Thermo-Fluids:
Carbon Neutral Housing

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Summary of Proposal

Beeston Regis caravan park, Norfolk.

Static caravans are a common sight in the UK, especially in coastal areas. They are a place for many families to spend time on holiday, and as my grandparents have owned one for many years, I have spent a lot of time in them and on caravan parks.

There has not been any great advancement in the static caravan industry in recent years compared to other sectors, mostly due to over 75% of the industry being dominated by 3 brands, so there is lack of competitors and therefore lack of innovation.

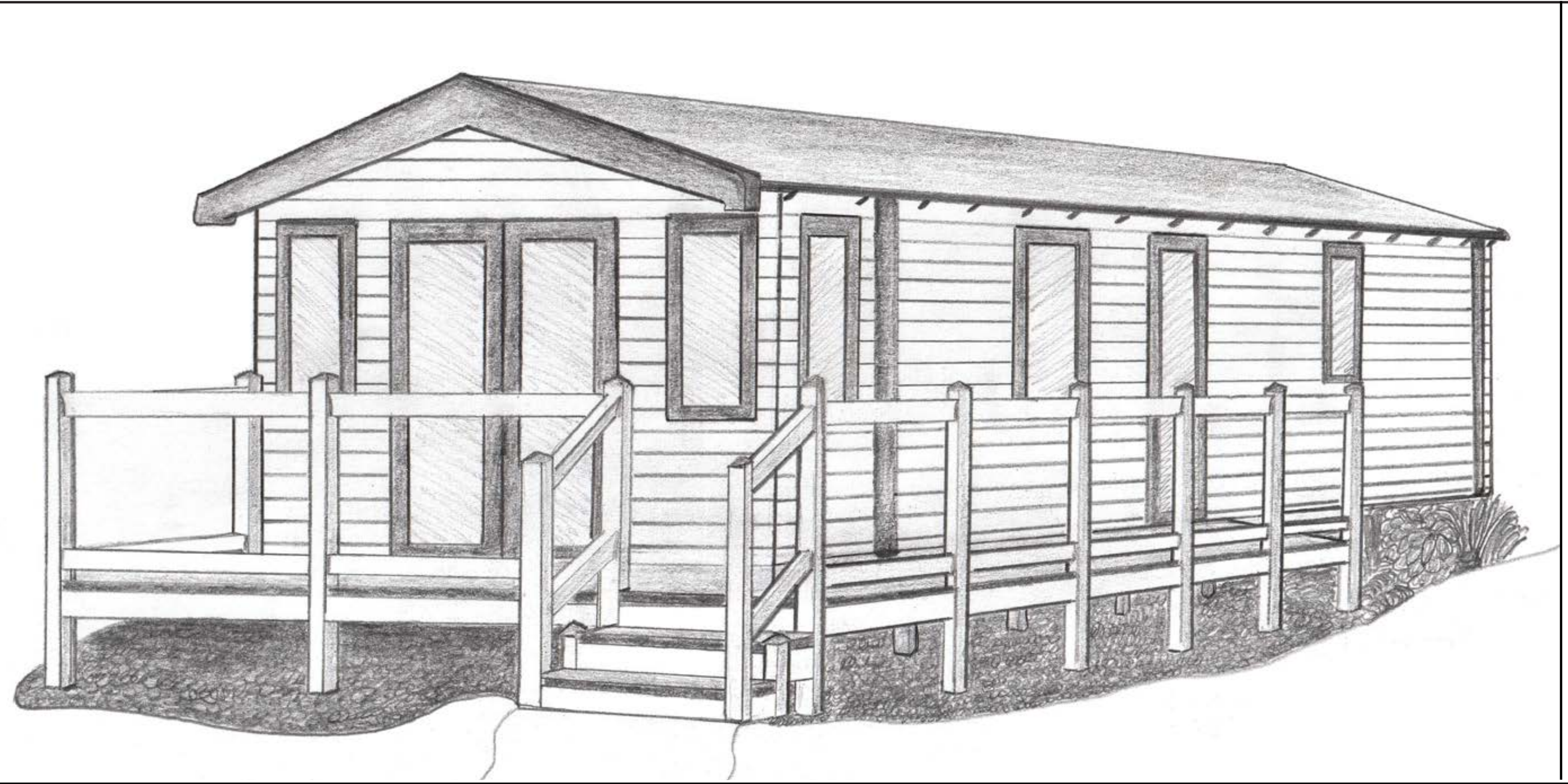
The subject of gas and electricity is always a controversial one on caravan sites, as owners are regularly charged above standard prices for their gas bottles and electricity, which the caravan sites control.

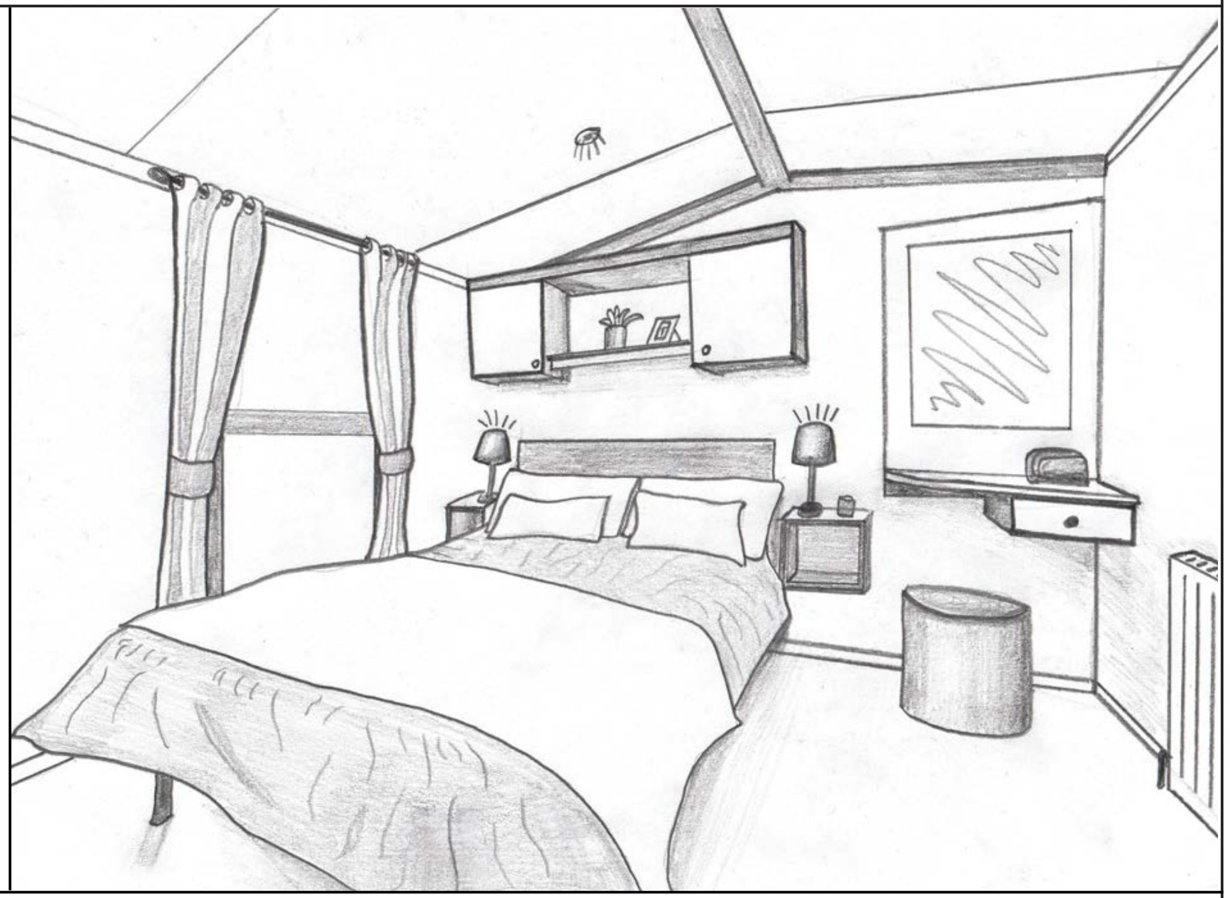
The caravans generally run off 47kg propane gas bottles, as well as being connected to electricity and water sources on the caravan park. Although Propane gas is though to be an environmentally accepted fuel, it does still have emissions including carbon monoxide, greenhouse gas, methane and non-methane overall organic carbon. The electricity is usually not from renewable sources, so in order to make this a carbon neutral home, we should look to produce clean power as part of the home, focus on insulation of the home, choose suitable materials, and energy saving appliances.

The static caravan architype has a very standard cuboid exterior shape with a gable roof, and inside usually compromises of 1 main bathroom, 2 bedrooms, and a open plan kitchen and lounge area. The four areas than I am going to look at in order to convert the caravan into a carbon neutral dwelling are heat flow out the external floors, heat flow in the radiators and the radiator pipes, hot water pipe flow and pressure, and finally solutions for renewable energy.

