<u>2015 Paper, Model Answers</u>

01. Energy in the finite sense refers to electricity as well as gas for heating/cooking and petrol/diesel for vehicles. Isolated UK islands are unlikely to have their own oil, gas or coal reserves available to mine/drill for to obtain energy security, should they choose to run primarily on non-renewable sources they will be dependent on imports of these fuels.

One advantage of using finite energy sources (e.g. coal for electricity) is that the plant can respond quickly to changing demand. During the day, demand for electricity will be far higher than during the night when the majority of the population are asleep. A coal-powered plant can burn more coal to produce more electricity at little notice and supply power, immaterial of the time of day or weather conditions.

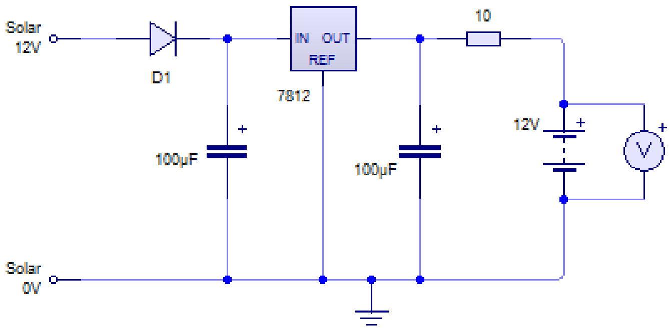
Using a wind turbine for power only provides electricity when the wind blows in a certain range of speed; on an island, wind could reasonably be expected (locating turbines in the sea will help as there are less natural wind-breaks), but not guaranteed. Relying solely on wind would cause power shortages on the islands, but would be used in conjunction with photovoltaic cells (which only work through the day) and tidal power to maximize the yield of power that can be generated.

From an environmental perspective, wind turbines do not cause any pollution while they run, and require significantly less maintenance and but it should be remembered that a large amount of energy is required to initially extract the aluminium they are made from out of the ground, to refine it, then machine it before transporting it to its eventual site. It is unlikely that a turbine will ever generate more power in its lifetime than it ever used in its manufacture.

This said, importing fossil fuels to remote islands is also undesirable as there is a pollution cost when tankers transport the raw materials to the island in question, then lorries transfer it to the power plant (for electricity) or gasworks for storage and distribution. The fuel itself is then burnt, further contributing to greenhouse gas emissions. Having the additional transport cost will also drive up the cost of energy from these sources to the consumer.

A strategy could be to use a spread of finite and non-finite sources so as to minimize reliance on imports by generating power on the islands when possible, but with the capacity to generate power (and heat homes) independently during times consistently for residents and businesses.

02. To charge a 12V battery on a yacht using the sun, I'd create the circuit to the right. The 7812 regulator will ensure the battery never receives over 12V from the solar cell, and the capacitors will smooth out any ripples in the input/output form the circuit. The voltmeter will allow the user to see when the battery is charged and disconnect the battery. Solar power can only be gathered through the day, and is most intense around midday. The protection I've put in place (including a 1W 10 Ohm resistor to limit the flow of current into the battery will help ensure it does not become over-charged.



To charge the battery using the wind, I'd get a 12V DC motor, and put a high-ratio gearbox onto it. On the output gear, I'd mount a fan-blade which would be fitted to the mast of the yacht to maximize exposure to the wind. As wind passes through the blades, it will force the motor to spin, inducing an electric current. This can be connected to the circuit drawn above, and will charge the battery. The wind can be unpredictable, and the charging circuit will ensure that the battery is not over-charged.

03. Method 1: Belt and pulley system. These systems can be quickly and cost-effectively set up compared to the other systems I will cover. A belt and pulley system can handle reasonably high-speed torque transfer although they can slip under wet conditions. They can also slip under excessive load, which can provide a safety mechanism to prevent damage, which other systems may not. Belts can easily traverse long distances, require minimal maintenance and are quiet in operation. Rotary motion can be amplified by changing the ratio between the radius of the driver pulley vs the driven pulley. A 100mm driver pulley and 300mm driven pulley would result in a 1:3 ratio, with the output turning three times more slowly (but with three times the torque). The output direction of a pulley can be reversed by putting a twist in the belt.

