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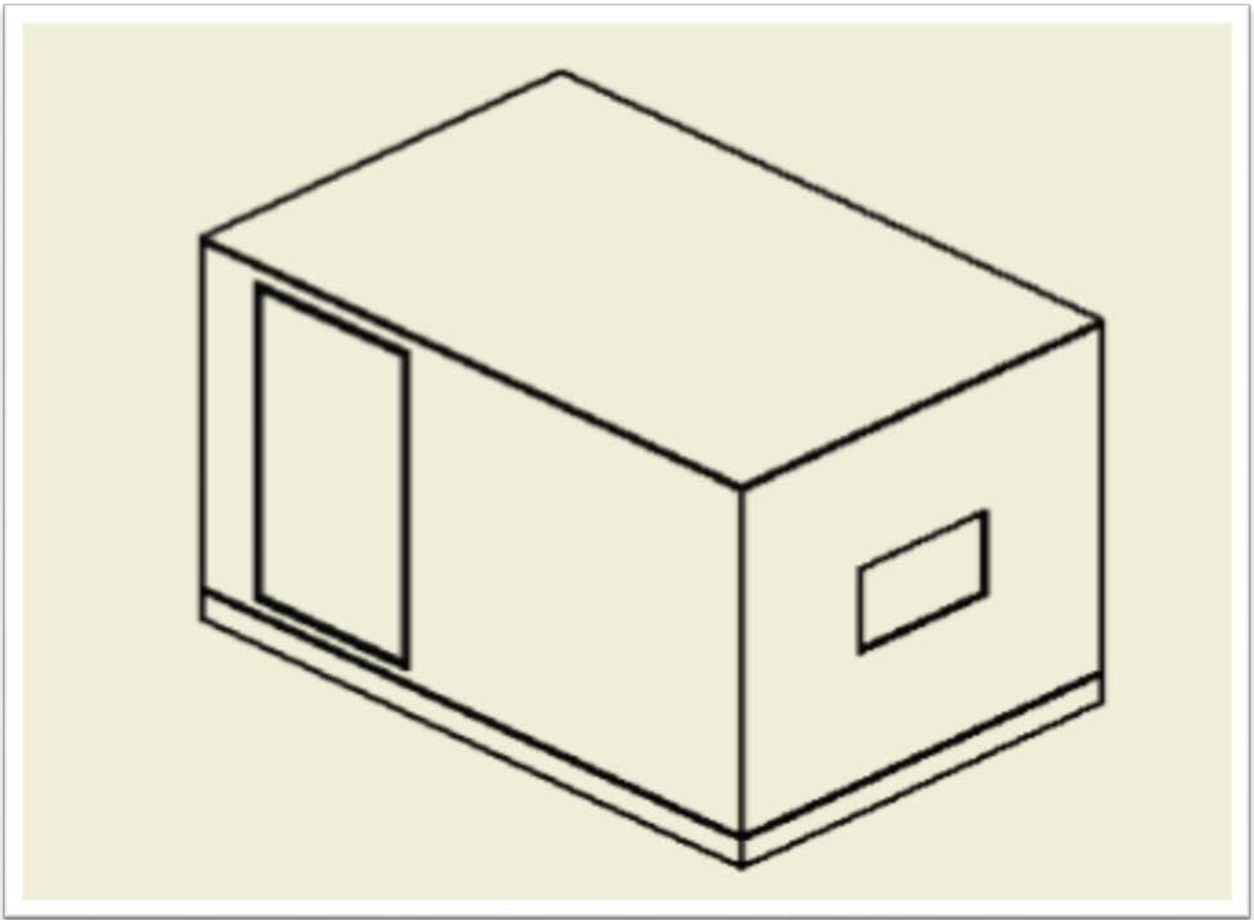
Thermal Consideration of a Shed



CONTENTS

PREFACE

This study is concerned with finding the heat loss from a shed. The shed will be used as office/retreat and it has one door two windows and ventilation.
An attached spreadsheet includes all the additional calculations that are not in the main body of the report.
It is attempted to reduce the heat losses with certain improvements such as insulation with environmentally friendly materials and other techniques like mixed mode ventilation and air gap filling.
The improvements cause a reduction in heat loss and heating cost. The cost for the improvements and the reduction of the heating cost are calculated and the payback is found to be 1.3 years.
The concept of degree days is then introduced for a more realistic approach with respect to the actual temperatures and the actual heat loss is determined.
The actual cost for heating is calculated and finally the actual payback is found to be 1.6 years.

INTRODUCTION

Buildings are subject to constant exchange of heat due to differences in temperature between the inside and the outside.
When the temperature outside is lower than inside heat is lost by conduction through the walls, floor, roof and windows and by convection due to infiltration when the cold air enters through gaps at the doors between and window frames.
Heat is also lost due to ventilation and by radiation from the windows and the roof.
In oppose to this, heat is gained with solar radiation through the windows.
A typical heat loss pattern from each section of a building is illustrated below.
Heat losses can be limited with insulation, carpet fitting, double glazed windows, curtains, and draught excluders. However the sustainability of such an action is not always guaranteed due to resulting long payback times.

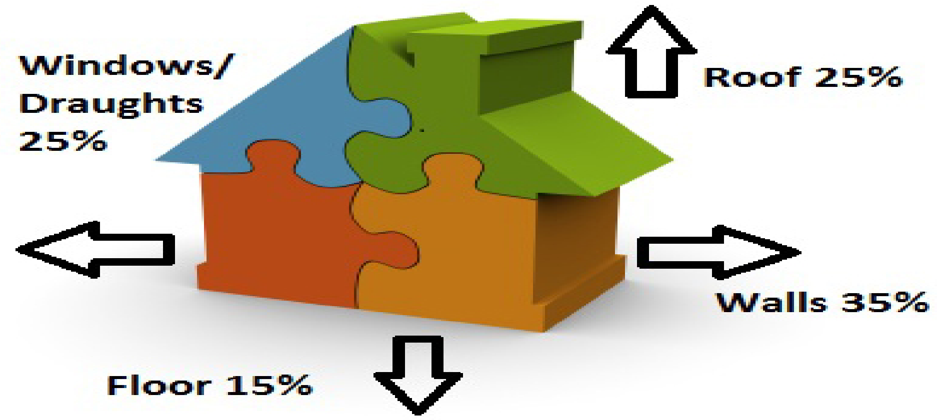


Figure 1 - Typical Heat Loss Distribution

In this study the heat losses from a shed are calculated. The shed is required to have 20C average internal temperature and 5C average external temperature, it will be used as office and has one door and two windows.