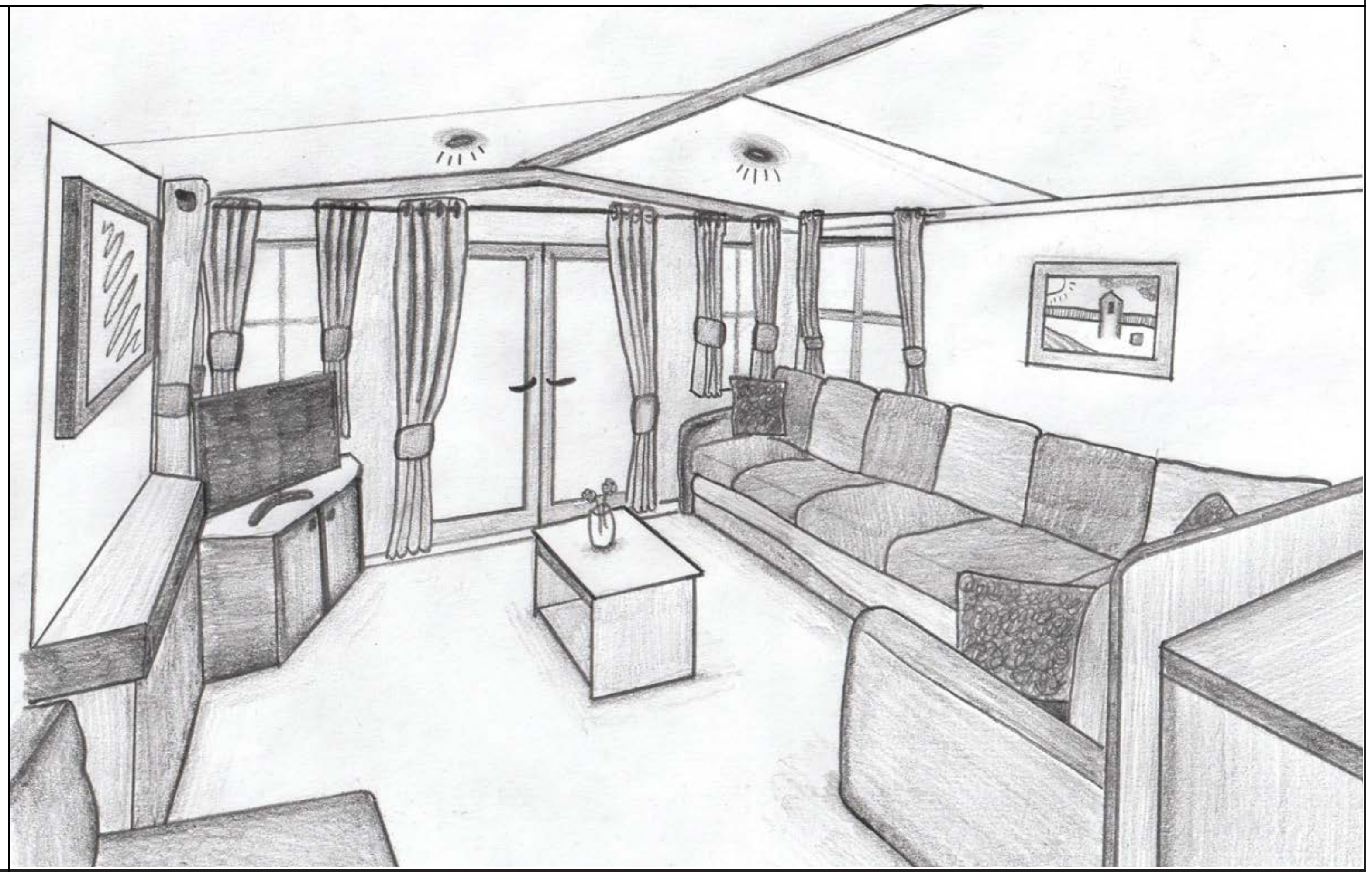
By making the static caravan 'off grid' it will end controversy about the expensive gas and electric prices that owners are charged by sites, and also reduce the carbon footprint.

Concept Sketches

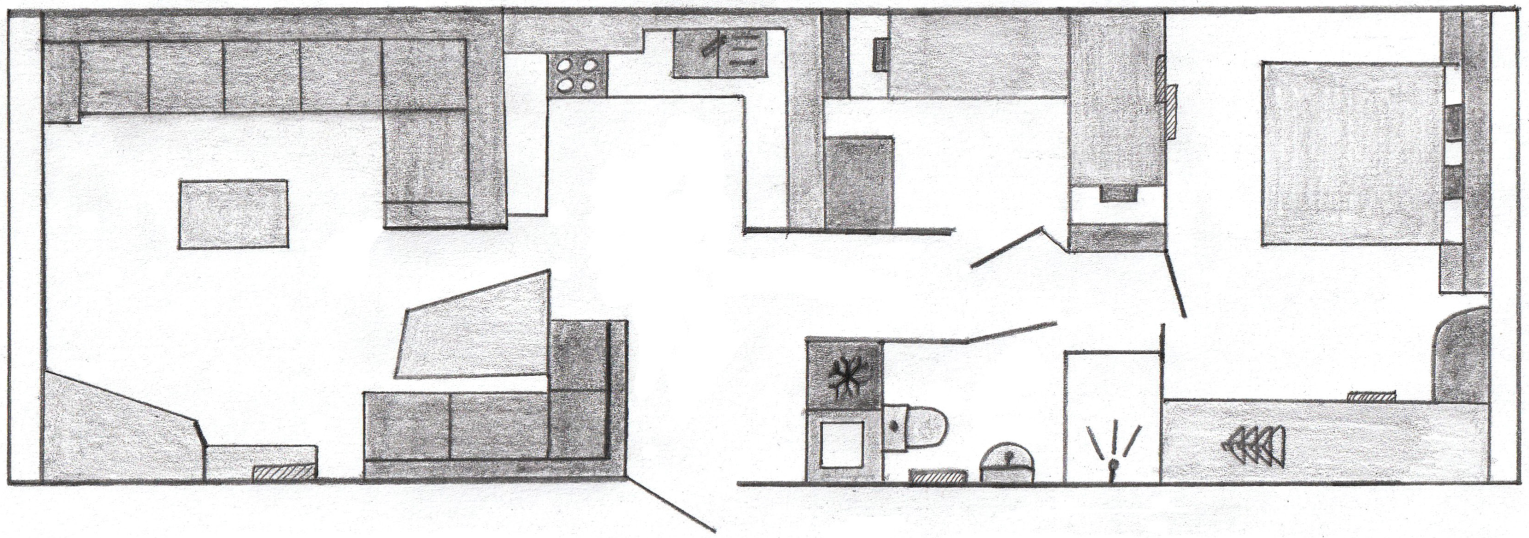


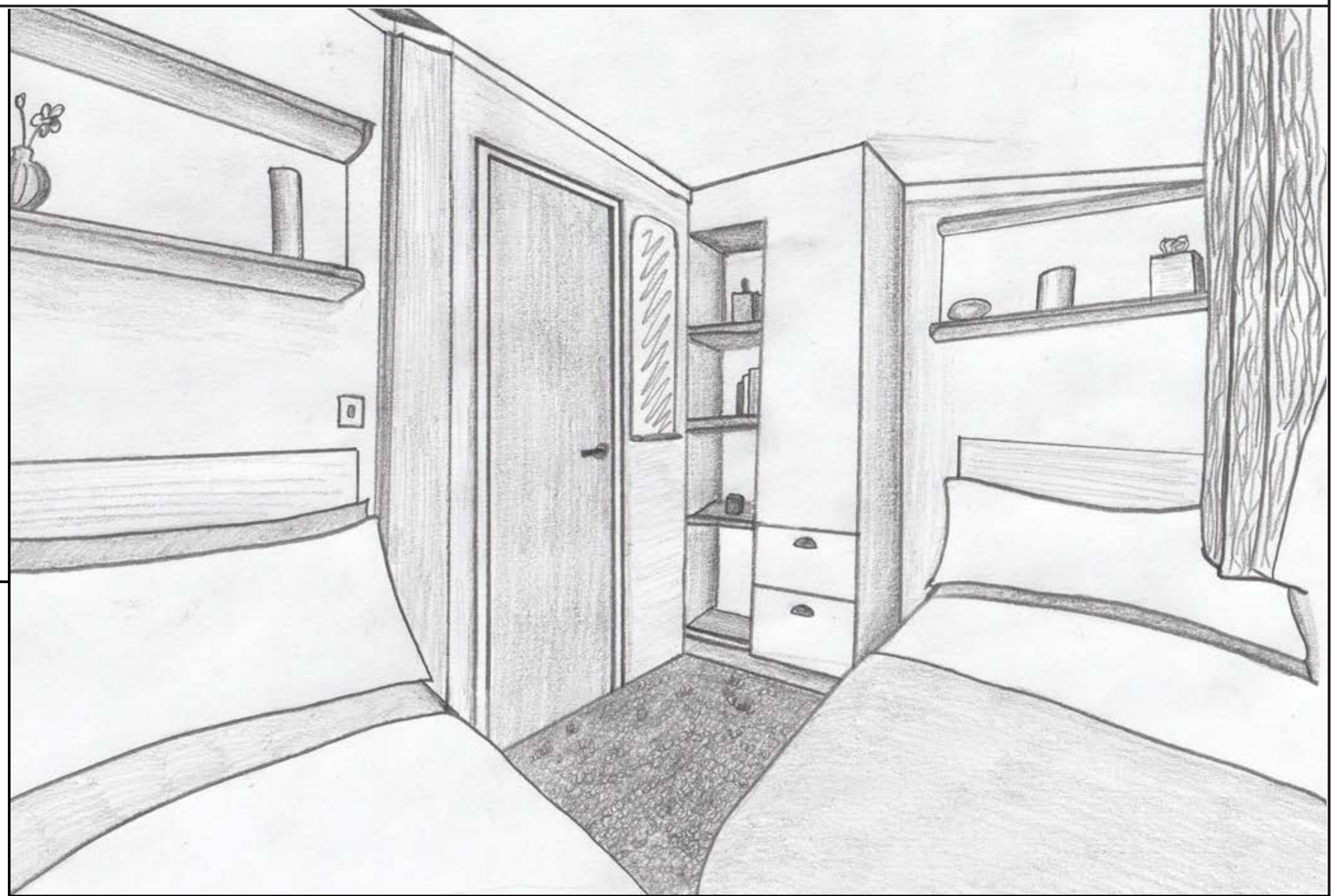


Exterior view of the caravan, including a veranda as well as sketches of the master bedroom, kitchen and lounge area.

