Grampian Transport Museum

Progress report on energy consumption improvements based on inventory of assets, building services & procurement policy since 2014

Your Route to Carbon Neutral Status

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GES
Energy Efficiency in Action

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Executive Summary

This report presents the results of an Energy Audit for the Grampian Transport Museum prepared by Trevor Gruban - ESOS Lead Assessor with GES Environmental Service. Appreciation is acknowledged for the assistance and co-operation extended by Museum Curator Mike Ward, his colleague John Rahtz and GES colleague Andre Bergh.

Purpose of Energy Audit - An energy audit has one principal purpose which is to identify Areas of Significant Energy Consumption and then explain or introduce measures to enable Practical Energy Efficiency measures.

This report however is slightly different because two detailed Energy Audits have already been delivered to your Organisation and substantially acted upon. Accordingly, this Route to Carbon Neutral Status is effectively a Progress Report which should assist you in reviewing your successful actions so far and encourage your team to complete remaining objectives.

Proposed Format - GES Environmental gathered energy and asset data from designated buildings and combining in a Reporting Format which is consistent with energy audit standard BS EN 16247. The agreed objectives of this report were to inspect the two museum halls and compare your present energy profile against data recorded in 2014/15 and assess today's performance compared with objectives set out over the past six years.

The energy sources and utilities consumed are:

- Grid electricity
- Kerosene heating oil

The principal cost centres identified for energy consumption are:

- Lighting
- Space heating & ventilation
- IT equipment

Following your Energy Audit in 2016, when the Grampian Transport Museum was consuming 282,000 kWh of fossil fuel and emitting 122.20 teCO_2 each year, your Organisation decided to make every effort to significantly reduce energy consumption on-site and in the long term, set GTM on a trajectory to Carbon Neutral Status.

This has been achieved in stages by implementing Energy Policy Objectives:

- Improve thermal integrity of roof
- Adhere to an Energy Efficient Procurement Policy for new assets when ever possible
- Reduce dependence on oil fired space heaters
- Replace all conventional induction, discharge, halogen & fluorescent lights with LED
- Up-grade customer toilets with water efficient devices
- Provide EV charging points for staff and visitors
- Replace conventional electric heaters with ASHP warm air heaters
- Install solar PV and battery derived energy storage

Implementation of these measures is well advanced and to date the value of these actions can be accurately quantified in the following summary:

• Energy consumed	159,000 kWh	**- 43.6%**
• Cost of energy ex VAT	£21,800	**- 12.8%**
• CO_2 emissions	40.7 teCO_2	**- 66.7%**

Definition of an Energy Audit

An Energy Audit is a statement which clearly shows how much energy is consumed by a list of assets which rely on fossil fuel or renewable energy to energise them over a set period of time. The Energy Audit is intended to act as a Base Line against which any actions to mitigate waste or mis-use of energy can be measured in future energy audits.

This report lists assets, machinery and plant which were observed during the site survey and references where possible the loading and energy consumption apportioned to each fixed asset, lighting circuit or specific piece of equipment. This list of assets will form the build-up for total load assigned to "Areas of Significant Energy Consumption" - ASEC.

Units of Measurement - All fuel sources can be expressed in terms of potential power but the most common unit is kilowatt and in this context, purchased mains electricity and heating oil consumed can easily be converted to kW or kWh.

Heating - For the purpose of this report, energy consumed by heating plant is calculated by number of litres purchased x calorific value of heating oil - 10.7 kWh/litre but this figure has no direct reference to the fuel conversion efficiency of the respective heating appliance.

Lighting - Every lighting appliance has an electrical load rating; for example sodium high bay fittings were rated at 400W but added to this we include induction and choke losses which account for at least 30%. Therefore six 400W sodium high bay lights may be rated at 2400W but in practice, consumed (2400 x 1.3) 3120W.

These figures are then added together and multiplied by the average operational hours to give us a gross total for energy consumption in terms of kWh/year.

Simplified Energy & Carbon Reporting - SECR - CO_2 Emissions Methodology

GES Environmental use carbon dioxide emission factors published by Zero Waste Scotland and up-dated in 2020. Mains electricity is the principal fossil fuel which is regularly reviewed and has constantly been reduced during the past ten years, due to increased supply of renewable power connected to the National Grid.

Our calculation procedure is as follows: All purchased energy sources consumed are expressed in kWh but in the case of mains electricity, the gross kWh is extracted from your energy bill and is always the units subject to Climate Change Levy - where this tariff is added to your account before VAT.