Method 2: Chain and sprocket. These are more expensive than belts and pulleys to configure, as they require a high degree engineering skill and precision when manufacturing the sprockets and chain links in order to ensure they mesh together as tightly as possible to avoid wear and unwanted friction between contact surfaces. This said, a chain and sprocket will not slip under a heavy load (making them ideal for timing applications), and if made from a tough material such as steel, are capable of transmitting considerably greater torque that a belt system which is why they are seen on machinery such as motorbikes. In order to maximize life, maintain efficiency and reduce the noise they can produce, they will need regular lubrication from oil or grease. Due to their precisely machined nature, chains and sprockets are harder to re-configure than a pulley as the entire arrangement will need re-designing. The speed/torque can be changed by changing the ratio in the number of teeth on the driver/driven gear in exactly the same way as described for belts and pulleys: More teeth on the driven gear means more torque and less speed.

Method 3: Meshed gears. While more difficult to span a distance (although a chain of idler gears could accomplish this), meshing gears directly together allows the transfer of the largest amount of force, and can be seen in engines and mills. As with chains and sprockets, they can be made from steel or other plastics (nylon is often chosen as it is self-lubricating). Double-gears can be used to set up very high gear ratios where extreme speed or torque is desirable, allowing the different ratios to be multiplied together in a small physical space where it would be impractical to create a second sprocket (for instance) of a suitably large size to fit inside a piece of machinery. Gears are also able to work at very high speeds, although they can be noisy and require lubrication to reduce the generation of unwanted heat and limit wear.

04. When designing a car seat, it is desirable to ensure that it can be driven comfortably and safely by as wide a spread of the adult population as possible. To that end, knowing the range of leg-lengths of adults would allow engineers to design an appropriate amount of adjustment. This said, there will always be statistical outliers at the extreme ends of any measurement that is taken (e.g. dwarves or those who are unusually tall). To try and engineer a seat that will fit everyone would likely be impossible, and so for those individuals special adaptations are available that are not part of the standard build of the car.

When designing an ear speaker for a mobile 'phone, it is useful to know how loud it should be able to produce sound at. For some users with hearing impairments, the standard 'maximum volume' that handsets produce is inadequate; for others with hyper-sensitivity this is far too loud.

Again, for both these statistical outlier groups, modifications are available to make products as accessible as possible.

05. Seats designed to accommodate the statistical mean average person (considering average leg length, back height, hip width, etc.) would be unlikely to be correct for many people. A seat designed this way would in reality only be a good fit for a minority of people and be uncomfortable for the majority. For this reason, it is better to provide as wide a tolerance for a broader spread of people so as to make the seating for accessible to all.

06. Thermal conductivity. When making saucepans, there are two considerations. The first is ensuring that there is a high level of thermal conductivity between the heat source and the food, then that there is minimal conductivity between the pan and its handle, so the chef can move the pan around without injury or needing an oven glove. Saucepans are often made from aluminium, which is a reasonable conductor of heat, and fitted with wooden or plastic (Bakelite used to be popular) handles which are poorer conductors of heat.

Hardness. Mobile 'phone screens are pulled in and out of pockets filled with keys and coins regularly during their working life. In order to keep the display attractive and easy to read for as long as possible, harder glasses are developed (e.g. gorilla glass) which are less susceptible to scratch damage from everyday use. Better glass technology and harder glass avoids insurance claims (from dropped units) and a longer working life for the handset.

Tensile strength. When designing steel cables for winches, a grade of steel must be select which offers the flexibility to be coiled easily for storage, but has sufficient tensile strength to be able to pull the weight of a vehicle in addition to extracting it from mud (or whatever it is stuck in). *As it may not be used for extended periods, it will also need to be corrosion resistant although this isn't part of the question*. This is important, as if it didn't have enough tensile strength, the cable could deform or suddenly shear under load, causing serious injury to those nearly.

Toughness. When designing a vice for a workshop, the engineer knows that it will likely receive many accidental blows from tools over its life. To keep it working optimally, the jaws of the vice need to hold their shape and not deform easily. For this reason, metal vices tend to be made from cast iron which is not easily deformed by blows.