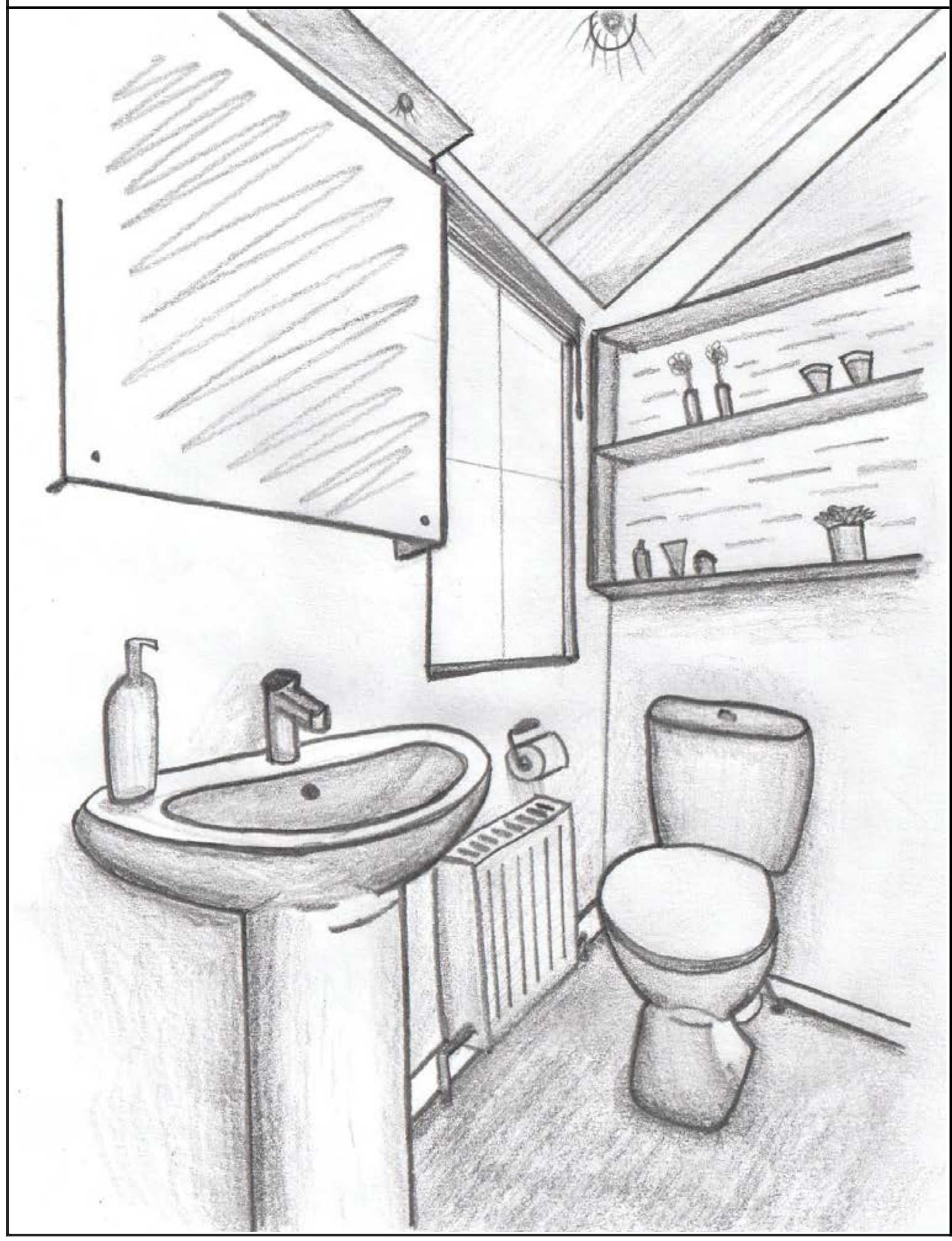


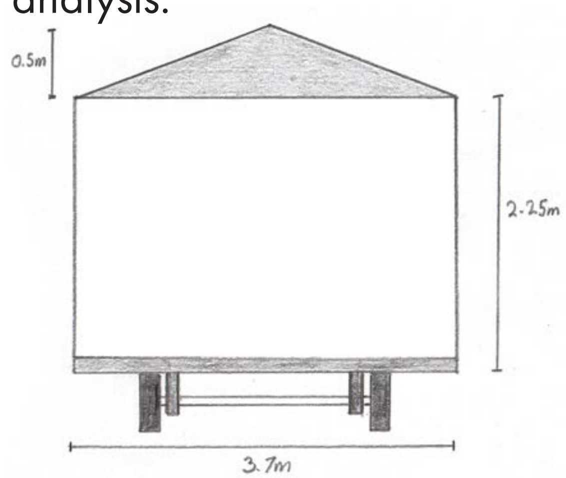
Concept Sketches

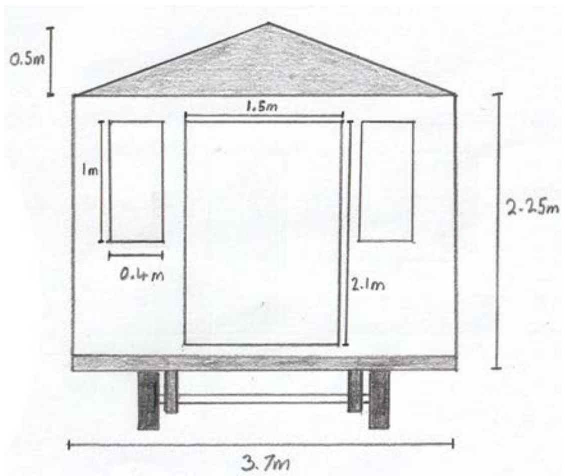


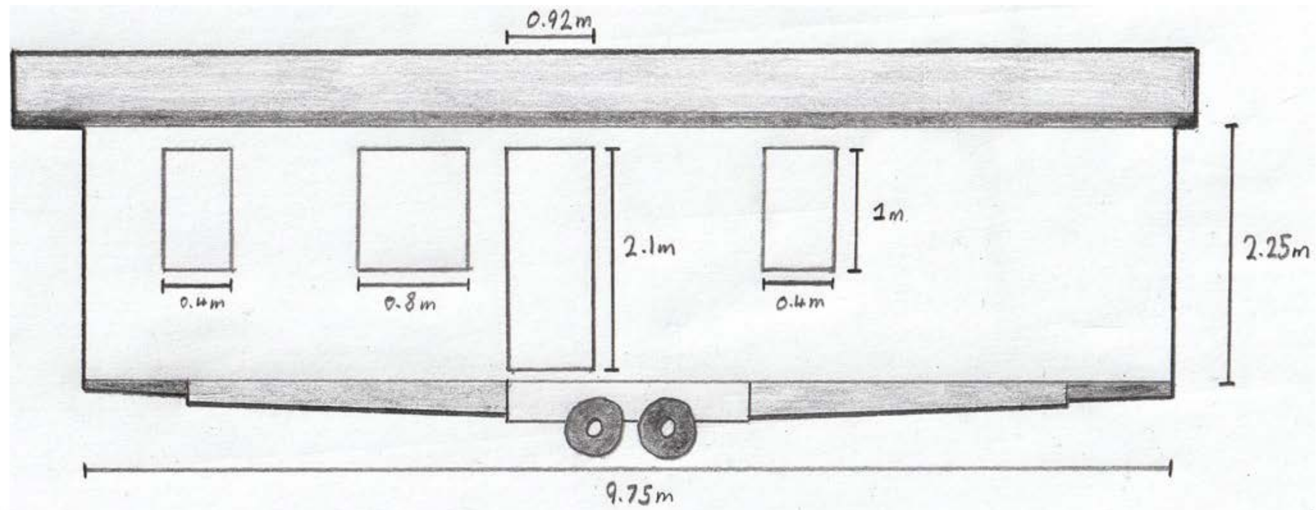


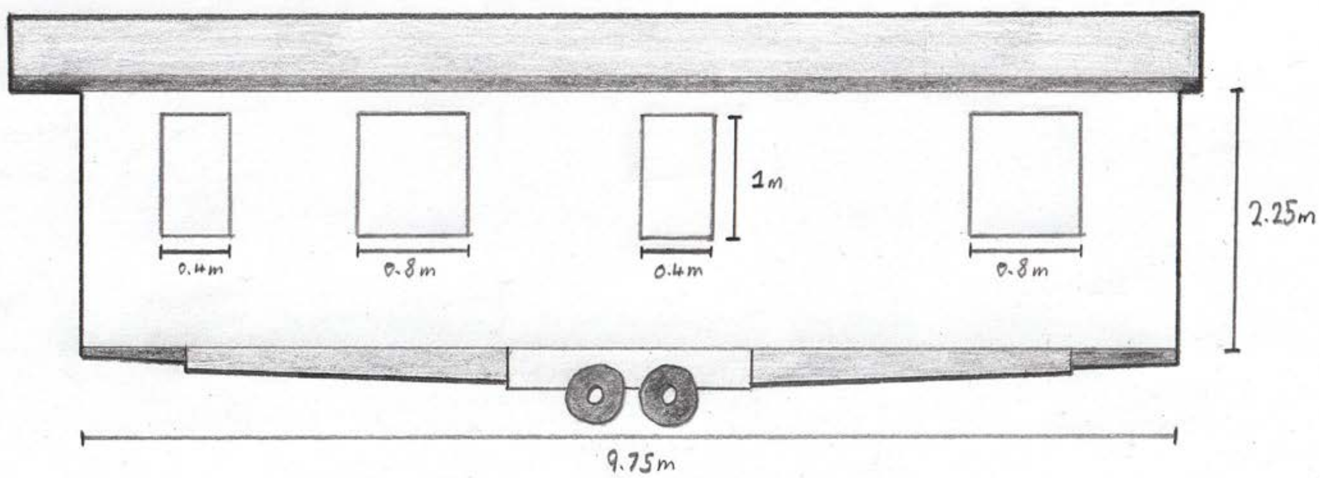
Above is a sketch of the twin bedroom, the bathroom on the left, as well as dimensioned drawings of the side and exterior views, and a floorplan of the interior. These dimensions below are used to calculate areas, used in the slab analysis.











