# OPPORTUNITIES FOR COMMUNAL PHOTOVOLTAIC-THERMAL HEATING SYSTEMS WITH STORAGE

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## Abstract

With 70% of the world's population projected to live in urban areas by 2060 (ARUP, 2016) and 67% of current energy related emissions produced in urban areas (IEA, 2008), there is a compelling case to investigate the reduction of $CO_2$ emissions from heating in densely populated areas in the UK or other regions with heating requirements. This paper investigates how a single PVT panel system with thermal and electrical storage could reduce heating emissions for a row of terraced houses. The main findings of the study carried out in Dymola/Modelica were that there is potential for greater thermal and electrical output with larger PVT systems and shared communal electrical and thermal storage. Pre-heating the mains water which supplies the hot water tank using the PVT both increased the PVT thermal efficiency and utilisation, and the electrical efficiency. In this configuration, the PVT system was able to supply all hot water demands of a row of terraced houses and supply about 91% of electricity demands.

## Introduction

As the UK works towards a target of 80% emissions reduction by 2050, relative to 1990 levels (CCC, 2018), a transformation in building energy systems and existing/new infrastructure will play an important role. With approximately 14% of the UK's emissions produced by gas for space and water heating (BEIS, 2018), and the domestic sector accounting for 53% of the UK's total energy demand (Ramos et al, 2017), this study investigates how to decarbonise the UK's residential heating systems.

There is a need to investigate the reduction of emissions in densely populated areas since 70% of the world's population are projected to live in urban areas by 2060 (ARUP, 2016). Since low-rise purpose-built flats, converted flats and terraced houses comprise about 68% of London building accommodation types (Greater London Authority, 2011), this study investigated emissions reduction amongst terraced houses. Future work could retrospectively extend the methods and findings of this study to other cities and building types.

Although in its infancy, with approximately 50 pilot installations in operation mainly in Europe, Power-to-Gas technologies could be a promising solution to low carbon heating in the UK (Lambert, 2018). Air source heat pumps (ASHPs) could also be important in decarbonising future domestic heating, however there are some challenges presented in the ease of installing in densely populated areas. The Microgeneration Installer Standards (MIS, 2005) states that *heat pumps should not be located adjacent to sleeping areas or on floors that can transmit vibration* and *the location of external fans* (ASHPs) *should be chosen to avoid nuisance to neighbours* (Building Performance Centre, 2011).
Solar photovoltaic-thermal (PVT) collectors could be a competitive alternative or supplement to heat pumps in areas with high energy density since PVTs simultaneously produce electricity and heat, whilst increasing the PVT efficiency through cooling. With 80% of the existing housing stock forecast to still be in use in 2050; alongside low carbon heating technologies, certainly also improving insulation, air-tightness and ventilation strategies will play an important role in meeting emissions targets (UKGBC, 2019).

This study investigates multiple dwellings sharing one PVT heating system. In addition to there being a research gap for PVT district heating, several potential benefits of using a single system spread across multiple buildings as opposed to individual buildings have been identified:

- Heat demand from a group of buildings may be asynchronous, particularly if it has different functions and occupants. With this added diversity, there is the potential for a more efficient system as what would typically be wasted heat when there is low demand, could be shared across a heat network instead of being stored in a thermal storage which would incur storage losses (The Association for Decentralised Heat (2018), Olsen et al (2014)).
- There may be more space to accommodate a shared plant facility, compared to a small flat which is unlikely to have the space or desire to accommodate battery and thermal storage.
- There is an added level of flexibility in the system design. For example, if one building is partially shaded, an unshaded roof of a neighboring building

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could be used instead to mount the PVT system. Buildings with less optimal mounting positions for PVT could compensate by housing the thermal and electrical storage system.

## Literature review

This section reviews literature and industrial developments of PVT systems. An important aspect of PVT heating is the thermal energy storage, therefore this is also considered in the review.

