball regains after a collision – with a racquet, bat, or in this case bouncing off the floor. It's numerical value must therefore lie between 0 (no rebound at all) and 1 (a perfectly elastic collision).

The value depends on the properties of both the ball and the surface it hits. So to compare different floorings, the same ball must be used in all the tests.

The ball's regained kinetic energy determines how high it will bounce, so the value of c can be determined by measuring the rebound when the ball drops from a known height.

$$\text{Coefficient of restitution, } c = \sqrt{\frac{\text{bounce height}}{\text{drop height}}} = \sqrt{\frac{h_2}{h_1}}$$

Students should decide their own range of floors to test. Experience of gyms and leisure centres will guide them towards hard materials, but they should be encouraged to test at least one soft surface to show why indoor courts have hard floors, not soft.

Tests need not be limited to existing floors in situ. Sheets of other materials may be tested in the laboratory, provided they are laid on a firm, hard foundation.

EQUIPMENT

- bouncy ball (e.g. tennis ball)
- tape measure (or 2 x metre rules)
- clamp stand(s)
- various in situ floor surfaces
- various flooring samples, such as ceramic floor tile; carpet (e.g. showroom sample); foam rubber underlay; bare floorboards; hardboard; chipboard; MDF
- video camera (optional) with tripod

HEALTH AND SAFETY

A risk assessment is required before any practical work, but the specified procedure involves no serious hazards.

METHOD

Students should work in pairs – one dropping the ball, the other taking readings. These should be made with the observer's eye level with the bottom of the ball.

If available, a tripod-mounted video camera would facilitate measurements by allowing the students to step through the recording to determine the top of the bounce. The camera should be level with the expected height, determined approximately by a trial bounce.

{TEACHER NOTES} COMPARING BOUNCE

EXTENSIONS

Students could extend their investigation by dropping:

- the same ball onto the same floor surface from different heights
- different types of ball onto the same surface from the same height.

These should show that the coefficient of restitution:

- does not depend on height – the ball bounces back with the same proportion of its original kinetic energy, and thus to the same proportion of the drop height
- depends on the 'bounciness' of the ball, as well as the type of floor.

When it hits a hard surface the ball becomes slightly flattened. The better it springs back to its original shape, the better it bounces. A ball of plasticine just goes 'splat' and hardly bounces at all.

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{TEACHER NOTES} FRICTION

Students may use this procedure to investigate the friction grip of a sports trainer shoe on various flooring surfaces, to help them decide on suitable materials for the venue floor: they measure the minimum force needed to pull a trainer across various floor surfaces.

No detailed understanding of friction is required, beyond knowing that it is a force that resists the sliding motion of one surface along another. Students should appreciate that it is friction that allows the players' feet to get good a good grip on the surface, so they can start, stop and change direction abruptly without skidding.

EQUIPMENT

- sports trainer shoe (students can probably supply their own)
- various newton meters (or tension forcemeters)
- 1 kg mass
- various types of floor surface

These should be existing floors, and also sample squares of other materials such as floor tiles, cushion floor and short-pile carpet.

Access to particular floor areas may need to be arranged in advance.

HEALTH AND SAFETY

A risk assessment is required before any practical work, though there are no significant hazards in this procedure.

METHOD

Students may work individually or in pairs – each using one trainer from the same pair. Results from different designs are not directly comparable.

The trainers are weighted down to avoid their tipping up when pulled backwards.

It is suggested that pre-testing is carried out to determine the range of Newton meters likely to be needed to obtain meaningful results on different surfaces.

Students should be encouraged to suggest the types of floor worth testing. A few unlikely floorings, such as carpet, should be included by way of contrast. Students may need help in identifying some existing floor types, such as poured plastic resin.

Rubber-soled trainers are likely to have high friction on most surfaces, so the results may not be significantly different. This is still a useful conclusion, since it means that the choice of floor material should be based on some other criteria.

EXTENSIONS

Students could extend their investigation by:

- comparing results for different footwear on the same surface, to see whether design factors such as sole material or tread pattern have any significant effect on friction
- adapting the procedure to test other applications of friction in the arena, such as contact between the ball and players' hands; seat covers in the spectator area; floors that may get wet, e.g. entrance areas and toilets / washrooms.

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{TEACHER NOTES} COLOUR IN SPORTS HALLS

Students may use this procedure to investigate the effect of differently coloured courts and balls.