Slab Heat Loss

One of the largest areas to save energy is by insulating the exterior walls of the static caravan. Slab analysis was carried out and power and cost savings were calculated from adding insulation as the intervention.

Exterior Wall Material Values (W/m K)

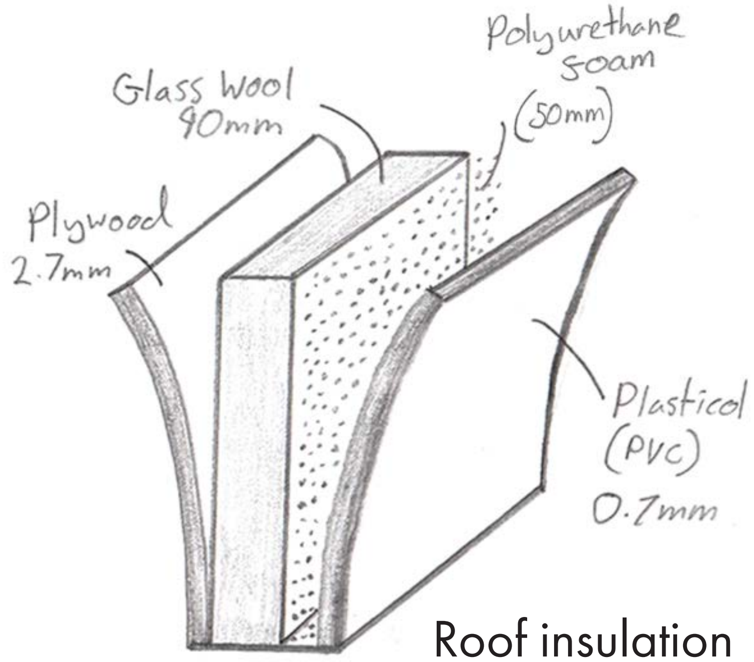
Plywood[1] - 0.13
Glass Wool[2] - 0.3
Polyurethane Foam[3] - 0.024
Plasticol[4] (PVC) - 0.14
Glass[5] - 0.8
Aluminium[5] - 205
Carpet[6] (Wool) - 0.193
Chipboard[7] - 0.1

Conditions

Temperature inside - 20°C
Temperature Outside[8] - 12°C
Roof Heat Transfer Coefficient[9] - 6 (all W/m²K)
Wall Heat Transfer Coefficient[9] - 8
Floor Heat Transfer Coefficient[9] - 11
Wind speed by walls (gentle breeze)[10] - 9

Area of Exterior Walls (m^2)

Roof - 37.37
Windows - 9.882
Wall (ex windows) - 52.493
Floor - 36.075



Roof insulation materials

Using Palyvos equation[11] to find outside heat transfer coefficient:

$$9\,mph = 4\,ms^{-1}$$

$$h_o \approx 5.7 + 3.8 \times v_w \approx 5.7 + 3.8 \times 4 \approx 20 \text{ W/m}^2\text{K}$$

Roof heat flow with insulation:

$$q = \frac{T_i - T_o}{\frac{1}{h_i} + \frac{L_A}{k_A} + \frac{L_B}{k_B} + \frac{L_C}{k_C} + \frac{L_D}{k_D} + \frac{1}{h_o}}$$

$$q = \frac{20 - 12}{\frac{1}{6} + \frac{0.0027}{0.13} + \frac{0.09}{0.3} + \frac{0.05}{0.024} + \frac{0.0007}{0.14} + \frac{1}{20}} = 3.05\ W\ m^{-2}$$

$$Q = qA = 3.05 \times 37.37 = 113.86\ W$$

Roof heat flow without insulation:

$$q = \frac{20 - 12}{\frac{1}{6} + \frac{0.0027}{0.13} + \frac{0.0007}{0.14} + \frac{1}{20}} = 32.998\ W\ m^{-2}$$

$$Q = qA = 32.998 \times 37.37 = 1233\ W$$

Roof energy and cost saving by using insulation:

$$365 \times 24 = 8760$$

$$\frac{\Delta Q \times T}{1000} = kW\ h$$

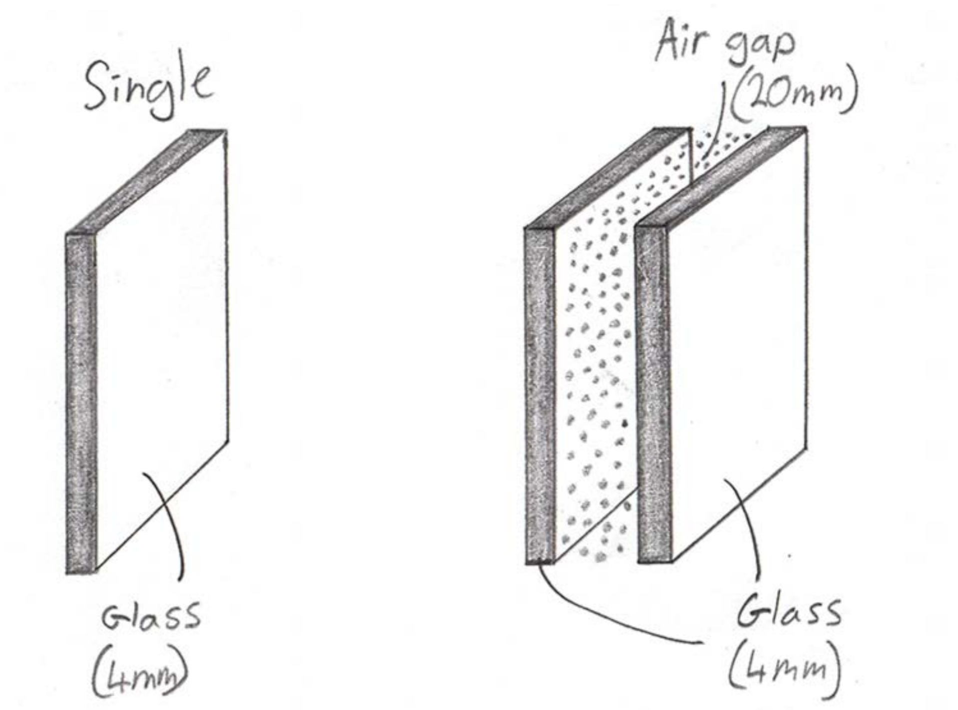
$$\frac{(1233 - 113.86) \times 8760}{1000} = 9803.7\ kW\ h$$

$$0.163 \times 9803.7 = £1598\ per\ annum$$

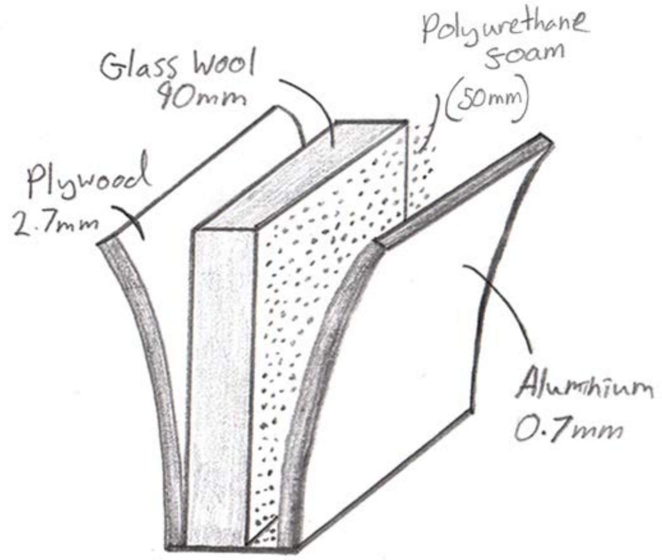
[1] http://www.farm.net/~mason/materials/thermal_conductivity.html plywood
[2] https://www.thermal-engineering.org/what-is-thermal-conductivity-of-glass-wool-definition/ glass wool
[3] https://www.nuclear-power.net/nuclear-engineering/heat-transfer/heat-losses/insulation-materials/thermal-conductivity-of-polyurethane-foam/
[4] https://en.wikipedia.org/wiki/Polyvinyl_chloride
[5] http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/thrcn.html
[6] https://www.eccarpets.com.au/images/downloads/Misc/Thermal_Properties_of_Wool_Carpet_2016.pdf
[7] https://www.new-learn.info/packages/clear/thermal/buildings/building_fabric/properties/conductivity.html
[8] https://www.timeanddate.com/weather/uk/london/climate
[9] https://www.sciencedirect.com/science/article/pii/S0360132319303609
[10] https://www.weather.gov/pqr/wind
[11] https://bigladdersoftware.com/epx/docs/8-3/engineering-reference/outside-surface-heat-balance.html

Slab Heat Loss

Window materials, single v double



Wall insulation materials



Double glazing heat flow:

$$q = \frac{T_i - T_o}{\frac{1}{h_i} + \frac{L_A}{k_A} + \frac{L_B}{k_B} + \frac{L_C}{k_C} + \frac{1}{h_o}}$$

$$q = \frac{20-12}{\frac{1}{8} + \frac{0.004}{0.8} + \frac{0.02}{0.024} + \frac{0.004}{0.8} + \frac{1}{20}} = 7.856\ W\ m^{-2}$$

