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Thermal Energy and the Human Body

The human body uses energy continuously. The main source of energy is food containing carbohydrates which store chemical energy. Body systems convert carbohydrates into simpler substances which allow the energy to be stored and transported around the body to supply the needs of muscles and vital organs. As energy gets used, respiration occurs and heat is produced. During periods of intense physical activity, the rate of heat generation rises substantially, but the body always maintains a constant temperature through a variety of processes which balance heat generation with heat losses to the surroundings.



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A. Introduction ●●

The theme of this module is the thermal energy balance maintained by the human body. The principal source of energy to the body is food and a major output of energy is in the form of heat. The activities focus on the processes associated with the input and output of energy. There are four types of activities:

1. **Data logging:** laboratory experiments:

- To investigate the energy value of food by measuring the heat produced when a potato chip is burnt.
- To investigate the cooling effect of evaporation.
- To calculate the heat generated by the human body by placing the subject in an enclosed box and recording temperature, humidity and CO₂ changes in the box.

2. **Simulation:** Visual aids to assist an interpretation of the data-logging experiment on food and to explore the processes of heat transfer in the human body.

3. **Modelling:** A mathematical model to predict the changes of temperature in the data-logging experiment on food and in the data-logging experiment with a liquid evaporating.

1. Background theory

1. THE ENERGY BALANCE

The human body does not consume energy it changes it from one form to another. If the weight and the temperature of the body remain constant and if the body performs no external work, the energy input to the body equals exactly the energy leaving the body:

$$\text{Energy input} = \text{Energy output}$$

The body takes in energy that is in the chemical bonds of the food molecules and converts it to heat which is dissipated to the surroundings. This balance can be expressed by (assuming that there is no external work):

$$M \pm C \pm R - E = 0$$

where M is metabolism,
 C is conduction and convection,
 R is radiation, and
 E is evaporation.

Note that although evaporation always results in a loss of heat, convection, conduction and radiation can either add or remove heat depending on surrounding conditions. With a comfortable ambient temperature of 21°C, and free convection, a clothed adult at rest would experience about 40% heat loss due to radiation, 40% due to conduction (very little) and convection, and 20% due to evaporation.

2. ENERGY INPUT

The energy input is delivered by the metabolism, where chemical energy stored in food is released in an oxidation process where enzymes act as catalysts. The process may be briefly described as the oxidation of glucose to carbon dioxide and water, where energy is released. The following equation summarizes what happens:



This process is called *aerobic respiration*. The unwanted waste products, carbon dioxide and water, must be removed and they are carried away by the blood. Water vapour and carbon dioxide gas are constituents of exhaled air.

Superficially, respiration is a similar chemical process to *combustion* in that both are oxidation processes, the reactants and products are the same, and, in both cases, energy is produced. This similarity can be usefully exploited to determine a measure of the energy content of food (see Activity 1).

Energy of food is usually measured by calories¹ or Joules per gram. The energy content of different type of food is summarised in the table below. Each type of food has a specific role to play in metabolism.

Food	Energy content (per gram)
Fats	9 kcal/g (37.7 kJ/g)
Alcohol	7 kcal/g (29.3 kJ/g)
Protein	4 kcal/g (16.7 kJ/g)
Carbohydrates	4 kcal/g (16.7 kJ/g)
Fibre	2 kcal/g (8 kJ/g)
Vitamins and Minerals	Nil
Water	Nil

¹ 1 cal = 4.186 J

The medium day demand for the energy is about 2000-3000 kcal. The energy consumption depends on the person gender, age and lifestyle.

3. ENERGY OUTPUT

If the body performs no external work then the energy output is in the form of heat. The heat is dissipated from the body to the surroundings. The mechanisms of heat transfer are radiation, conduction and convection. The heat may also be transported when water is evaporated from the skin or by breathing.

Radiation

Black-body laws can be applied to human beings. Some of a body heat is radiated away in the form of electromagnetic radiation, most of which is infrared. The human body radiates heat in all directions. Heat is also being radiated from the walls and other objects towards the body.

Heat loss due to radiation can be approximated by:

$$\frac{\Delta Q}{\Delta t} = -e\sigma \cdot A \cdot (T^4 - T_s^4)$$

where A is the area of the human body, a typical naked body area $A = 2 \text{ m}^2$,
 e is emissivity of the skin, human skin is near-ideal radiator in the infrared $e=0.97$,
 $\sigma = 5.67 \cdot 10^{-8} \text{ W/m}^2 \cdot \text{K}^2$ - Stefan-Boltzmann constant,
 T is the temperature of skin $T = 34^\circ\text{C}$,
 T_s is the temperature of surroundings.

This approximation is however only valid under temperature of 40°C .



Figure. Much of a person's energy is radiated in the form of infrared energy.

Conduction

Heat conduction takes place if there is a difference in temperature. The rate of loss of heat will depend upon the insulating properties of the clothes being worn and it varies in proportion to the temperature difference between the surface of the body and its surroundings:

$$\frac{\Delta Q}{\Delta t} = \frac{-kA \cdot (T - T_s)}{d}$$

where k is thermal conductivity of the air surrounding the body,
for still air $k = 5.7 \times 10^{-5} \text{ cal/s} \cdot \text{cm} \cdot ^\circ\text{C}$

d is the distance between the temperature of the body and the temperature of surroundings, in other words it is an assumed distance

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from the skin for the temperature to drop to the ambient temperature of surroundings, for still air we can assume a value of 5 cm.

Convection

The removal of heat from the body by convection air currents is commonly called heat loss by convection. Actually the heat must first be conducted to the air and then carried away.

The best approach to an estimate of heat loss by this mechanism may be to calculate the heat loss by conduction and to adjust the effective distance d used in the conduction calculation to take in to account the fact that air motion will strip away the heated layer surrounding the skin and increase the transfer of heat to the air.

Evaporation

When the temperature of surroundings is above body temperature, then radiation, conduction and convection transfer heat into body rather than out. The mechanisms of heat loss during such conditions are the evaporation of perspiration from the skin and the evaporative cooling from exhaled moisture.

The evaporation of the sweat droplets involves the loss of latent heat and causes a cooling effect on the skin. The rate of heat loss is:

$$\frac{\Delta Q}{\Delta t} = \frac{L \cdot \Delta m}{\Delta t}$$

where L is the heat of vaporization of water, this heat of vaporization is 540 cal/g at the boiling point but even larger, 580 cal/g, at the normal skin temperature.

Even when a person is not sweating, water still evaporates insensible from the skin and lungs (at a rate of about 450 – 60 ml per day, this cause heat loss at a rate of 12 to 16 cal per hour).

4. HEAT-REGULATING MECHANISMS OF THE HUMAN BODY

Humans maintain a steady body temperature. The temperature of deep tissues of the body – the “core” remains almost exactly constant 37°C. The skin temperature, in contrast to the core temperature, rises and falls with the temperature of the surrounding.

To maintain its temperature the human body has an excellent heat-regulating mechanism and under normal conditions can adjust its temperature and keep the appropriate heat balance. Under desirable temperature and humidity conditions (e.g. 23° C and 50 % of relative humidity) most body heat dissipation occurs through radiative and convective heat transfer with only 20% occurring through evaporation. Very little loss occurs by conduction.

However, as surrounding conditions change, body temperature regulation system reacts accordingly. For instance, in dry air surroundings and temperature of 32°C, about 80% of the body’s heat loss must occur through evaporation, requiring profuse perspiration. Under these conditions radiation and convection are much less important than evaporation. As surrounding air temperature approaches temperature of 37°C most body heat loss occurs through evaporation (perspiration).

If the skin temperature drops below 37°C a variety of responses are initiated to conserve the heat in the body and to increase heat production. The heat can be gained by:

- ‘burning up’ food, for extra heat the body ‘burns up’ food at faster rate,
- reducing the blood flow to skin so that less heat is carried to the surface and lost,
- shivering - the rapid twitching muscle movements increase heat production in the muscles,
- exercise - muscles give off heat when they move.

REFERENCES:

1. <http://hyperphysics.phy-astr.gsu.edu/HBASE/thermo/coobod.html>
2. Mats Areskoug (2002) “The power of the human body” In: electronic proceedings of GIREP conference: *Physics in New Fields, Lund, Sweden, July 2002.*
3. Weinstock, H. (1980) “Thermodynamics of a cooling (live) human body”, *American Journal of Physics* 48 (5) May 1980.

2. Pre-requisite knowledge required

- Food types (carbohydrate, protein, fat)
- Aerobic respiration
- Temperature measurement
- Celsius scale of temperature
- Effects of heating and cooling substances
- Heat transfer by convection
- A temperature difference causes the transfer of heat

3. Science concepts developed in the module

- Energy content of food
- Heat of combustion
- Latent heat of vaporisation
- The rate of cooling of a substance depends upon the temperature difference between the substance and its surroundings

4. Other useful information

- Further background theory about metabolism, body cooling and associated topics may be found at:

<http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>

- A summary is attached as Appendix 1.

B. Didactical approach ●●

1. Pedagogical context

Possible contexts in which the topic might be introduced:

- Comparing the energy values of a variety of different foods
- Discussion of balanced diet and methods of dieting
- Consideration of the energy transfers when engaging in sporting activities
- Consideration of sweating as a process which accelerates the loss of body heat.

CONSTRUCTING A TEACHING SEQUENCE:

Each of the contexts suggested above will involve different starting points for teacher exposition or class discussion, but it is strongly recommended that this leads promptly to one of the data-logging activities. Such practical activity is valuable for providing firsthand experience of the phenomenon which can be used to stimulate questions about the underlying scientific processes. The need for further investigation is a likely outcome and the simulation and modelling activities provide a useful means of extending investigation and deepening thinking. The simulation and modelling activities both demand quantitative description and analysis.

2. Common student difficulties

- Confusion between respiration and breathing
- Confusion between heat and temperature
- Understanding rate of change
- Understanding of energy conversion and energy conservation

3. Evaluation of ICT

This section considers some of the practical arrangements for exploiting the use of ICT to best effect, and discusses the qualities of the ICT methods which make a special contribution to students' learning.

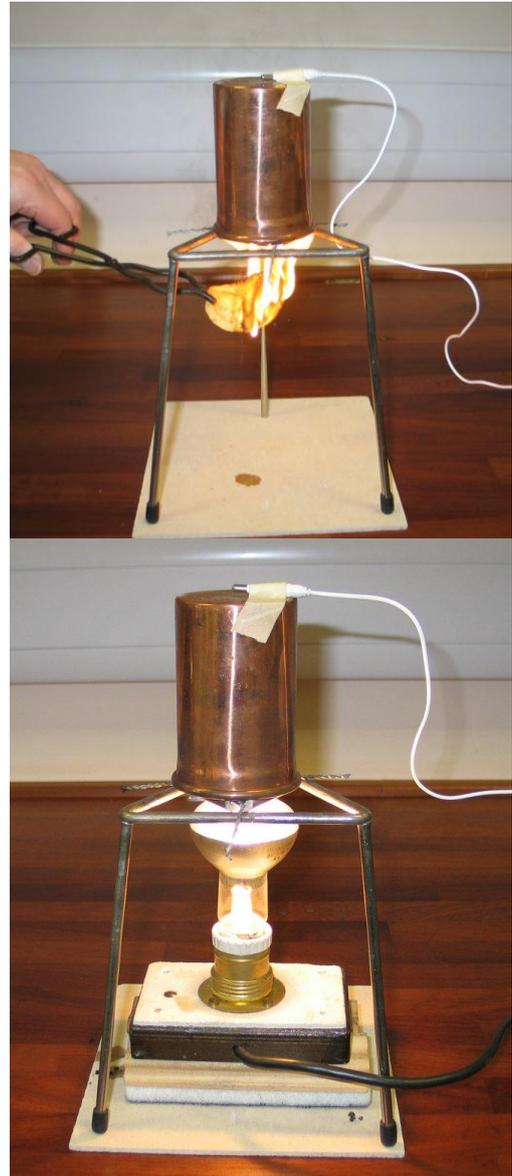
DATA-LOGGING

Both experiments use temperature probes which are generally very useful for conducting a large variety of simple experiments involving heating and cooling. Quite cheap probes can offer excellent sensitivity and accuracy well suited to real-time experiments.