Calculations will be made first for the shed in its original form as it is sold by the manufacturer, and then certain improvements will be applied to reduce heat loss. This will be done using insulation from environmentally friendly materials and other techniques such as mixed mode ventilation and gap filling.

The results will be evaluated in terms of efficiency, cost and sustainability and a proposal with the most suitable selection of materials and characteristics will be made.

SHED SPECIFICATIONS

The shed located in Edinburgh Scotland and it is made by TGB with pine and has 14 mm thick walls and door. It is supplied pre-treated with an eco-friendly preservative basecoat in red cedar colour that makes it air tight and protects is from humidity. Dimensions in appendix 1.

The roof and the floor are flat and they are made of 18mm thick plywood covered with liquid rubber felt on the outside to keep them watertight. A small extractor fan will be pre-installed and the structure is placed on an elevated -pallet type- base that in turn is placed on concrete ground for more stability.

The shed originally comes with 2 single glazed windows of 4mm thick glass, and dimensions 50mmx70mm, the frame is made of pine and is14mm thick, the same as the wall.

For these particular characteristics and dimensions the total cost including free delivery and installation comes to £740.

Figure 2 - Shed Representation in Inventor

HEAT LOSS CALCULATIONS

ASSUMPTIONS

- The required temperatures are 20C inside and 5C outside.
- The shed will be used daily for 10 hours in average, between 8am and 6pm and the heating demand is restricted in these hours.
- On annual basis Scotland has an average humidity of 80% (appendix 6). At the given range of temperatures and for the given humidity, pine has thermal conductivity k=0.12W/m.K.
- Heat loss is assumed to take place mainly in a convection conduction convection pattern. The thermal effect of the frame of the shed and of the additional framing that will be used for insulation is neglected.
- The contact resistance between the various layers of materials is neglected.
- The thermal effect of the preservative basecoat, and of the glues and all the fillers that will be used is neglected.
- For the values where units are not noted it is implied that it is SI units

WALLS AND DOOR

Assuming that heat loss takes place with convection from the inside the room to the wall, then with conduction through the wall and then again with convection from the wall to the outside.

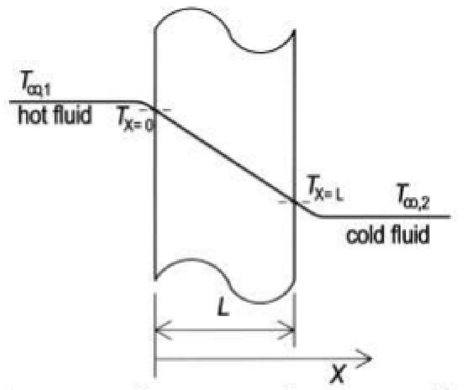


Figure 3 - Heat Loss through Wall

Assuming an initial surface temperature for the inner wall surface of T_{wi}=16C

The thermal properties of air inside the shed are calculated based on the resulting film temperature T_{fi}=18C or 291.2K

Tfi K	ρ-kg/m^3	Cp-kJ/kg.K	μ-N.s/m^2	v-m^2/s	k-W/m.K	α-m^2/s	Pr
291.2	1.203	1.007	1.80E-05	1.51E-05	2.56E-02	2.13E-05	0.709

Heat Flux Inside, $q_i=h_i(T_i-T_{wi})=h_i(20-16)=4h_i$ equation 1

Wall Height, L=2.1m

Rayleigh Number, $\mathrm{Ra} = \frac{\mathrm{g\beta(Ti-Twi)L^3}}{\nu\alpha} = \frac{9.81\frac{1}{18}(20-16)2.1^3}{1.51\ 10^{-5}\ 2.13\ 10^{-5}} = 3.87\ 10^9$

The calculated Rayleigh Number lies in the range $10^{-1} < Ra < 10^{12}$, and therefore the following formula for the Nusselt Number applies

Nusselt Number, $\mathrm{Nu} = \left\{0.825 + \frac{0.387\mathrm{Ra}^{\frac{1}{6}}}{\left[1+\left(\frac{0.492}{\mathrm{Pr}}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}}\right\}^2 = \left\{0.825 + \frac{0.387\left(3.87\ 10^9\right)^{\frac{1}{6}}}{\left[1+\left(\frac{0.492}{0.709}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}}\right\}^2 = 187.2$

$\mathrm{Nu} = \frac{\mathrm{hiL}}{\mathrm{k}}$, $\mathrm{hi} = \frac{\mathrm{kNu}}{\mathrm{L}} = 2.56\ 10^{-2}\frac{187.2}{2.1} = 2.28$ i.e. hi=2.28 $\mathrm{W/m^2}K$

Substituting in Equation 1: q_i=4x 2.28=9.12 W/m^2

The heat flux is constant and therefore heat fluxes inside and outside the shed are equal, q=qi=qw=qo

For wall thickness 14mm and pine thermal conductivity k=0.12 W/mk

$$qw = \frac{k}{t}(Tsi - Tso), Tso = Tsi - \frac{t\,qw}{k} = Tsi - \frac{t\,qi}{k} = 16 - 0.014\frac{9.12}{0.12} = 14.9C$$

Tso=14.9C

Thus the outside film temperature is Tfo=10C or 283.12K, and at this temperature the thermal properties of air are:

Tfo K	ρ- kg/m^3	Cp-kJ/kg.K	M- N.s/m^2	v- m^2/s	k- W/m.K	α- m^2/s	Pr
283.12	1.240	1.007	1.76E-05	1.44E-05	2.49E-02	2.03E-05	0.711

Again but this time for outside the same sequence of calculations will is applied to determine the heat transfer coefficient of air.