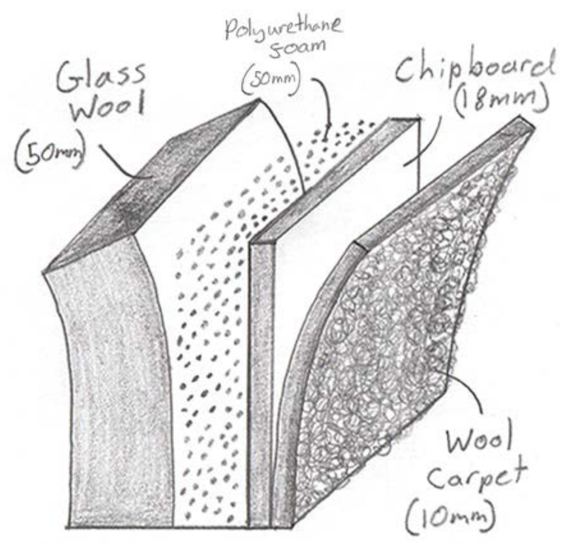
$$Q = qA = 7.856 \times 9.882 = 77.63\ W$$

Single glazing heat flow:

$$q = \frac{20-12}{\frac{1}{8} + \frac{0.004}{0.8} + \frac{1}{20}} = 44.4\ W\ m^{-2}$$

$$Q = qA = 44.4 \times 9.882 = 439.2\ W$$

Floor insulation materials



Window energy and cost saving:

$$365 \times 24 = 8760$$

$$\frac{\Delta Q \times T}{1000} = kW\ h$$

$$\frac{(439.2 - 77.63) \times 8760}{1000} = 3167\ kW\ h$$

$$0.163 \times 3167 = £516.27\ per\ annum$$

Rest of Walls heat flow:

$$q = \frac{20-12}{\frac{1}{8} + \frac{0.0027}{0.13} + \frac{0.09}{0.3} + \frac{0.05}{0.024} + \frac{0.0007}{205} + \frac{1}{20}} = 3.10\ W\ m^{-2}$$

$$Q = qA = 3.10 \times 52.49 = 162.82\ W$$

Floor heat flow:

$$q = \frac{20-12}{\frac{1}{11} + \frac{0.01}{0.193} + \frac{0.018}{0.1} + \frac{0.05}{0.024} + \frac{0.05}{0.3} + \frac{1}{20}} = 3.05\ W\ m^{-2}$$

$$Q = qA = 3.11 \times 36.075 = 110.04\ W$$

Total power lost from house:

$$113.86 + 162.82 + 77.63 + 110.04 = 464.35\ W$$

$$0.464\ kW$$

$$0.464 \times 24 = 11.1\ kW\ h\ per\ day$$

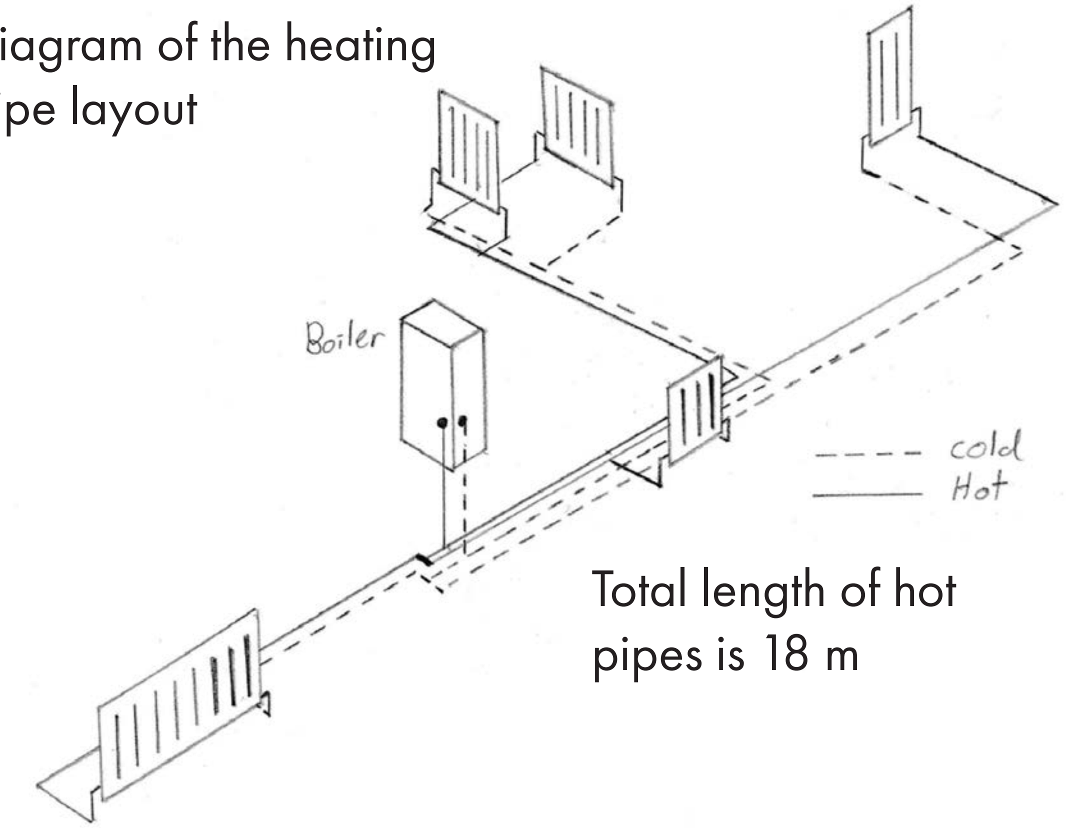
This total heat flow will be replaced by the boiler heating the radiators, which will be explored in the next intervention.

[10] https://www.johnknightglass.co.uk/about-us/blog/triple-glazing-is-it-really-worth-it/#:~:text=Today's%20standard%20double%20glazing%20units,cavity%20depth%20and%20glass%20thick-

Radiator Pipe Heat Loss and Heat transfer of the Appliance

With the boiler heating water for radiators in all the rooms, of the house, the total length of these hot water pipes were calculated, and then heat loss values could be calculated, before and after insulation

Diagram of the heating pipe layout



Total length of hot pipes is 18 m

Pipe Material Values (W/m K)

Copper[1] - 385
Polyurethane Foam[2] - 0.03
h_{int}[3] - 150
h_{ext} - 8

Radii of Pipe (from Sketches) (m)

r_1[4] - 0.0075
r_2 - 0.0085
r_3 - 0.0585 (only for insulated)

Other Values

T_{int}[5] - 60°C
T_{ext} - 20°C
L - 18 m

Insulated pipe - calculating the heat

$$Q = \frac{2\pi L k_{cu}(T_1 - T_2)}{\ln(\frac{r_2}{r_1})} = \frac{2\pi L k_{ins}(T_2 - T_3)}{\ln(\frac{r_3}{r_2})} = 2\pi r_3 L h_{ext}(T_3 - T_{ext}) + 2\pi r_1 L h_{int}(T_{int} - T_1)$$

Eliminating unknown surface temperatures, the above equation can be rearranged, with U, A and change in T having to be found:

$$\frac{1}{U} = \left(\frac{r_3}{r_1 \times h_{int}}\right) + \left(\frac{r_3 \times \ln(\frac{r_2}{r_1})}{k_{cu}}\right) + \left(\frac{r_3 \times \ln(\frac{r_3}{r_2})}{k_{ins}}\right) + \left(\frac{1}{h_{ext}}\right)$$

$$\frac{1}{U} = \left(\frac{0.0585}{150 \times 0.0075}\right) + \left(\frac{0.0585 \times \ln(\frac{0.0085}{0.0075})}{385}\right) + \left(\frac{0.0585 \times \ln(\frac{0.0585}{0.0085})}{0.03}\right) + \left(\frac{1}{8}\right) = 3.938$$

$$U = \frac{1}{3.938} = 0.2539$$

$$A = 2\pi r_3 L = 2\pi \times 0.0585 \times 18 = 6.6162\ m^2$$

Calculating power:

$$Q = U \times A \times \Delta T$$

$$Q = 0.2539 \times 6.6162 \times 40 = 67.19\ W$$

No insulation (no r_3 terms)

$$\frac{1}{U} = \left(\frac{r_3}{r_1 \times h_{int}}\right) + \left(\frac{r_3 \times \ln(\frac{r_2}{r_1})}{k_{cu}}\right) + \left(\frac{r_3 \times \ln(\frac{r_3}{r_2})}{k_{ins}}\right) + \left(\frac{1}{h_{ext}}\right)$$

$$\frac{1}{U} = \left(\frac{1}{8}\right) = 0.125$$

$$U = \frac{1}{0.125} = 8$$

$$A = 2\pi r_2 L = 2\pi \times 0.0085 \times 18 = 0.9613\ m^2$$

Calculating power:

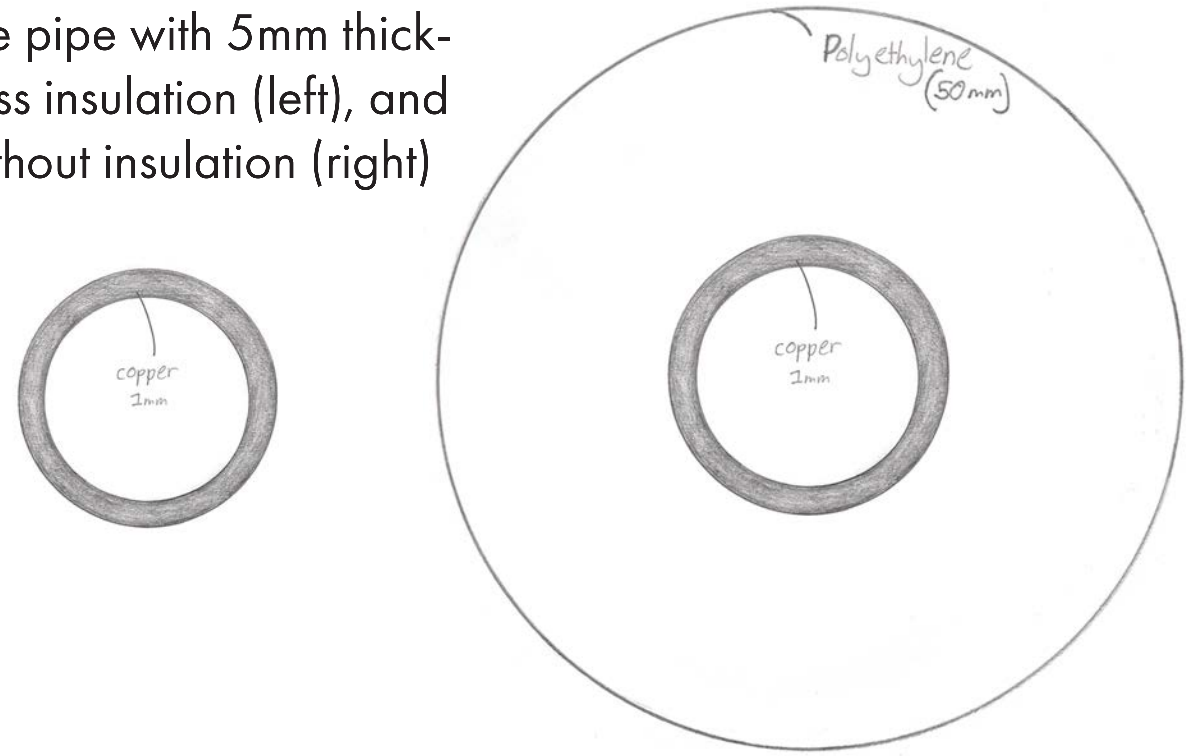
$$Q = U \times A \times \Delta T$$

$$Q = 8 \times 0.9613 \times 40 = 307.6\ W$$

[1] http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/thrcn.html
[2] https://www.nuclear-power.net/nuclear-engineering/heat-transfer/heat-losses/insulation-materials/thermal-conductivity-of-polyurethane-foam/
[3] https://www.engineersedge.com/thermodynamics/overall_heat_transfer-table.htm
[4] https://www.cityplumbing.co.uk/Wednesbury-Copper-Pipe-15mm-x-3m/p/313813
[5] https://www.greenerkirkcaldy.org.uk/heating-controls-ake-control-of-your-bills-while-keeping-warm-this-win-

Radiator Pipe Heat Loss and Heat transfer of the Appliance

The pipe with 5mm thickness insulation (left), and without insulation (right)



Energy Saving and cost saving:

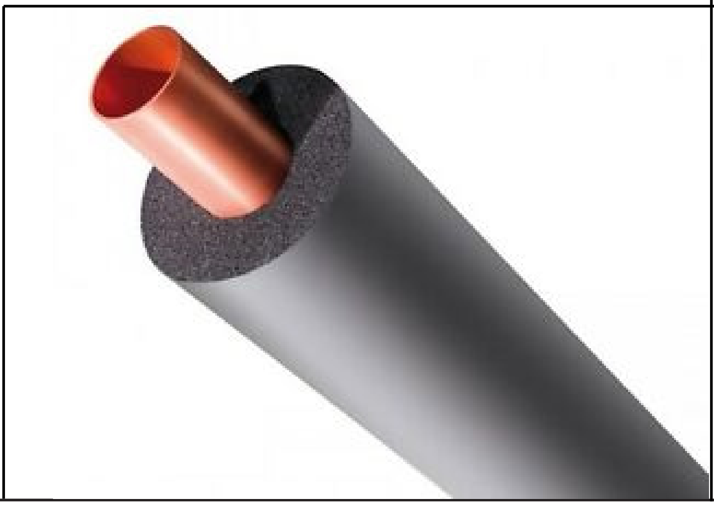
$$365 \times 24 = 8760$$

$$\frac{\Delta Q \times T}{1000} = kW\ h$$

$$\frac{(307.6 - 67.19) \times 8760}{1000} = 2106\ kW\ h$$

$$0.163 \times 2106 = £343\ per\ annum$$

We can therefore see that by adding 50mm thickness of insulation that the energy and cost savings can be significantly reduced.



We can now determine the contributions of radiation and convection to the total heat transfer.

Pipe Material Values (W/m K)

$T_{radiator}$ [1] - 70°C
T_{room} - 20°C
h[2] - 10
ε[3] - 0.95

Standard type of radiator in static caravans

$$E = \varepsilon\sigma\left(T_{radiator}^4 - T_{room}^4\right) = 0.95 \times (5.671 \times 10^{-8}) \times ((273+70)^4 - (273+20)^4)$$

$$q_{radiation} = E = 348.1\ W/m^2$$

Due to the high emissivity value of the radiator (hence the name), it would be hard to improve this radiation value.

$$q_{convection} = h(T_{radiator} - T_{room}) = 10 \times (70 - 20) = 500\ W/m^2$$

The convection value could only be improved by having a higher heat transfer coefficient value of the radiator.

Next Steps

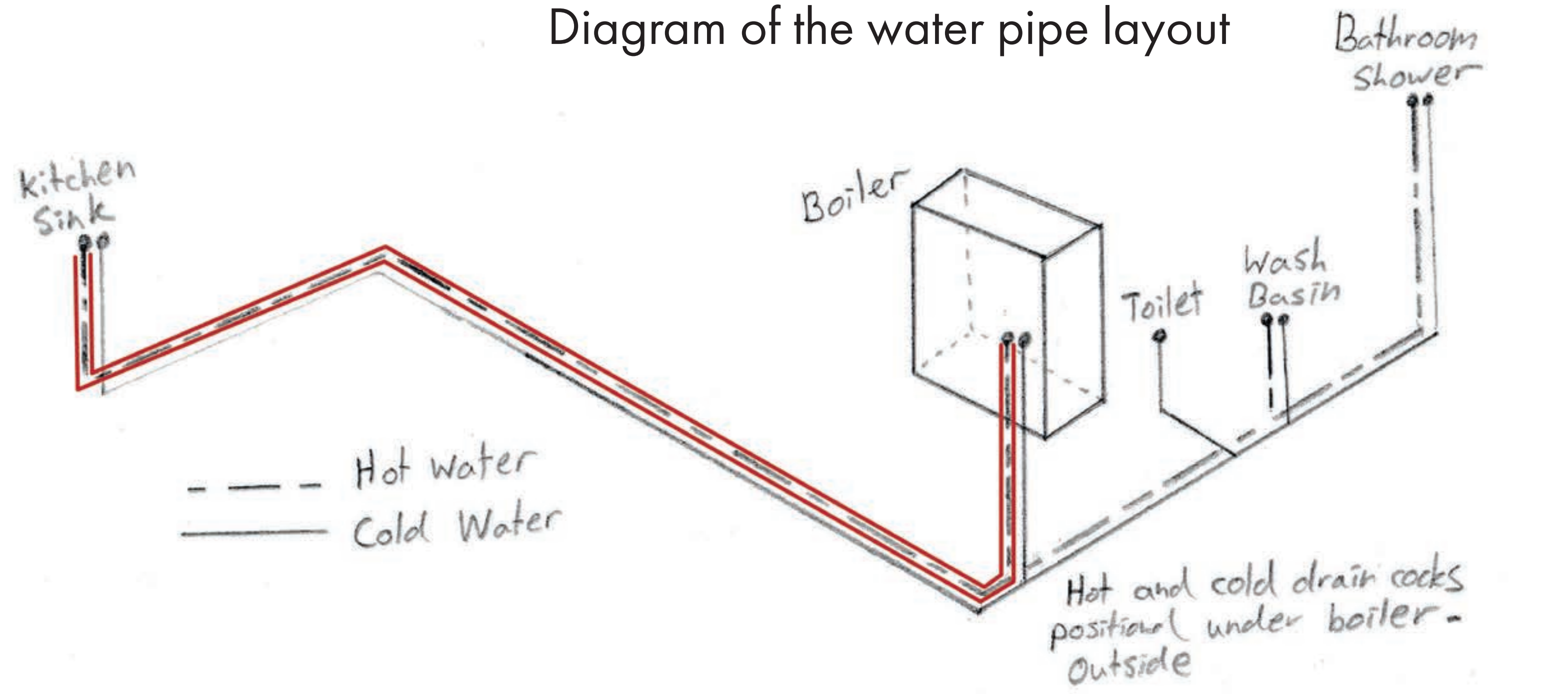
Now that values of the heat loss have been calculated for the external walls, and the heating pipes, and interventions have been put in place, the pipes that connect the water pipes can be analysed to minimise pressure loss and therefore reduce the energy needed. After this, the total energy use for the whole static caravan can be calculated, and renewable energy sources can be installed.

[1] http://www.yougen.co.uk/energy-saving/Heating+Hot+Water/#:~:text=Traditionally-%2C%20radiators%20fed%20by%20central,because%20it%20is%20more%20efficient.
[2] https://www.engineeringtoolbox.com/overall-heat-transfer-coefficient-d_434.html
[3] https://www.researchgate.net/publication/245383145_The_effect_of_wall_emissivity_on_radiator_heat_output

Pipe Flow Calculation

In this calculation, the current two different diameter pipes in series connecting the boiler to the kitchen sink (longest pipe) are evaluated, and an intervention to reduce head loss is calculated.