For liquid fuels - Gasoil & Kerosene we calculate the total number of litres purchased.
1 litre of gasoil or kerosene fuel represents a calorific value of 10.7 kWh/litre

CO_2 emissions - Conversion factors expressed as teCO_2:

Mains electricity	0.233 gm/kWh
Natural Gas	0.183 gm/kWh
Heating Oil	0.257 gm/kWh

Mains Electricity	129,000 kWh x 0.233 = 30 tonnes CO_2
Heating Oil	2,800 litres x 10.7 kWh/litre x 0.257 = 7.70 tonnes CO_2

Energy Consumption & CO_2 Emissions
over 7 year period from January 2014 to December 2020

Year 2014/15	**Electricity**	**Heating Oil**	**Total**
Cost Ex VAT	£20,000 11.65 p/kWh	£5,000 4.55 p/kWh	**£25,000**
%	80%	20%	**100%**
Energy	172,000 kWh	110,000 kWh	**282,000 kWh**
%	61.0%	39.0%	**100%**
CO_2 Emissions	94.0 teCO_2	28.2 teCO_2	**122.20 teCO_2**

Year 2018/19	**Electricity**	**Heating Oil**	**Total**
Cost Ex VAT	£20,000 15.50 p/kWh	£1,800 6.0 p/kWh	**£21,800**
%	91.8%	8.2%	**100%**
Energy	129,000 kWh	30,000 kWh	**159,000 kWh**
%	81.1%	18.9%	**100%**
CO_2 Emissions	30.0 teCO_2	7.7 teCO_2	**37.7 teCO_2**

Year 2020/21	**Electricity**	**Heating Oil**	**Total**
Cost Ex VAT	£7,000 16.70 p/kWh	£920 7.0 p/kWh	**£7,920**
%	88.4%	11.6%	**100%**
Energy kWh	41,920 kWh	13,200 kWh	**55,120 kWh**
%	76.0%	24.0%	**100%**
CO_2 Emissions	10.7 teCO_2	3.4 teCO_2	**14.1 teCO_2**

Your Progress at a Glance

Comparison between 2014 & 2019 Energy Profile
Stage 1 - Energy Efficiency Improvements

Normally the Summary Table below would use years 2014/15 and 2020/21 as Base Line and current reference period but due to Covid, we do not have representative data for the months between March 2020 and the present date. Consequently, the Summary Table compares energy consumption over a period before Covid disruption but still demonstrates significant improvements completed during that five year period.

Project forward to November 2022 - We anticipate that after one full year of PV input and energy storage, your mains electricity account will reflect reduced energy purchase due to ASHP and PV infrastructure at which point columns 3,4 & 5 can be re-populated.

1	2	3	4	5
GTM - Alford	**2014/15**	**2018/19**	**DIFFERENCE**	**%**
Electricity Cost	£20,000	£20,000	**NIL**	**0%**
Energy kWh	172,000 kWh	129,000 kWh	**- 43,000 kWh**	**- 25%**
CO_2 Emissions	94.00 teCO_2	33.00 teCO_2	**- 61.0 teCO_2**	**- 64.9%**
Heating Oil	£5,000	£1,800	**- £3,200**	**- 64%**
Energy kWh	110,000 kWh	30,000 kWh	**- 80,000 kWh**	**- 72.7%**
CO_2 Emissions	28.2 teCO_2	7.7 teCO_2	**- 20.5 teCO_2**	**- 72.7%**

Original Lighting Installation - Halls 1 & 2

The initial Resource Efficient Scotland survey and report was conducted in October 2013 and used year 2012/13 as its reference period for overall energy consumption with this date as baseline against which to measure future improvements to your building's infrastructure.

Extracts from that original report are reproduced in this section because this is the best way to recall the primary reasons for embarking on your journey towards energy efficiency.

Overview *- The standard luminaires used throughout the internal areas are twin 6' x 80W fluorescent fitting, PAR 60 conventional spotlights and sodium or metal halide high bay flood lights. Together with conventional security lights, these luminaires are based on 1980s discharge technology and range from 80w to 400W but none of the fittings can be considered energy efficient by current standards.*

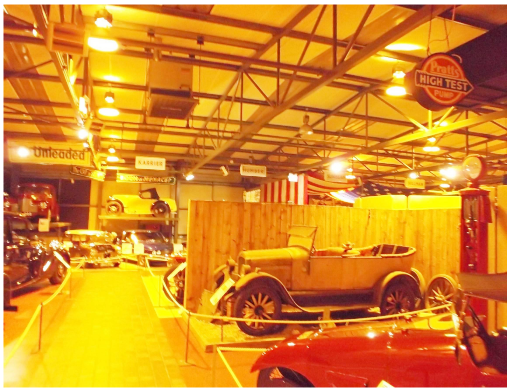
Lighting requirements *- **T**his venue provides display and inter-active accommodation for a very wide range of machinery, vehicles and allied equipment associated primarily with mechanised transport. Artefacts and vehicles are often on loan from other museums or private collectors and need the ability to adapt or modify display presentation to the best advantage of respective exhibits. The Curator sees this factor as an important issue and is therefore keen to use his lighting refurbishment programme as an opportunity to install a more versatile light plan that will enhance the display environment more effectively.*