Heat Flux Outside, qo=qi=ho(Two-To), 9.12=ho(14.9-To)=9.9ho , equation 2

Rayleigh Number, $Ra = \frac{g\beta(Two-To)L^3}{\nu\alpha} = \frac{9.81\frac{1}{10}(14.9-5)2.1^3}{1.44\ 10^{-5}\ 2.03\ 10^{-5}} = 1.09\ 10^{10}$, $10^{-1} < Ra < 10^{12}$

Nusselt Number, $$Nu = \left\{0.825 + \frac{0.387Ra^{\frac{1}{6}}}{\left[1+\left(\frac{0.492}{Pr}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}}\right\}^2 = \left\{0.825 + \frac{0.387\left(1.09\ 10^{10}\right)^{\frac{1}{6}}}{\left[1+\left(\frac{0.492}{0.711}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}}\right\}^2 = 259.6$$

$Nu = \frac{hiL}{k}$, $ho = \frac{kNu}{L} = 2.49\ 10^{-2}\frac{259.6}{2.1} = 3.08$i.e. h_o=3.08 W/m^{2}K

And so equation 2 gives, 9.12=3.08(14.9-To)

Solving for To, To=11.08C

The result should be 5C and so the process is repeated with a different selection for the assumed inside temperature in order to produce a result closer to the given outside temperature value.

For calculations in hand the process needs to be repeated until the result is of the desired accuracy. However in the case of the spreadsheet and using the goal seek function by setting the heat flux difference as 0, and changing the inside surface temperature the results are found to be, T_{si}=13.5C, T_{so}=11.4C

The total area of wall and door excluding the windows, A_w=2 [(2+3) 2.1]-2(0.7x0.5)=20.3m^2

Heat Loss through walls and door, Q_w=q x A=17.4*20.3, **Qw=353.1W**

FLOOR AND ROOF

The floor and the roof are both made of the plywood 18mm thick with thermal conductivity k=0.16W/m.K
Heat loss takes place in the same pattern as for the walls with the only difference being that there is additional heat loss from the roof due to radiation and that different formulas apply for Nusselt number.

ROOF
Heat is lost through the roof as a combined effect of conduction and radiation.

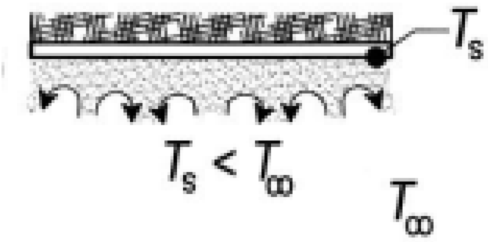


Figure 4 - Roof Heat Loss

Using the characteristic length L=Area/perimeter the average Rayleigh Number is found to be $\mathrm{Ra} = 1.55\ 10^8\ , 10^7 < Ra < 10^{11}$
Nusselt Number is, $\mathrm{Nu} = 0.15\ \mathrm{Ra}^{\frac{1}{3}}$

The surface temperatures that determine the properties of the surrounding air are, T_{Ri}=13.7C and T_{Ro}=11.3C, and the heat loss through the roof, Q_{RC}=127.8 W
In addition to the above, radiation contributes to the heat loss giving a total of,
$Q_R = \varepsilon A \sigma (\mathrm{T}^4 o - \mathrm{T}^4 \infty)$, σ= 5.67* 10^{-8} W/mK^{-4}
The roof is covered with rubber felt which is assumed to raise the surface temperature of the roof by an additional 0.5C, i.e. T_{RO}=11.8c.

Taking ε=0.92 for rubber then heat loss due to radiation is,
Q_{RR}=0,92 (2*3) 5.67*$10^{-8}$$((11.8 + 273.15)^4 - (5 + 273.15)^4)$, **$Q_{RR}$ =190W**

FLOOR

The shed is placed on a pallet type base made of wood with a plywood panel on the top. Assuming that heat is lost from in a convection-conduction-convection pattern ignoring the contact imperfections between the floor and the base top as a layer of filler foam unifies the two turning them effectively into one.

The base top is 10mm plywood and so a total of 28 mm plywood is considered as the overall thickness of the floor.

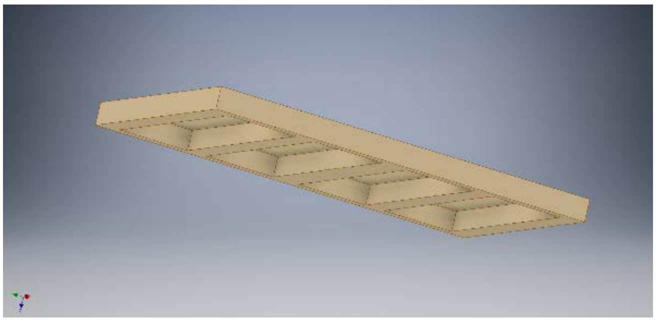


Figure 5 - Shed Base

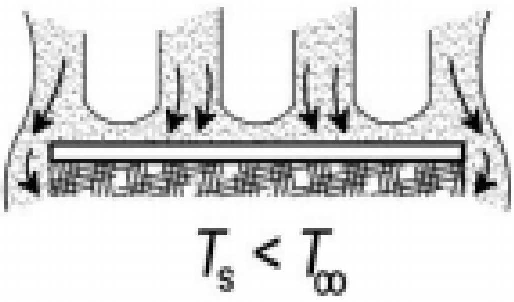


Figure 6 - Floor Heat Loss

Characteristic Length, L=Area/perimeter,

The average Rayleigh Number is Ra_{aL}=1.66 10^8 $10^5 \leq Ra \leq 10^{10}$

Nusselt Number is, $Nu = 0.27Ra^{\frac{1}{4}}$

The surface temperatures determining the air properties are found to be

T_{Fi}=13.2C and T_{Ro}=11.7C,

And the heat loss through the floor is, **Q_F =52 W**

WINDOWS

Assuming heat loss due to radiation to be negligible due to the small area of the windows, then heat is lost only with conduction. There are 2 single glazed windows with wooden frames are installed on two of the walls of the shed. They have a glass 4mm thick and the frames are 14mm thick, same as the walls. Similarly as before the properties of air at both sides of the glass are calculated and the heat transfer is obtained.