The method should be carried out under various lighting: outside on a bright day, under floodlighting and in a school sports hall. Suitable floodlighting may be available from a drama department rather than trying to carry this out on a sports field, in the evening.

EQUIPMENT

- tape measure
- target cards (see student sheet)
- access to sports hall, an outside space and other locations
- other materials to use as background for the targets
- scissors to cut out different coloured letters and a means of glueing to the background

HEALTH AND SAFETY

A risk assessment is required before any practical work. Students must observe usual safety practices for working outdoors. They will need to be supervised when working in other locations such as the sports hall.

METHOD

This activity should be carried out in groups. Ideally, results from several groups could be pooled to enable clearer inferences to be drawn.

BACKGROUND

Materials can be differentiated from one another because of the way each interacts with the light that strikes it. Different colours reflect differently from the object, affecting the colour seen. The colour that we see corresponds to different frequencies of the electromagnetic wave.

The structure and smoothness of the surface also affect the way the light reflects. Smooth surfaces reflect light specularly – that is, each ray reflects off the surface such that the angle between it and the surface normal does not change. Rougher surfaces reflect light in many directions: each individual ray obeys the law of reflection but the direction of the surface normal varies across the surface and so that the angle of reflection also varies.

Together with the varying response of different colours, this scattering affects the sharpness with which the edges of an object, seen against a background, can be discerned.

VISUAL ACUITY

The letters on the cards approximate to the mid range of normal vision. The middle letter, at 6 metres distance, subtends an angle of 5° at the eye. This corresponds to 6/6 vision.

{TEACHER NOTES} TESTING A WIND TURBINE

The procedure focuses on the use of wind energy to carry out useful work by lifting a load. In practice, a wind turbine might be pumping water or generating electricity. Wind turbines can be tested by measuring their capacity to do work for a given wind speed. Students can use a modelling situation with a constant air flow provided by an electric fan. Wind turbines may be compared by finding the maximum load that they can lift or by finding their efficiency. The efficiency of wind turbines can be calculated if the energy from the moving air is compared to the energy used to do useful work. To do this, it is necessary to find the speed and power of the wind and the useful energy output of the wind turbines. The Centre for Alternative Technology (http://www.cat.org.uk) provides a wind turbine kit and various publications. The website also shows how wind turbine designs have been trialled at the Centre. Sources of useful materials for building wind turbines include http://www.tts-group.co.uk (e.g. type *wheels* into the Product finder at the top left of the web page) and www.mindsetsonline.co.uk (e.g. for corriflute and small generators).

EQUIPMENT

- model wind turbine (e.g. from the Factsheet, Making a wind turbine)
- electric fan
- clamp and stand
- thin string or thread and adhesive tape
- slotted masses and hanger (10 x 10 g)
- box of crumpled paper
- stopwatch
- measuring tape or metre rule
- electric fan
- measuring tape or metre rule
- an anemometer or clamp and stand, table tennis ball attached to light nylon thread and a protractor

HEALTH AND SAFETY

A risk assessment is required before any practical work, but the specified procedure contains no serious hazards. The wind turbine should be fixed firmly so it does not blow away. The electric fan must have an appropriate guard.

METHOD

The method allows students to find the air speed generated by an electric fan and calculate the efficiency of a wind turbine used to lift a given load. Students can modify the design to attempt to increase efficiency, for example, by altering the pitch of the blades; increasing the number of blades; changing the shape or length of the blades (limited by the range of movement made possible by the frame); using blades with an aerofoil shape; reducing friction at the bearings e.g. by waxing or using ball races.

For the purposes of comparison, it is very important that the electric fan and wind turbine are aligned in exactly the same position and exactly the same distance apart each time. Repetitions using the same wind turbine configuration can help to establish how reliable the method is.

Students can work as a team to build and test wind turbines, or they may compete with each other to make the most efficient or most powerful wind turbine.

EXTENSIONS

Students could be asked to design a spreadsheet to calculate the efficiency of their wind turbines.

Wind turbines are used very successfully to generate electricity. Students could use a pulley and band to drive a small generator. They could investigate the output of the generator for different wind speeds.