Business hours *– This museum is open to the public from April to October which amounts to about 2,140 hours under full load but maintenance work, requiring illumination is carried out during shut period which could add an additional 1,000+ hours/year.*

Lighting Inventory in 2013

Area	Number	Type of Fitting	Lighting Load - W	Average LUX Level
Hall 1 - High Bay	6 6	MH 250 SON 400	1950 3120	120 - 200
Railway Exhibition	4 16	twin 6' fluorescent PAR 60 spotlight	620 960	170
Chitty Chitty Bang Bang	6 40	twin 6' fluorescent PAR 60 spotlight	920 2400	230
Future Cars	22	PAR 60 spotlight	1320	60
Café	5	6' fluorescent	380	230
Hall 2 - High Bay	12	SON 400	6240	200
Cars in Society Horse Power Motor Cycles	18	PAR 60 & halogen spotlights	1080	135 600 550
Mezzanine Level	6 10	6' fluorescent PAR 60 spotlight	920 600	210
	151 Fittings		**22.50 kW**	

Hall 1



Hall 2

Further extracts from original report: *- The lighting inventory shown on page 7 is a summary of all fittings and shows total lighting load is 22.50 kW which represents your baseline average input of 15.0 W/m^2. This achieves lighting levels shown in the table and values measured with a lux meter form the base line for energy management. They act as a bench mark for all proposed refurbishment plans to the lighting installation.*

This difference in light quality is attributed to several factors which include:

- *Initial design specification*
- *Size, output and colour temperature of installed luminaire*
- *Derogation of tube / bulb output with age*
- *Density of fittings*
- *Mounting height*

PHASE 1 - Proposed improvements

In order to present a modern energy efficient lighting solution, the baseline must specify GTM's lighting requirements for these specific areas as this norm will influence energy input. The steel frame construction has enabled a symmetrical lighting plan to be installed but we recommend the average quality of high bay light is specified at 200 lux with 500 - 1000 on specific displays which utilise spot lights.

Summary of luminaries to be replaced with modern energy efficient LED alternatives

Existing Fitting	Recommended Alternative	Load	Energy Saving
High Bay MH 250 250 watts	LED wide angle flood light	110W	56%
High Bay SON 400 400 watts	LED wide angle flood light	200W	50%
Twin 6' fluorescent 140 watts	LED linear fitting	60W	56%
Single 6' fluorescent 70 watts	600 x 600 LED flush panel	32W	66%
PAR 60 spotlight 60 /100 watts	LED track line spotlight	24W	60%

Lighting appliances - The most common luminaires used in commercial applications since the 1960s have been based on fluorescent fittings, halogen / tungsten lamps and high bay sodium or metal halide discharge lamps. All these luminaries, with the exception of tungsten, increase their energy consumption due to choke and ballast losses. This figure is a minimum of 10% with fluorescents but MH & SON can rise above 30%.

Metal halide and sodium have other disadvantages, the most obvious being warm-up time which prevents any form of automatic lighting controls being used with these installations.

Energy efficient lighting - The choice of luminaires is vast and there is an LED version for every application but the advantages with this modern technology are multiple:

- LED luminaires emit at least 100% more light compared to ordinary lamps
- LED luminaires consume 50% less energy for the same light quality
- LED offer a very versatile lighting effect
- LED are available in a wide range of colour tones (CCT Kelvin)

Colour rendering – Energy efficiency projections are based on three colour temperatures available with LED which offer a degree of flexibility when selecting light fittings for specific applications or areas. These are warm white (3500K) to cool white (6500K). In your museum, we recommend 5000K for high bay, 5500 for spot lights and 4000K in the cafe.

Choice of Luminaires - The table below lists conventional light fittings still currently installed and average energy each appliance consumes in terms of Watts/lumen and the corresponding advantage with LED based luminaires.

Conventional	Nominal wattage Lumens/Watt	Lumens Output	LED Version	Lumens Output
SON 400 high bay	400W 60 lumens/watt	24,000	200W - LED high bay 140 lumens/watt	28,000
1 x 6' - T8 fluorescent	70W 50 lumens/watt	3,500	40W - LED linear 130 lumens/watt	5200
2 x 6' - T8 fluorescent	58W 50 lumens/watt	2,900	32W - LED linear 130 lumens/watt	4,160
PAR 60	60W 40 lumens/watt	2,400	24W - LED Spot 130 lumens/watt	3,120

LED lighting - This is the most modern form of energy efficient lighting and technology is constantly evolving. Early LED chips produced about 70/80 lumens/watt but the latest generation emit light up to 160 lumens/watt with a wide colour temperature band.

