Loughborough University

LoT-NET

Advisory Board Meeting 5th October 2021

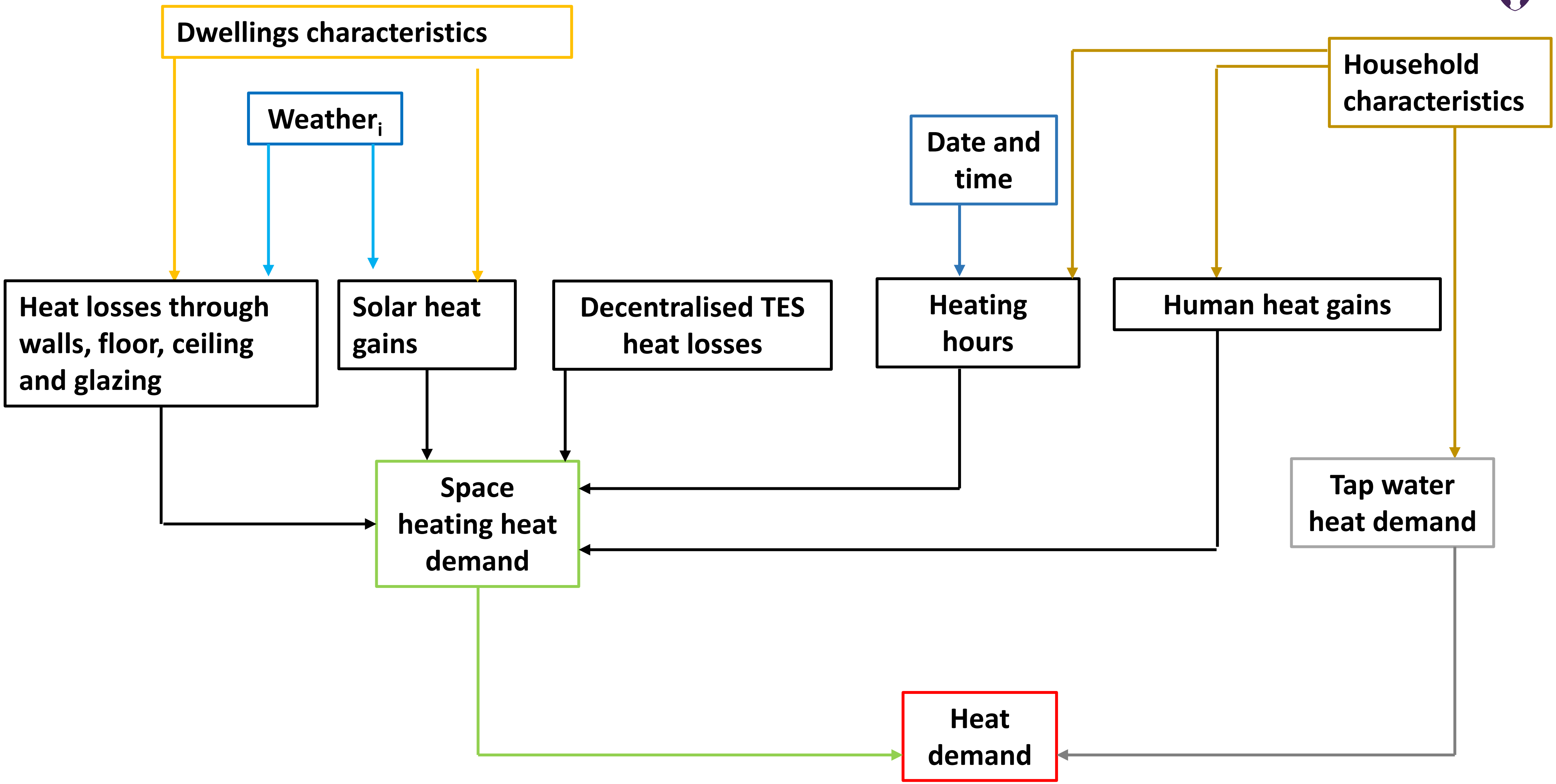
WP1.1, 1.2,1.3 and 2.2

Miguel Pans Castillo

Philip Eames

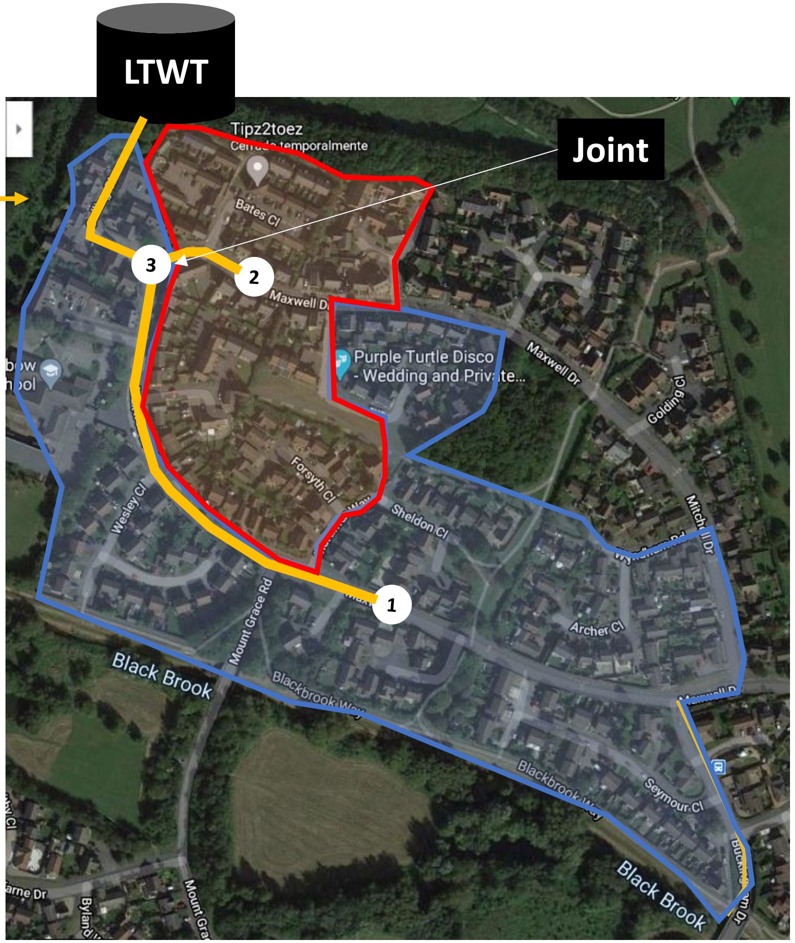
Low Temperature Heat Recovery and Distribution Network Technologies