Activity 1. Energy content of food

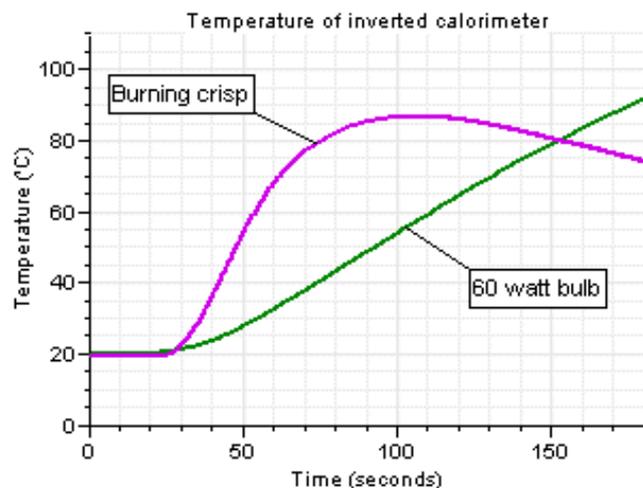
Foods, depending on their carbohydrate/fat composition, have different energy content that can be determined by measuring the heat release from their combustion. In this activity the energy value of different food items like a potato chip or peanut is calculated.

In this example, the probe is secured in good thermal contact to the top of the calorimeter resting in an inverted position on a tripod. The principle is that when an item of food is ignited and burnt underneath the calorimeter, the rising hot gases heat up the calorimeter. The data-logging technique makes the graph of temperature against time visible immediately and when the burning is complete, the maximum temperature may be read from the graph accurately. Since we are interested in the total heat given out during burning, the calorimeter needs to be calibrated so that the temperature rise may be used for calculating the heat output. This is done by repeating the experiment using a standard mains electric spot lamp inside the calorimeter in the place of the burning food. The new graph of rise in temperature can be compared with the first graph and the time taken to reach the former maximum temperature may be measured. Multiplying this time by the wattage of the lamp gives the energy output of the food.



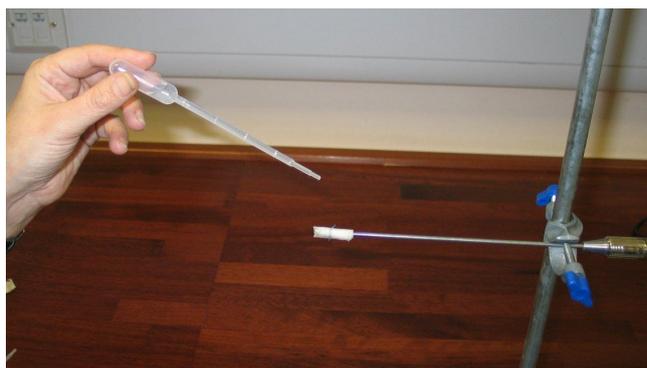
$$\Delta\text{Heat (in joules)} = \text{Power (in watts)} \times \Delta\text{Time (in seconds)}$$

This is the same as the amount of heat produced when the crisp has completely burnt.



Activity 2. Evaporation of liquid

In this experiment students observe process of cooling by evaporation. The temperature probe is set up with a small strip of tissue paper rolled around its tip. After moistening the paper with several drops of water (or alcohol), the cooling effect due to evaporation becomes evident on the temperature versus time graph which develops while the experiment is in progress.



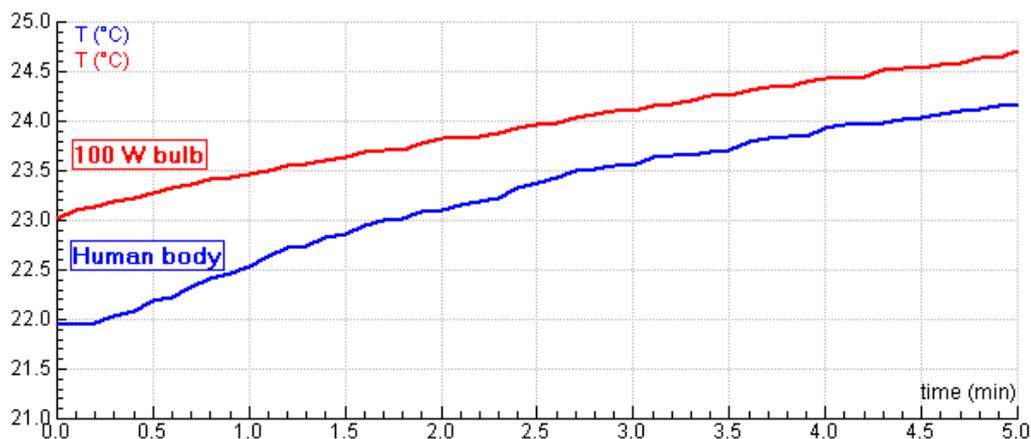
Activity 3. Energy emitted by a human body

This experiment is designed to measure the rate of energy emission from the human body. In this experiment the different contributions to the energy balance of the human body can be measured and analysed. The experiment was devised by Mats Areskoug, and his paper describing the theory and experiment is provided in Appendix.

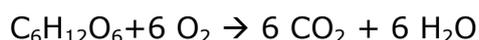
The experiment is enriched with video recording.

The experiment may be reproduced in the school laboratory, but in view of the unusual apparatus, the video recording conveniently allows the experiment to be studied and results analysed without the expense of too much time and money.

A thermally insulated box is prepared, containing sensors for temperature, humidity and CO₂ concentration. A data-logger records readings from the sensors whilst a person spends a few minutes inside the box. The rise in temperature can be obtained from the graph and used to calculate the heat energy output from the person's body. The completion of the calculation requires a separate calibration experiment similar to that used in data-logging Activity 1; a mains light bulb of known power output is placed inside the empty box and the rate of temperature rise again recorded using the data-logger.



The measurements of CO₂ concentration and relative humidity are useful as evidence supporting the chemical description of aerobic respiration in the body:

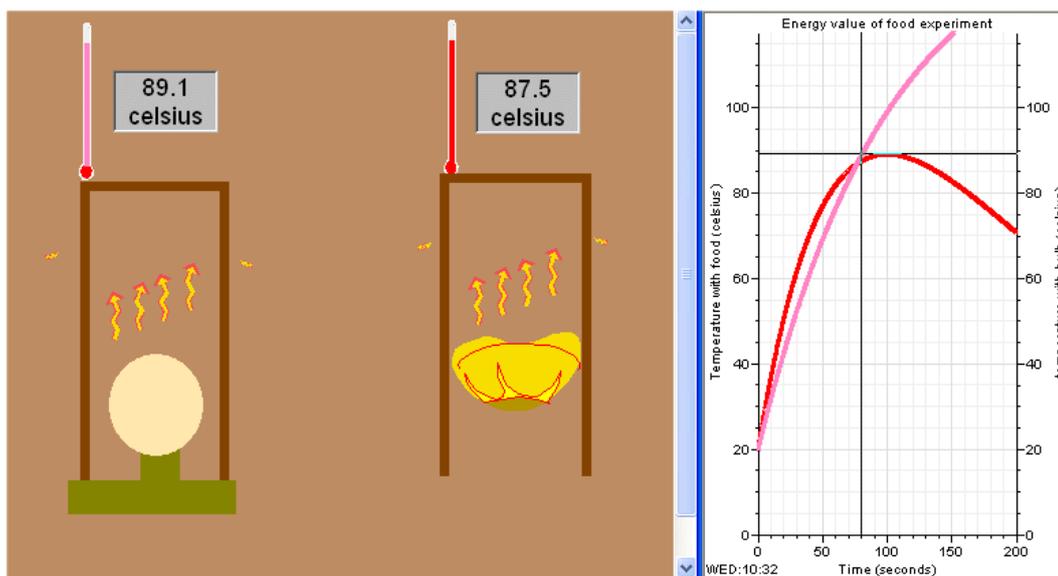


Further, the increase in CO₂ concentration can be used to calculate the amount of glucose metabolised during the experiment. Since the Heat of Combustion (enthalpy) of glucose is known, the amount of heat generated by respiration may be calculated and compared with the result obtained from the rise of temperature. Calculations from sample data are included in Activity 3. A full explanation of the theory behind these may be found in the paper by Mats Areskoug 'The Power of the Human Body' provided in Appendix 2.

SIMULATION

Activity 4. Energy value experiment

This simulates the data-logging experiment of Activity 1a. Both parts of the experiment, the burning of the potato crisp and the calibration with the electric bulb, run simultaneously side by side with both sets of results displayed on the graph. The simulation may be used to prepare pupils thinking before performing the experiment, or it may be used for discussing the analysis of the results from the experiment. The cursor controls make it possible to take accurate readings from the graph.



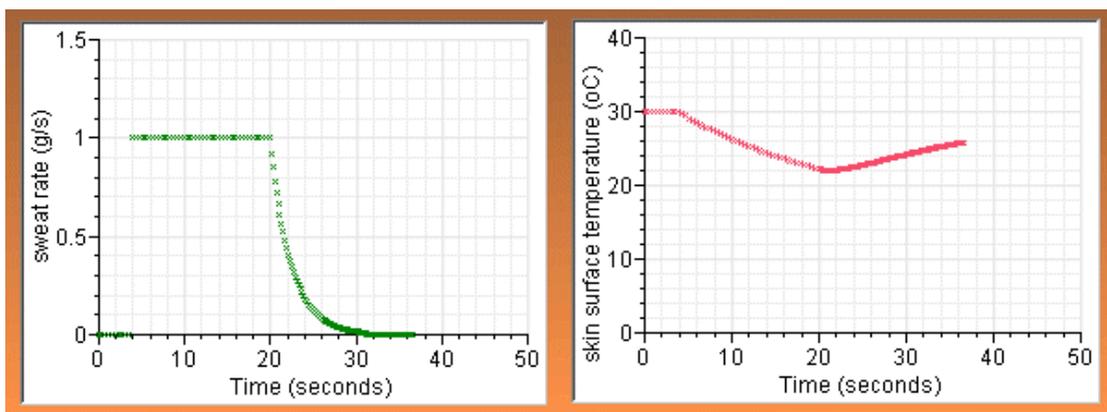
The remaining simulations facilitate a discussion of the main processes involved in heat transfer for the human body: the generation of heat in internal organs and through exercise, and heat losses through convection and evaporation. In the human body, the latter are automatically controlled by self-regulating physiological mechanisms, but the simulations allow these to be controlled by the user so that the individual factors involved may be investigated.

Activity 5. Energy changes in the human body - convection:

This allows control of the two main variables determining the rate of convection, the ambient temperature of the surroundings and the skin surface temperature. It is soon apparent that the heat loss depends upon the difference between these two temperatures, moreover the relationship is found to be linear; that is, for every 1 degree increase, the rate of heat loss increases by the same amount. Thus the model for the simulation assumes Newton's Law of Cooling. Discussion can consider the conditions for this simple relationship: If, for example, convection is forced by movement, wind or a fan, then a different relationship applies. Here is an example of how simulations and models usually contain simplifying assumptions about variables and the relationships between them. The limitations of models need to be questioned and their data tested against real data from experiments.

Body evaporation:

This simulation allows the user to control the rate of sweating at the surface of skin. The consequent cooling effect due to the evaporation of the sweat may be observed on the graph. This shows that the skin temperature decreases whilst the sweat rate is finite. The larger the sweat rate, the larger the rate of fall in temperature; however, the rate of fall is not constant because the model allows for the absorption of heat from the surroundings. A further investigation could find out the effect of the room temperature on the rate of change of skin temperature. Again, for the sake of simplicity, the scope of the simulation is limited. For example, the model takes no account of the effect of the relative humidity on the rate of evaporation.