Refurbished Lighting Installation

This was implemented in stages spread over a period of four years during each winter shutdown and commenced in 2015/16 when the two main halls & cafe were completely re-fitted with LED lights. The next major installation was implemented during construction of the front entrance foyer and shop but up-grading has continued with the addition of several track line mounted spot lights in specific display areas.

At each stage where facilities have been improved, modified or created from scratch; for example, toilet refurbishment and interactive displays, standards for LED lighting set out initially in 2015 have been referred to and replicated to good effect.

Lighting Inventory in 2021

Area	Number	Type of Fitting	Lighting Load - W	Average LUX Level
Hall 1 - High Bay	6 6	LED 100 - High bay LED 200 - High Bay	600 1200	220
Electric Cars Heavy Vehicle Displays Trams & Buses	36	LED 24 - Spotlights	870	650
Mezzanine Level History of Bicycles	24	LED 24 - Spotlights	580	700
Café	8	32W - LED panels	260	430
Hall 2 - High Bay	12	LED 200	2400	210
Cars & Horse Power Motor Cycles Aero Engines	44	Track Line & LED 24 - Spotlights	1060	640
136 Fittings		**Energy Saving - 68.9%**	**7.00 kW**	


Travellers Rest Cafe - Before & After


Horse Power - Before & After

PHASE 2 - New Entrance Foyer & Shop

The new entrance foyer and shop was constructed in 2017 but it was immediately noted that conventional lighting accessories had been specified on the drawings which was contrary to GTM's *Energy Efficiency and Low Carbon Procurement Policy.*

The design was modified to include LED high bay emitting 4000 kelvin with polycarbonate shades and track line mounted LED spotlights, similar to those installed in Halls 1 & 2.

The table below is a summary of actual energy savings over one year by using energy efficient LED fittings compared to your original design specification based on metal halide.

Number	Original Design		Energy	GTM Specification		Energy	Saving
	Highbay	Spot Lights		High Bay	Spot Lights		
12	MH 250	PAR 80	10,000 kWh/year	LED 110	LED 24	**3,200 kWh/year**	**6,800 kWh/year 68%**
TOTAL	**3.9 kW**	**1.2 kW**		**1.3 kW**	**0.3 kW**		

PHASE 3 - Move towards Renewable Energy

This stage of improvements was designed and managed during the COVID lock down period with a specific intention of expanding the museum's infrastructure to include on-site generation of renewable energy.

This report has shown that over a period of about five years, energy to heat this building reduced by nearly 50% following major roof repairs & infrastructure improvements but mains electricity consumption has also reduced by 68% due to total adoption of LED lights.

Mike Ward drafted an Energy Policy with the specific purpose of plotting a trajectory towards Carbon Neutral Status for the Grampian Transport Museum and the first major stage was to stabilise the building's infrastructure by reducing conventional energy consumption to an absolute minimum by implementing *Energy & Resource Efficiency.*

Summary of Stage 1 Mile Stones

- Retro-fit insulated steel clad roof across Halls 1 & 2
- De-commission industrial scale, high bay oil fired heaters
- Install smaller scale space heaters as an interim measure
- Replace all sodium and metal halide high bay lights in Halls 1 & 2 with LED
- Replace all halogen & tungsten spot lights with LED
- Replace all fluorescents with LED linear fittings
- Refurbish cafe lighting
- Up-grade lighting specification for new Entrance Foyer & Shop
- Refurbish Visitor toilets with energy efficient water devices, lights & hand dryers
- Install Type 2 - EV charging point for Staff & Visitors

All objectives in Stage 1 have been materially achieved and installation of alternative energy commenced during 2021 in the knowledge that the Museum was now in a stable position, to gain maximum benefit from renewable energy and lower CO_2 heating.

Space Heating - Halls 1 & 2

Building description - This museum occupies two adjacent industrial style, steel portal buildings constructed in the 1980s, to standards of heating and insulation consistent with that era. The two main buildings have a total internal volume of approximately 4,500m^3 and these spaces were originally heated by high level, oil fired warm air blowers.

The first round of major re-furbishment comprised re-cladding the entire roof and using this opportunity to improve its thermal performance by retro-fitting dense roof insulation, sandwiched between the existing roof and new metal, profile roof cladding. This major insulation and infrastructure up-grade proved very successful which reflected directly in subsequent lower heating oil bills.

Halls 1 & 2 - Oil fired stand-by heaters

As a direct response to improved building performance, the high bay oil heaters were dismantled and removed but because there would still be a requirement for "rapid response" space heating, two smaller capacity warm air heaters were installed at lower level. These units, one mounted in each hall - run on heating oil and are supported by the original pumped fuel distribution circuit, fed from an internal bunded fuel tank.