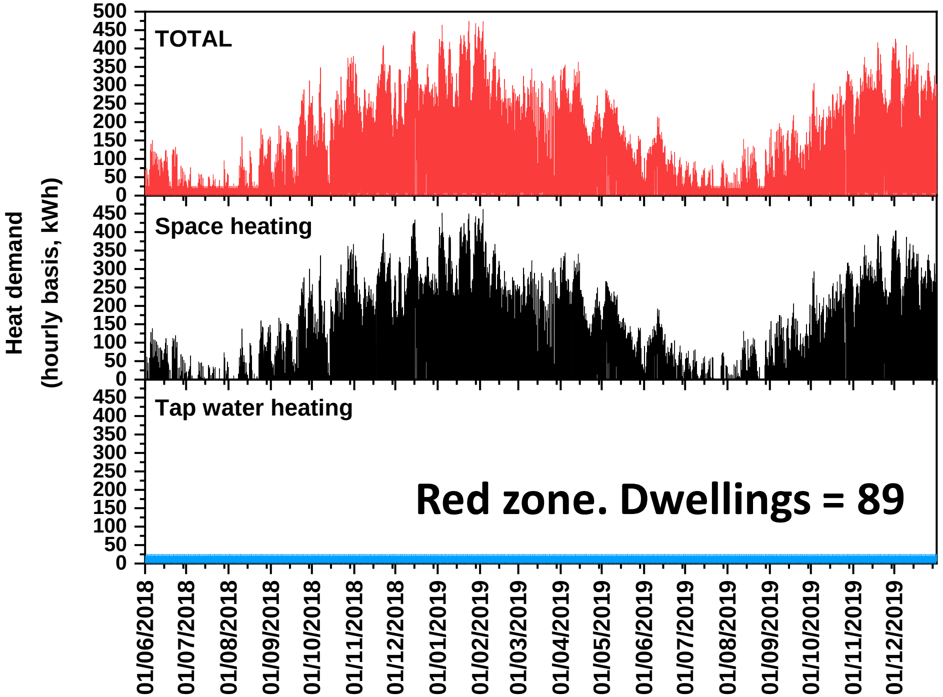
WP1: Heat mapping and analysis.