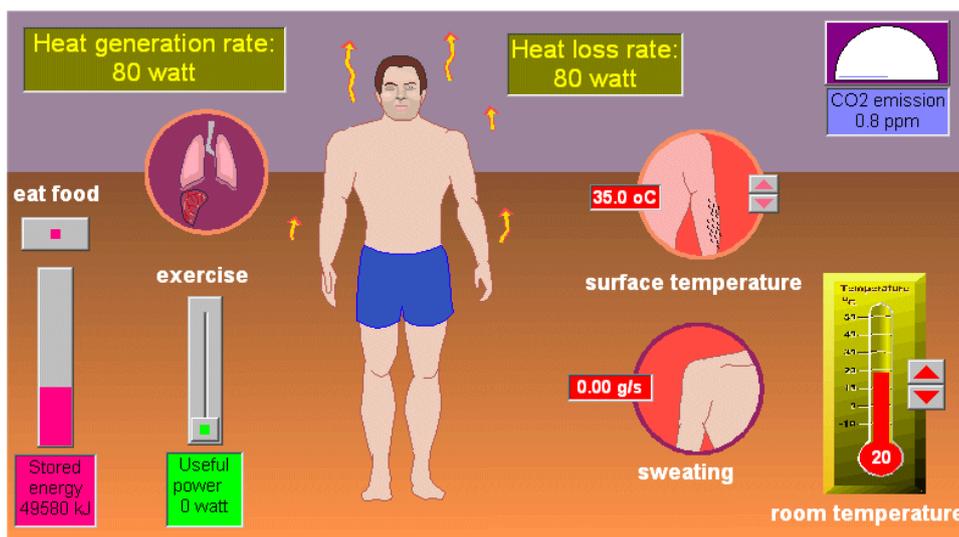


Body energy balance:

This simulation calculates the combined heat losses due to evaporation and convection and allows them to be compared with the main sources of heat generation within the body. Its main teaching purpose is to prompt thinking about the sophistication of the self-regulatory processes which contribute to homeostasis, which results in a stable internal body temperature of 37 °C. The philosophy behind this simulation is for the user to attempt to control these processes in a way which imitates the perfect balance normally achieved by the body automatically. The difficulty of achieving this balance leads one to admire

even more the sophistication of the natural control systems within the human body.

Food is the main source of supply of energy to the body and its slow metabolism in internal organs results in the generation of heat (mainly in the liver). The simulation demonstrates the slow release of heat from this process, normally about 80W. In contrast, muscular activity in exercise produces 'waste' heat much more quickly. Typically, muscles produce heat at three times the rate of useful mechanical power. For heat losses by convection and evaporation, the simulation incorporates ideas from the previous two simulations. Although this simulation gives the user independent control of skin surface temperature, in reality this is automatically controlled by systems within the body. Sweating is not normally triggered until skin reaches a temperature of 37 °C.



MODELLING

The purpose of these activities is to use formulae to generate a set of data which approximates as closely as possible to the data captured in the data logging activities.

Activity 6. Energy content of food

The model in this activity simulates the data-logging experiment of Activity 1. Model consists of two parts, one for the burning food (the potato crisp) and one for the calibration with the electric bulb. The model can be used to discuss the energy conservation.

The model assumes these physical concepts:

1. The rate of mass burning varies in proportion to the mass of the food remaining. This is represented in the formula which calculates the rate of change of mass during a time interval Δt is:

$$\frac{\Delta m}{\Delta t} = -b * m \text{ where}$$

m is the mass of food remaining, and
 b is a constant representing the rate of burning.

2. The rate of heat gained due to warming by burning a food item or by using an electric bulb varies in proportion to the rate of mass burning and the energy value of the food item. This is represented by a formula:

$$\frac{\Delta Q_{gained}}{\Delta t} = e_v \frac{\Delta m}{\Delta t} \text{ where}$$

e_v is the energy value of a burning food item.

3. The rate of heat lost into surroundings varies in proportion to the difference in temperature between the calorimeter and its surroundings. This is represented in the formula:

$$\frac{\Delta Q_{lost}}{\Delta t} = K \cdot (T - T_s) \text{ where}$$

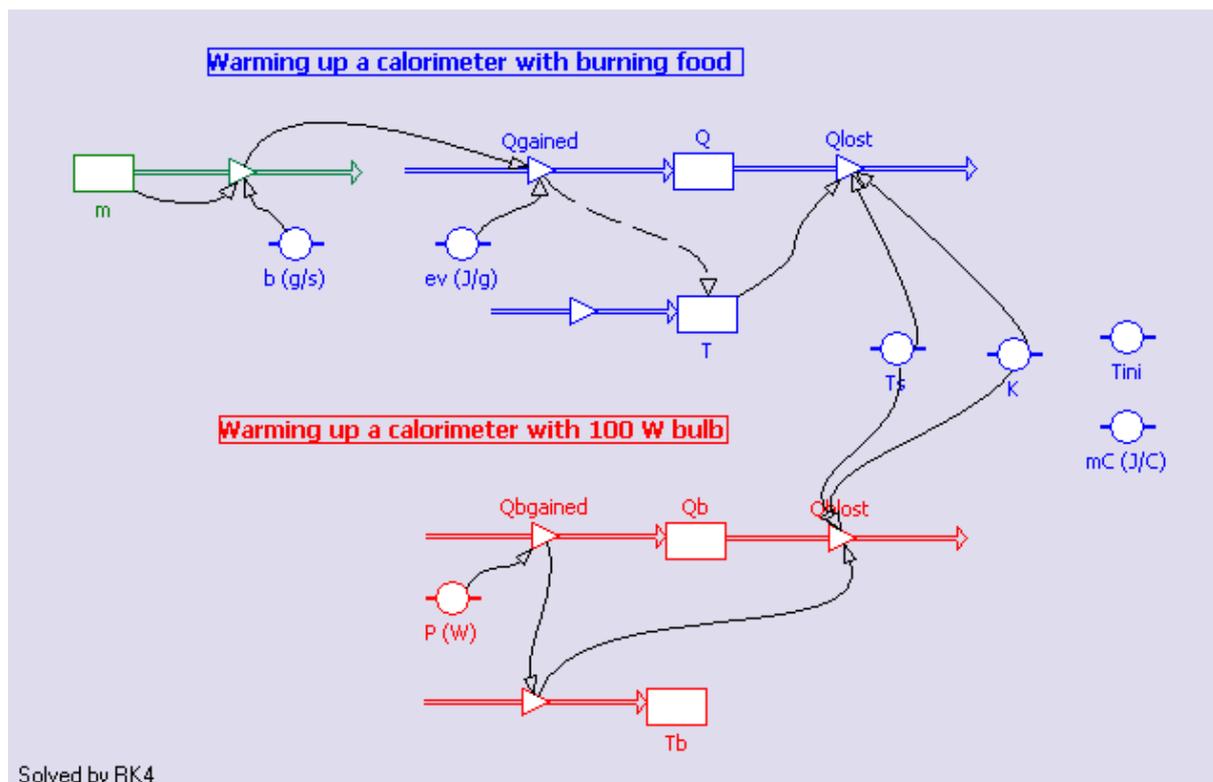
T_s is the temperature of the surroundings, and K is a constant of proportionality.

4. The temperature change depends upon the net heat transfer and the thermal capacity of the calorimeter and temperature probe. The resulting change of temperature ΔT is calculated by summing heat lost and heat gained:

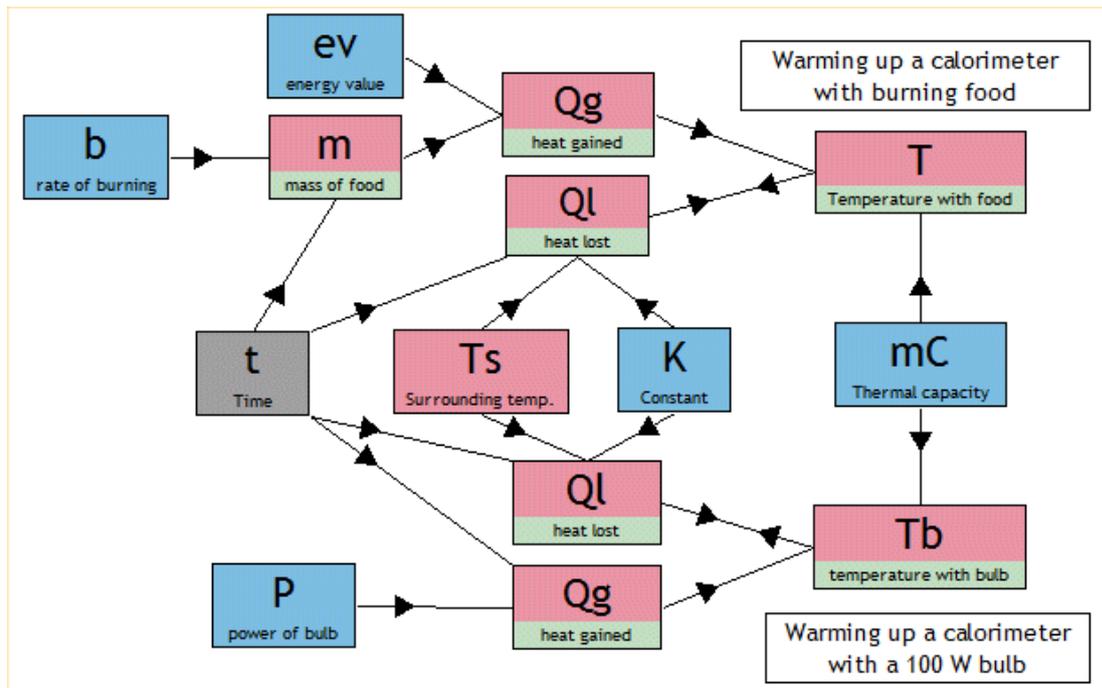
$$\Delta T = \frac{(\Delta Q_{gained} + \Delta Q_{lost})}{mC} \text{ where}$$

mC is the thermal capacity of the calorimeter.

In the model it is also assumed that the system is isolated; no energy can flow into or out of it.



Model for Activity 6 in Coach 6



Model for Activity 6 in Simulation Insight

Activity 7. Model of liquid evaporation

The model in this activity simulates the data-logging experiment of Activity 2. The model performs a sequence of calculations, aimed at calculating small changes of *temperature* and *mass* of liquid during a short interval of *time*. Repetition of the calculations results in a set of data showing the temperature and mass of liquid varying with time. The model shows how the calculations are broken down into a few simple steps, each using a basic principle in physics.

The model assumes these physical concepts:

1. The rate of evaporation of the liquid contained in the tissue paper around the temperature probe varies in proportion to the mass of liquid remaining. This is represented in the formula which calculates the rate of change of liquid mass during a time interval Δt is:

$$\frac{\Delta m}{\Delta t} = -V * m$$

where m is the mass of liquid remaining, and V is a constant representing the volatility of the liquid.

2. The rate of loss of heat due to evaporation varies in proportion to the rate of evaporation of the liquid and its latent heat of vaporisation. This assumption is represented in the formula:

$$\frac{\Delta Q_{lost}}{\Delta t} = L \frac{\Delta m}{\Delta t}$$

where ΔQ_{lost} is the heat lost when mass Δm evaporates, and L is the latent heat of vaporisation of the liquid.

3. The rate of heat gained from the surroundings varies in proportion to the difference in temperature between the liquid and its surroundings. This is represented in the formula:

$$\frac{\Delta Q_{\text{gained}}}{\Delta t} = K \cdot (T - T_s)$$

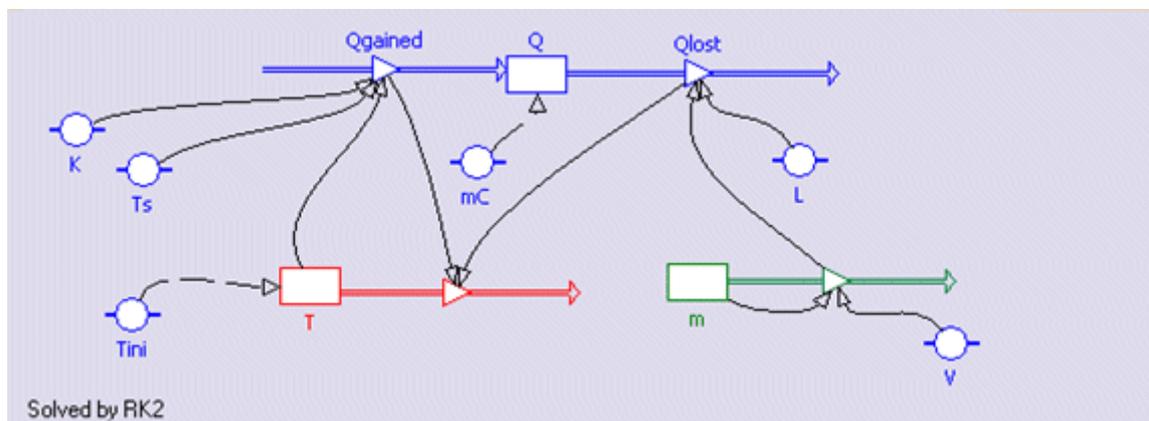
where T_s is the temperature of the surroundings, and K is a constant of proportionality.