### PVT Studies

There have been previous studies investigating PVT systems in single dwellings with hot water tank storage or GSHPs. A modelling study found that a PVT collector (2.25kWp) with a water storage tank met 51% of total electricity and 36% of total domestic hot water (DHW) demand for a 3-bedroom terraced house with 15m$^2$ available roof area (Herrando et al, 2014); only a closed loop PVT to storage tank configuration was modelled. This study also investigates the most common dwelling in London – a 3-bedroom terraced house, however an open loop PVT and water tank configuration was also investigated.

A study by Xia et al (2017) investigated the performance of a GSHP-PVT system supplying space and water heating to a two-storey house in Australia with 248m$^2$ floor area. It was concluded that when the PVT collector area was less than 54m$^2$ it was more effective for the PVT thermal output to be used for DHW, otherwise it was more effective to recharge the ground in non-heating seasons and to retrieve the heat via the GSHP during heating periods. Three scenarios were modelled in TRNSYS, again all with a direct closed loop heat exchanger to the 60°C tank and PVT system, there were no considerations or discussion on the electrical performance of the PVT and how different configurations could increase the PVT electrical efficiency through cooling. The study modelled how over 20 years the ground temperature was maintained at about 16°C with PVT ground charging, but without ground charging the ground temperature declined down to about 7°C meaning the heat pumps energy consumption progressively increased each year. A limitation on the 20-year analysis was that the climate conditions remained the same each year, there was uncertainty how ground temperature would vary under future climate conditions.

A comparison of a Matlab PVT and solar thermal collector model found the thermal efficiency was 58.7% and 71.5% respectively. The electrical side of the PVT had 13.69% efficiency, giving a combined PVT efficiency of 72.39%, leading to 16% greater energy savings (details of how the energy savings were calculated were not included in the paper) (Raut & Bhattrai, 2012).

### PVT Installations

There are about 500 PVT installations in the UK, but few have credible monitoring methods (BEIS, 2016), the BEIS PVT report has some brief details on an installation in Leicester on a new detached house, the PVT system contributes about 17% to the heating and DHW demands, and about 40% of electrical loads with inter-seasonal storage (BEIS, 2017). An air-cooled PVT solarwall installed in Concordia University is expected to have a total system efficiency (heat and electricity) over 60% compared to 10-15% for conventional PV modules (SolarWall 2018), it has ongoing monitoring. Although there is technically great potential for PVT the high initial costs and uncertainties caused by poor knowledge of the technology was found to be limiting market penetration and installation growth (Ramos et al, 2017).

### Storage

Whilst there are several studies which have demonstrated promising potential to increase PVT efficiency and output with phase change materials (PCMs) (Atkin & Farid (2015), Park et al, (2014), Browne et al, (2016), and Das et al, (2018)), and PVT-GSHP systems (Xia et al, 2017), this study implements a hot water tank since this is the most common thermal storage in domestic heating applications which makes it an appropriate starting point for a base case study, which could be built upon in future studies.

There is also justification to explore how thermal and electrical storage could support PVT systems by storing energy and supplying on demand. A study by Uribarri et al (2017) demonstrated how larger PVT roof coverage did not necessarily equate to cost savings due to asynchonicity between high energy demands and high solar conversion hours. Therefore, thermal and electrical storage could enable solar conversion to be utilized in demand hours whilst potentially also reducing total heat generation capacity and costs (Gudmundsson, 2016).

A techno-economic comparison between lead-acid batteries, li-ion batteries and a hot water tank for PV storage for a representative UK household with 3kWp PV array concluded that the hot water tank (100-200l) was the most economic choice, if the tank was previously heated with grid electricity. However, it was discussed that there may be a stronger economic case for battery storage in other setups, and it also enables it to connect to the grid. With larger storage tanks not necessarily equating to higher solar thermal energy utilisation due to higher tank losses (Uribarri et al, 2017), and a techno-economic potential for battery storage, this research study investigated the use of battery storage to power an auxiliary heater found in a hot water storage tank.