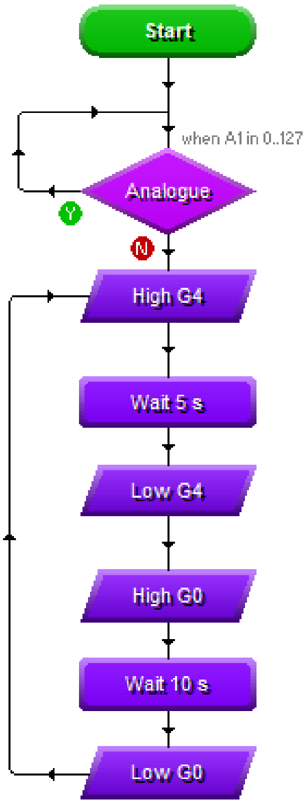
07. Environmentally, during their operation an electric vehicle doesn't directly emit any CO_2, NO_2 or other greenhouse gasses which would be considered an advantage. Trains running on electricity can run continuously, as long as they have access to electrified track, and enjoy the efficiency of not consuming any energy when not moving; a diesel engine would continue to idle when static.

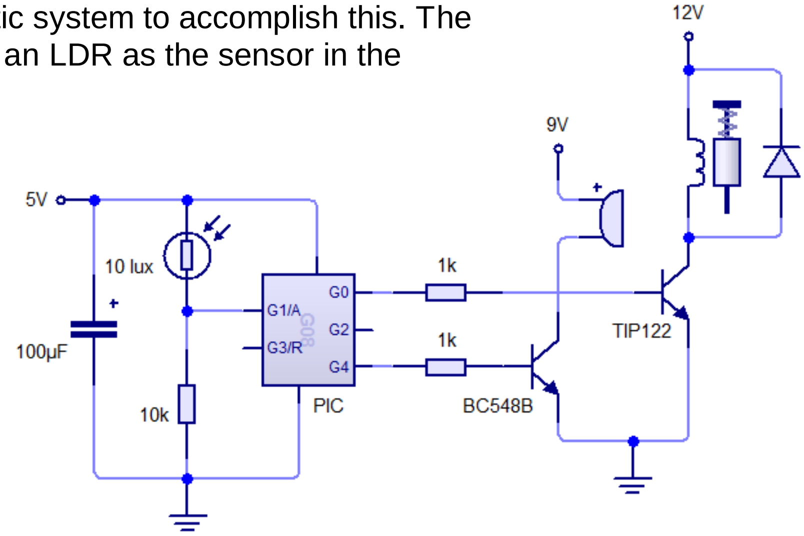
Electrically powered busses and trams are quieter than their diesel counterparts, reducing the amount of noise pollution output into the environment which will be especially beneficial in rural areas.

In terms of performance, electric aeroplanes have only ever been used as ultra-light concept models, and at current are not suited to carrying large numbers of passengers or freight. This is principally because these vehicles need to carry heavy batteries, since solar cells are not sufficiently technologically developed as to deliver enough current for continuous operation.

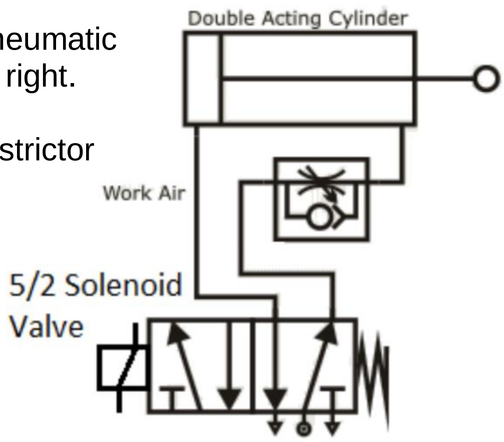
Early electric cars suffered speed and range limits that are not so significant in high-end consumer models now available; some can achieve speeds of 130mph and a range of over 200 miles on a single charge. The charge times themselves remain an issue however, running to several hours. Cost of electric vehicles continues to remain a barrier to many, as they are generally more expensive than the petrol alternative.

08. I'd create an electro-pneumatic system to accomplish this. The circuit would be as follows, using an LDR as the sensor in the question.





The microcontroller (PIC) would run the program shown to the left, which provides the behaviour described in the problem. The solenoid shown would be connected to a 5/2 pneumatic spring-return value, in a pneumatic circuit as shown in the diagram to the right.



By using a unidirectional valve and restrictor in parallel, the double-acting cylinder will go positive quickly as its airflow is unimpeded, and return slowly as air exhausts through the restrictor valve.

The correct amount of linear movement can be achieved by selecting a cylinder with a 300mm stroke when ordering the part.