4. The temperature change depends upon the net heat transfer and the thermal capacity of the liquid and temperature probe. The resulting change of temperature ΔT is calculated by summing heat lost and heat gained:

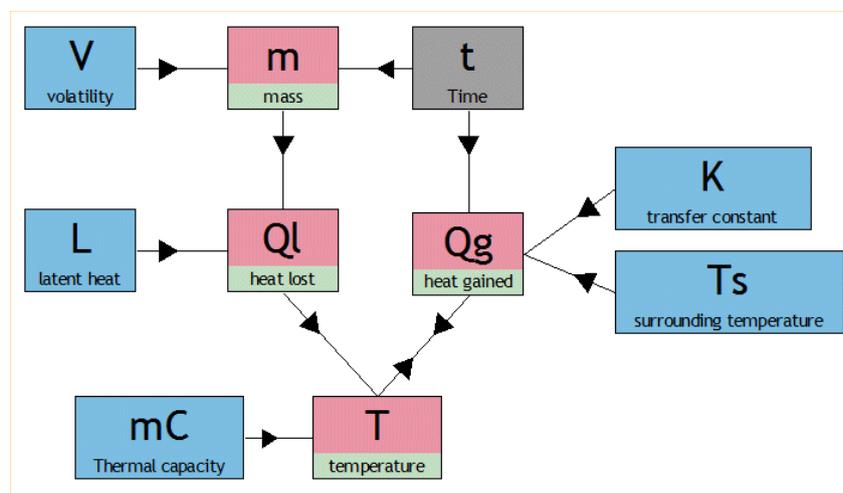
$$\Delta T = \frac{(\Delta Q_{\text{gained}} + \Delta Q_{\text{lost}})}{mC}$$

where mC is the thermal capacity of the temperature probe.

Since the mass of liquid in the tissue paper is very much smaller than that of the temperature probe, its thermal capacity is ignored compared with that of the probe.



Model for Activity 7 in Coach 6



Model for Activity 7 in Insight iLOG Simulation Insight

4. Teaching approaches

The five activities presented here offer distinctive but complementary insights into the science involved in this topic. For the activities to be effective for teaching and learning, it is helpful for teachers to consider two types of skills in using the software tools:

- **Operational skills** which concern the manipulation of the computer hardware and knowledge of the features in the software.
- **Procedural skills** which concern the manner in which the software tools are employed in the lesson context for the purpose of achieving learning benefits. A dominant aspect of these skills is the development of an inquiring approach to the analysis and interpretation of data and to making links with previous knowledge.

Such skills are important for the preparation of pupils for the activities, and the activity sheets below each contain indications of the skills needed for the particular activity.

For the teacher, there are further *pedagogical skills* which contribute to the effectiveness of the activities:

1. Clarity of learning objectives for each activity.
2. Understanding of the special value of the ICT method and exploiting its full potential in purposeful ways.
3. To manage the activity in a way which promotes 'appropriate' rather than 'indiscriminate' use of ICT.

4. To integrate the learning from each activity to develop pupils' understanding of the topic.

The development of the last of these is a particular aim of the ICT for ICT Project, and the activities presented below have been specially selected to illustrate how integration might be achieved. Comparisons of the observations and results of each activity form a central role in this integration process. For example:

- Compare the two sets of data collected in the first data-logging experiment; the data obtained with the electric lamp is used to calibrate the data from burning the potato crisp;
- Use the results from the two data logging experiments (1. burning, 2. evaporation) to contribute to a discussion about human respiration and the energy balance maintained by the human body;
- Use the simulations to amplify the discussion of respiration and energy;
- Compare data from the model with experimental data;
- Compare the data from the video-recorded experiment, data-logging experiments and the models.

In these, the graph is a key tool in facilitating comparisons and interpretations and skills with graphs generally provide a common thread in exploiting ICT for IST activities.

Teachers will usually have their preferred sequence of teaching themes involving, demonstrations, explanations, class experiments, but the table below suggests a suitable sequence exemplifying a logical development of concepts. The right hand column shows how the activities in this module may be chosen to enhance the teaching sequence.

Teaching sequence	ICT for IST Activities
Oxidation liberates energy in a fuel *Experiments with burning fuels to find energy content Food is fuel to the human body <ul style="list-style-type: none"> • Experiment burning an item of food in a quasi calorimetric bomb 	D-Logging: 1. Energy content of food Simulation: 4. Energy content of food Model: 6. Energy content of food
Heat energy emitted from a human body comes from 'burning' food in the process of 'Aerobic respiration' <ul style="list-style-type: none"> • Experiment to measure heat emitted from human body in insulated box Calculations of energy balance (optional)	D-Logging: 3. Energy emission from human
Heat energy is lost when a liquid evaporates <ul style="list-style-type: none"> • Experiment to measure the temperature of an evaporating liquid 	D-Logging: 2. Evaporation of a liquid Model: 7. Evaporation of a liquid
Thermal energy changes in the human body	Simulation: 5. Body evaporation Body convection, Body energy balance

The non-computer experiments (*) are not described here, since their details are well established in conventional teaching schemes and text books.

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The management of the classroom setting also has an important influence on the successful integration of activities. When access to computer equipment is scarce it is likely that the teacher will wish to present the activity as a demonstration in a didactic manner. In this mode, the teacher can give strong guidance to pupils' thinking about the comparisons between the activities. Alternatively, pupils could perform the activities in small groups of three or four pupils, each group engaged on a different activity. Integration might be achieved by each group making a presentation of their results to the whole class. In chairing these presentations the teacher can prompt discussion of the significant findings of each group.

It is worth considering that all the activities may be used in a variety of learning contexts; it is not necessary to consider their mode of use exclusively as a first experience of the topic. For example, the simulations could be used to prepare thinking about the video-recorded experiment. Similarly, the evaporation model could be used either before the data-logging experiment to prepare thinking about the experiment, or it could be used as a means of extending the

investigation, or as a revision exercise, or for distance learning. Although the activities have been designed to provide complementary experiences, it is not essential to use all of them; two, three or four activities might be chosen according to how well they suit the needs of teachers and pupils in a particular context. In varying conditions between schools and within schools at different times of the year or different stages in the curriculum, needs and appropriateness are likely to change; for example, data-logging equipment might not be available at the time of need, an individual pupil might need a revision or extension activity, an enrichment activity might be required to occupy some spare time, a quick activity might be needed if time is scarce. The overlapping features, such as graphical presentation, between the activities allows them to be used to a certain extent as alternatives, but their distinctive features also allow them to be used as complements to each other. The table below summarises the distinctive potential learning benefits of each. It is a useful guide to the special value of each ICT activity.

Activity	Potential learning benefits, 'ICT value'
Data-logging 1. Burning 2. Evaporation 3. Energy in food	<p>Whole process of heating or cooling may be observed without interruption.</p> <p>Graph of temperature changes is displayed during experiment</p> <p>Results may be related to visual observations (e.g. the times for the beginning and end of burning)</p> <p>Graph analysis tools facilitate detailed investigation of data.</p>
Simulation 4. Energy content of food 5. Body evaporation Body convection, Body energy balance	<p>Animated graphics provide a visual stimulus for thinking about the roles of evaporation and convection in maintaining temperature balance in the body.</p> <p>The complexity of controlling several processes associated with heat generation and loss within the human body may be appreciated.</p> <p>The simulation of the burning crisp may be used to brief students for performing the data-logging experiment.</p>
Modelling 6. Energy content of food 7. Evaporation of a liquid	<p>The model demonstrates how the relevant physical principles can be expressed in simple stages using mathematical formulae.</p> <p>The model calculates temperature data which can be compared with data obtained from the real experiment (data-logging) on evaporation.</p> <p>The effect of altering parameters such as surrounding temperature, mass of substance, thermal capacity and latent heat capacity may be investigated.</p>

5. Resources for Student Activities

USING INSIGHT SOFTWARE

Activity	Software program	Files available
1. Data-logging	Insight iLOG	1. 'Energy value set up' 1. 'Energy value data' (sample data)
2. Data-logging	Insight iLOG	2. 'Evaporation set up'. 2. 'Evaporation data' (sample data)
3. Data-logging	Media player Insight iLOG	'Body heat expt' (Video recording) 3. 'Human body data' (Sample data)
4. Simulation	Simulation Insight	4. 'Energy value expt'
5. Simulation	Simulation Insight	5a. 'Body convection' 5b. 'Body evaporation' 5c. 'Body energy balance'
6. Modelling	Simulation Insight or Insight iLOG	6. 'Energy value model'
7. Modelling	Simulation Insight or Insight iLOG	7. 'Evaporation model'

USING COACH SOFTWARE

Activity	Software program	Files available
1. Data-logging	Coach 6	01.Energy content of food.cma (activity file) 01. Energy content of food.cmr (result file with exemplary data)
2. Data-logging	Coach 6	02.Evaporation of liquid.cma (activity file) 02. Evaporation of liquid.cmr (result file with exemplary data)
3. Data-logging	Coach 6	03. Energy emitted by a human body.cma (activity file) 03. Energy emitted by a human body.cmr (result file with data analysis) 03a. Human in the box.cmr (result file with exemplary data) 03a. 100W bulb in the box.cmr (result file with exemplary data)
6. Modelling	Coach 6	06. Model of energy content of food.cma (activity file)
7. Modelling	Coach 6	07. Model of liquid evaporation.cma (activity file)

EQUIPMENT AND MATERIALS FOR ACTIVITIES 1 AND 2 (DATA-LOGGING)

- Computer
- Software – *See table above*
- Interface (data-logger)
- Temperature sensor
- Copper calorimeter
- Tripod and heat resistant mat
- Packet of potato crisps
- Tongs
- 100W bulb in holder
- Matches, Adhesive tape, Pipette, Filter paper

C. Student Activities ●●

ACTIVITY 1. ENERGY CONTENT OF FOOD

Learning Objectives:

1. To measure the rise in temperature of a copper calorimeter when an item of food is burnt inside it.
2. To calibrate the calorimeter for heat transfer using a standard electric bulb.
3. To calculate the amount of heat given out by the item of food when burnt.