{TEACHER NOTES} HEAT ABSORPTION OF METAL SHEETS

The first solar heating panels were just central heating radiators put in the sunshine. Water was pumped through them and warmed up. These panels are usually made of painted steel. However, they absorb only a small amount of the available energy. Students can use thermocolour film to compare metal sheets heated by a lamp. They can try and determine what factors affect the rate at which heat from the lamp is absorbed by timing the colour change of the thermocolour film. They can be challenged to come up with a design for a thermal solar collector that makes heat transfer into the water more efficient than using old radiators. Thermocolour film and A4 size metal sheets can be obtained from MindSets www.mindsetsonline.co.uk. Information on solar water heating systems can be found on a variety of websites, for example: http://www.solarhotusa.com/support/literature.html

EQUIPMENT

- thermocolour film with self adhesive backing (or use transparent adhesive tape)
- 100 W spotlight or 150 W lamp (or similar, to act as a source of radiant heat)
- stopclock or stopwatch
- metre rule or tape measure
- spirit in glass thermometer
- standard size metal sheets (these do not need to be large)
- insulating materials (such as corrugated cardboard, mineral fibre or polystyrene)
- shallow box with transparent lid into which the metal sheets can fit
- clamp and stand

HEALTH AND SAFETY

A risk assessment is required before any practical work. Particular care should be taken if using mains electricity for the lamps under test.

METHOD

Thermocolour film is black below 25 °C, changes to brown at about 26 °C, to green at around 29 °C and to blue above 30 °C. Students will need to carry out pilot experiments to establish the best set up distances, the colour change to use (may be through more than one change) and so on. In trying out and refining the method, they should get an idea of which factors to investigate. These could include the type of metal; colour; thickness; shiny or a matt surface; insulation of the non-heated surface (a small hole will need to be cut in the insulation to make the thermocolour film visible); prevention of convection currents (for example, by placing the metal sheet in a box with a transparent face – cling film could be used).

EXTENSIONS

Students could attempt to build a working solar panel to heat water. Various methods can be found on the web, for example:

http://www.builditsolar.com/Projects/WaterHeating/DougsSolarWater.htm.

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{TEACHER NOTES} HEAT INSULATION

Students may use this procedure to investigate suitable materials for insulating the arena walls and roof. The terms thermal conductivity and transmittance (U-value) are mentioned, but not defined. The procedure simply compares the effectiveness of various insulating materials rather than determining values, which can be obtained from databases.

For those who wish to know the underlying science:

Thermal conductivity (symbol λ or k) is a measure of the rate at which heat is conducted through a material.

The rate (in $J\ s^{-1}$, or W) depends on the area of material (in m^2) and the temperature gradient across it (in $K\ m^{-1}$). So,

$$\text{Thermal conductivity, } \lambda = \frac{\text{rate of heat conduction}}{\text{area x temperature gradient}} = \frac{\text{rate of conduction x thickness}}{\text{area x temperature difference}}$$

λ is measured in $W\ m^{-1}\ K^{-1}$

Thermal transmittance (U-value), measured in $W\ m^{-2}\ K^{-1}$, is a more useful figure, since it is a measure of the rate of heat transfer through a particular structure, such as a wall, window or roof. It takes into account the combined effects of conduction, convection and radiation through all the components; for instance, the frame, glass panes and air-gap in a double-glazed window.

The lower the value of λ or U, the more effective the insulation.

EQUIPMENT

- boiling tube
- 400 cm^3 beaker (large enough to hold a reasonable amount of insulation, but short enough to allow boiling tube to be clamped while resting on the cork)
- cork or bung (large enough to support bottom of boiling tube)
- clamp stand
- various insulation materials
- 50 or 100 cm^3 measuring cylinder
- long 110 °C thermometer
- stopclock (or watch showing seconds)
- source of hot water (at about 75 °C)

Test samples should be types of materials used by the building industry, rather than layers of cloth or newspaper sometimes used in this type of science investigation. Students should be encouraged to research what types of materials are used in practice.

Blocks of plastic foam may be pre-cut to fit the beaker and tube.

HEALTH AND SAFETY

A risk assessment is required before any practical work. Students may require supervision while dispensing hot water. Some insulation materials present physical hazards.

{TEACHER NOTES} HEAT INSULATION

METHOD

Students should work in teams, with each member testing different materials. Graphs will become over-crowded if more than three or four materials are plotted together. For ease of comparison, further graphs should use identical axes.