09. If two materials are to be only temporarily joined, then a mechanical fixing like nuts and bolts offers security, with the option to conveniently separate the parts for inspection/maintenance later without the need to apply heat. Car tyres need changing from time to time. Recognising this, wheels are bolted to the car and then tightened with a torque wrench (to avoid over-tightening and damaging the threads) to ensure they will remain in place when the car is moving at speed.

Riveting can also be used for a semi-permanent solution and is used in aircraft where panels may require replacement; rivets can be drilled out without having to heat the parts of the airframe which over time would weaken them, and possibly cause warping. Aerodynamics are also a key consideration in aircraft and vehicle design: Countersunk rivets are used in aircraft to ensure the aerodynamic profile of the plane is unaffected by the additional drag that would otherwise be caused.

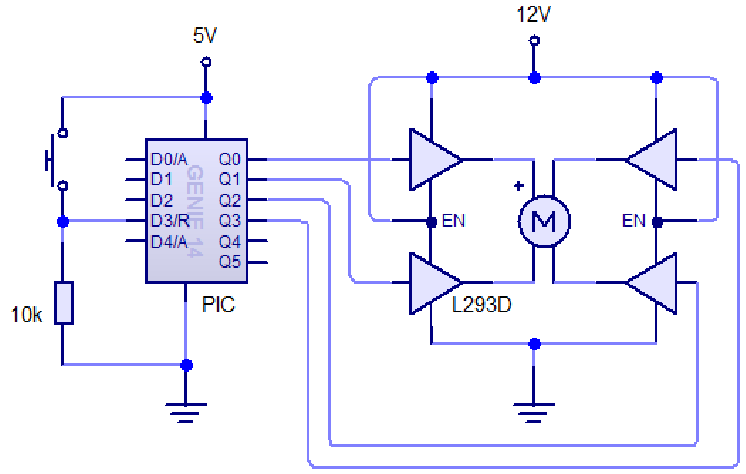
If a permanent joint is needed (such as bonding car body panels together), different types of welding produce strong joins between two metals.

Another consideration is considering the materials to be joined together. Aluminium is popular in aeroplane engineering and increasingly popular in cars due to its light-weight and corrosion resistance. It is also notoriously difficult to weld, as it changes state from solid to liquid very quickly, making it easy to put holes in sheet material. Steel, by comparison, softens rather than liquefies making it easier to weld.

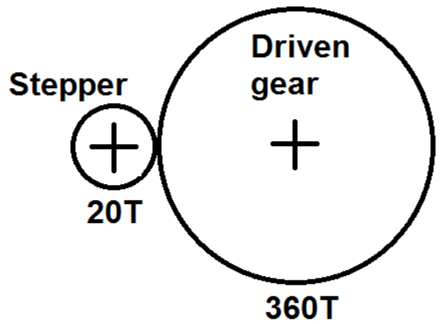
The use of the materials are also a factor. In PCBs, a lead-solder joint allows the copper track on a PCB to be bonded to the mild steel leg of the component. This is preferred to gluing (for instance) as the solder is a low-resistance electrical conductor that will allow the circuit to operate as intended, which also holding the component firmly in place.

Accessibility is also important to consider. Inside the cockpit of an F1 car, there will likely be very limited room for engineers to manoeuvre tools such as welding gear but will require structural strength at the same time. Specialist versions of welding or riveting tools for one-off jobs may need fabricating to solve unique scenarios.

10. To achieve 0.1° rotary precision, a bipolar stepper motor will be used. I will drive it using a microcontroller to provide the correct excitation sequence, which will output to a full H-bridge driver IC such as the L293d or the more capable L298n, which will energise the coils inside the motor as required.