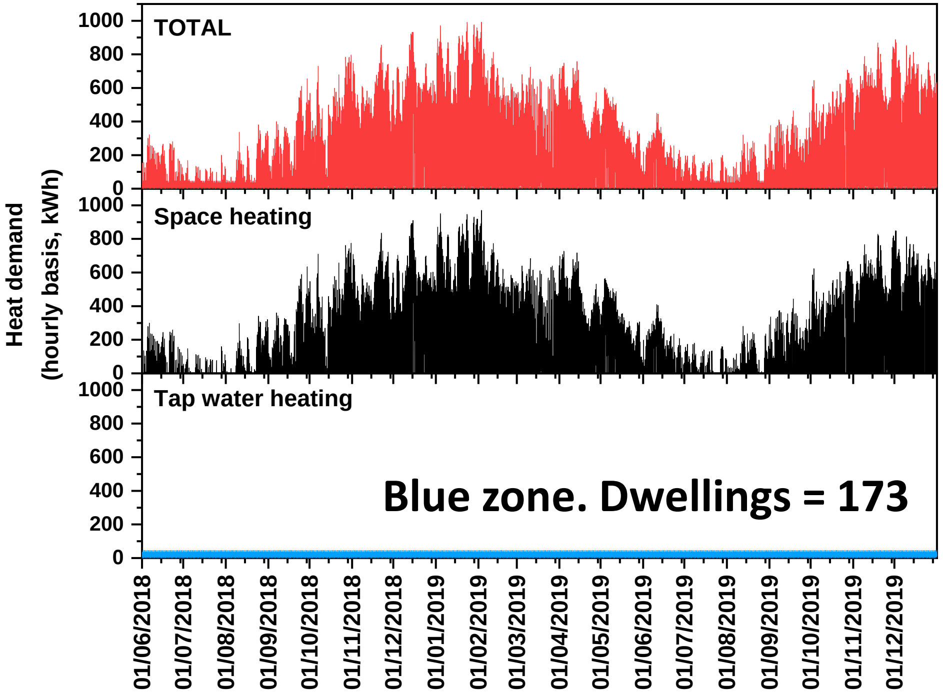


WP1: Heat mapping and analysis

Loughborough town







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