To the author’s knowledge there have been no studies investigating the potential of using PVT systems to power larger more complex systems such as a row of terraced houses. There are also no studies investigating how PVT systems could be optimised with both thermal and electrical storage, or for district scale systems, and how PVT systems could be optimised in this scenario. Therefore, the objective of this study was to quantify what percentage of space heating and DHW could be provided by 1 PVT system with thermal and electrical storage across the roof area of a series of terraced houses whilst addressing the above research gaps.

## Simulation methodology

Since the nature of this study would benefit from rapid prototyping, design optimisation and analysis of innovative energy and control systems, Modelica was selected to model the system in this study (Modelica Association, 2017).

The high-level system (Figure 1) modelled comprised of the following sub-systems: weather, solar PVT, auxiliary heater, hot water tank and terraced house heating demand. Modified components and examples from the Buildings Modelica library were used to develop the system used in this study.

Table 1 summarises the parameters of the base case scenario modelled for hot water demand. Four other scenarios were modelled by adjusting the base case parameters in Table 1 to; 15000W auxiliary heater, 80°C tank set point, 1380 litres/day hot water demand (4 people in each house) and an open loop pre-heating mains water configuration. In total five system configurations were modelled.

Table 1: Base Case Scenario Parameters (10 houses)

| Parameter | Value |
|---|---|
| Storage Tank Vol ($m^3$) | 1 |
| Aux Heater Power (W) | 9600 |
| Tank Set Point (°C) | 60 |
| DHW (Litres/day) | 1880 |
| Configuration | Closed loop to supply DHW |

The following subsections detail each of the subsystems.

### Weather

An IWEC EnergyPlus weather file for London (EnergyPlus, 2018) was input to the model using the weather reader in the Modelica Buildings library (BoundaryCondition.Weather Reader.TMY3). The data contained 1 year of data starting at 1:00AM on January 1st, with hourly data ending midnight on December the 31st. IWEC weather files are compiled from up to 18 years of weather data, the files represent 'typical' weather data suitable for use in simulations (EnergyPlus, 2019). Uncertainty lies here in how the future weather may differ from the IWEC weather file.

### Solar PVT

The typical available roof area for mounting solar panels on period and modern mid or end-terraces was assumed to be $16m^2$ (EST, 2015). The electrical and thermal functions of the PVT system were modelled as separate components to utilise the existing PV and solar collector models in the Building Modelica libraries. Simulated separately, there was no interaction between the thermal characteristics of the panel and PV efficiency. Therefore, an estimate on the annual PV output without any temperature de-rating was outlined in the 'Analysis and Discussion' section.

### Solar PV

The PV model was based on the TESZEUS PVT 250W collector (Teszeus, 2018), with a PV maximum efficiency of 16.83% and $1.62m^2$ area. The direct and diffuse radiation from the weather reader were summed to get the total irradiation reaching the solar panel and mounted at 45° on south facing roofs. The temperature of the PV module was not included in the model but calculated using the results of the simulation.

### Solar Thermal

The solar thermal collector used the diffuse and direct radiations together with the outdoor dry bulb temperature