Heating and De-humidification - Maintaining internal environment within the correct tolerable limits is a delicate balance, particularly during winter shut-down period but GTM's team understand their responsibility to care for the exhibits and have developed procedures, over several years to mitigate these issues. Following completion of new roof and insulation, they were confident that IAT could be maintained, even in the coldest weather by a stepped approach to heating & de-humidification.

- Stage 1 - 6 x EBAC De-humidifiers
- Stage 2 - Back-up heat by 2 x 6.0 kW Chromalox warm air heaters
- Stage 3 - Benson oil fired warm air heaters - maximum 60.0 kW

2018/2019 heating costs - Although main bus bars are not sub-metered to measure power consumed by six de-humidifiers we know winter shut-down is the period during which maximum heat is consumed and this is accounted for by heating oil and mains electricity. The table below represents our estimate for fossil fuel consumed over a twelve month period which includes heating oil and mains electricity but this figure is also the baseline against which to measure future performance from your ASHP heating system.

Accounting Period	**Mains Electricity**	**CO_2**	**Heating Oil**	**CO_2**
October 2019 to September 2020	60,000 kWh 15.50 p/kWh	23.4 teCO_2	30,000 kWh 6.00 p/kWh	7.7 teCO_2
Estimated total energy consumed to heat Halls 1 & 2		**90,000 kWh emitting 30.8 te$C0_2$/year**		

Low Carbon Heating System

Installation of an energy efficient heating system based on heat pump technology was considered the most appropriate form of modern low carbon heating for your two main halls. Due to the COVID crisis, we have used energy data for the last full year of operation as shown in the Summary tables on page 7. The 2018/19 table clearly shows the reduced oil consumption and even with your heating load shifted to electric heaters, overall energy consumption is reduced by 123,000 kWh. This is entirely due to specific measures completed in Stage 1 of your Route to Carbon Neutral Status.

We have shown that this building consumes about 90,000 kWh with two fossil fuel sources, to heat the buildings at a current cost of £11,100/year and this is the base line against which the viability of heat pump derived space heating will be compared.

This building's heat energy source has shifted over the past few years as your dependence on oil has moved more in the direction of mains electric powered EBAC units. Also, it is worth noting that with SSE grid accepting an increasing amount of renewable energy, CO_2 emissions assigned to your electricity bill have reduced by 68% since 2010. In the past ten years, grid electricity emission factor has reduced from 0.556 to 0.256 gm/kWh.

However, this building still uses mains electricity for space heating and humidity control, so in this context, a system based on heat pumps would be practical and fully compatible with your long term objective of achieving Carbon Neutral Status. It is important to stress that elevation to CNS will be achieved by actual production & storage of renewable energy on-site, coupled with implementation of your established Energy Efficiency Policy.

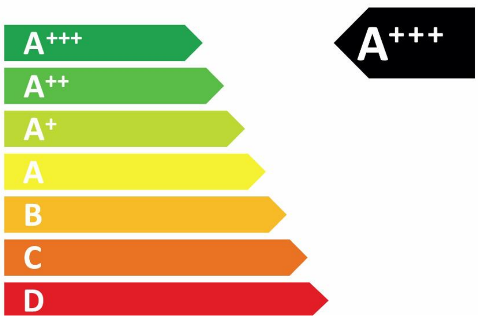
This is in contrast to organisations who aspire to this target but their CNS is able to be negotiated through third party carbon off-setting and only achievable by indirect measures.

Basic description of ASHP & GSHP - Heat pumps basically extract solar energy stored in outside ambient air and the ground but convert this to a higher temperature for use in a building's heating distribution system. The Ground Source Heat Pumps extract heat from ground by circulating a solution of water with anti-freeze through buried pipes and pumped across a refrigerant plant heat exchanger. After passing through the compressor, hot gas is created and transferred to a second heat exchanger which generates hot water to feed radiators and domestic hot water if an in-direct cylinder is installed.

An option to install a GSHP was discussed during an earlier survey but after weighing the advantages and disadvantage, was dismissed for the following reasons:

- GSHP normally produce hot water for use in wet radiators
- Retro-fitting a radiator infrastructure is far to disruptive and impractical
- Installing a Slinky Heat Collector required outside digging which was not acceptable
- An alternative bore hole was quoted over £20,000 which was also unacceptable

Air Source Heat Pump option - Temperature levels in your two halls are currently managed by EBAC de-humidifiers with back-up from two Chromalox warm air blowers and finally Benson oil heaters. De-humidifiers have a total combined load of 9.0 kW, with 12.0 kW electrical back-up and oil fired heaters are rated at 60.0kW Therefore you have a maximum heat input of 72.0 kW with an energy efficiency performance below 80% which rates your original heating plant as **Band D.**



This area is estimated to be costing about £11,000/year to heat and is our base line against which to compare an alternative heating system. Air source heat pumps work on a completely different principle and their efficiency in converting electrical energy to warm air is defined as 'Coefficient of Performance' but averages 3.5 to 4.0 and rated **Band A+++.**

ASHP Installation Description

Two 16.0 kW MAXA air source heat pumps were installed in this museum during Spring 2021 - one each in Halls 1 & 2. These units have been fully commissioned and have effectively replaced the EBAC de-humidifiers.