Results tables should be used in addition to plotting readings as they go along, to enable mis-plotting to be corrected.

Some students may need help with drawing the graphs, particularly with the concept of best-fit curves.

If available, dataloggers with digital thermometers may be used to gather data continuously, producing more accurate graphs.

EXTENSIONS

Students could extend their investigation by testing the effects of:

- temperature on the rate of cooling – by using their graphs to calculate *t* for 70 °C to 60 °C, and for 60 °C to 50 °C, or by repeating the experiment with hotter or cooler water
- thickness on the rate of cooling – by using a larger diameter beaker
- sealing in the insulating material – by adding a lid to the beaker
- changing the packing density – by wrapping / packing the insulation less or more tightly.

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{TEACHER NOTES} USING PVs TO HEAT WATER

At first glance, PVs seem to offer a useful way to heat water by generating electricity, not least because the extensive plumbing required by solar heating panels can be avoided. In fact, PVs are very expensive for the amount of solar energy that they convert and large areas are needed to generate useful amounts of electricity. Students can investigate this by measuring the heating effect obtained by connecting a low voltage immersion heater or coil of resistance wire to a PV panel. PV panels may be made by connecting cheap PV cells together (e.g. small solar cells can be obtained from Phillip Harris) or commercial panels can be bought (e.g. from Maplin). The procedure also includes a simple method for using solar energy to heat water directly, for comparison. A case study of the use of PVs can be found here and a description of domestic use of PVs can be found here. The heating effect of electric current is described here.

EQUIPMENT

For measuring the heating effect of the electricity produced by a PV panel:

- PV panel, clamp and stand
- temperature probe and meter or thermometer
- multimeters or voltmeter and ammeter (if available, datalogging equipment could be used to continuously monitor changes)
- low voltage immersion heater or 25 cm of thin nichrome wire
- lagged beaker
- magnetic stirrer or low heat capacity stirrer such as a glass rod
- switch, cables and connectors
- direct sunlight or lamp
- ruler or tape measure
- balance
- timer

For comparison with solar thermal heating (heating water directly with sunlight):

- 1.5 dm^3 plastic bottle (empty mineral water or soft drink bottle)
- temperature probe and meter or thermometer
- clamp and stand
- sleeve from an old black sweatshirt
- thin wooden dowel to use as a stirrer

HEALTH AND SAFETY

A risk assessment is required before any practical work, but the specified procedure contains no serious hazards unless water is heated to a high temperature.

METHOD

The procedure is similar to the standard method used to find the heat capacity of water, except that a glass beaker is used instead of a metal (e.g. aluminium) calorimeter. If desired, this could be used instead, but students will need help to be able to include the heat absorbed by the metal calorimeter in their calculations. They will also need to be conversant with setting up data logging equipment, if this is used. They may need to know some of the following relationships, depending on the approach taken:

volts = amperes x ohms

amperes = volts/ohms

ohms = volts/amperes = watts / (amperes x amperes)

watts = volts x amperes = watts = (volts x volts) / ohms = amperes x amperes x ohms

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{TEACHER NOTES} USING PVs TO HEAT WATER

EXTENSIONS

Students could investigate the use of PV panels to power water pumps for solar heating systems or the use of wind turbines for water heating. Wind power is a viable alternative, because more electricity can be generated and much more cheaply than by using PV panels, for example, see **here**.

{TEACHER NOTES} BACTERIA IN WATER

The bacterial content of rainwater samples that have been treated in different ways can be safely estimated using simple culture techniques as set out in the procedure, providing that the plates are not opened after incubation, and are autoclaved before disposal.

Advice on microbiological techniques and safety is provided by MiSAC (The Microbiology in Schools Advisory Committee), SGM (The Society for General Microbiology), ASE, CLEAPSS, and SSERC.

MISAC defines work with microbes at three levels. Level 2 is: '…work where there may be some risks of growing harmful microbes but these are minimized by careful choice of organisms or sources of organisms and by culturing closed containers which are taped before examination and remain unopened unless the cultures inside have been killed. Level 2 work may be carried out with pupils aged 11-16 (Key Stages 3 and 4) and by teachers who may require training and some supervision which can be provided through a short course or in school by another experienced biology teacher.'