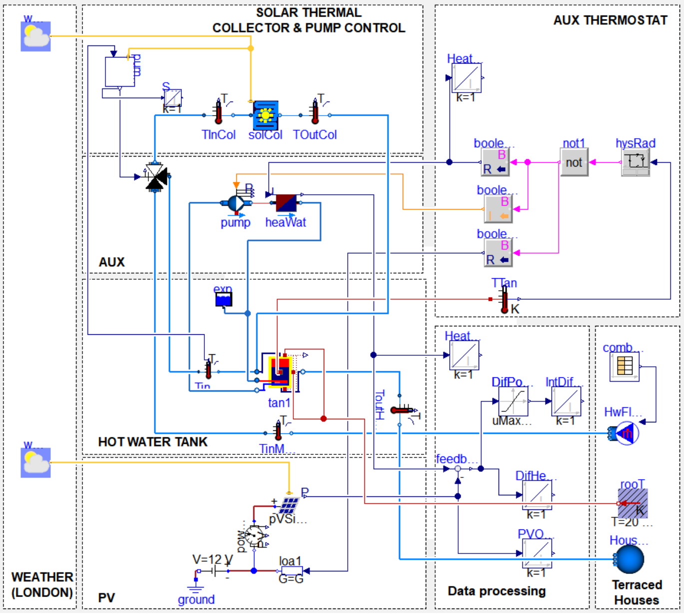

*Figure 1: High level system diagram in Dymola of pre-heating configuration*

to calculate the solar heat gain in the collector mounted at 45° on a south facing roof with a maximum of 65% efficiency based on the Teszeus PVT 250W. The heat gain and losses were calculated based on equations used in EnergyPlus (2011).

The thermal losses to ambient of the solar thermal collector were dynamically calculated using the PVT fluid temperature in each of the 3 segments ($T_{flu[i]}$), outdoor dry bulb temperature ($T_{env}$), array are ($A_c$) and heat transfer co-efficient (-slope) (Duffie and Beckham, 2006):

$$Q_{los,i} = -slope\ x\ \frac{A_C}{n_{seg}(T_{env}-T_{flu,i})} \qquad (1)$$

The heat transfer co-efficient used was based on ratings data for a glazed flat plate thermal collector from the Solar Rating and Certification Corporation (SRCC), which was -5.103 W/m$^2$.K (SRCC, 2012). Although it is common to approximate thermal heat loss as a linear function of the temperature differential between the environment and collector, it should be noted that the co-efficient is not a constant and would realistically vary according to the collector tilt, absorber type, air temperature, wind speed and sky temperature (Harrison and Cruickshank, 2012). Since the selected PVT specification for the study did not have all the required information to characterise the heat losses (SRCC results) an assumption was made that the thermal losses would be the same as a flat glazed solar thermal collector.

## PVT pump control

The pump for the PVT collector was controlled using the PVT fluid inlet temperature, outdoor dry bulb temperature and total incident radiation to calculate the critical radiation ($G_{TC}$) which is defined by the *Solar Engineering of Thermal Processes* book (Duffie and Beckham, 2006).

When the incident irradiation was greater than the critical radiation, the tank could gain heat from the PVT, so the pump was turned on. This theoretical pump controller has been used in other solar water heating analysis and design studies (RETSCREEN 2005, Kulkarni et al 2017). The flow rate of the pump was set to 0.03kg/s, the minimum required to maintain the tank set point.

## Hot Water Demand

The DHW demand was calculated based on the number of occupants (N), it is defined in the BRE Domestic Energy Model (BREDEM) as (Anderson et al, 2008):

$$Hot\ water\ demand = 38 + 25N \qquad (2)$$

Two different hot water scenarios were modelled, one with 4 occupants in each dwelling and another with 6 in each dwelling. The hourly profile for a typical day was based on measurements of domestic hot water consumption in study by the Energy Savings Trust (2008). Together with the average daily hot water demand (sample size =124 dwellings) and the BREDEM model formula a profile was created for the study with peaks at 8am and 7pm as shown in Figure 2. The same profile was used throughout the year as hot water demands are fairly constant throughout the year (Energy Savings Trust, 2008).

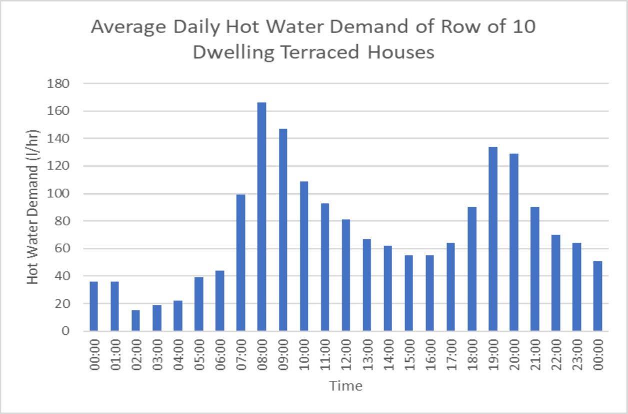

*Figure 2: Average daily hot water demand of row of 10 dwelling terraced houses with 6 occupants in each house*