Full analysis of their energy performance is yet to be confirmed but the table below is our assessment which will be compared against next quarter's electricity bill.

ASHP - Internal & External Components

Location Installed	Unit Installed	Electrical Load	Heating Capacity	Estimated Energy Consumption
Hall 1	MAXA - C140 R	TBC	17.0 kW	13,900 kWh
Hall 2	MAXA - C140 R	TBC	17.0 kW	13,900 kWh
Estimated annual cost @ 16.70 p/kWh = £4,640 compared to £11,100				**27,800 kWh**

Projected energy consumption for next full 12 month period

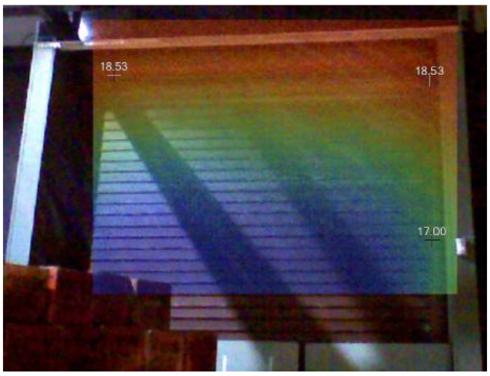
Excluding any Solar PV energy off-set

Year 2021/22	**Electricity Lighting IT & Cafe**	**Electricity ASHP Space Heating**	**Total**	**SAVING**
Cost Ex VAT	£11,520 16.70 p/kWh	£4,640 16.70 p/kWh	**£16,160**	**£5,640 25.9%**
%	79.3%	20.7%	**100%**	
Energy kWh	69,000 kWh	27,800 kWh	**96,800 kWh**	**72,000 kWh 39.1%**
%	79.3%	20.7%	**100%**	
CO_2 Emissions	16.1 teCO_2	7.1 teCO_2	**23.2 teCO_2**	**17.5 43.0% teCO_2**

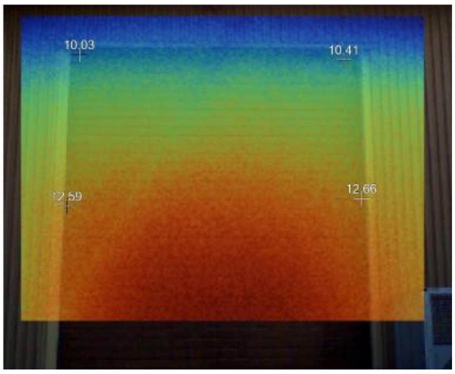
Thermal survey - The true value of a thermal survey which is based on the most modern technology and software is too often, not fully appreciated although it is known that energy consumed in the UK by heating devices, exceeds all other disciplines and building services.

Thermal survey procedure - The site survey was conducted on 29th September 2021.

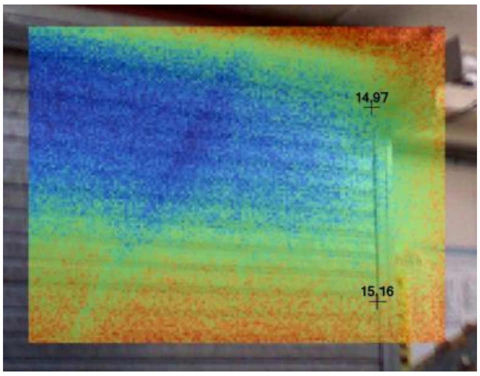
- Instrument details - Fluke Thermal Imager TiS 65
- Calibrated 28th September 2021 - Scotia Instrumentation
- Outside ambient temperature +12.0°C
- Average inside ambient temperature +17.0°C
- Average temperature differential 5°C