APPLIED ICT TECHNOLOGY:
DATA LOGGING

STUDENT LEVEL:
AGE 14-17

RECOMMENDED SETTINGS:
STUDENT ACTIVITY IF
ENOUGH EQUIPMENT IS
AVAILABLE, OTHERWISE
TEACHER DEMONSTRATION

Operational Skills:

- Connecting sensors and interfaces
- Choosing logging parameters
- Starting and finishing real-time logging
- Using the cursor tools for obtaining measurements from the graph

Procedural Skills:

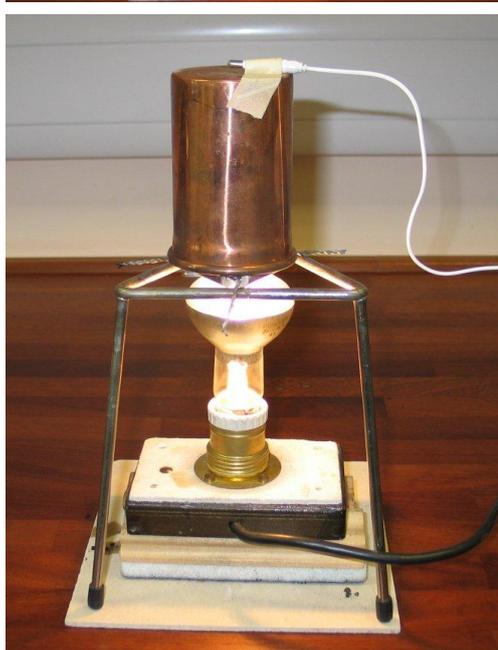
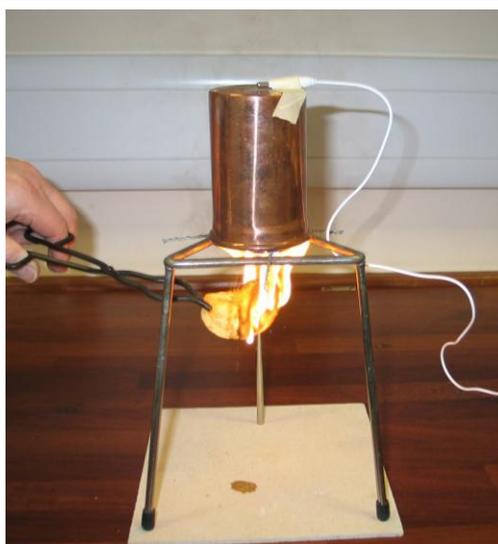
- Evaluating measurement quality
- Analysing data using graph
- Reading values/slopes

Materials:

- Interface (data-logger)
- Temperature sensor
- Copper calorimeter on a tripod on a heat resistant mat
- Handling tongs
- Food item (potato crisp)
- 100W bulb in holder (reflector type)
- Matches
- Adhesive tape

Activity method:

1. Place the calorimeter in an inverted position on the tripod.
2. Use adhesive tape to secure the temperature probe on the top of the calorimeter, ensuring that it makes good thermal contact.
3. Set the data logging software to record temperature for about 2 minutes. Start recording.
4. Grip the potato crisp in the tongs and carefully light it with a match. Immediately hold the burning crisp under the calorimeter.
5. Observe the Temperature vs Time graph.
6. Save your data.
7. Allow the calorimeter to cool down to room temperature. Since you are interested in the total heat given out during burning, the calorimeter needs to be calibrated so that the temperature rise may be used for calculating the heat output. This is done by repeating the experiment using a standard mains electric spot lamp in the place of the burning food.
8. Switch off the lamp when the temperature reaches the maximum temperature of the first experiment.
9. Overlay the new Temperature vs Time graph on the previous graph.



Analysing activities (using *Insight iLOG*):

1. *Sweeping cursors*
After the experiment, the real-time experience can be re-lived to a certain extent using the graph cursors and bar display: Drag the X cursor slowly across the screen, and note how the bars grow and shrink in the same manner as the changes of the temperature values during the experiment, creating an 'action replay' effect.

2. *Add captions to graph*

Annotate each graph to indicate the experiment which produced the line: the food experiment or the bulb experiment.

3. *Take readings from the graph*

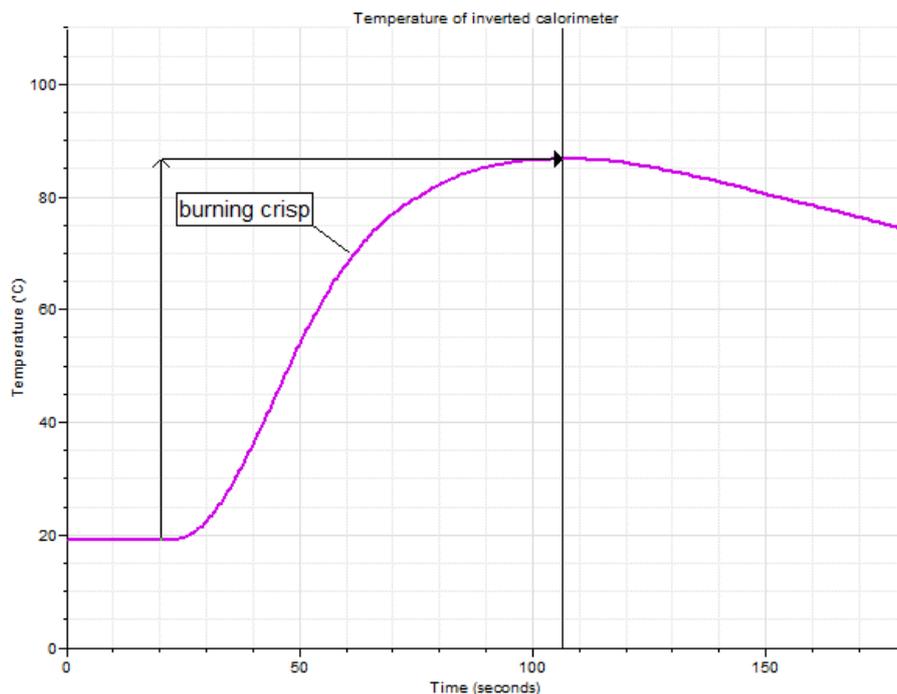
Record the highest temperature reached in the potato crisp experiment. Use the *Interval* graphing tool to measure how many seconds it took the mains bulb to reach the same temperature. Calculate the energy supplied using $\Delta Q = 100 \times \text{interval}$.

4. *Time measurements*

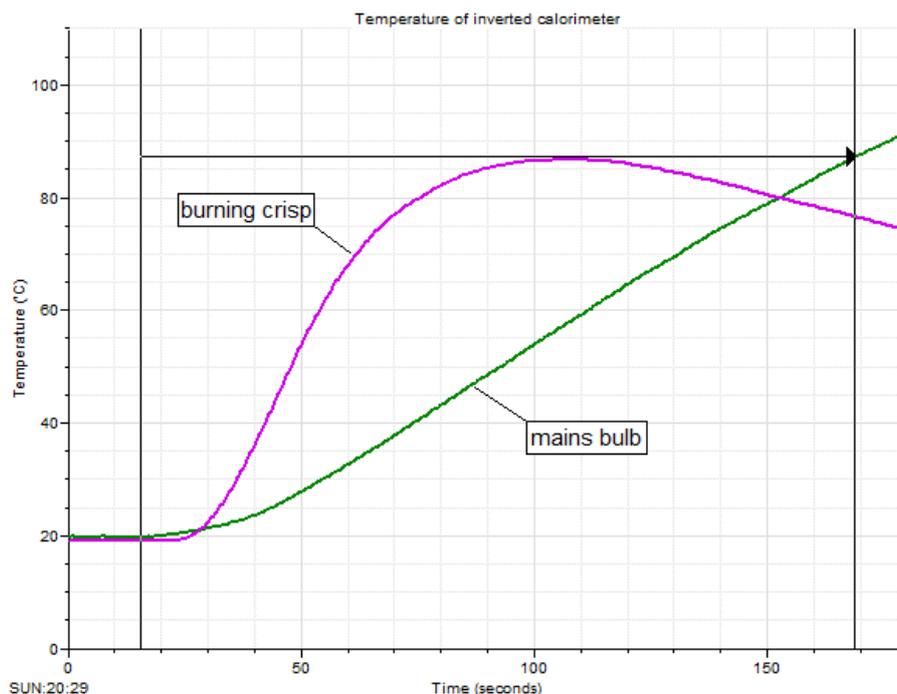
Find the time period for which the potato crisp was burning.

5. *Measure rate of change*

Use the *Rate* and *Gradient* graphing tools to measure and compare the rates of warming up in each experiment. Could these values be used to calculate the energy in the food?



Burning crisp: Reading highest temperature and time for burning



Mains bulb: Time to reach highest temperature with crisp

Questions and Assignments (using *Coach 6*):

- Overlay the new Temperature vs Time graph on the previous measurement graph (use the *Import Background Graph* option.)
- Record the highest temperature reached in the experiment.
- Find out how many seconds it took for the mains bulb to reach the same temperature.
- Calculate the energy supplied by the bulb by using $\Delta H (J) = \text{Power of the bulb } (W) \times \text{time interval}(s)$.
- Determine the amount of heat produced when the crisp was burnt.
- Determine the energy content of the crisp per gram.
- Measure and compare the rates of warming up in each experiment. Could these values be used to calculate the energy in the food?
- Repeat the experiment with other fast food products. Which food sample produces the most energy? Compare the results with the values of energy content displayed on the packets.
- Obtain the data for the energy content of a range of food products by recording the values displayed on the side of the packet. Make a list of the results and sort them in order from high to low energy content.

Analysing activities (using *Coach 6*):

Students measure the temperature change of copper calorimeter heated by burning a food item and by a (60W) bulb. Based on the temperature measurements, calculate the energy released (J) from the burnt food item. If you know the mass (in g) of the burnt item (the final mass – initial mass) you can calculate the energy content per g (J/g).

Compare the energy values of different food with values from the experiment. Usually, on the packaging, this value is quoted for 100 g of the food.

(Although joules are the SI units for energy, it may be approached in terms of calories when discussing food. Most students will be more familiar with thinking about calorie content than joule content of foods!)

FURTHER WORK - IDEAS FOR RELATED AND EXTENDED ACTIVITIES

1. Repeat the experiment with other fast food products and compare the results with the values of energy content displayed on the packets.
2. Obtain the data for the energy content of a range of breakfast cereals by recording the values displayed on the side of the packet. Make a list of the results and sort them in order from high to low energy content.

ACTIVITY 2. EVAPORATION OF LIQUID

Learning Objectives:

1. To measure the fall in temperature of a liquid when it evaporates.
2. To understand the factors which influence the cooling effect of evaporation.

APPLIED ICT TECHNOLOGY:
DATA LOGGING

STUDENT LEVEL:
AGE 14-17

RECOMMENDED SETTINGS:
STUDENT ACTIVITY IF
ENOUGH EQUIPMENT IS
AVAILABLE, OTHERWISE
TEACHER DEMONSTRATION

Operational Skills:

- Connecting sensors and interfaces
- Choosing logging parameters
- Starting and finishing real-time logging
- Using the cursor tools for obtaining measurements from the graph

Procedural Skills:

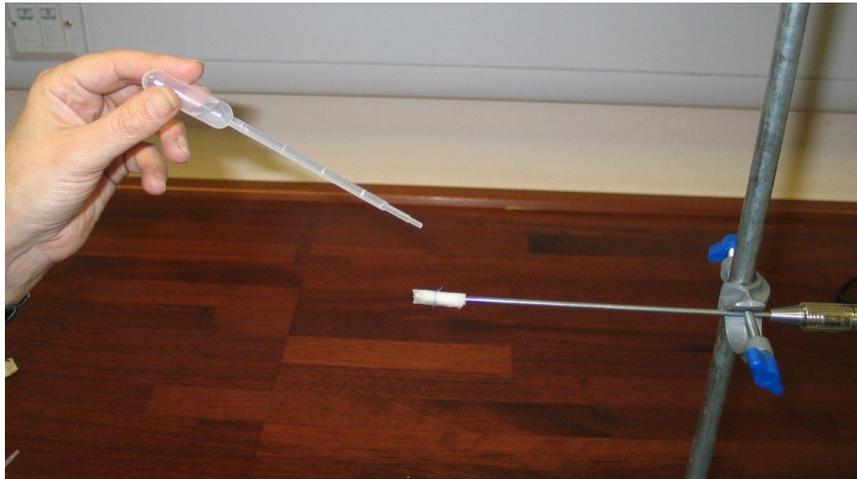
- Evaluating measurement quality
- Analysing data using graph
- Reading values/slopes

Materials:

- Interface (data-logger)
- Temperature sensor
- Tissue paper or cotton wool
- Pipette