## Auxiliary Heater

An auxiliary heater was included in the model to maintain the hot water tank temperature set point. This is particularly important when the tank is directly supplying hot water demands since the water must be kept above 60°C to prevent the cultivation of legionnaire's bacteria (HSE, 2018). The operational auxiliary heater power was calculated based on the electrical demand required to heat the hourly peak hot water demand (litres/hour) from 10°C up to the tank set point with the auxiliary heater power efficiency assumed to be 1 (CSE, 2018).

## Tank

The tank incoming mains water was assumed to be at a fixed temperature of 10°C, however there would be some temperature deviations throughout the year (Davies et al, 2016). The hot water tank was modelled with a high density 2" foam insulation (R = 12.5, equal to about 0.08W/m$^2$.k) and a sturdy steel jacket (Solar Panels Plus, 2018). Three different tank set points were modelled; 45, 60 (base case scenario) and 85°C. The new flow rate for each tank temperature set point was calculated using the following equation, where ΔT = 70, instead of ΔT = 50 in the base case scenario.

$$\dot{m}_{80°C} = \frac{Q_{BaseCase}}{C_P\ x\ \Delta T} \qquad (3)$$

## Space Heating

Low temperature (LT) heating was selected for investigations since such systems could be integrated with ground source heat pump systems which is a promising configuration for future work to investigate (Xia et al, 2017). Also, LT district heating ensure greater energy efficiency on the consumer side since typically LT heating is installed in renovated buildings with a reduced heating demand. With lower heating supply temperatures there are also lower distribution losses (Olsen et al, 2014). Typically, LT heating should be installed in well insulated homes to implement LT heating efficiently. However, due to lack of data/access to data on insulated terraced house heating demands, the theoretical space heating for an insulated house was modelled with results extended to a discussion on insulated house heating demands in the Analysis and Discussion section.

The design heat loss for a post-1919 terraced house with uninsulated cavity walls, solid ground floors, single glazing and loft insulation for a row of 10 terraced houses was assumed to be 47058W based on calculations by Allen & Pinney (1990). An average internal temperature of 19°C, external temperature of -1°C, distribution losses assumed at 16% (GSE, 2016), and a hot water supply of 45°C were used in the model.

## Analysis & Discussion

### Scenario comparison

Figure 3 shows how the daily auxiliary heating power consumption varied with each scenario against the daily total solar irradiation over 16 sample days selected over the course of the year. Note that all other result calculations are calculated with the entire annual dataset. Spikes were observed on cold days ($T_{env} \approx -1°C$) in the electrical consumption for 2 reasons; there were greater PVT thermal losses due to the greater ΔT between the PVT and ambient, and the mains water temperature being cooler in the pre-heating scenario since it passed through the PVT and was exposed to ambient temperature.

Below about 3780W/m$^2$/day solar irradiance, the auxiliary heater power consumption remained quite constant for all non-pre-heating scenarios. This is because on days with lower solar irradiance, the PVT did not output enough thermal energy to add useful energy to the tank set point (60°C or 80°C) and with the solar pump control based on critical radiance, the PVT thermal output was not utilised very much in the direct closed loop configurations. Figure 3 shows how the pre-heating scenario stopped the auxiliary heater consumption flat lining on days with less solar irradiance, this demonstrated how the thermal output of the PVT was being fully utilised even at times with low solar irradiance. Note that in the UK, the pre-heating scenario would require a closed loop anti-freeze mixture so future studies could model this in a separate pre-heating exchanger or tank.

### Grid Dependency and Battery Storage

The grid dependency of the auxiliary heater was investigated by implementing data processing shown in Figure 4 into the model. The grid dependency was defined as the percentage of time the auxiliary heater's ON state did not match the solar PV giving an output. The instantaneous difference in power consumption between the heater and PV was found with the output from a limiter block which removed negative values and was then integrated to find the total of the limiter output over the entire year (1). The grid dependency was then found by dividing the limiter output (1) over the total heater power (2) at the end of the year.