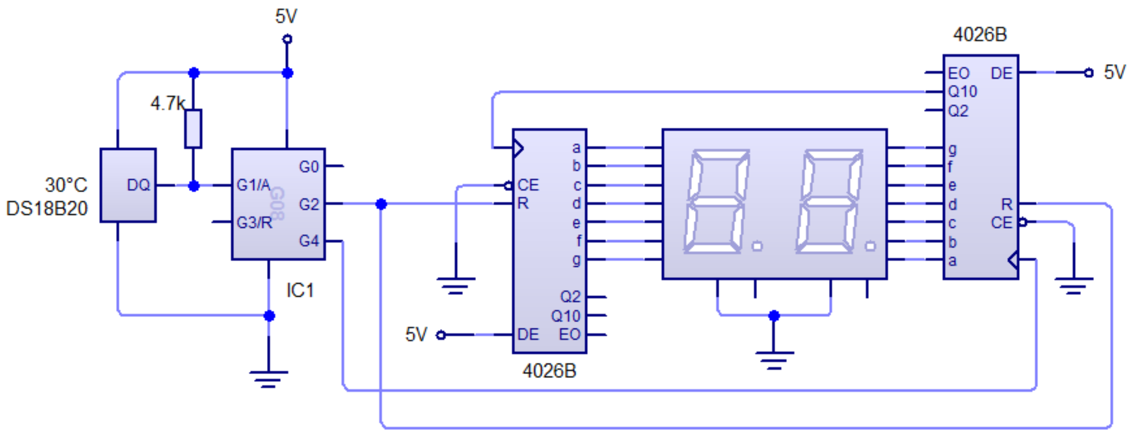
This system has the advantage of being '*open-loop*'; no feedback information about the motor position is needed, as position is known simply by keeping track of the input step pulses and storing them in a variable in the PIC program. This eliminates the need for additional sensing and feedback devices such as optical encoders.



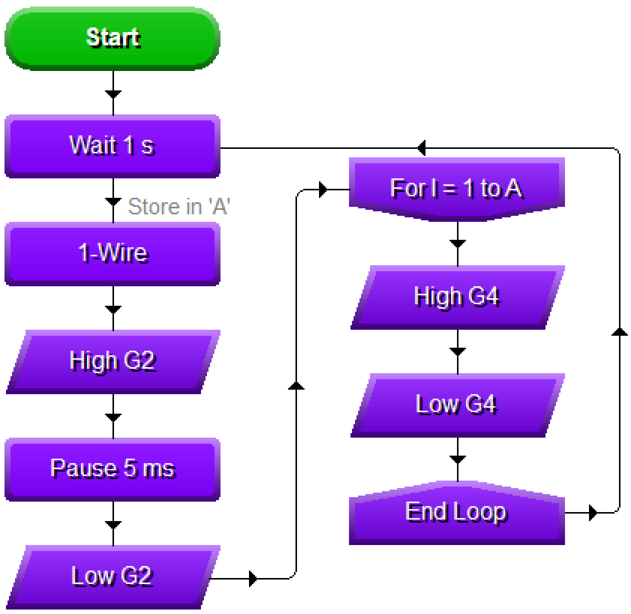
Most stepper motors have a single step size of 1.8°, so that 200 steps provides one full rotation of 360°. As this is 18x less accurate than needed a pair of gears giving an 18:1 velocity reduction is required; while the output will be considerably slower than the stepper motor by itself, this will carry the added benefit of additional torque on the output gear. A 20T gear can be mounted to the prime mover (the stepper), meshed to a 360T gear on an output shaft to achieve the desired result. To reverse the direction of rotary movement, the order of the output pulses is simply reversed. If the step order was Q0-Q3-Q1-Q2, to take steps back, the order would be Q2-Q1-Q3-Q0.

11. To measure and show a range of 0-60°C using a microcontroller, the temperature sensor needs to be carefully selected. A thermistor does not produce a change in resistance directly

proportional to the change in temperature. As such, I will instead use a dedicated component to solve this problem: the DS18B20 digital thermometer, which uses the 1-wire protocol.



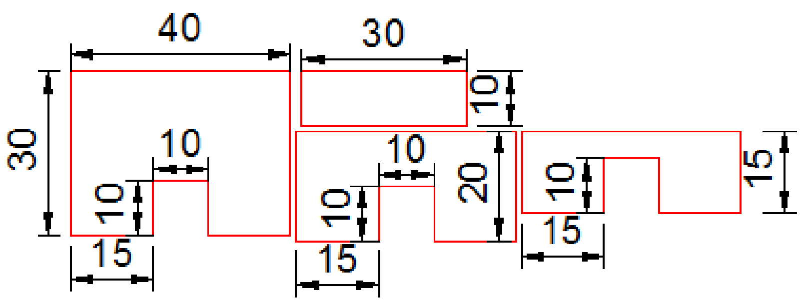
1. The waits 1s, then the digital thermometer reads the ambient temperature, and sends the integer value to the PIC as serial data.
2. The PIC stores the value in a variable (A), and resets the pair of 7-segment displays using the reset pin on both of the 4026b 7-segment out decade counters by momentarily sending output G2 high on the PIC.
3a. The clock pin on the right-most 4026 IC is then repeatedly clocked at high speed for the number of times stored in A. This happens so quickly that a human eye will not perceive the change in numbers.
3b. The 10-output pin on the right-most 4026 is clocked once every 10 input clocks. This will ensure that numbers up to 99 (although only 0-60 are needed) can be rendered using both digits.