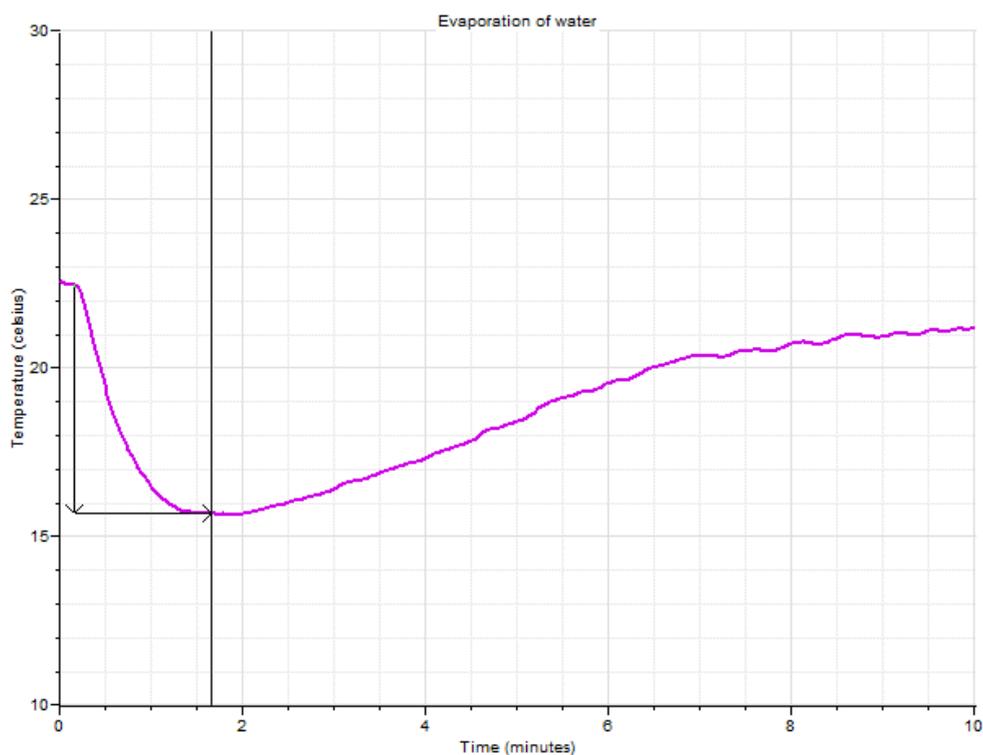
Activity method:

1. Assemble the temperature probe in the stand with a piece of tissue paper or cotton wool wrapped around its tip (secured by a small rubber band).
2. Fill a pipette with water.
3. Set the data logger to record temperature for 15 minutes.
4. Use the pipette to soak the tissue paper with water.
5. Observe the Temperature vs Time graph.



Analysing activities (using *Insight iLOG*):

1. *Magnify the graph*
Use the Zoom or scaling tool to increase the vertical scale so as to magnify the change of temperature.
2. *Sweeping cursors*
After the experiment, the real-time experience can be re-lived to a certain extent using the graph cursors and bar display: Drag the X cursor slowly across the screen, and note how the bars grow and shrink in the same manner as the changes of the temperature values during the experiment, creating an 'action replay' effect.
3. *Take readings from the graph*
Record the lowest temperature reached in the experiment.
Use the *Change* graphing tool to measure the maximum fall in temperature.
4. *Time measurements*
Use the *Interval* graphing tool to measure how many seconds it took the for the lowest temperature to be reached.



Taking readings of *Change* and *Interval*.

Questions and Assignments (using *Coach 6*):

- How quickly does the liquid cool?
- How long does the cooling last?
- Record the lowest temperature reached in the experiment.
- How many seconds it took for the lowest temperature to be reached?
- Find out the maximum fall in temperature (use the Slope option).
- Do different liquids cool at different rates?
- Does the cooling depend on the amount of liquid?
- Does the cooling depend upon the temperature of the air?

FURTHER WORK - IDEAS FOR RELATED AND EXTENDED ACTIVITIES

1. Repeat the experiment with other volatile liquids and compare the rates of cooling. By comparing different alcohols (general formula $C_nH_{2n+1}OH$ for example series: methanol CH_3OH , ethanol C_2H_5OH , 1-propanol C_3H_7OH and 1-butanol C_4H_9OH) the rates of cooling can be related to the strength of intermolecular forces of attraction.

ACTIVITY 3. ENERGY EMITTED BY A HUMAN BODY

Learning Objectives:

1. To measure the rate of heat emitted by the human body

Operational Skills:

- Using the cursor tools for obtaining readings from the graph

Procedural Skills:

- Relate the graphs to the theory of respiration

Materials needed for repeating the experiment:

- Interface
- A thermally insulated and tight box
- Sensors: Temperature, Relative humidity, CO₂ sensor (optional O₂ sensor)

Activity method:

The experiment may be reproduced in the school laboratory, but in view of the unusual apparatus, the video recording conveniently allows the experiment to be studied and results analysed.

The video shows an experiment in which a person sits inside a thermally insulated box for a few minutes. During that time a data-logger records measurements of temperature, humidity and carbon dioxide concentration inside the box. Afterwards a similar experiment is conducted, but with an electric bulb instead of a person inside the box.

By comparing the temperature increases in each experiment, the rate of heat emitted by the person may be calculated.



APPLIED ICT TECHNOLOGY:
DATA-LOGGING AND VIDEO
RECORDING

STUDENT LEVEL:
AGE 15-17

RECOMMENDED SETTINGS:
STUDENT ACTIVITY OR
TEACHER-LED CLASS
DISCUSSION

Questions and Assignments:

- What happens during the experiment?
- Why is the temperature increasing?
- Where does the carbon dioxide come from?
- Where does the humidity come from?
- What is changing most rapidly?
- How does everything relate?

Temperature measurements:

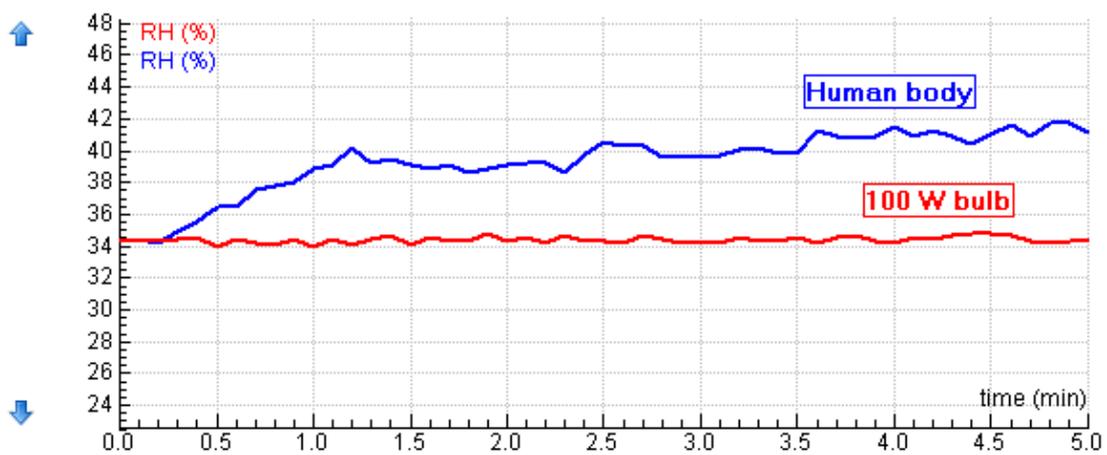
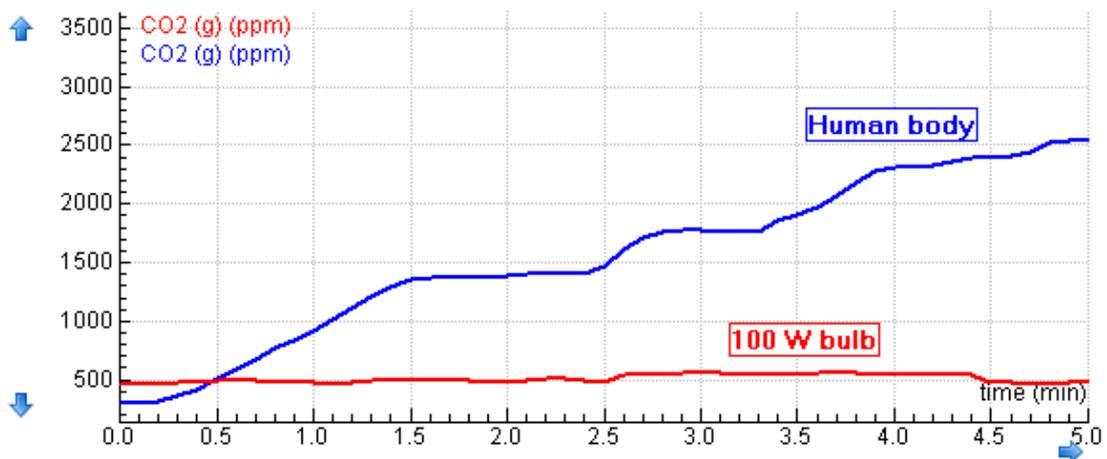
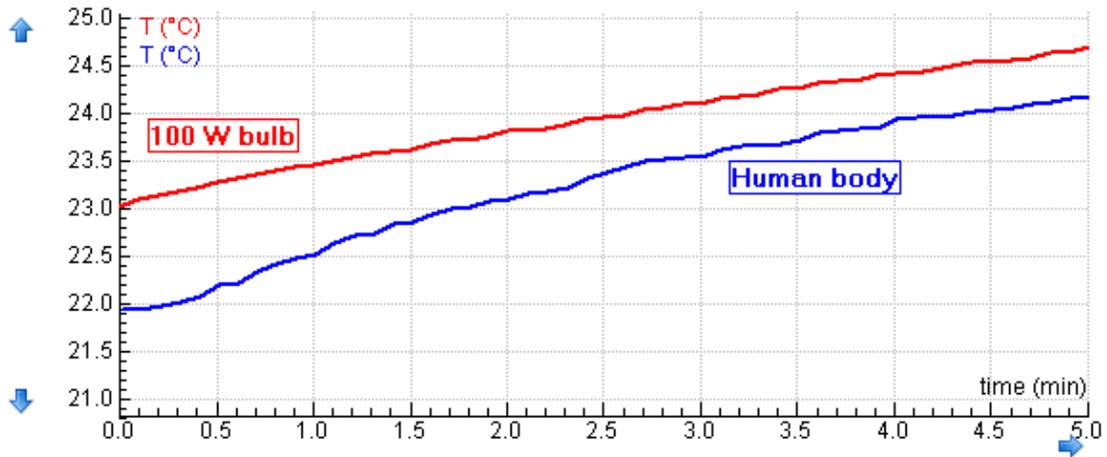
- Make a note of the *temperature* reached after 5 minutes when the person is in the box.
- Note the *time* taken to reach the same temperature with the electric bulb in the box.
- Calculate the amount of heat given out by the bulb during this time using:
Heat (in joules) = **power** (in watts) x **time** (in seconds)
This is the same as the amount of heat emitted by the person during 5 minutes.
- Calculate rate of heat emission using:
Rate of emission (in watts) = **Heat** (in joules) / **time** (in seconds)

CO₂ and humidity measurements:

- Take readings of the *increase* in relative humidity and the *increase* in CO₂ concentration during the 5 minute period of the experiment. Discuss the reasons for these increases in relation to the process of aerobic respiration in the human body.
- Calculate the amount of emitted CO₂ in mol.
- Calculate the amount of glucose metabolised during the experiment and the consequent rate of heat generation in the human body.
- Calculate the power required for water evaporation.
- Discuss calculated results. Is energy of the body balanced?

Analysing activities:

Using the sample data, the graphs may be analysed and calculations performed.



Sample data from video recording:

Volume of chamber: 1 m³

Duration of experiment: 300 s (5 minutes)

Increase in temperature: 2.3 degrees Celsius, raising from 21.9 C to 24.2

Increase in CO₂ concentration: 2259 ppm

Increase in Relative humidity: 6.9 %

Time for 100 W bulb to increase chamber temperature by 2.3 deg C: 418 s (6.97 minutes)

Temperature versus time graphs allow to assess the power from the rate of increase of the temperature, shown by the slopes of curves

Calculation of rate of heat emission

Heat emitted by 100W bulb in 418 seconds = 100 * 418 = 41800 J

Rate of heat emission by human body over 300 seconds = 41800 / 300 = 139 W

Emitted CO₂ in mol:

1 ppm (part per million) corresponds to 1 cm³ in 1 m³. Since the volume of the box in the experiment is 1 m³, the increase in CO₂ corresponds to a volume $\Delta V = 2259 \text{ cm}^3 = 2.259 \text{ litre}$.