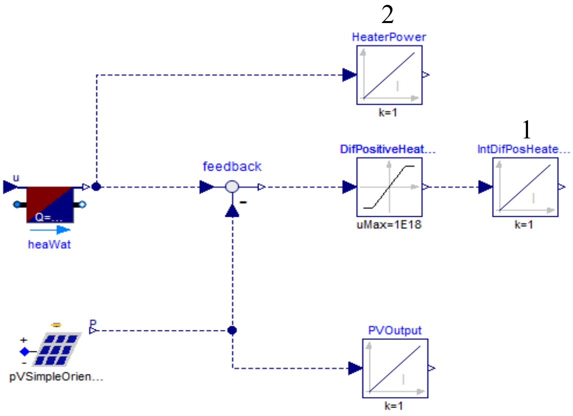

*Figure 4: Data processing to calculate auxiliary heater grid dependency*

All scenarios had a high grid dependency (71 – 87%). With a high grid dependency and an annual PVT electrical output greater than the annual auxiliary heating requirement, there was a case to investigate storing the PVT electrical output in battery storage reducing the reliance on the grid. Figure 5 shows how the total auxiliary heater power consumption was 114.5kWh on the foggy day and 21.4kWh on the sunny day. The varying environmental temperatures between the foggy and

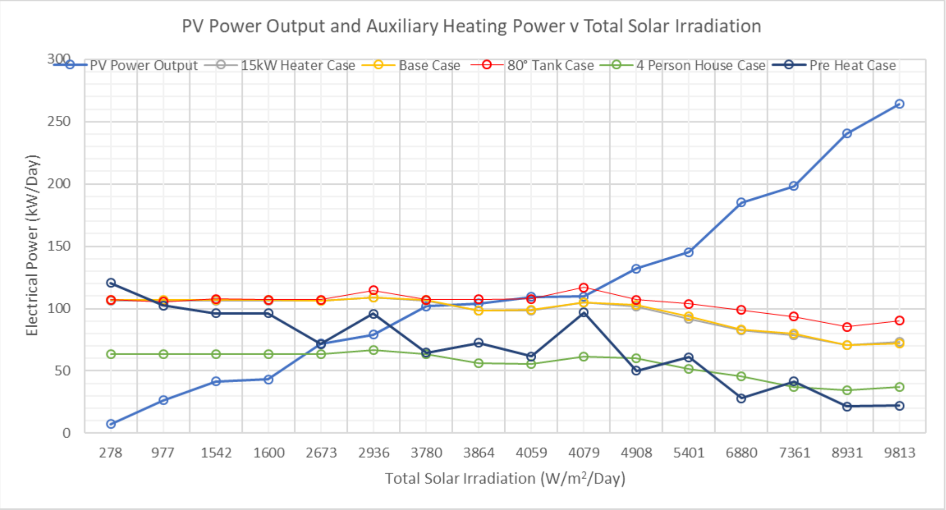

*Figure 3: Daily auxiliary heating power consumption over sample days*

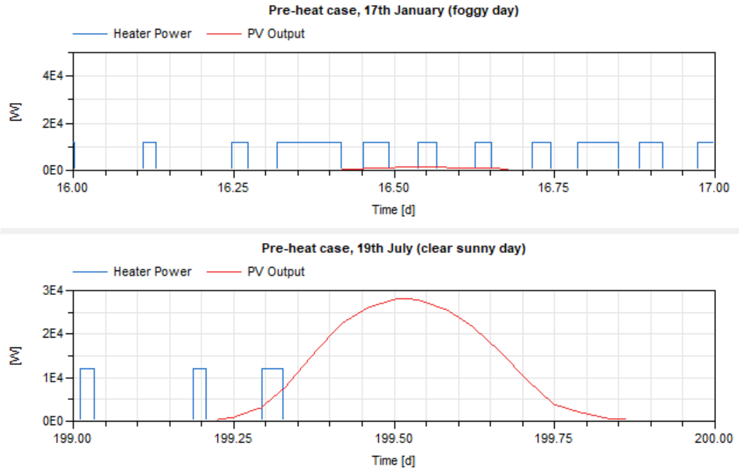

*Figure 5: Pre-heating scenario, auxiliary heater power consumption and PV output on a foggy and sunny day*