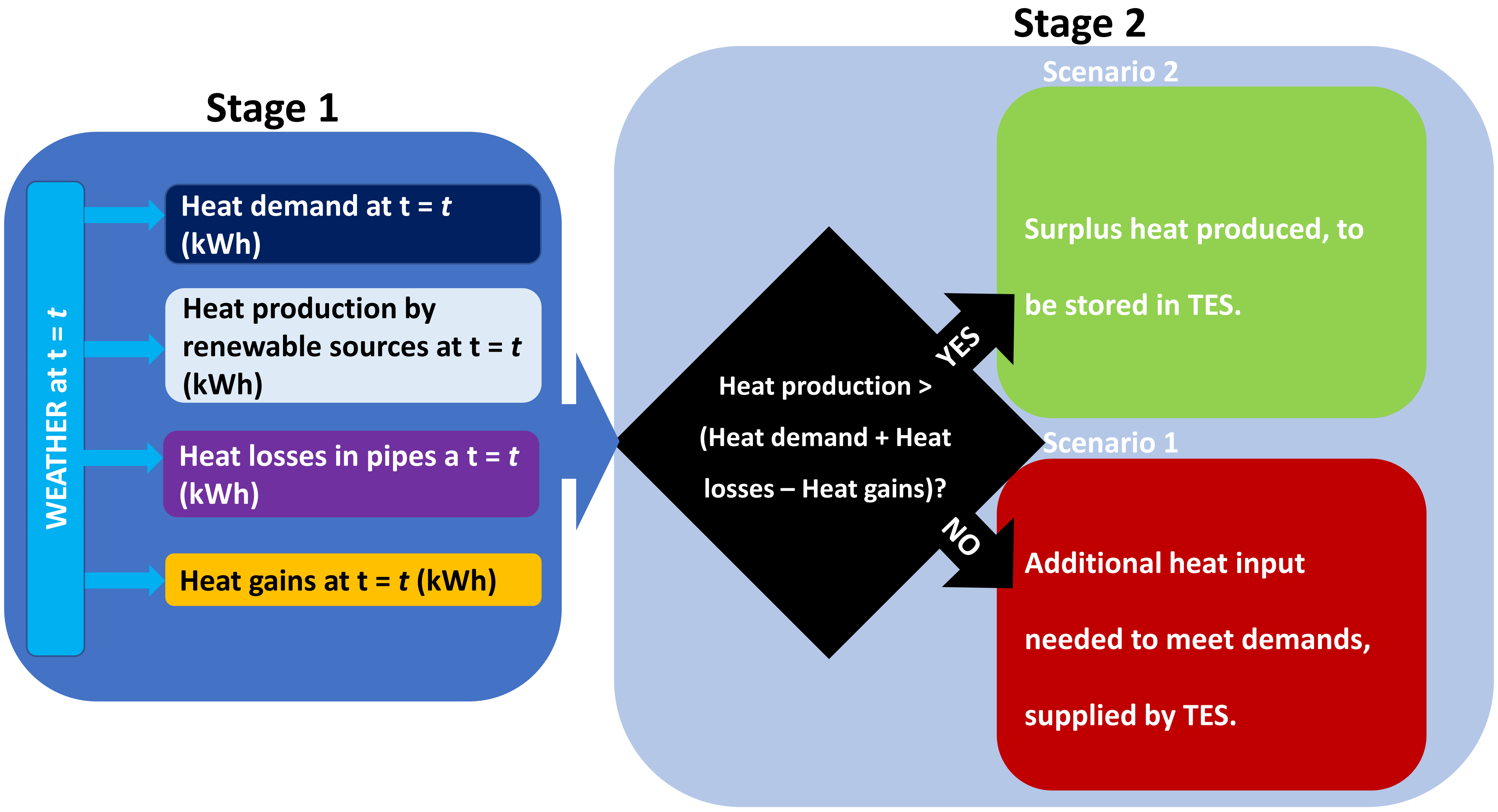
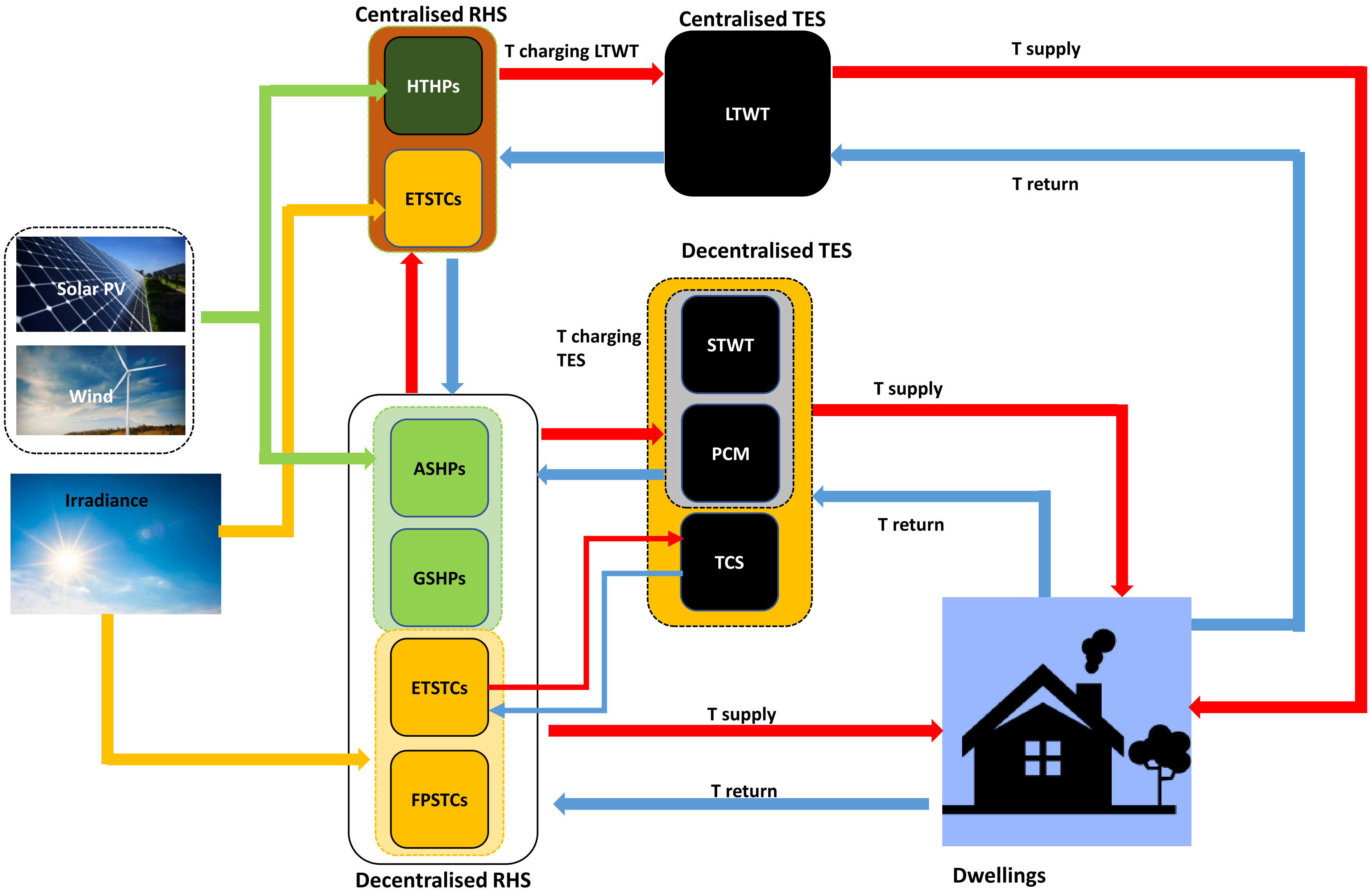
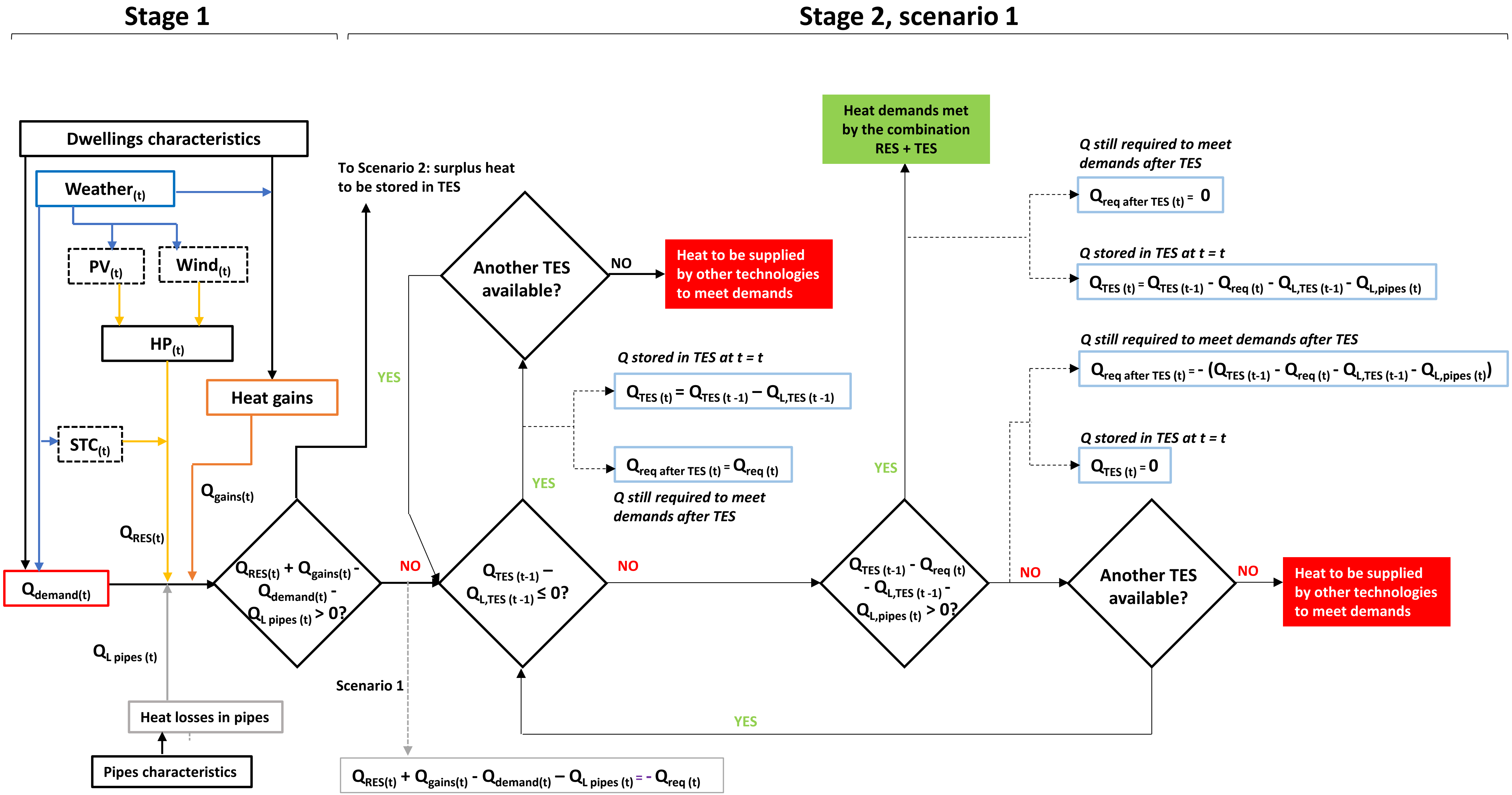