NB: Further reading on thermistor to temperature conversion [here](#).

12. *Note: My first thought was to use a line bender and a former to wrap a rectangular piece of acrylic tightly around it. I abandoned this, as the result would have fileted (curved) corners rather than the sharp angles shown in the sketch.*

Firstly, CAD software (e.g. Solidworks) will be used to draw the component pieces. As there are three distinct 'peaks' in this part that are each 10mm wide, they can be drawn conveniently as three rectangles. To help ensure accurate fabrication, I will also produce a forth piece which I will use to make assembly more accurate. My parts will be as follows:

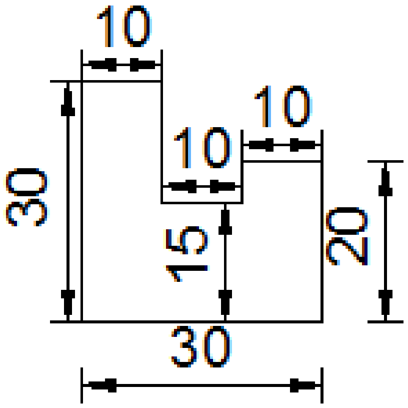


Once the parts were prepared, I would transfer these onto a tightly packed cutting sheet so as to minimize waste, then use a laser-cutter to cur the individual pieces from 10mm acrylic. A laser cutter can typically cut +/- 0.2mm, which is sufficiently accurate for this application. To ensure the best possible result, I'd need to ensure the laser optics are clean, the beam calibrated and the extractor unit on.

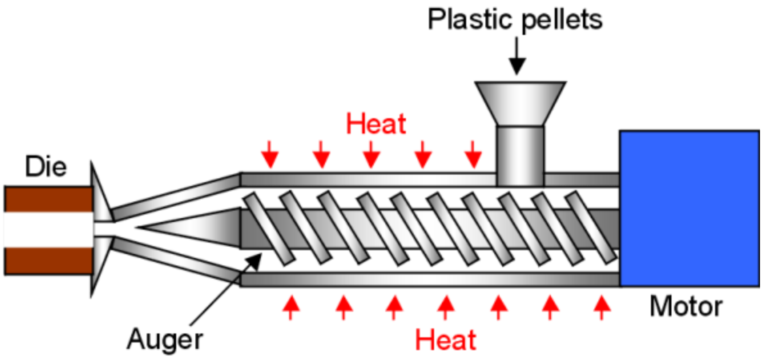
Once cut, the pieces can then be cleaned to remove any oils from my fingers and other contaminant, before being clamped together firmly with either a wood vice, or G-clamp. Using a fine-nozzled dispenser, I'd then apply Tensol liquid cement (designed for bonding acrylic) along the seams of the parts to be bonded. As they are clamped, the adhesive will be drawn into the join by a capillary action and the excess can then be wiped off. The pieces would then be left undisturbed for the adhesive to bond the parts together for around 20 minutes before the clamps are removed. A light sanding of the laser-cut ends with wet and dry paper would help give a good overall finish.

13. To mass-produce this product using deformation/redistribution, I would use extrusion-moulding and make the parts from ABS. This is similar to injection moulding, except a die is used in place of a mould and the plastic is continuously extruded.

Firstly, a suitable die would need producing from steel. This could be made by casting the steel with the desired profile (shown to the right) in it, or milling the shape out with a CNC milling machine. Either of these will ensure a consistent level of accuracy in the finished product.



Once produced, the die could be secured at the end of the setup below, almost identical to injection moulding:



As the ABS pellets melt, they are pulled along by the Archimedean screw and heated, to ensure a well-mixed molten plastic. As they reach the end, they are forced through the die, forming a long, continuous run of the profile of the part desired. This is passed through a water bath to quickly cool the newly formed parts. Lengths of this can then be fed through an automated shearing machine, which will cut the parts into 40mm sections as per the design requirement.