sunny day would have also affected the thermal losses and PV temperature de-rating. However, even though the foggy day analysed was a cold day in January, given that there was no thermal PVT output and minimal electrical output, the thermal losses and PV temperature de-rating do not affect the following discussion. Approximately 32% of the days in the weather file would require an auxiliary heating power consumption of about 100kWh per day, with roughly an 85% grid dependency, this means 85kWh design useable capacity. Assuming an 80% Depth of Discharge, the nominal battery capacity would be about 102kWh. To put this into perspective it was estimated that this battery bank capacity could fit into an 8ft shipping container with space for wiring and the inverters for the PVT system, based on the lithium ion specification in Table 2. Future work could investigate suitable control methods for PVT-battery systems. If the PVT system were grid tied, without careful controls the batteries could be fully charged by 11am for example, meaning the peak PV production would be exported to the grid at its maximum output which may not correspond to the peak demands of the grid. With other PV systems in the area, there could be an oversupply of PV to the local grid distribution area leading to excessive voltages above the tolerable limit (IRENA, 2015). Future work could also investigate how float charging from the grid required on consecutively foggy days may impact the cost and suitability of battery storage for PVT systems.

Table 2: Lithium-ion specification (Victron, 2018)

| | |
|---|---|
| Energy (Wh) | 3840 |
| Efficiency | 99% |
| Dimensions (HxWxW, mm) | 347x425x274 |
| Total Energy Capacity (28 Batteries, Wh) | 107520 |

The hot water tank outlet temperature had periods of constant or fluctuating temperatures (57-64°C). Analysis revealed how on sunny days the hot water tank temperature outlet fluctuated (down then up) between 8-9am, this coincided with a point where the incident radiation was above critical radiation but the collector temperature was below 60°C. These findings highlighted how pumps based on critical radiance should include controls in accordance with the tank set-point so that it does not lower the tank temperature below the set point.

### PV temperature de-rating

A standard PV module can reach 110 °C on a sunny day in direct sunlight, which would equate to about a 43% drop in efficiency (Renugen, 2018). The PVT electrical efficiency drop was optimised in the pre-heating scenario since the fluid entered the collector at 10°C, which actively cooled the PVT. The total annual PV output (with and without temperature de-rating) was calculated using the hourly dry bulb temperature and diffuse and direct irradiance. A de-rating factor of 0.452%/°C was applied to the PV output. The PV cell temperature was calculated with the following equation (G = total irradiance):

$$T_{cell} = T_{air} + 0.035\ x\ G\ (Migan,\ 2013) \qquad (4)$$

The annual PV output was increased by about 15% without temperature de-rating (61264kWh with de-rating, 71768 without de-rating). Therefore, in the pre-heating case scenario, there was an electrical output increase of up to 15% compared to standard PV.

### Space Heating and Refurbished Terraced House Opportunities

From January to March, the PVT thermal output provided about 7.5% of the space heating, the PVT electrical output was about 31,800kWh, which could cover about 33% of the auxiliary heating power (with battery storage). In this configuration, the PVT system met about 41% of the total space heating for the uninsulated post 1919 terraced houses over three months.