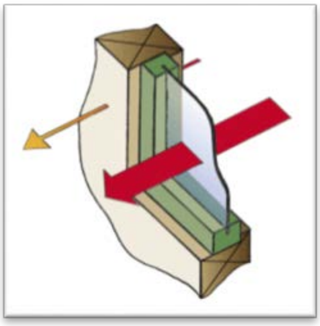


Figure 7 - Single Window

Due to the small thickness of the glass and its relatively high thermal conductivity, it is assumed that the glass is at constant temperature equal to the film temperature Tg=(Ti+To)/2=(20+5)/2=12.5C

Heat loss through the glass, $Q_{SG}=A_G(T_i-T_o)/R_{SG}$

Thermal resistance, $R_{SG}=1/h_i+1/(k_G/t_g)+1/h_o$

The heat transfer coefficients are given from the module example 6-6B, at 20C hi=9 and at 0C ho=16. Assuming ho to be 16 for 5C

For the glass tg=0.004m and kg=1.2 W/m.K, Hence R_{SG}=0.18

Substituting, Q_{SG}=0.7*0.5(20-5)/0.18, **Q_{SW}=29.2W**

There is an additional amount of heat loss from to radiation which however due to the percentage contribution of the windows to the total heat loss and also because of the small size of the windows it is neglected

INFILTRATION

Heat is lost with infiltration as a result of air shifting due to leakage through the edges between the walls, from the door frame, from the window frame, and from the holes made for the electric and telecommunication cables.

Assuming that initially the air shifts by n=4 times per hour or 0.0011 per sec

The heat loss caused by infiltration is given by the following formula

$Q_I = c_p \rho n V (T_i - T_o)$

For volume of room V=2x3x2.1=12.6m^2

At film temperature T_f = (20+5)/2=12.5C, C_p and ρ are determined.

Substituting in the above equation, Q_i= 1007*1.228*0.0011*12.6*(20-5)=257.1W

And heat loss due to infiltration, **Qi=257.1 W**

VENTILATION

Ventilation is important for a healthy and comfortable environment however it usually accounts for more than 50%, of the total heat loss. Ventilation can be mechanical (forced), natural or hybrid. Mechanical systems use electricity to power fans that extract air. Natural ventilation is the process by which airflow through ventilation openings is driven by the natural forces of wind and temperature difference and hybrid is a mix of both with optimum results. (CIBSE, 2015)The given shed comes with a simple 2 speed with fan with timer that is pre-installed on the roof. When the fan on operating mode, ventilation is forced and when the fan is off ventilation is natural.

- Fan-On

Heat loss due to forced ventilation is, $Q_{VM} = C_p\ \rho\ q\ (T_i - T_o)$

C_p and ρ are calculated for the film temperature 12.5C.

The low speed extraction volume rate of air which is sufficient for a satisfactory ventilation is given to be q_v=85/2=42.5 m^3/h or 0.0118m^3/s (appendix 1)

Substituting, Q_{VM}=1007*1.228*0.0118*(20-5) =219, Q_{VM}=219W

On top of that an additional 20 W of electricity is required to run the fan must to be added to the above value for the heat recovery calculations.Hence**, Q_{VM}=239W**

- Fan- Off

Ventilation in this case is natural and heat is lost with natural convection through the fan frame.

$Q_{VN} = C_p\ \rho\ V\ (T_i - T_o)$, with V being the volume flow rate of air through the fan

Assuming that the speed of air leaving the building is u=0.1m/s and given that the fan has diameter d=0.11m^2 then the volume of air leaving escaping to the atmosphere is

V=uA=$0.1 * \pi * \frac{0.11^2}{8} = 0.000475\frac{m^3}{s}$, or 1.71$m^3/h$

Q_{VN}= 1007 1.228 0.000475 (20- 5), **Q_{VN} =8.8W**

The ventilation mechanism has diameter 0.01m^2, i.e. a negligible area comparing with the total area of the roof and so it does not affect the heat loss by conduction through the roof.

TOTAL HEAT LOSS

The total heat loss calculated for the shed in its original form is

$Q_{TOT1}=Q_W+Q_R+Q_F+Q_W+Q_I+Q_{VM}$=353.1+190+52+2*29.2+257.1+239

Q_{TOT1}=1149.6W

HEAT LOSS REDUCTION

WALLS, ROOF & FLOOR

Figure 8 - Insulation Process

Various insulation materials like Rockwool, Natural Wool, Wood Fibre, and Cork Boards are considered. Efficiency will be determined in terms of thermal performance, cost per insulation area and environmental impact.

The above materials are close in price and have reasonable thickness.

ROCKWOOL

It is made from volcanic rock, and has good acoustic and thermal properties, high compressive resistance and it is easy to handle and fit.

WOOD FIBRE

Excellent thermal performance, hygroscopic properties provide vapour control, acoustically effective, sustainable and environmentally friendly, safe and easy to handle.

CORC BOARD

Cork board insulation is made entirely from natural and renewable cork. The boards offer a vapour permeable insulation with excellent acoustic performance.

NATURAL WOOL

Natural wool is an easy to use sheep wool based insulation material supplied in compressed packed. It is made from 75% sheep wool, with a high recycled content which makes it a truly sustainable material.

The option of recycled rubber made from used tyres is not examined due to concerns for high toxicity and health hazards.

Insulation is done by spreading one layer of the insulating material on top of the surface of interest held in place by framing blocks. An additional plywood board 6 mm thick covers the insulation.

To calculate the new heat loss the same method as before is applied with the appropriate additions. All calculations are made in the spreadsheet and the results are given below.