At 273 K (0°C) at 1 atm pressure, 1 mole of gas has a volume 22.4 litre (V₀).

It follows, at 293 K (20°C) at 1 atm pressure, 1 mole of gas has a volume given by

$$V_t = V_0 \frac{T}{T_0} = 22,4 \frac{298}{273} = 24,45$$

Thus 1 litre contains 1 / (24.45) mol

Hence, 2.259 litre contains 2.259 / 24.45 = 0.092 mol of CO₂

Combustion of glucose:

For the oxidation of glucose, $\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O}$ one mole of glucose being burned yields 6 moles of CO₂. Therefore 0.092 mol of CO₂ emitted in the experiment originates from 0.015 mol of glucose being burned.

The Heat of Combustion (enthalpy) of glucose is 2812 kJ/mol

The yielded heat is therefore $\Delta H_b = 0.015 * 2812 = 42.2 \text{ kJ}$.

Power of combustion is $P = 42200 \text{ J} / 300 \text{ s} = 141 \text{ W}$

Energy for water vaporisation:

Relative Humidity change $\Delta RH = 6.9\%$

Saturated vapour pressure of water at 278 K is 3167 Pa

Thus, change of water vapour pressure $\Delta p = 6.7\% * 3167 \text{ Pa} = 218 \text{ Pa}$

Number of moles emitted:

$$\Delta n_{H_2O} = \frac{\Delta p V}{RT} = \frac{212 \text{ Pa} \times 1 \text{ m}^3}{8.31 \text{ J/mol/K} \times 298 \text{ K}} = 0.0856 \text{ mol}$$

The Latent heat of Vaporisation of water is 44 kJ/mol

Thus, heat required is $\Delta H_w = 0.0856 \text{ mol} * 44 \text{ kJ/mol} = 3.766 \text{ kJ}$

Hence, power required for water evaporation = $3766 / 300 = 12.5 \text{ W}$

Comparison of calculated results

According to the measurements of CO_2 emission, the metabolism of glucose in the human body generated 141 W. The emission of water vapour required 12.5 W, leaving 128.5 W to be emitted as heat. Within experimental error this compares well with the calibration value of 139 W obtained with measurements with the bulb.

A full discussion of the background theory to the experiment and explanation of the calculations may be found in the paper by Mats Areskoug 'The Power of the Human Body' provided in Appendix 2.

ACTIVITY 4. SIMULATING THE 'ENERGY CONTENT OF FOOD' EXPERIMENT

Learning Objectives:

1. To understand the energy transfers which cause changes of temperature of the calorimeter in the data-logging experiment 1.
2. To understand the use of the mains bulb as a means of calibrating temperature changes of the calorimeter to determine heat transfer.

APPLIED ICT TECHNOLOGY:
SIMULATION

STUDENT LEVEL:
AGE 14-17

RECOMMENDED SETTINGS:
STUDENT ACTIVITY OR
TEACHER-LED CLASS
DISCUSSION

Operational Skills:

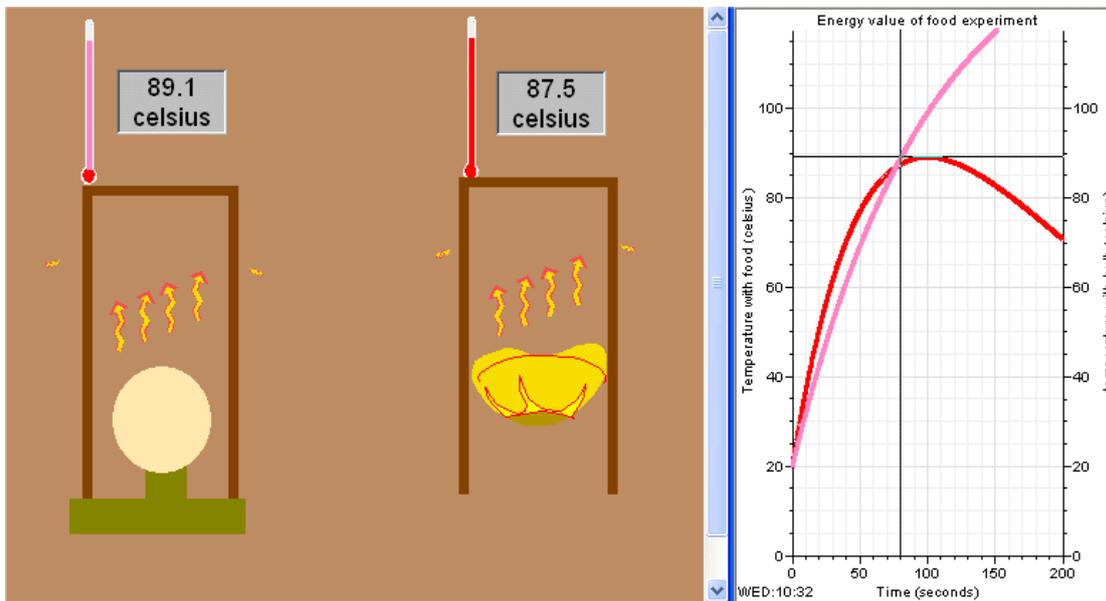
- Using the software controls for running the simulation
- Using the cursor tools for obtaining readings from the graph

Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph
- Describe observations and link these with theoretical explanation

Activity method:

1. Open the *Insight* file 'Energy value expt'.
2. Look carefully at the simulation window and notice that it shows two experiments which will run at the same time. The experiment on the left shows a mains bulb heating up the inside of the calorimeter. The experiment on the right shows an item of food being burnt inside the calorimeter.
3. Look at the graph and notice that this shows temperature of the calorimeter against time. By comparing the two graphs, it is possible to calculate the amount of heat produced by the burning crisp.



Analysing activities (using *Simulation Insight*):

1. Sweeping cursors

After running the model and observing the heating and cooling, replay the changes using the graph cursors and bar display: Drag the X cursor slowly across the screen, and note how the bars grow and shrink in the same manner as the changes of the temperature values during the experiment, creating an 'action replay' effect. Observe that the temperature begins to fall when the crisp has finished burning.

2. Add captions to graph

Annotate the point on the graph to show where the crisp stopped burning.

3. Take readings from the graph

Make a note of the *maximum temperature* reached when the crisp burns. Find the *time* taken for the bulb to reach the same temperature.

Calculate the amount of heat given out by the bulb during this time using:

$$\mathbf{Heat} \text{ (in joules)} = \mathbf{power} \text{ (in watts)} \times \mathbf{time} \text{ (in seconds)}$$

This is the same as the amount of heat produced when the crisp has completely burnt.

ACTIVITY 5. SIMULATING ENERGY CHANGES IN THE HUMAN BODY

Learning Objectives:

1. To understand the factors which affect the loss of heat energy by the convection of air around the body.
2. To understand how sweating and evaporation allow the human body to lose heat.
3. To understand how food and exercise create heat energy in the body and how this needs to balance the body's losses of heat through convection and evaporation.

APPLIED ICT TECHNOLOGY:
SIMULATION

STUDENT LEVEL:
AGE 14-17

RECOMMENDED SETTINGS:
STUDENT ACTIVITY OR
TEACHER-LED CLASS
DISCUSSION

Operational Skills:

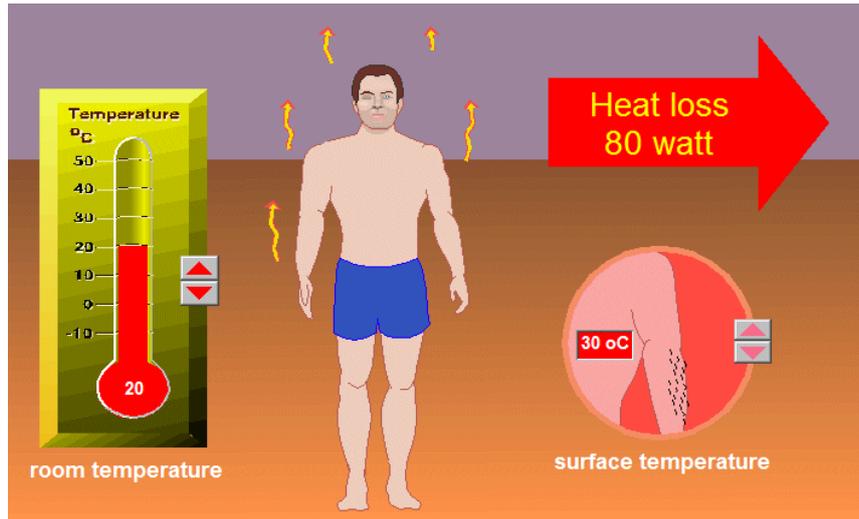
- Using the software controls for running the simulation
- Using the cursor tools for obtaining readings from the graph

Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph
- Describe observations and link these with theoretical explanation

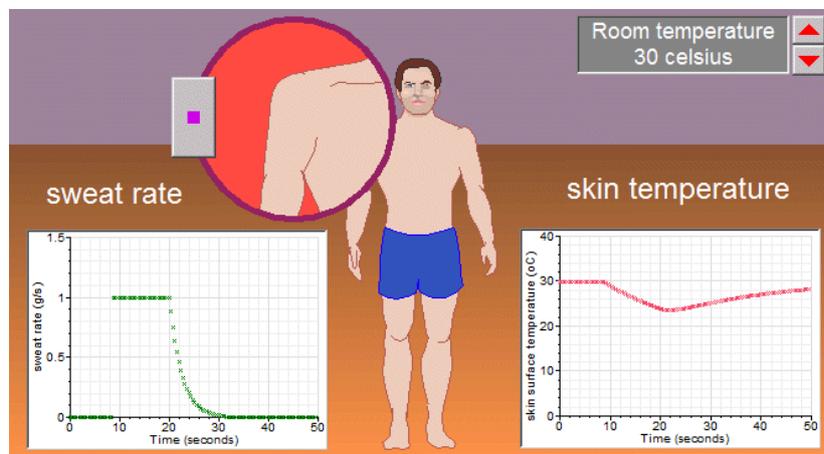
Investigating convection:

1. Open the *Insight* file 'Body convection'.
2. Adjust the value of room temperature and notice its effect on the rate of loss of heat. (If the heat loss shows as negative, this corresponds to the body gaining heat from the surroundings.)
3. Adjust the value of room temperature and notice its effect on the rate of loss of heat against time.
4. Adjust the value of skin surface temperature and notice its effect on the rate of loss of heat against time.
5. Make a simple rule which predicts the rate of loss of heat to the surroundings.
6. How would the rate of heat loss be affected by the wearing of clothes? Explain.



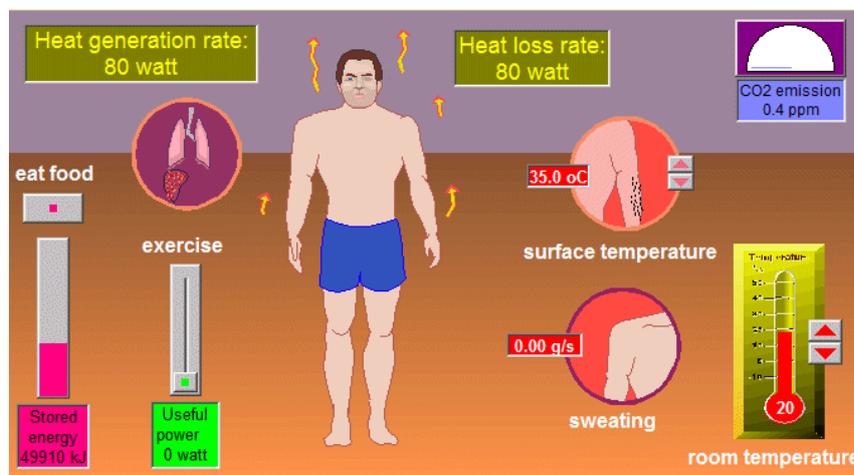
Investigating evaporation:

1. Open the *Insight* file 'Body evaporation'.
2. Click and hold on the sweat rate button to cause sweating to start. Notice the effect on the skin surface temperature whilst sweating occurs.
3. Think about why the sweat rate reduces when you release the button.
4. What causes the skin temperature to rise when sweating ceases?