SGM provide resources and training. School membership is £10 per year. It provides links to safety issues can including *Safety guidelines for basic practical microbiology*, *Safety resources* and *Good laboratory practice for all*.

SGM emphasise: *'Before any practical activity is undertaken the golden rule is to carry out a risk assessment. This should ensure that there is minimal risk to all concerned.'* Information on model risk assessments and the factors to be considered are provided in Part 1 of *Basic Practical Microbiology: A Manual.* This publication gives full guidelines for the necessary risk assessments and is the single most useful resource for safety issues and procedures. If your school does not have a copy, it may be obtained by emailing education@sgm.ac.uk.

Other publications giving guidelines on risk assessment include *Topics in Safety*, 3rd edition, (ASE 2001), *Microbiology: an HMI Guide* (DES,1990) and *Safety in Science Education* (DfEE, 1996).

As it is impossible to be certain that pathogens are not inadvertently cultured, **all cultures should be treated as if they are pathogenic.** Some points to note:

- Cultures should not be incubated above 30 °C.
- Sterile equipment and media should be used to transfer and culture micro-organisms. Aseptic technique should be adopted at all times to reduce the risk of accidental contamination of cultures and the escape of pathogens from them.
- Food or drink should not be stored or consumed in a laboratory or prep room that is used for microbiology.
- There should be no hand-to-mouth operations – no-one should lick labels, apply cosmetics, suck pens or pencils or smoke in a laboratory or prep room.
- Hands should be washed with soap before and after handling microbial cultures and whenever leaving the lab. Paper towels or some other hygienic method should be used for drying hands.
- If contamination of hands is suspected, they should be washed immediately with soap and water.
- Cuts or abrasions should be protected by the use of waterproof dressings or by wearing disposable gloves.
- Safety glasses may be worn, according to local requirements.
- A spillage kit should be available at all times and all spillages reported immediately to a teacher or technician who should keep a record of the incident.
- Benches used for microbiology should be disinfected before and after use.

{TEACHER NOTES} BACTERIA IN WATER

EQUIPMENT

- water samples in sterile containers
- self adhesive labels, wax pencil or spirit marker pen
- sterile Petri dishes
- McCartney bottles or capped test tubes containing molten sterile nutrient agar, stored in a water bath
- discard pot containing disinfectant
- incubator at 25-30 °C
- Bunsen burner
- transparent adhesive tape to tape the lid on Petri dishes
- sterile Pasteur pipettes

A separate test plate will be needed for each water sample being tested.

HEALTH AND SAFETY

A risk assessment is required before any practical work. Incubated dishes should be autoclaved unopened before disposal. Students should be told not to drink water samples, even after treatement.

METHOD

The procedure described can be used by students to compare rainwater samples that have been treated in a variety of ways, for example by filtering or adding sterilising tablets.

EXTENSIONS

Students could build their own water filters, for example using active charcoal and/or sand in plastic drinks bottles which have had the base removed. A procedure is given below:

EQUIPMENT

- large plastic bottle
- activated charcoal
- washed gravel
- water sample
- sterile container (for collecting filtered water)
- sterile bottles
- cotton wool
- washed fine sand
- clamp stands, clamps and bosses
- labels
- support for the filter

METHOD

1. Cut the bottom off a large plastic bottle.
2. Plug the neck of the bottle with cotton wool.
3. Clamp the bottle upside down with one clamp to the neck of the bottle and one higher up. Additional support may be needed.
4. Place 2 cm layers into the bottle, on top of the cotton wool, of activated charcoal, washed sand and, lastly, gravel.
5. Put a sterile container under the opening in the bottle to collect the filtered water.
6. Slowly add the water sample to the top of the filter. Make sure you do not filter more water than you can collect.
7. Water samples should be stored in sterile bottles, sealed, kept cool and tested as soon as possible.

{ROLE MODELS} CLAIRE GREENWOOD

NAME: CLAIRE GREENWOOD

ORGANISATION: LAND & WATER SERVICES

JOB TITLE: CONTRACTS MANAGER

1. WHAT DO YOU DO?

I plan and co-ordinate construction projects to ensure that they are managed and completed correctly.

2. DESCRIBE YOUR TYPICAL WORK DAY

A typical day could include travelling to meet with clients; providing engineering advice and solving engineering problems; visiting construction sites and managing my team to make sure all tasks are delegated and delivered properly.