Stage 1
WEATHER at t = t
Heat demand at t = t (kWh)
Heat production by renewable sources at t = t (kWh)
Heat losses in pipes a t = t (kWh)
Heat gains at t = t (kWh)
Stage 2
Heat production > (Heat demand + Heat losses – Heat gains)?
YES
NO
Scenario 2
Surplus heat produced, to be stored in TES.
Scenario 1
Additional heat input needed to meet demands, supplied by TES.

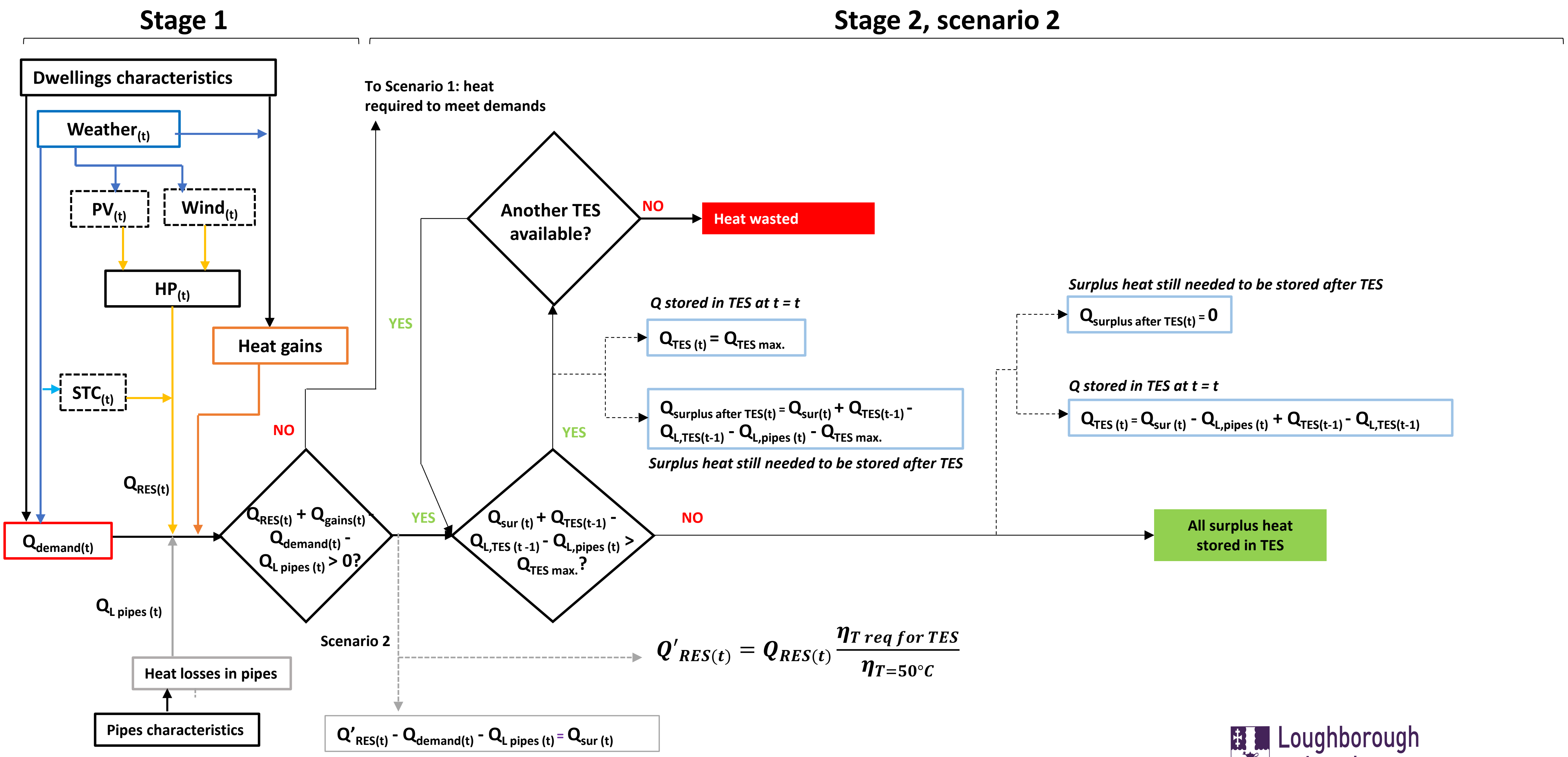
WP2: Methodology. DH system layout.



WP2: Methodology. Scenario 1: Heat required to meet demands.



WP2: Methodology. Scenario 2: Surplus heat produced.



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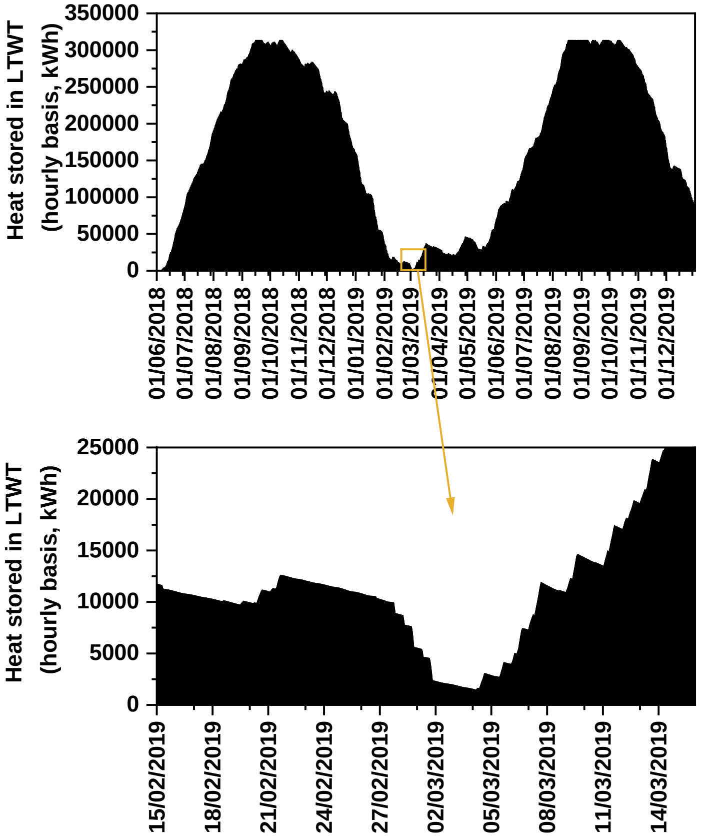
WP2: Methodology. DH system optimisation.