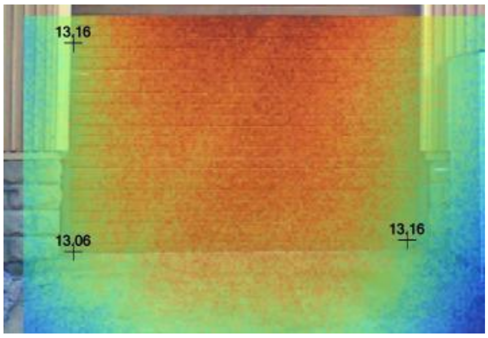
Door 1 - Internal - ASHP 1



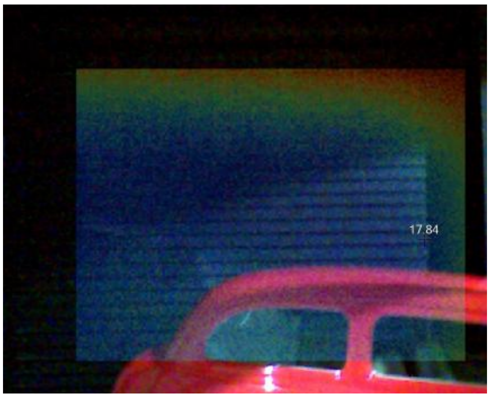
Door 1 - External



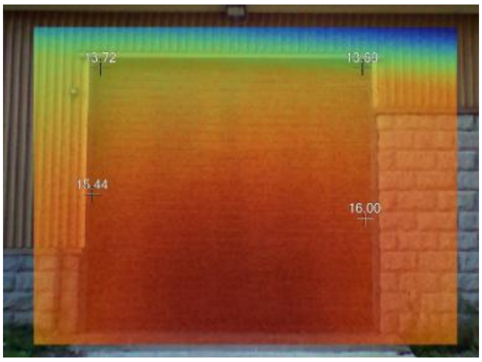
Door 2 Internal



Door 2 - External



Door 3 - Internal - ASHP 2



Door 3 - External

TI Data interpretation - The images require careful analysis but basically show different quality of door insulation and heat loss through the roller shutter door fabric.

We know that although this thermal imaging survey was conducted on a mild day with only 5°C temperature differential between inside & out, clearly the door's external surface temperature above OAT varied from 13.16°C to 16.0°C.

On warmer days this could be due to sun's influence but it may be worth noting doors 1 & 3 are directly adjacent to ASHP blowers and are effectively in the warmest environment.

Conversely, the doors' internal surface temperature varied from 14.5°c to 18.5°C. This indicates thermal transfer or heat loss through un-insulated steel panels and although it is not possible to fully quantify the effect this would have in winter conditions, there seems little doubt that these steel panel doors will be radiating heat to the outside.

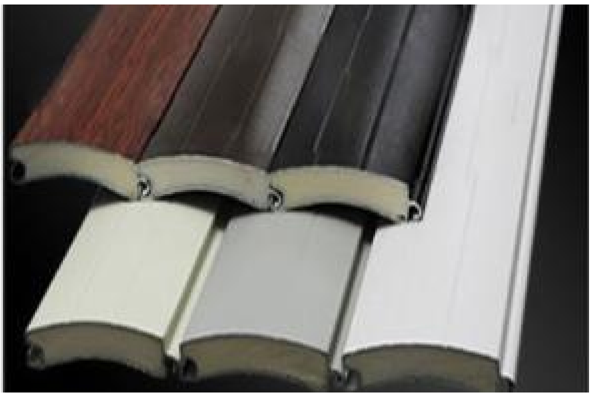
Building integrity - It is very easy to walk through a building and point out air gaps, ill fitting doors, lack of insulation etc. and actions to mitigate these conditions often involve considerable expense but the principal benefit of TI imaging is the ability to locate heat loss paths which are not visible or immediately obvious.

Long term solution - This is not an un-common issue which needs to be addressed by all organisation which utilise roller shutter doors for plant or vehicle access. Buildings which experience frequent traffic through their doors, tend to install rapid opening fabric shutters as a secondary barrier and retain the principal steel door for security purposes.

Grampian Transport Museum, however only use these doors for specific access and therefore the doors are generally closed throughout the visitor season. To mitigate against permanent heat loss, consideration should be given to replacing the un-insulated doors with the latest generation roller shutter doors which are constructed to a higher specification to address these heat loss issues

Typical rapid close roller door

Conventional roller shutter door section



Insulated sections developed to mitigate heat loss

Power Self Sufficiency

GTM's team embraced the ambition of generating their own electricity on-site some years ago and implementation of this policy was to be a main stay of their *Route to Carbon Neutral Status* but would have to be managed in several stages.

- Install 24 kW Solar PV array on Spectator Stand roof
- Install 60 kWh battery storage / inverter interface facility
- Install 2nd solar PV array on Entrance Foyer roof
- Expand battery storage capacity
- Install vertical axis wind turbine
- Develop EV charging capacity for staff & visitors

Initiating your Renewables Programme - In January 2021 John Rahtz summarised his research into the feasibility and immediate financial viability of investing in solar PV with capacity for low voltage energy storage supporting inverter interface to the bus bars.