3. WHAT HOURS DO YOU WORK?

I usually work between 50 and 60 hours a week.

4. WHICH SUBJECTS DID YOU ENJOY MOST AT SCHOOL?

I enjoyed Maths, Physics, Chemistry and Design Technology

5. WHAT QUALIFICATIONS DO YOU HAVE?

I have A Levels in Maths, Physics, Chemistry and Theology. I also have a BEng in Civil Engineering with European Studies and I'm a Chartered Member of both the Institution of Civil Engineers and the Institution of Highways and Transportation.

6. TO WHAT DEGREE WERE STEM SUBJECTS IMPORTANT IN GETTING YOUR JOB?

Maths and Physics were essential for me to train as a civil engineer as it is important I understand how the forces work in structures when under loading, as well as the properties of different materials and how they are affected by different pressures and forces. This helps me ensure I can cost a construction properly and use the right types of materials that won't break. Design and technology helped with my practical knowledge of how to build things.

7. WHAT WERE THE MAIN FACTORS THAT ATTRACTED YOU TO YOUR CURRENT JOB?

The opportunity to build different structures and work on varied projects including bridge building, railways, water and the Olympics! I enjoyed studying Maths and Physics and wanted to apply them in a practical way. I also like problem solving engineering issues like working out ways to build a bridge or road for example, in difficult situations.

8. HOW DID YOU GO ABOUT ENTERING INTO THIS CAREER/ GETTING EXPERIENCE

I went on an Insight course (now Headstart: www.etrust.org.uk/headstart/courses.cfm) aimed at girls interested in Engineering. This provided me with an opportunity to interact with female Civil Engineers and find out more about what an Engineering career could involve. I did work experience at a consultancy to see if I liked design work (I didn't) and then I got experience of working on an open cast mining site whilst at university. After graduating, I was recruited by a large construction company to start my career and carry out on the job training.

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{ROLE MODELS} CLAIRE GREENWOOD

9. DO YOU HAVE ANY ADVICE FOR SOMEBODY LOOKING INTO THE SAME CAREER?

My advice to anyone interested in a similar career would be to try and get some work experience with a company, even if you have to volunteer. It can be difficult but not impossible to do if you are under 18, so it might be easier to gain experience in an office working with engineering consultants. Contact local businesses and see if they can show you round, even if it is just for a day.

10. WHAT ARE THE BEST/ WORST THINGS ABOUT YOUR JOB? WHAT DO YOU FIND MOST REWARDING ABOUT IT?

The best is the legacy I leave behind. The projects I have worked on will still be there in years to come, including the North Park at the Olympics, the water works in Essex and the road to Wembley stadium. The worst is the red tape that we sometimes have to work through to get projects up and running and completed.

11. WHAT ARE THE CHALLENGES OF YOUR JOB?

Dealing with technical issues and trying to find a way to build a construction quickly or to a restricted budget can be challenging. Also adapting construction techniques to modify projects when problems arise, either through unforeseen problems or mistakes can be difficult.

12. WHAT HAS BEEN THE HIGHLIGHT OF YOUR CAREER SO FAR? WHAT HAS BEEN THE MOST EXCITING/ INTERESTING PROJECT YOU HAVE WORKED ON?

The most exciting was working on the Olympics on the landscaping of the North Park, which was the first park of its size to be built for 150 years! Working in an area of that magnitude; learning about trees, wetland plants, fish passes; and working within significant constraints in relation to the construction practices and techniques we could use was amazing!

13. HOW DO YOU HOPE TO PROGRESS IN YOUR FIELD OVER THE COMING YEARS?

I would like to continue to learn and expand my civil engineering knowledge in the environmental sector. Eventually, I would like to become a director and be as successful as I can be in my field.

14. WHAT PASSIONS AND INTERESTS DO YOU PURSUE IN YOUR PERSONAL TIME?

I am a keen rugby league fan and enjoy reading and watching movies with my family. I enjoy walking and running with my chocolate Labrador who comes to work with me.

Claire's dog

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{ROLE MODELS} MATTHEW BREEZE

NAME: MATTHEW BREEZE

ORGANISATION: MORGAN SINDALL UNDERGROUND PROFESSIONAL SERVICES

JOB TITLE: GRADUATE ENGINEER

1. WHAT DO YOU DO?

I am an engineer working on tunnelling projects and I design solutions to structural, geotechnical and civil engineering problems.