INSULATION	K W/m.K	t m	HL WALL W	HLROOF W	HLFLOOR W	HLTOTAL W	COST£/m2
Rockwool	0.044	0.100	87.9	27.3	20.7	135.9	5.19
Natural Wool	0.040	0.050	129.7	41.2	27.9	198.8	4.37
Wood fibre	0.040	0.050	129.7	41.2	27.9	198.8	6.77
Cork Board	0.045	0.020	211.7	58.6	35.1	305.4	7.60

Table 1 - Reduced Heat Loss by Insulation Material

Rockwool and Natural Wool appear to be the most effective with respect to heat loss reduction and cost per unit area.
Rockwool is selected in order to proceed with our study

Using the value for heat loss through the wall and for assuming an additional 0.5C to the external temperature, To=7.5C and therefore heat loss from the roof by radiation is,
$Q_{R2} = \varepsilon A\sigma(T^4{}_o - T^4{}_\infty) = 0.92*6*5.67*10^{-8}((7.5+273.15)^4-(5+273.15)^4)$, $\mathbf{Q_{R2} = 68.3W}$

DOUBLE GLAZED WINDOWS

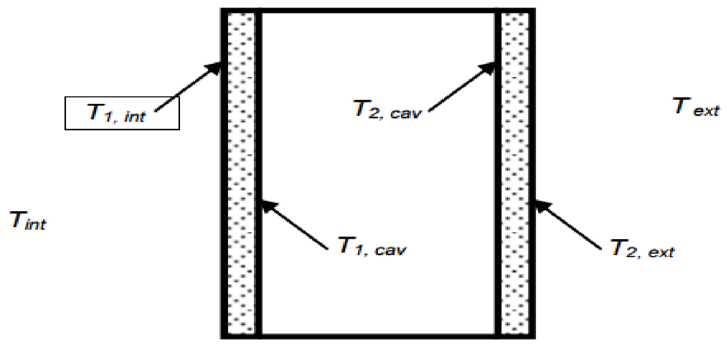


Figure 9 - Double Glazed Windows

For double glazed windows filled with argon gas,

$Q_{SG}=A_G(T_i-T_o)/R_{SG}$

This time the process of convection in the cavity and radiation are considered

Hence, $R_{SG}=1/h_i+2/(k_G/t_g)+1/(h_{Ccav}+h_{Rcav})+1/h_o$

h_{Ccav} =kc/tc=0.017/0.006=2.83 W/m^2 K

$h_{Rc}=\frac{4\sigma T^3 f}{2/\varepsilon g-1}$=4.1W/m^2 K, hi=9 W/m^2 K, ho=16 W/m^2 K

Substituting,

For the glass tg=0.004m and kg=1.2 W/m.K

R_{SG}=1/9+2/(1.2/0.004)+1/(2.83+4.1)+1/16=0.32

Substituting, QSG=0.7*0.5(20-5)/0.32=16.4W

Q_{DW}=16.4W

VENTILATION

According to Cibse the minimum ventilation requirement per person is 0.5 l/s.

It is assumed that the timer allows the fan to work for 5 minutes at low speed and then stops for 5 minutes and so on. This way a cheap mixed modes operation is achieved giving heat loss, Q_V=0.5QVM+0.5QVN=0.5*239+0.5*8.8=123.9W

Q_{V2}=123.9W

INFILTRATION

Infiltration heat loss is reduced by applying filer material in the gaps between each section of the shed and around the door frame and the window frames, by filling the cable installation holes with filler foam, using curtains for the windows and draft excluders for the door.

It is assumed that these measures reduce the air-shifts by half.

Therefore Q_{I2}=257.1/2 **Q_{I2}=128.5W**

THEORETICAL HEAT LOSS DIFFERENCE

Q_{TOT2}=87.9+68.3+20.7+2*16.4+123.9+128.5

Q_{TOT2}=454.1W

On annual basis the heat loss with insulation is, Q_{TOT2}=454.1*365*10=1658kWh

ANNUAL HEATING SAVINGS

Given that all other factors that affect the heat gain and heat loss remain unchanged , then, the drop in heating demand is Dq=1149.6-454.1=695.5W

For 10 hours of use and 365 days a year this converts to energy demand of 695.5*10*365=2539kWh

Assuming that heat is provided with a resistance heater of 100% efficiency and taking the cost to be 15p/kWh (BritishGas, 2015)

The savings on heating in a year comes to 2539*0.15=£381

Annual Heating Savings=**£381**

THEORETICAL PAYBACK

Assuming that all the insulation work is done by the owner without having to purchase any additional tools than what is already available, then the total cost for reducing the heat loss is the sum of the following costs:

Insulation+ Double Glazed Windows+ Curtains+ Drought Excluders+ Fillers+ Framing+ screws and nails

Insulation Cost=(Cost of Rockwool per area+Cost of Plywood 6mm) x Insulation Area=(5.19+5.44)*[2*(2+3)*2.1+2*(2*3)-2*0.7*0.5]=£388

Double Glazed Windows

Assuming that the shed can be ordered with double glazed windows pre-installed instead of the single glazed ones. Then for additional £25 per m^2 the cost difference will be 25*2*07*05=£17.5

For the rest assuming £100 of total cost

The total cost is 388+17.5+100=£505.5

Theoretical Payback=505.5/381=1.3 years

REAL HEAT LOSS

In reality there is a substantial error resulting from the simplification of the average temperatures assumption. Energy Calculations are commonly made using degree days (DD). For the Edinburgh Airport area and based on the data from appendix 5 it is given that for a base temperature of 20 degrees the annual degree days are 4136. Converting this back to average temperatures we find that the average outdoors temperature is 20-4136/365=8.7C. Hence for air at the indoors film temperature $\frac{20+\frac{20+8.7}{2}}{2} = 17.2\text{C}$ with hi=2.55 W/m^2 K and at $\frac{\frac{20+8.7}{2}+8.7}{2} = 11.5\text{C}$ with ho=3.02 W/m^2 K

The total thermal resistances will be used and annual heat losses in kW will be obtained for 10 hours a day before and after insulation. Adding their differences together gives the actual total heat loss difference.