Investigating heat changes in the human body:

1. Open the file 'Body energy balance'.
2. The simulation shows three processes which generate heat in the body: heart and lungs function, food metabolism and performing exercise.
3. Press the 'eat food' button for a few seconds and notice the effect on the energy stored. Describe the process in the body which generates heat from stored energy.
4. Set the 'exercise' on for a few seconds and notice the effect on the heat generated. Describe the process in the body which generates heat during exercise.
5. Adjust the value of room temperature and note its effect on the rate of heat loss. At what value of room temperature does the heat loss reduce to zero?
6. Adjust the value of skin surface temperature and note its effect on the rate of heat loss. How does the body control the skin surface temperature?
7. At what value of skin surface temperature does sweating begin? Notice the effect of sweating on the rate of heat loss.
8. Choose a value of room temperature. Then adjust the controls for food, exercise and skin temperature so that the rate of heat generated balances the rate of heat loss. The human body performs this process automatically. Can you control the functions as well as your body does?



ACTIVITY 6. MODEL OF ENERGY CONTENT OF FOOD

Learning Objectives:

1. To understand the energy transfers which cause changes of temperature of the calorimeter in the data-logging experiment 1.
2. To understand the use of the mains bulb as a means of calibrating temperature changes of the calorimeter to determine heat transfer.

APPLIED ICT TECHNOLOGY:
MODELLING

STUDENT LEVEL:
AGE 14-17

RECOMMENDED SETTINGS:
STUDENT ACTIVITY OR
TEACHER-LED CLASS
DISCUSSION

Operational Skills:

- Using the cursor tools for obtaining readings from the graph

Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph
- Describe observations and link these with theoretical explanation

Questions and Assignments:

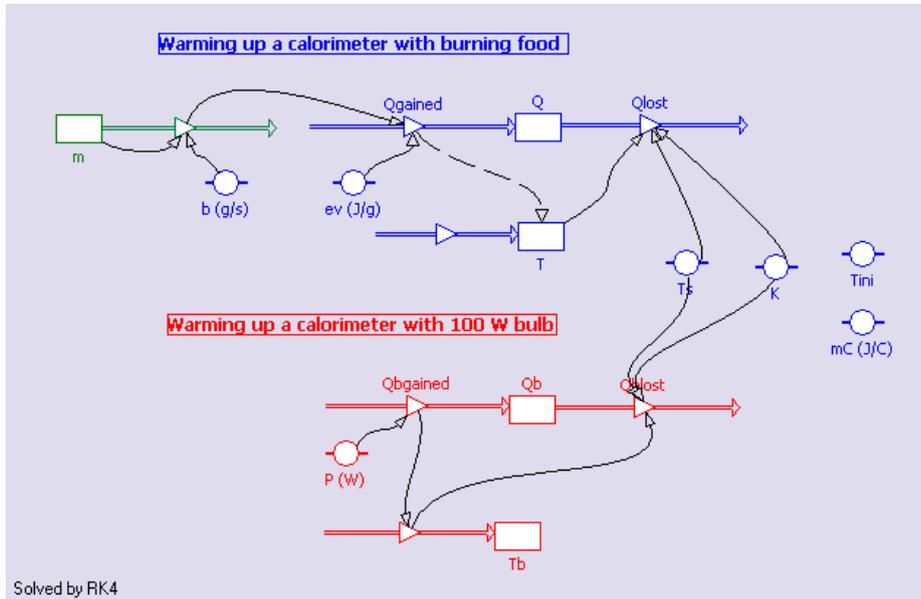
- Look at the model window below and distinguish two models which describe two different processes of heating the calorimeter; one burning an item of food and one by using an electric bulb.
- Compare these two models. What is the difference between them? Explain.
- Run your model and observe the shape of the Temperature vs Time graph and try to explain it?
- Annotate the point on the graph to show where the crisp stopped burning.
- Now look at the model and try to explain it.
 - How the rate of loss of heat of the temperature probe is calculated in each model?
 - How the rate of heat gained by the temperature probe is found in each model?
 - How the rate of food burning is calculated?
 - How the temperature change is calculated in each model?
- If the food would have more energy, the constant 'energy' would be larger. Change the value of this constant and run the model again. How does the graph differ from before?

- Compare the experimental data (recorded in Activity 1) with your model data.

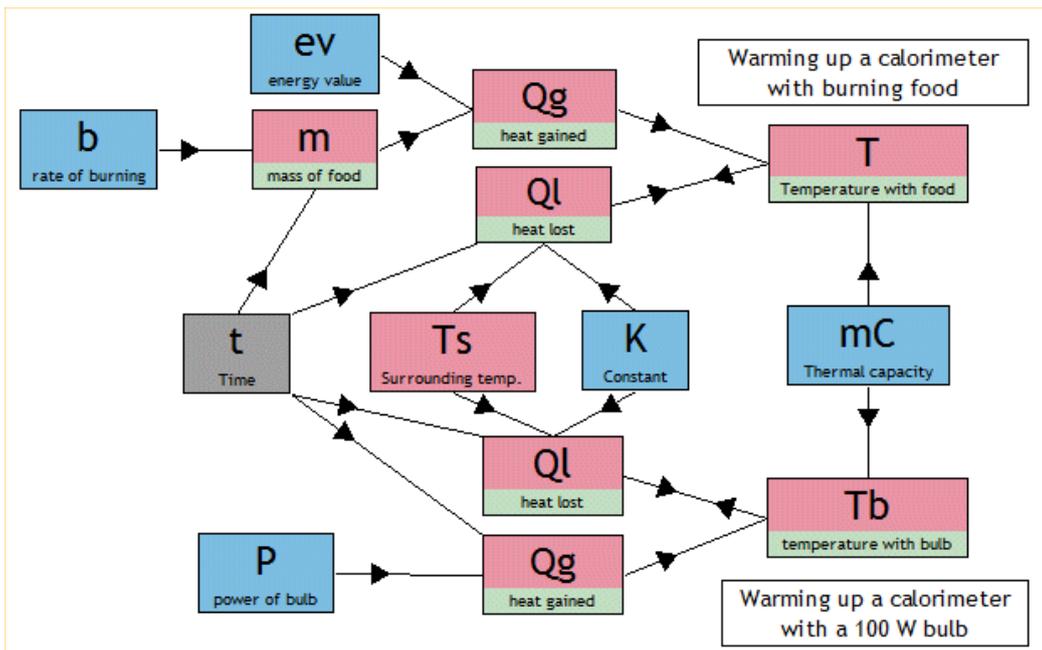
Analysing activities:

Students analyse the model and the resulting temperature graphs. They use the model to see what happens when a different food is burnt (by changing energy value parameter).

The model can be used to discuss the energy conversion and energy conservation issues.



Coach 6 Graphical model



Model in Simulation Insight

ACTIVITY 7. MODEL OF LIQUID EVAPORATION

Learning Objectives:

1. To understand that the rate of cooling during evaporation depends upon the mass of water present, its volatility and latent heat.
2. To understand that when the temperature of a body is lower than the temperature of its surroundings, the body receives heat from the surroundings.

APPLIED ICT TECHNOLOGY:
MODELLING

STUDENT LEVEL:
AGE 14-17

RECOMMENDED SETTINGS:
STUDENT ACTIVITY OR
TEACHER-LED CLASS
DISCUSSION

Operational Skills:

- Using the software controls for running the models
- Using the cursor tools for obtaining readings from the graph

Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph
- Describe observations and link these with theoretical explanation

Questions and Assignments:

- Run your model and observe the shape of the Temperature vs Time graph and try to explain it.
- How quickly does the liquid cool?
- How long does the cooling last.
- What was the lowest temperature reached?
- When the liquid stopped evaporating??
- Now look at the model and try to explain it.
 - How the rate of loss of heat of the temperature probe is calculated?
 - How the rate of heat gained by the temperature probe is found?
 - How the rate of evaporation is calculated?
 - How the temperature change is calculated?
- If the liquid were more volatile, the constant 'V' would be larger. Change the value of V to 0.2 and run the model again. How does the graph differ from before?
- Does the cooling depend on the amount of liquid? How would you simulate

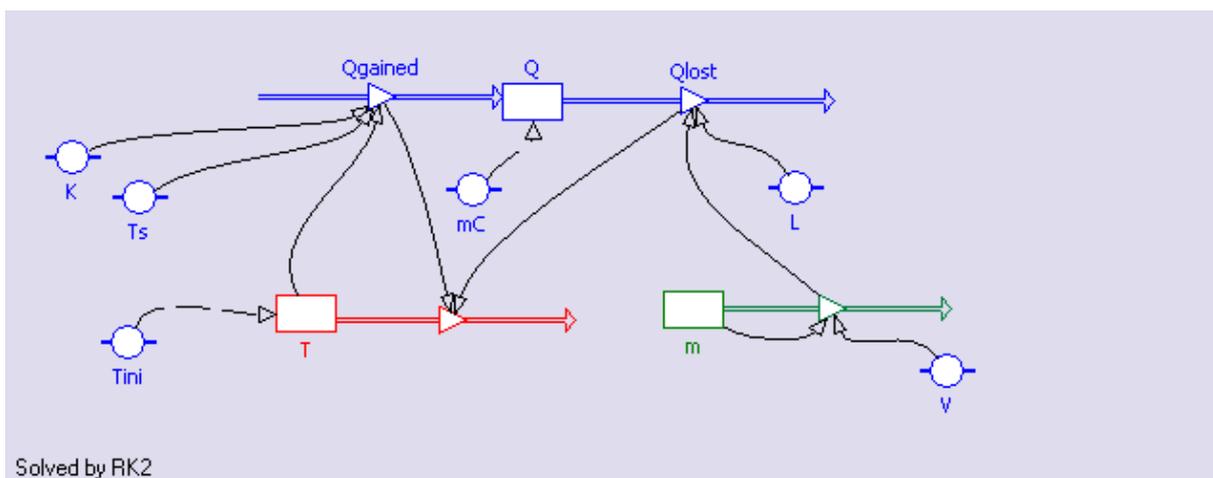
this?

- Does the cooling depend upon the temperature of the air? Use your model to check this.
- Compare your experimental data (recorded in Activity 02) to your model data.

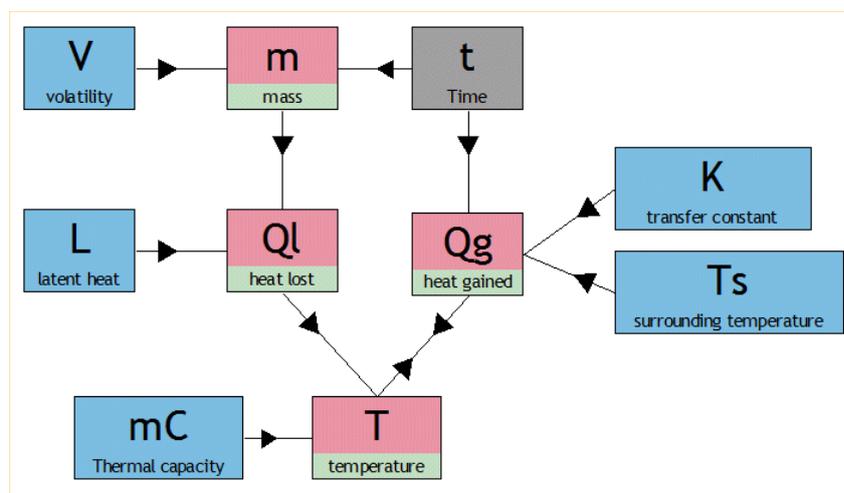
Analysing activities:

Students analyse the model and the resulting temperature graph. They use the model to see what happens when a different liquid evaporates (by changing energy value parameter).

The model can be used to discuss the energy conversion and energy conservation issues.



Model of evaporation in Coach 6



Model of evaporation in Insight iLOG and Simulation Insight

Further work: Body energy models (using *Simulation Insight*)

- Open each of the previous simulation files, show the model window and find out how the models work:
 - 'Body convection'
 - 'Body evaporation'
 - 'Body heat balance'