Diagram of the water pipe layout



Pipe Values

Copper roughness[1] = 0.0015

Water Density[2] = 1000kg/m^3

Water Viscosity at 60 degrees[3] = 4.6x10^{-4}kg/ms

Pipe 1 diameter = 0.015m

Pipe 1 length = 6.7m

Pipe 2 (M10) diameter = 0.001m

Pipe 2 length = 0.5m

Tap flow rate[4] = 6 litres/minute

Pipe 1 - Head loss (first section):

$$Q = \frac{6}{60 \times 1000} = 1 \times 10^{-4}\ m^3 s^{-1}$$

$$u_1 = \frac{4Q}{\pi d_1^2} = \frac{4 \times (1 \times 10^{-4})}{\pi \times 0.015^2} = 0.5659\ m\ s^{-1}$$

$$v = \frac{\mu}{\rho} = \frac{4.6 \times 10^{-4}}{1000} = 4.6 \times 10^{-7}$$

$$Re_1 = \frac{u_1 \times d_1}{v} = \frac{0.5659 \times 0.015}{4.6 \times 10^{-7}} = 18453.26$$

$$\frac{e_1}{d_1} = \frac{0.0015}{15} = 1 \times 10^{-4}$$

$$f_1 = 4C_f = 4 \times 0.032 = 0.128$$

$$\Delta H_{f_1} = f_1\left(\frac{l_1}{d_1}\right)\left(\frac{u_1^2}{2g}\right) = 0.128\left(\frac{6.7}{0.015}\right)\left(\frac{0.5659^2}{19.62}\right) = 0.9332\ m$$

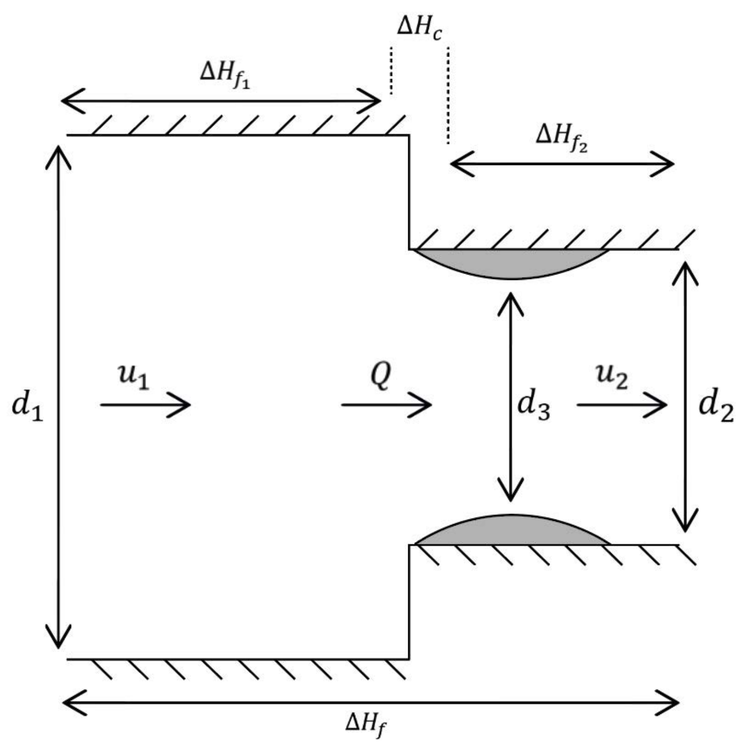


Diagram of the pipe diameter change, with grey flow separation bubbles

Pipe 2 - Head loss (second section):

$$u_2 = \frac{4Q}{\pi d_2^2} = \frac{4 \times (1 \times 10^{-4})}{\pi \times 0.01^2} = 1.273\ m\ s^{-1}$$

$$Re_2 = \frac{u_2 \times d_2}{v} = \frac{1.273 \times 0.01}{4.6 \times 10^{-7}} = 27679.1$$

$$\frac{e_2}{d_2} = \frac{0.0015}{10} = 1.5 \times 10^{-4}$$

$$f_2 = 4C_f = 4 \times 0.029 = 0.116$$

$$\Delta H_{f_2} = f_2\left(\frac{l_2}{d_2}\right)\left(\frac{u_2^2}{2g}\right) = 0.116\left(\frac{0.5}{0.01}\right)\left(\frac{1.273^2}{19.62}\right) = 0.479\ m$$

Overall head loss

$$\Delta H_f = \Delta H_{f_1} + \Delta H_{f_2} = 0.9332 + 0.479 = 1.412\ m$$

[1] https://www.enggcyclopedia.com/2011/09/absolute-roughness/
[2]https://www.simetric.co.uk/si_water.htm
[3] https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html
[4] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/482120/gbs-taps-automatic-sprays-showers-urinal-2015.pdf

Pipe Flow Calculation

Head loss (in change section), using Weisbach contraction coefficient[2]:

$$\mu = 0.63 + 0.37\left(\frac{A_2}{A_1}\right)^3 = 0.63 + 0.37\left(\frac{0.01^2}{0.015^2}\right)^3 = 0.794$$

$$A_3 = \mu \times A_2 = 0.794 \times 0.01 = 0.00794$$

$$\Delta H_c = \left(\frac{A_2}{A_3} - 1\right)^2\left(\frac{\bar{u}_2^2}{2g}\right) = \left(\frac{0.01^2}{0.00794^2} - 1\right)^2\left(\frac{1.273^{\,2}}{19.62}\right) = 0.028$$

Calculating P_1: $H_1 = H_2 + \Delta H_f + \Delta H_c$ (Modified Bernoulli)

$$\left(\left(\frac{p_1}{\rho g}\right) + \left(\frac{u_1^2}{2g}\right) + z_1\right) = \left(\left(\frac{p_2}{\rho g}\right) + \left(\frac{u_2^2}{2g}\right) + z_2\right) + \Delta H_f + \Delta H_c$$

$$p_1 = (\rho g)(\left(\frac{u_2^2 - u_1^2}{2g}\right) + (z_2 - z_1) + \Delta H_f + \Delta H_c$$

$$p_1 = (1000 \times 9.81)\left(\left(\frac{1.273^{\,2} - 0.5659^{\,2}}{19.62}\right) + (0) + 1.412 + 0.028\right) = Pa$$

$$14776\ Pa = 0.148\ bar$$

Intervention[1] - Using a standard 22mm d_1 pipe:

$$u_1 = \frac{4Q}{\pi d_1^2} = \frac{4 \times (1 \times 10^{-4})}{\pi \times 0.022^2} = 0.263\ m\ s^{-1}$$

$$Re_1 = \frac{u_1 \times d_1}{v} = \frac{0.263 \times 0.022}{4.6 \times 10^{-7}} = 12581.42$$

$$\frac{e_1}{d_1} = \frac{0.0015}{22} = 6.8 \times 10^{-5}$$

$$f_1 = 4C_f = 4 \times 0.0034 = 0.136$$

$$\Delta H_{f_1} = f_1\left(\frac{l_1}{d_1}\right)\left(\frac{u_1^2}{2g}\right) = 0.136\left(\frac{6.7}{0.022}\right)\left(\frac{0.263^2}{19.62}\right) = 0.146\ m$$

$$\Delta H_f = \Delta H_{f_1} + \Delta H_{f_2} = 0.146 + 0.479 = 0.625\ m$$

Bends head loss:

There are 3 bends and 1 t-junction in the pipe section:

$$\Delta H = 0.9 \times \left(\frac{u_1^{\,2}}{2g}\right)$$

For the initial pipe 1, the head loss

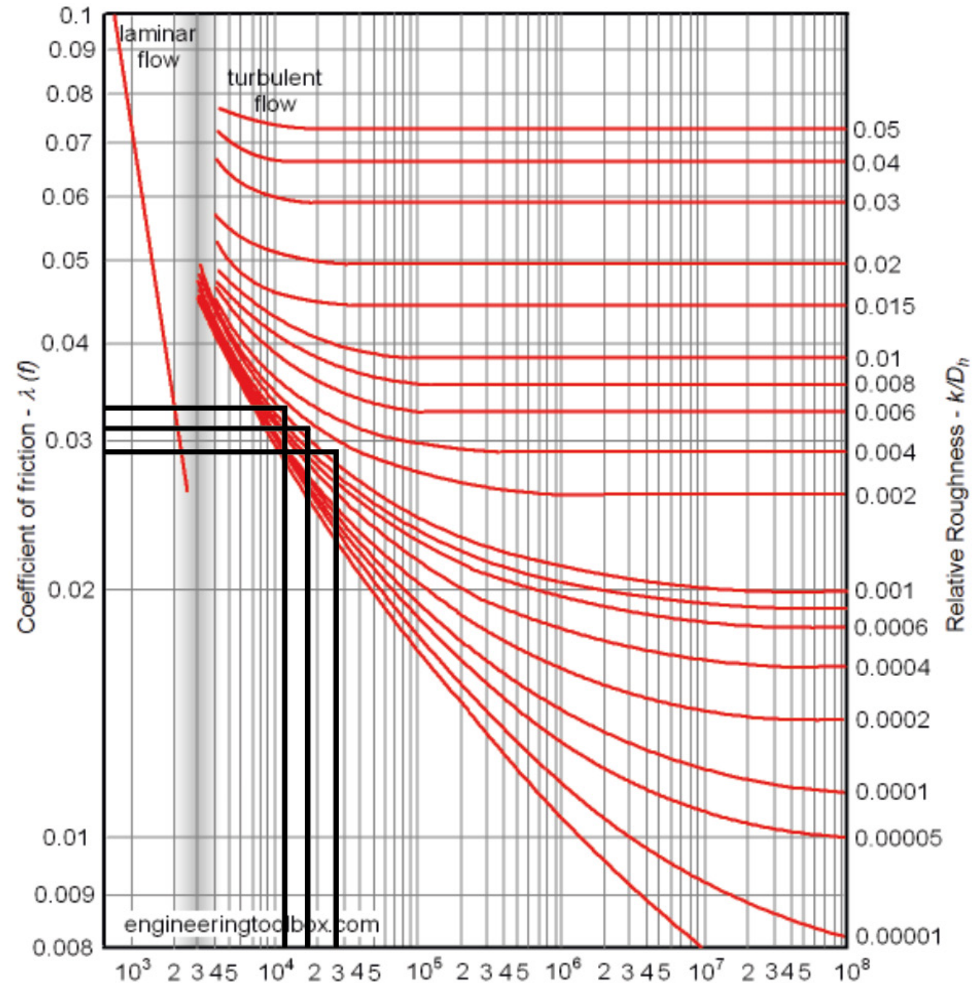
$$4\Delta H = 4 \times 0.9 \times \left(\frac{0.5659^{\,2}}{19.62}\right)$$
$$= 0.059\ m$$

For the new pipe, the head loss is:

$$4\Delta H = 4 \times 0.9 \times \left(\frac{0.263^{\,2}}{19.62}\right)$$
$$= 0.013\ m$$

We can see that although the intervention reduces head loss, it is negligible in overall head loss.