The optimisation was done using the Microsoft Excel add-in program Solver. The Solver parameters introduced were:

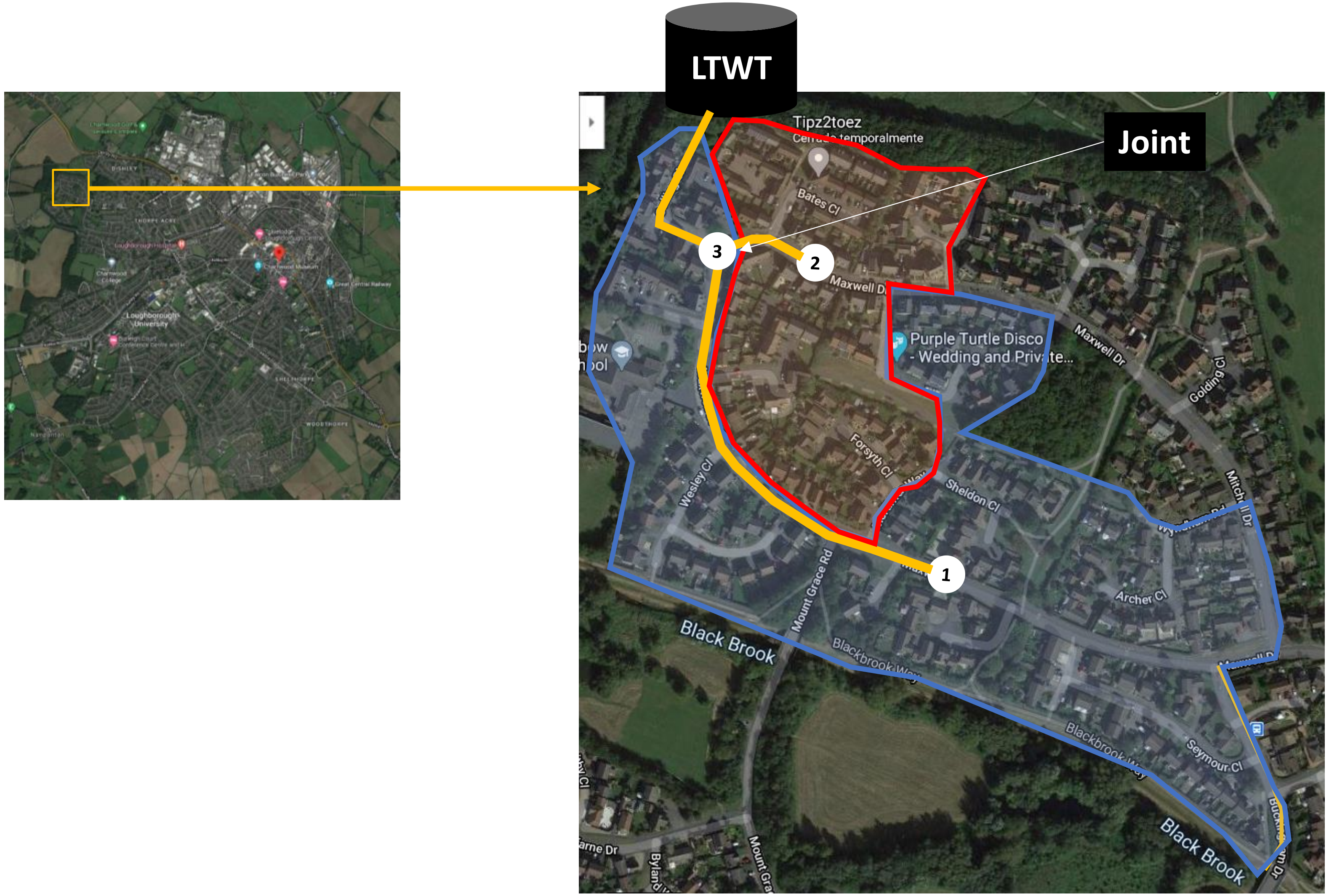
- **Objective:** Cost per dwelling, to be minimum.
- **Variables:** the optimisation was carried out by modifying the following parameters:
  1. Installed capacity of PV used to power domestic HPs, ($\mathbf{PV_{dwellings}}$).
  2. Installed capacity of Wind used to power domestic HPs, ($\mathbf{WIND_{dwellings}}$).

  The PV and Wind capacity needed to power the HTHPs required to lift the temperature of water prior charging the LTWT (PVLTWT and WINDLTWT) are not included here, as these two are calculated depending on the amount of heat to be charged in the LTWT at every hour.

- **Constrains:** the following constraints were applied:
  1. Domestic heat demands to be met at every hour for the whole time-period considered for the simulation ($\Delta_{dem\text{-}prod} \leq 0$ kWh).
  2. **0.5 MW ≥ $\mathbf{PV_{dwellings}}$ ≥ 0 MW.**
  3. **0.5 MW ≥ $\mathbf{WIND_{dwellings}}$ ≥ 0 MW.**
  4. **0.05 $\mathbf{LTWT_{max}}$ ≥ $\mathbf{LTWT_{min}}$ > 0**, where $\mathbf{LTWT_{min}}$ is the minimum accumulated heat stored in LTWT between 01/09/2018 00:00:00 and 30/06/2019 23:00:00, and $\mathbf{LTWT_{max}}$ the maximum heat storage capacity of the LTWT. This last constraint was introduced to make the software find the solution faster and avoid local minimums, as it was observed that in all cases the global minimum cost that ensures to meet demands for the whole simulation period is obtained when the minimum heat stored in the LTWT between two summer maximums is the smallest possible (but higher than 0 kWh). In this case, it was assumed that the minimum should be less or equal than the 5% of the maximum heat storage capacity of the LTWT.