WALLS

For the walls the heat transfer coefficients are, hi=2.55 W/m^2 K, ho=3.02 W/m^2 K

Total thermal resistance, R_{W1}= 1/hi+1/ho+L/k=1/2.55+1/3.02+0.014/0.12=0.84 m^2 K/W

Q_{W1}=10Aw*DD/1000Rw=10*20.3*4136/1000*0.84=999.5 kWh per year

R_{W2}= R_{W1}+L2/k2+L3/k3 =0.84+0.1/0.044+0.006/0.16=3.15 m^2 K/W

Q_{W2}=10Aw*DD/1000Rw2=10*20.3*4136/1000*3.15=266.5 kWh per year

DQw=976.3-256.8=733 kWh per year

FLOOR

For the floor the heat transfer coefficients are, hi=1.28 W/m^2 K and ho=1.29 W/m^2 K

R_{F1}=1/hi+1/ho+L/k=1/1.28+1/1.29+0.028/0.16=1.73 m^2 K/W

Q_{F1}=10*A_F*DD/1000R_{F1}=10*6*4136/1000*1.73=143.5kW per year

R_{F2}= R_{F1}+ L2/k2+L3/k3 =1.73+0.1/0.044+0.006/0.16=4.04 m^2 K/W

Q_{F2}=10*A_F*DD/1000R_{F2}=10*6*4136/1000*4.04=61.4kW per year

<u>DQ_F=143.5-61.4=82.1 kW per year</u>

ROOF

For the roof the heat transfer coefficients are, hi=3.43 W/m^2 K and ho=3.26 W/m^2 K

R_{R1}=1/hi+1/ho+L/k =1/3.43+1/3.26+0.018/0.16=0.7 m^2 K/W

Q_{R1}=10*AR*DD/1000Rr1=10*6*4136/1000*0.7=354.5kW per year

R_{R2}= R_{R1}+ L2/k2+L3/k3 =0.7+0.1/0.044+0.006/0.16=3 m^2 K/W

Q_{R2}=10*AR*DD/1000Rr2=10*6*4136/1000*3=82.7kW per year

<u>DQ_R=354.5-82.7=271.8 kW per year</u>

WINDOWS

Using the R values calculated previously,

R_{SG}=0.18 m^2 K/W

Q_{SG}=10*Aw*DD/1000R_{SG}=2*10*0.7*0.5*4136/1000*0.18=160.8kW per year

R_{DG}=0.32 m^2 K/W

Q_{DG}=10*Aw*DD/1000R_{DG}=10*0.7*0.5*4136/1000*0.18=80.4kW per year

<u>DQ_{Win}=160.8-80.4=80.4 kW per year</u>

INFILTRATION AND VENTILATION

The new values are reduced because of the increase of the average outdoor temperature from 5Cto 8.7C. Therefore the new temperature difference that determines the corresponding heat losses change from 20-5=15C to 20-8.7=11.3C

Thus <u>Infiltration QI=128.5x11.3/15=97W or 97*10*365=354kWh</u>

And <u>Ventilation Qv=123.9x11.3/15=93.3 or 123.9*10*365=452.2kWh</u>

ACTUAL PAYBACK

The actual heat loss difference is given by the sum of the heat loss differences by section as calculated above plus the heat losses due to infiltration and ventilation.

$DQ_{TOT}=DQ_W+DQ_F+DQ_R+DQ_{WIN}+DQ_V+DQ_i$

DQ_{TOT} =733+82.1+271.8+80.4+ (239*10*365/1000-452.2)+(257.7*10*365/1000-354)=2174kWh

The cost of heating demand difference is 2174*0.15=£326.1 per year

And therefore the Actual Payback is 505.5/326.1=1.6 years

RESULTS ANALYSIS AND EVALUATION

The calculations for the actual heat loss were made based on the reduction of the heating demand as it was obtained from the actual degree days. Degree days is a very accurate and simple method to calculate heating demand. Variation between the spreadsheet and the degree days method is mainly because of the difference of the actual and the given outdoor temperatures.

ORIGINAL SHED	Tsi	hi	Tso	ho	Q
WALLS/DOOR	13.5	2.67	11.4	2.7	353.1
ROOF	13.7	3.36	11.3	3.4	190
FLOOR	13.2	1.28	11.7	1.29	52
SG WINDOWS	R=0.18	K=1.2			58.4
INFILTRATION	n=4				257.1
VENTILAITON m	v=0.0059				239
VENTILATION n	v=0.000475				8.8
TOTAL HL W					1149.6

IMPROVED SHED	Tsi	hi	Tso	ho	Q
WALLS/DOOR	17.7	1.91	7.2	1.94	87.9
ROOF	18	2.27	7	2.32	68.3
FLOOR	16.8	1.06	8.2	1.07	20.7
DG WINDOWS	R=0.32	K=1.2			32.8
INFILTRATION	1/2(Qm+Qn)				128.5
VENTILAITON m	v=0.0059				123.9
VENTILATION n	v=0.000475				8.8
TOTAL HL W					454.1
	HEAT LOSS REDUCTION W				695.5

Having a very long life cycle and certainly longer than pine, rockwool insulation is an appropriate choice as it offers payback in 1.6 years. Small differences in price comparing with natural wool cannot change the outcome of the research.

For a 10 hour use a day, the total heat loss in kW in a year is

Q_{TOT}=266.5+1.15x82.7+61.4+80.4+354+452.2=1309.6kWh

Walls:266.5/1309.6=20.3%

Roof:1.15x82.1/1309.6==7.2%

Floor: 61.4/1309.6=4.7%

Windows:80.4/1309.6=6.1%

Infiltration:354/1309.6=27%

Ventilation:452.2/1309.6=34.5%

Infiltration accounts for 32.9% of the total heat loss and it is the one that could be improved further without significant and costly changes, a better air tightening could reduce it even further.