Moody Chart to calculate coefficient of friction



Pipe Cost

It is worth noting the increased expense of 22mm pipe v 15. For 1m of 22mm pipe (£4.22 /m) it is almost double that of 15mm pipe (£2.33 /m)[3]. As out pipe is only 6.7 m it shouldn't affect cost too much

New head loss (in change section):

$$\mu = 0.63 + 0.37\left(\frac{A_2}{A_1}\right)^3 = 0.63 + 0.37\left(\frac{0.01^2}{0.022^2}\right)^3 = 0.633$$

$$A_3 = \mu \times A_2 = 0.633 \times 0.01 = 0.00633$$

$$\Delta H_c = \left(\frac{A_2}{A_3} - 1\right)^2\left(\frac{\bar{u}_2^2}{2g}\right) = \left(\frac{0.01^2}{0.00633^2} - 1\right)^2\left(\frac{1.273^{\,2}}{19.62}\right) = 0.185$$

New P_1:

$$p_1 = (1000 \times 9.81)\left(\left(\frac{1.273^{\,2} - 0.263^{\,2}}{19.62}\right) + (0) + 0.625 + 0.185\right) = 8721.78\ Pa$$

$$8721.78\ Pa = 0.0872\ bar$$

Then working out the power that the pump needs for this pipe given 50% pump efficiency:

$$Power = \frac{Q\Delta P}{\eta} = \frac{(1 \times 10^{-4}) \times 8721.78}{0.5} = 1.74\ W$$

[1] https://www.diy.com/ideas-advice/how-to-understand-a-central-heating-system/CC_npcart_400300.art#:~:text=The%20radiator%20circuits%20in%20most,22mm%20or%2028mm%20in%20diameter.
[2] https://en.wikipedia.org/wiki/Borda%E2%80%93Carnot_equation
[3] https://plumbingsuppliesdirect.co.uk/copper-pipe-1-meter-long-in-15mm-22mm/

Carbon Neutral Energy

Now that the main energy losses from the pipes and walls are known in the house, the energy for other appliances can be calculated, then renewable energy sources can be added.

Appliance Values in the Static Caravan [1] (per day) Energy = $\frac{P \times T}{1000}$

Time	Use Time	Energy
TV 20W	2 Hours	0.04
Main Lights (10 lights at 6W) 60W	4 Hours	0.24
Fridge 90W	24 Hours	2.16
Phone Charger 5W	3 Hours	0.015
Kettle 900W	20min	0.6
Microwave 600W	10min	0.1
Toaster 700W	10min	0.12
Extractor Fan 200W	30min	0.1
Oven 2150W	30min	1.1
Power Shower 7500W	30 minutes	3.75
		Total
		8.225 kW h

As I wanted to try and avoid gas as an energy source, due to environmental factors as it still does produce some wastes and there are risks or carbon monoxide leaks, I ran my oven and combi boiler off electric. The heat losses from the house and the pipes can be used to work out how much energy the boiler needs to heat the house. An electric boiler also has solar comparability and takes up less space[2].

Combi boiler Energy Use:

Heating pipe and the loss through exterior walls:

$$0.06719 + 0.464 = 0.531\ kW$$

$$0.531 \times 24 = 12.75\ kW\ h$$

A 60W boiler pump[3] standard power rating for a pump, making up for head loss) running for 5 hours gives:

$$\frac{P \times T}{1000} = \frac{60 \times 5}{1000} = 0.3\ kW\ h$$

As combi boilers have two hot water pipes[4], one for radiators and one for taps, as we have found energy use for the radiators, we need energy use for taps.

The average hot water energy consumption based on 122[5] litres of hot water at 55°C and inlet water at average 15°C[6] is:

$$Q = mc\Delta T = 122 \times 4200 \times (55 - 15) = 204960000\ J$$

$$\frac{20496000}{3600000} = 5.69\ kW\ h$$

Therefore in total, the boiler output value can be calculated:

$$12.75 + 0.3 + 5.69 = 18.74\ kW\ h$$

[1] https://www.nimblefins.co.uk/how-much-does-it-cost-own-caravan#nogo
[2] https://www.boilerguide.co.uk/articles/running-electric-combi-boiler-solar-pv
[3] https://www.viessmann.co.uk/heating-advice/does-a-boiler-need-electricity
[4] https://www.boilerguide.co.uk/articles/what-is-a-boiler-and-how-does-it-work
[5] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf
[6] https://www.earth.org.uk/note-on-data-for-16WW-mains-water-inlet-temperature.html#:~:text=What%20is%20the%20domestic%20water,C%20(winter%20vs%20summer).

Carbon Neutral Energy

We now have a daily power use value from all appliances, and the boiler. We can also assume that power needed from the pressure lost in the pipe flow calculations is compensated for by the 60W pump:

$$18.74 + 8.225 = 26.96\ kW\ h$$

Using standard 250W solar panels, of area 1.6m^2, and using the caravan roof area of 37.37m^2. The size of the system can be calculated:

$$\frac{37.37}{1.6} = 23.3\ Panels$$

In reality, there will probably be space for only 20 , due to the apex on the roof:

$$20 \times 250 = 5\ kW$$

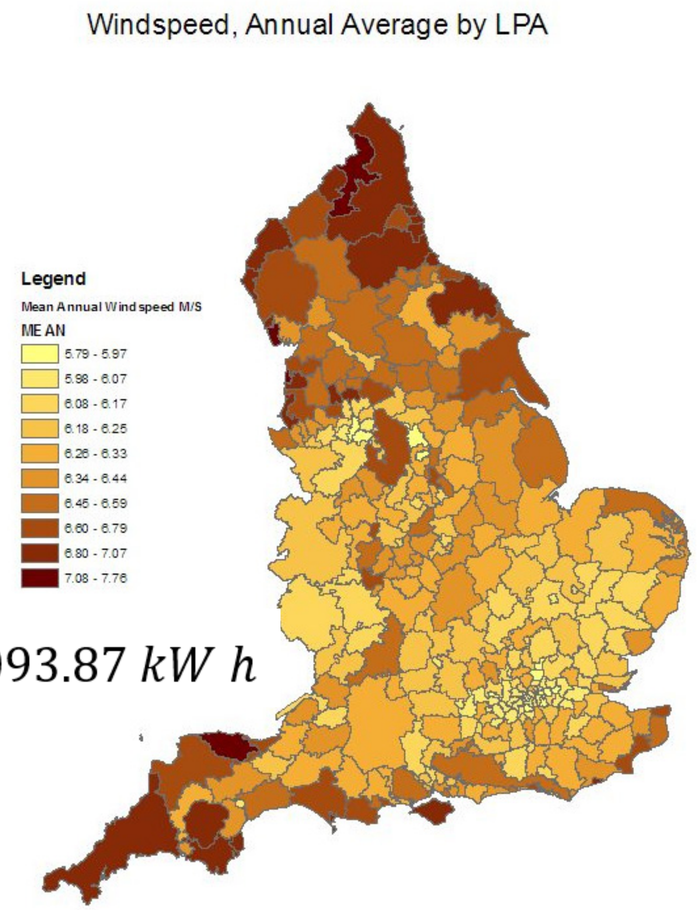
5 kWh solar systems can only output 20 kW h per day[1], which will not cover the overall energy requirement for the home:

$$26.96 - 20 = 6.96\ kW\ h$$

Another source must provide the extra 6.96 kW h needed.

With many static caravans being situated in coastal areas with high wind speeds, it was an obvious choise to select wind turbines as the solution to covering the extra 6.96 kW h energy demand. Larger turbines are already frequent in coastal areas so this intervention shouldn't be contriversial with environmentalists and local communities.

We can see from the wind speed figure that even the lowest wind speeds in the country are around 6 ms^{-1}, and this equates to 13.4mph. If the blades are 1.5m radius this equates to 9.84 foot diameter Using the turbine AEO formula[2], we can find the annual energy output:



$$Q = 0.01328 \times D^2 \times V^3$$

$$Q = 0.01328 \times 9.84^2 \times 13.4^3 = 3093.87\ kW\ h$$

$$\frac{3092.87}{365} = 8.47\ kW\ h$$

There is now enough renewable energy by using the solar panels and the turbine to cover all the energy use in the Static caravan. You can see that there is excess energy left over that can be stored.

$8.47 + 20 = 28.47\ kW\ h$	Total renewable energy
$28.47 - 26.96 = 1.51\ kW\ h$	Excess energy

<u>Summary</u>

Therefore apart from a water supply being needed, the static caravan is now 'off grid' and is carbon neutral, which was the aim of this analysis and calculations.

[1] https://www.greenmatch.co.uk/solar-energy/solar-system/5kw-solar-panel-system#:~:text=Power%20Output%20of%20a%205kW%20Solar%20Panel%20System&text=The%20system%20will%20generate%20approximately,panels%20have%20250%20watt%20capacity.

[2] https://www.nrel.gov/docs/fy07osti/42005.pdf

[3] https://andrewlainton.wordpress.com/2012/05/09/englands-windiest-and-least-windy-lpas-nppf/