WP3: Applications to case-study regions. Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings). Inputs.

City/town	Loughborough (UK)
Time-period considered	From 01/06/2018 00:00 to 31/12/2019 23:00



	RED AREA	BLUE AREA
Dwelling type		
detached	44.90%	46.20%
semidetached	29.20%	45.10%
terraced	15.70%	7.50%
flat	10.10%	1.20%
Total number of dwellings	89	173
Household type		
One person household	**25.80%**	**17.90%**
Married couple household	**41.60%**	**49.10%**
With dependent children	24.70%	20.20%
1	6.00%	10.95%
2	14.22%	5.89%
3	4.48%	3.36%
no dependent children	16.90%	28.90%
Same sex couple	**0.00%**	**0.00%**
With dependent children	0.00%	0.00%
1	0.00%	0.00%
2	0.00%	0.00%
3	0.00%	0.00%
no dependent children	0.00%	0.00%
Cohabiting couple	**13.50%**	**14.50%**
With dependent children	3.40%	8.70%
1	0.83%	4.72%
2	1.96%	2.54%
3	0.62%	1.45%
no dependent children	10.10%	5.80%
Lone parent	**10.10%**	**16.70%**
With dependent children	9.00%	12.10%
1	2.19%	6.56%
2	5.18%	3.53%
3	1.63%	2.01%
no dependent children	1.10%	4.60%
Multiperson houshold	**9.00%**	**1.80%**
Students	1.10%	0.60%
Other	7.90%	1.20%

[1] Official labour market statistics, NOMIS, (n.d.). https://www.nomisweb.co.uk/.

WP3: Applications to case-study regions. Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings). Inputs.

RHSs main parameters	
USED IN DWELLINGS	
Renewable power sources used to power domestic HPs	
Wind assumed installed capacity ($WIND_{DWELLINGS}$, MW)	0 – 0.5
Solar PV assumed installed capacity ($PV_{DWELLINGS}$, MW)	0 – 0.5
STCs	
$\%ETSTC_{DWELLINGS}$	50%
%FPSTC	50%
Area of STC per dwelling (m^2)	0 - 3
HPs	
%ASHP	50%
%GSHP	50%
ASHPs capacity per unit (kW)	As required
GSHPs capacity per unit (kW)	As required
USED TO CHARGE LTWT	
Renewable power sources used to power HTHPs needed to lift temperature of water prior charging LTWT	
Wind assumed installed capacity ($WIND_{LTWT}$, MW)	As required
Solar PV assumed installed capacity (PV_{LTWT}, MW)	As required
$ETSTC_{LTWT}$ area (m^2)	As required

TES main parameters	
Penetration (% of dwellings with stores)	
STWT	50%
PCM	30%
LTWT	NA
TCS	10%
Charging temperature (°C)	
TCS	120
STWT	50
PCM	50
LTWT	50 - 90
Volume	
STWT volume per dwelling (m^3)	1
PCM volume per dwelling (m^3)	1
TCS volume per dwelling (m^3)	1
LTWT (m^3)	Variable

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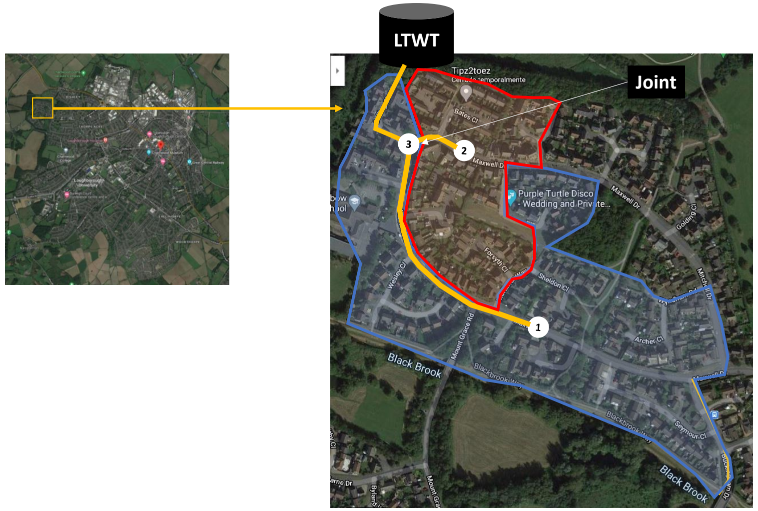
Methodology: Case-scenario: 2 urban areas in Loughborough, UK (262 dwellings). Inputs.

Piping network main parameters	
Distance between Point 2 and Point 3 (m)[1]	80.5
Distance between Point 1 and Point 3 (m)[1]	291.5
Distance between Point 3 and LTWT (m)[1]	162.0
Inner diameter of pipes (m)	0.4
Thickness of pipes (m)	0.01
U-value (W/m K)	0.023[2]
Material	AluFlex[2]
Costs of variable parameters	
Variable parameters	
Installed PV (£/MW)[3]	1000000
Installed Wind (£/MW)[4]	1610000
LTWT (£/m³)[5]	50
ASHPs (£/unit)	5000
GSHPs (£/unit)	13000
HTHPs (£/kW)[7]	250
Fixed parameters	
TCS (£/m³)[8,9]	100
PCM (£/kWh)[5]	45
STWT (£/m³)[5]	30
Piping network (£/dwelling), [10,11]	800

[1] Obtain by means of google maps.