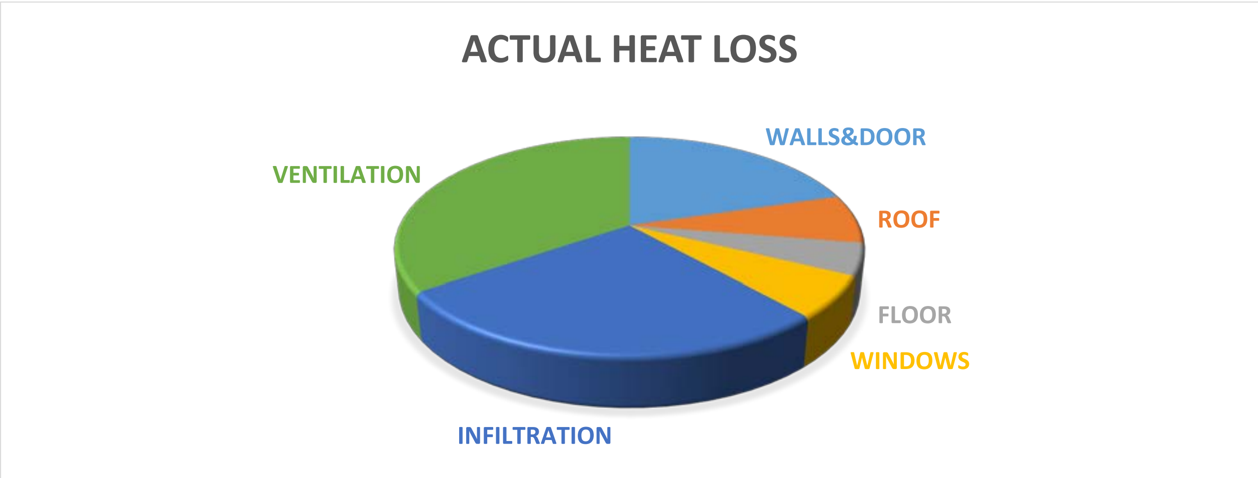


Figure 10 - Heat Loss by Element

CONCLUSION

Research was made for selecting an appropriate shed for office use. Several assumptions were made among which that the office will be used for average 10 hours a day and based on this the annual heating demand was calculated.

The concept of degree days made the calculations more realistic and closer to real world calculations, however in the case of infiltration and ventilation reverting from degree days back to average daily temperature was the key for making calculations more accurate. Improvements for reduced heating demand were introduced for a cost of reasonable payback. The objectives set for this assignment with the use of a process that gives accurate and reliable results.

REFERENCES

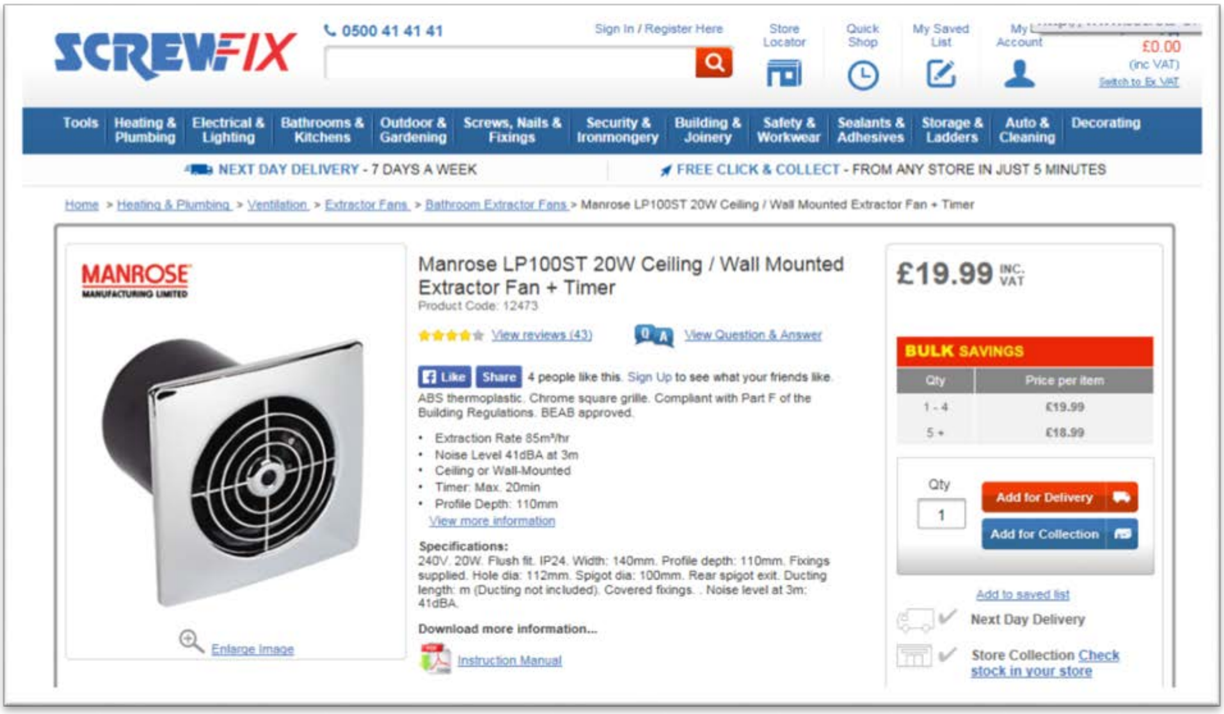
BritishGas, 2015. [Online]
Available at: http://www.britishgas.co.uk/
[Accessed 2015].
CIBSE, 2015. *Environmental Design Guide.* s.l.:CIBSE.
TGB, 2015. *A1 Sheds.* [Online]
Available at: TGB Superior Pent Shed