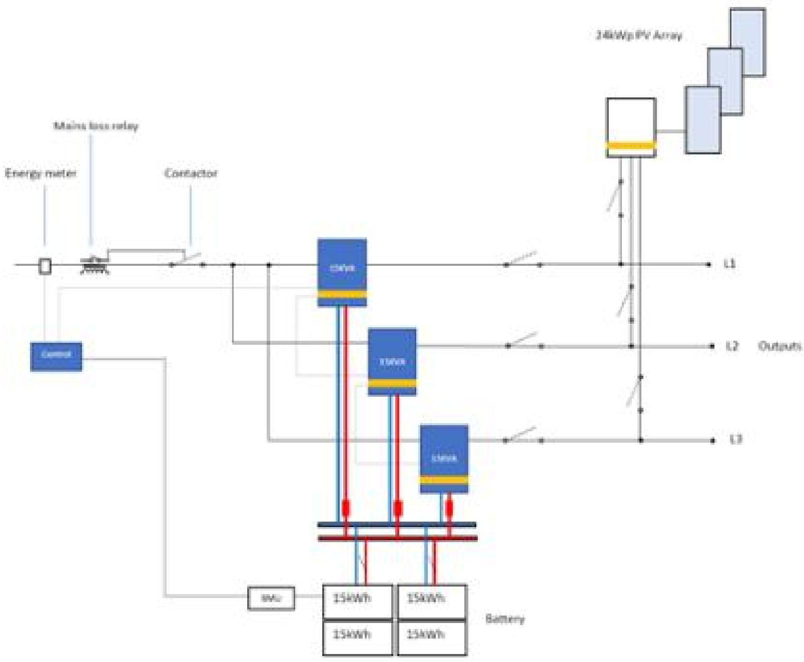
Extracts from his Feasibility Study are reproduced as follows:

Financial Sustainability - We will not know until some time after installation how the hour to hour fluctuations in solar power generation and power consumption will be balanced by the batteries but even with only one cycle per day they will generate £3000 in savings per annum at 2021 power costs.

Summary - The output from solar panels will fluctuate up and down during the day with a peak of 24 kW. The museum's peak load is 17 kW meaning that excess power will be generated by the solar panels at times. A battery storage system can capture this excess power to be used when solar panel output is lower but generation is higher in the summer as daylight hours are longer. This will help the museum reach its aim of being independent from the grid and substantially reduce operating costs.

Initial results - During the first few months of solar PV operation, GTM started to develop an energy monitoring procedure which indicates balance between imported power from the solar array and energy being directly consumed on-site. This has already proved that on a bright day, during minimum load conditions, surplus PV derived power is diverted to battery storage. This is precisely how the design philosophy is intended to function and has acted as real encouragement to expand the system to achieve GTM's target of self sufficiency.

Conceptual Plan & Implementation of Stages 1 & 2 - Solar PV & Energy Storage



Solar PV panels mounted on Spectator Stand roof

60 kW - Battery fed Inverters

60 kWh Battery Modules

Conclusion & Future Works

During the past five years, Grampian Transport Museum has navigated their path through an Energy Policy which was drafted to achieve Carbon Neutral Status at the earliest possible opportunity. Their route to achieve this target was based on observations and procedures identified during their first energy audit in 2013 which set out the following parameters:

- Building's age, construction specification and maintenance regime
- Director's Energy Management Policy and willingness / ability to engage
- Staff awareness & willingness to co-operate with Management
- Type of lighting and quality of ambient illumination standards
- Heating infrastructure, insulation standards & heat losses
- Water consumption, waste management & re-cycling potential
- Opportunities for renewable energy, interface and support
- On-site catering or sector specific machinery and assets

Implementation of these objectives commenced in 2016 and has continued in stages each year to present time with the following mile stones achieved:

- Thermal integrity of roof significantly improved
- Energy Efficient Procurement Policy fully practiced
- Oil fired space heater dependency reduced by 90%
- All conventional lights replaced with LED
- Customer toilets up-graded with water efficient devices
- Type 2 - EV charging point installed
- Two ASHPs installed to service Halls 1 & 2
- Solar PV and battery derived energy storage system installed & commissioned

Overall energy consumption, in real terms has reduced by >50% up to December 2019 but after one full year's benefit from renewable energy, to the end of 2022 this figure is expected to reach 70%. The final stage, to implement measures and technology to enable the remaining 30% be met from renewable and energy storage, is the next main objective.

Projects described in this report to achieve your final target are:

- Install 2nd solar PV array on Entrance Foyer roof
- Expand battery storage capacity
- Install vertical axis wind turbine
- Develop EV charging capacity for staff & visitors

De-commission BENSON heaters - It is anticipated and remains the final target, that after one year's full operation of your ASHPs, the Benson oil fired warm air heaters will become totally redundant and can be de-commissioned and their support infrastructure removed.

Implementing this final stage to enabling energy self sufficiency, will also require re-design of your heating and de-humidification control philosophy but this is best addressed in 2022 after sufficient energy data is available to fully analyse your projected future energy profile.

For further advice or assistance please contact:

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