Uninsulated terraced houses are common in the UK, about two thirds of the existing housing stock are currently band C or lower (LCEA, 2018). However, with 80% of the existing housing stock forecast to be in use in 2050, the clean growth report stated that as many homes as possible are to be upgraded to band C by 2035 (BEIS, 2017). There has been some traction on studying/investigating suitable home upgrade roll outs, such as 20 dwellings being upgraded by East Thames Housing Group. This included a 1930s end terraced house which had loft and internal wall insulation, energy saving light bulbs, solar thermal, PV and low-flow taps, in this case the home moved from EPC band F to B (heating demands were not detailed in the report) (BRE, 2006). Upgrading from band F to B equates to approximately 50% less gas consumption (GOV, 2015). Theoretically with a 50% heating demand reduction applied to the PVT space heating scenario, the PVT system would be able to supply about 80% of the space heating, with battery storage. It should be noted that LT heating would require re-sizing of radiators/underfloor heating which carries an additional refurbishment and ‘hassle cost’, this was identified as the largest barrier to the UK’s heat pump uptake which would pertain to PVT systems (Frontier Economics and Element Energy, 2013). However, given the requirement to upgrade existing homes to higher sustainability levels, there could be a huge opportunity to transform homes to LT space heating systems alongside the UK housing stock upgrade.

### Emissions Savings

Based on a carbon intensity of 0.185kg$CO_2$/kWh of gas and 0.270 kg$CO_2$/kWh of electricity ((Carbon Trust (2008), ElectricityInfo (2019)), each terraced house could save about 3.2 tonnes $CO_2$/year if previously gas heated, and about 2.3 tonnes of $CO_2$/year if previously electrically heated. This was calculated based on the pre-heating scenario where the PVT system met all DHW and 91% of electricity demands. In perspective, the average UK household emitted 8.1 tonnes $CO_2$/year in 2014 (CCC, 2016), based on the findings of the study there is a great potential to reduce emissions with PVT and storage systems. However, uncertainty with emission savings lie in the future carbon intensity of the electric grid, which is expected to fall in the future (James and Edwards, 2010).

## Future work & conclusions

The space heating demands were derived from empirical data in this study. Future work could implement heat zoning (Dumont et al, 2015), with a limited number of more easily identifiable parameters to setup and calibrate the model, full transparency of the model could be achieved with an engineering equation solver (Bertagnolio, 2008). To reduce complexity and solving time in larger buildings with heat zoning, co -simulation with a validated building simulation program such as EnergyPlus has potential to improve the simulation efficiency and accuracy (Nicolai & Paepcke, 2017).

Future work could also build upon studies investigating the use of ground source heat pumps (GSHPs) as a secondary heating source in winter for space heating (Xia et al, 2017). It would be interesting to investigate how GSHP-PVT systems would perform in urban scenarios and how using the PVT to pre-heat the incoming mains water could improve upon the findings from the study by Xia et al, 2017. Phase change materials also have promising potential to increase the PVT thermal efficiency which could also be investigated in future studies.

This initial study of PVT systems and storage in urban areas has produced promising results. Coming back to the study by Herrando et al (2014) of a 3-bedroom terraced house, 15m$^2$ roof area for PVT and a hot water tank storage configuration which met 51% of total electricity and 36% of the total hot water demand. When the PVT system was scaled up to a row of 10 terraced houses with electrical storage as done so in this study; the PVT system could deliver all the hot water demands and 91% of the electricity demand. The results of this study have demonstrated how there is potential for greater thermal and electrical output with larger systems and the opportunity for shared communal electrical and thermal storage. Although the findings of this study are geographically sensitive (London based), similar modelling approaches could be applied to other locations. The main outcomes of the study are summarised in the following points:

- There is a case to implement battery storage with PVT systems due to the auxiliary heater demands and PVT electrical output only matching 13-29% of the time.
- PVT electrical efficiency and thermal output is increased when the mains water is pre-heated in the PVT (because of cooling) before entering the hot water tank. In this study, this equated up to a 15% electrical output increase in London highlighting the importance of active cooling across PVT systems.
- There is potential for meeting a higher proportion of occupant energy demands with larger PVT systems using shared communal electrical and thermal storage compared to single dwelling systems.

With the renewable heat incentive confirmed until 2021 which could help subsidise early PVT and storage system installations and help with market penetration, there is a case to further investigate PVT district heating opportunities.

## Acknowledgements

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