APPENDICES

1. SHED
   http://www.simplygardenbuildings.co.uk/tgb-superior-pent-shed-assembled-1778-p.asp

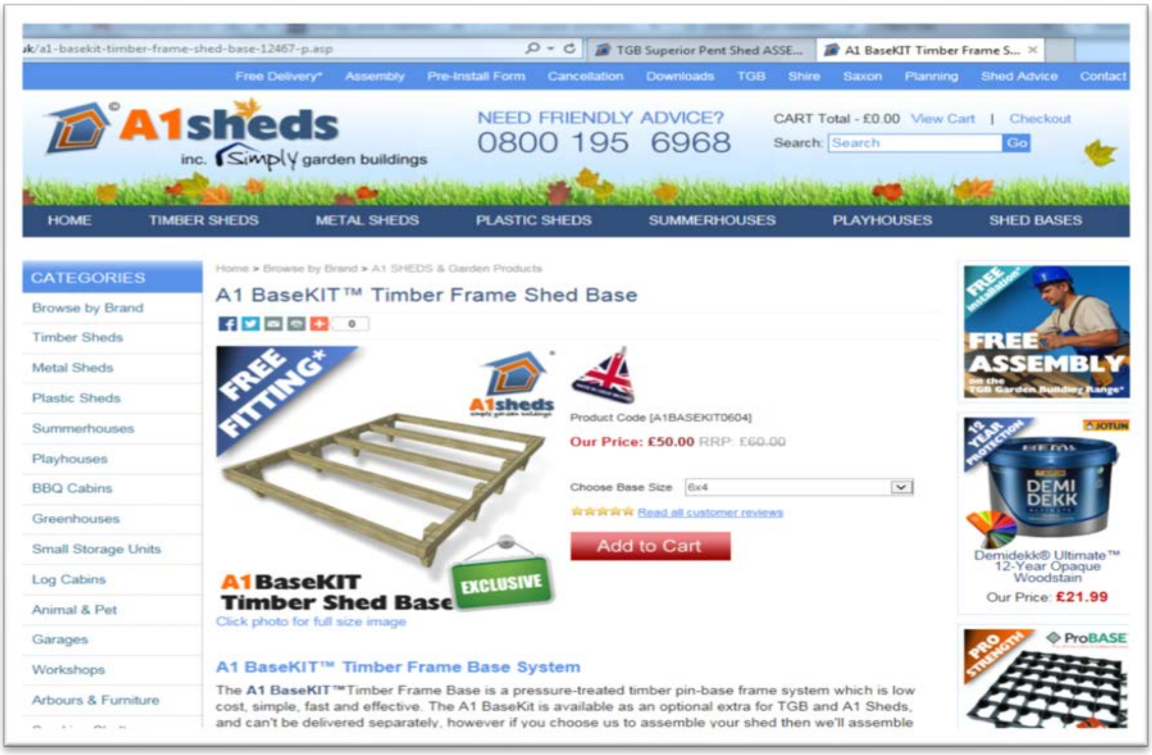
DIMENSIONS		
Shed Length	W (m)	3.000
Shed Width	D (m)	2.000
Shed Height	H (m)	2.100
Door Height	Ld (m)	1.800
Door Width	Wd (m)	0.800
Windows Width	Ww (m)	0.700
Windows Height	Lw (m)	0.500

2. EXTRACTOR FAN



3. PALLET TYPE BASE

http://www.simplygardenbuildings.co.uk/a1-basekit-timber-frame-shed-base-12467-p.asp



4. POWER DEMAND OF DOMESTIC APPLIANCES

Kitchen (w)	Office (w)	DIY (w)
Coffee Pot - 200	Laptop Computer - 20-50	Weeder - 500
Coffee Maker - 800	Desktop Computer - 80 - 150	Hedge Trimmer - 450
Toaster - 800-1500	Printer - 100	1/4" Drill - 250
Popcorn Popper - 250	Scanner - 14	1/2" Drill - 750
Blender - 300	Shredder - 100	1" Drill - 1000
Microwave - 600-1500	Hard Drive - 15	8 1/4" Circ. Saw - 1400
Waffle Iron - 1200	Typewriter - 80-200	9" Disc Sander - 1200
Hot plate - 1200	Ceiling Fan - 10-50	3" Belt Sander - 1000
Frying Pan - 1200	Table Fan - 10-25	12" Chain Saw - 1100
Dishwasher - 1200-1500	Electric Clock - 3	14" Band Saw - 1100
Gbg. Disposal - 450	Answering Machine - 10	7 1/4" Circ. Saw - 900
Fridge Freezer - 200-400	Electric Pencil Sharpener - 100	Electric Mower (n/a) - 1500
Food Blender - 350	Wireless Router - 7	AC Grinder 1/2 hp - 1080
Electric Whisk - 120		

5. ANNUAL DEGREE DAYS EDINBURGH www.degreedays.net

Description:	Celsius-based heating degree days for a base temperature of 20.0C
Source:	www.degreedays.net (using temperature data from www.wunderground.com)
Accuracy:	No problems detected
Station:	Edinburgh Airport (3.35W,55.95N)
Station ID:	EGPH

Month starting	HDD
01/11/2014	377
01/12/2014	488
01/01/2015	502
01/02/2015	447
01/03/2015	448
01/04/2015	368
01/05/2015	335
01/06/2015	226
01/07/2015	201
01/08/2015	174
01/09/2015	249
01/10/2015	321
TOTAL	4136

6. AVERAGE ANNUAL HUMIDITY IN EDINBURGH

http://www.edinburgh.climatemps.com/humidity.php

Relative Humidity in Edinburgh, Scotland, Uk

- The average annual relative humidity is 80.1% and average monthly relative humidity ranges from 75% in April to 84% in January.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Relative Humidity (%)	84	83	81	75	76	75	78	80	80	82	83	84	80.1
Average Dew Point Temperature °C (°F)	0.8 (33.4)	0.7 (33.2)	2.1 (35.8)	3 (37.4)	5.9 (42.6)	8.7 (47.6)	10.7 (51.3)	10.9 (51.6)	9 (48.1)	6.6 (43.9)	2.7 (36.9)	1.4 (34.6)	5.2 (41.4)
Interpretation	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry	Very comfort-able	Very comfort-able	A bit dry	A bit dry	A bit dry	A bit dry	A bit dry