2. DESCRIBE YOUR TYPICAL WORK DAY

Most days consist of completing calculations, performing analyses, producing drawings and writing reports. I can also be on site with the team deciding on the safest and most sensible solution to problems and checking to ensure what I design then works.

3. WHAT HOURS DO YOU WORK?

Usual hours are 9am to 5pm but it can be longer depending on the construction team's requirements.

4. WHICH SUBJECTS DID YOU ENJOY MOST AT SCHOOL?

I enjoyed Maths, Science, Design and Technology as these subjects taught me problem solving skills and I liked learning the different methods and techniques to approach these challenges. I also enjoyed History as it taught me the human aspect and I think helped me in learning and understanding how best to communicate with different types of people.

5. WHAT QUALIFICATIONS DO YOU HAVE?

I have A-Level Maths, a BTEC National Diploma in Maintenance and Operations Engineering, an MEng in Civil Engineering and an MSc in Tunnelling and Underground Space. I also have various job related Health and Safety certificates.

6. TO WHAT DEGREE WERE STEM SUBJECTS IMPORTANT IN GETTING YOUR JOB?

The STEM subjects were critical. My job demands mathematical and analytical skills as well as good communication skills. You don't necessarily realise how much you use the skills until you sit back and think about it. It's also really important to do things you enjoy.

7 WHAT WERE THE MAIN FACTORS THAT ATTRACTED YOU TO YOUR CURRENT JOB?

I enjoy working in the tunnelling industry as it combines many aspects of civil engineering and provides me with many unique challenges. I get to use my geotechnical, structural and materials knowledge on a daily basis and always know that something new and exciting is just around the corner. I also love the opportunity to work on major schemes to improve the countries water and transport infrastructure.

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{ROLE MODELS} MATTHEW BREEZE

8. HOW DID YOU GO ABOUT ENTERING INTO THIS CAREER/ GETTING EXPERIENCE AND DO YOU HAVE ANY ADVICE FOR SOMEBODY LOOKING INTO THE SAME CAREER?

During my undergraduate degree I sought a job role that I thought would challenge me. When Morgan Sindall gave a presentation at university, I approached them about possible work opportunities and now work for them! They also sponsored my postgraduate studies in tunnelling and provided me with placements so that I could gain experience. There are many ways into civil engineering so make sure you do your research and choose the right path for you. You could follow an academic route (like me) or a practical path like many of my colleagues. It is a wide field with many opportunities. Never be afraid to write to a company to make an opportunity for yourself. My boss and company director both started as apprentices when they were 16!

9. WHAT ARE THE BEST/ WORST THINGS ABOUT YOUR JOB? WHAT DO YOU FIND MOST REWARDING ABOUT IT?

The best thing about my job is that the work I do improves the world and makes a real difference for all of us. It is very rewarding to know this and it is what keeps me motivated. I want to be making a difference. The worst part can be the long hours and the pay, although good, is not as much as my university friends who work in finance.

10. WHAT ARE THE CHALLENGES OF YOUR JOB?

When I am given a problem I have to quickly understand it, then analyse and devise a solution. This can be very challenging purely because of the technical complexity; and even more so when there are time constraints. Ensuring the customer, contractors carrying out the work and the local community are happy with project progress can also be challenging as projects can often cause some I often have to convince others to agree to a compromise.

11. WHAT HAS BEEN THE HIGHLIGHT OF YOUR CAREER SO FAR? WHAT HAS BEEN THE MOST EXCITING/INTERESTING PROJECT YOU HAVE WORKED ON?

My highlight so far was my first major work package, designing the shaft walls and temporary works for a water project in Yorkshire. My most interesting project is for Crossrail where I am involved in the construction of two stations for the new underground railway.

12. HOW DO YOU HOPE TO PROGRESS IN YOUR FIELD OVER THE COMING YEARS?

I am working towards becoming at Chartered Engineer which will provide professional recognition of my skills. I hope to become Chartered in the next three years and eventually be promoted to manage a team.

13. WHAT PASSIONS AND INTERESTS DO YOU PURSUE IN YOUR PERSONAL TIME?

I am a gym fanatic in the winter and a keen cyclist in summer and do lots of swimming all year round. I also have a passion for science fiction and fantasy books and films.

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