[2] M. Brand, J.E. Thorsen, S. Svendsen, Numerical modelling and experimental measurements for a low-temperature district heating substation for instantaneous preparation of DHW with respect to service pipes, Energy. (2012). https://doi.org/10.1016/j.energy.2012.02.061.

[3] S.T.A. (STA), Solar Trade Association (STA), (n.d.). https://solarenergyuk.org/.

[4] Briefings for britain, No Title, (n.d.). https://briefingsforbritain.co.uk/.

[5] E. Guelpa, V. Verda, Thermal energy storage in district heating and cooling systems: A review, Appl. Energy. 252 (2019) 113474. https://doi.org/10.1016/J.APENERGY.2019.113474.

[6] UK suppliers.

[7] C. Arpagaus, F. Bless, M. Uhlmann, J. Schiffmann, S.S. Bertsch, High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials, Energy. 152 (2018) 985–1010. https://doi.org/10.1016/j.energy.2018.03.166.

[8] T. Yang, W. Liu, G.J. Kramer, Q. Sun, Seasonal thermal energy storage: A techno-economic literature review, Renew. Sustain. Energy Rev. 139 (2021) 110732. https://doi.org/10.1016/J.RSER.2021.110732.

[9] F. Desai, J. Sunku Prasad, P. Muthukumar, M.M. Rahman, Thermochemical energy storage system for cooling and process heating applications: A review, Energy Convers. Manag. 229 (2021) 113617. https://doi.org/10.1016/J.ENCONMAN.2020.113617.

[10] Energy technologies institute, DISTRICT HEAT NETWORKS IN THE UK: POTENTIAL, BARRIERS AND OPPORTUNITIES, (2018) 1–17. www.eti.co.uk (accessed August 18, 2021).

[11] Energy research partnership, Potential Role of Hydrogen in the UK Energy System, 2016. https://erpuk.org/wp-content/uploads/2016/10/ERP-Hydrogen-report-Oct-2016.pdf.

WP2.2 Thermal Storage

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- Large scale sensible heat store performance predictions, importance of SA/Vol Ratio, energy storage capacity, energy storage duration, losses
- Latent heat store designs, simulations and experiments for small capacity 5-10kWh stores with PCM temps less than 62°C. HX designs to provide specified power output rates.
- Thermochemical heat stores, materials $MgCl_2$ SiO_2, $MgSO_4$ Zeolite charge/discharge characterisation and small scale lab systems. Larger systems modelled and to be built.

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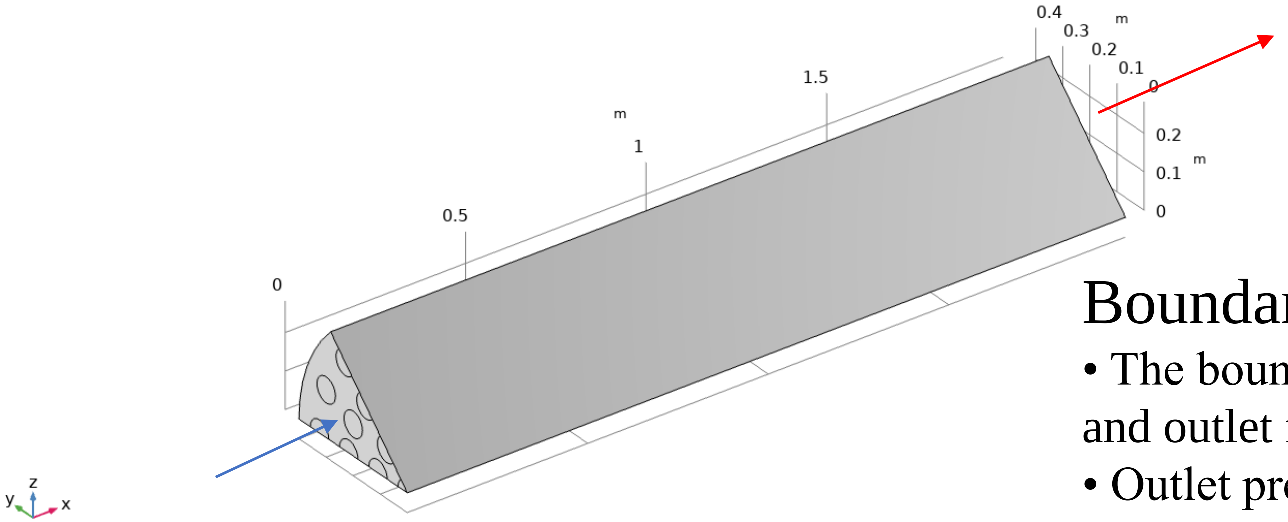
Extracted from James Delaney's MSc Thesis

COMSOL Modelling and Parametric Analysis of Thermochemical Energy Storage Systems and Their Domestic Applications

MgCl2.2H2O selected for storage material due to low cost, non-toxic, high energy density of 544kWhm-3 and equilibrium reaction temperature approximately 400K making it suitable for a domestic TCES reactor

At this temperature in the UK a Vacuum Flat Plate Solar Thermal Collector would be able to provide heat to the reactor.

Comsol model of a 1m3 volume packed bed reactor established,



Assumed reactive material density 1100kgm-3
Reactor energy storage density 254 kWh/m-3

Boundary conditions

- The boundaries are perfectly impermeable except for the inlets and outlet for the reactor.
- Outlet pressure of the packed bed, as well as the initial pressure, is atmospheric, and the inlet pressure changes for variable mass flow rates.
- Zero heat flux across the boundaries of the reactor other than the inlet and outlet for the moist air.
- Constant inflow temperature of the air at 288.15K.
- Gravity acts with a constant acceleration of -9.81ms-1-in the x-direction of the geometry seen in Figure 1.
- Pellets are perfectly uniform in the reactor for a defined spherical radius.

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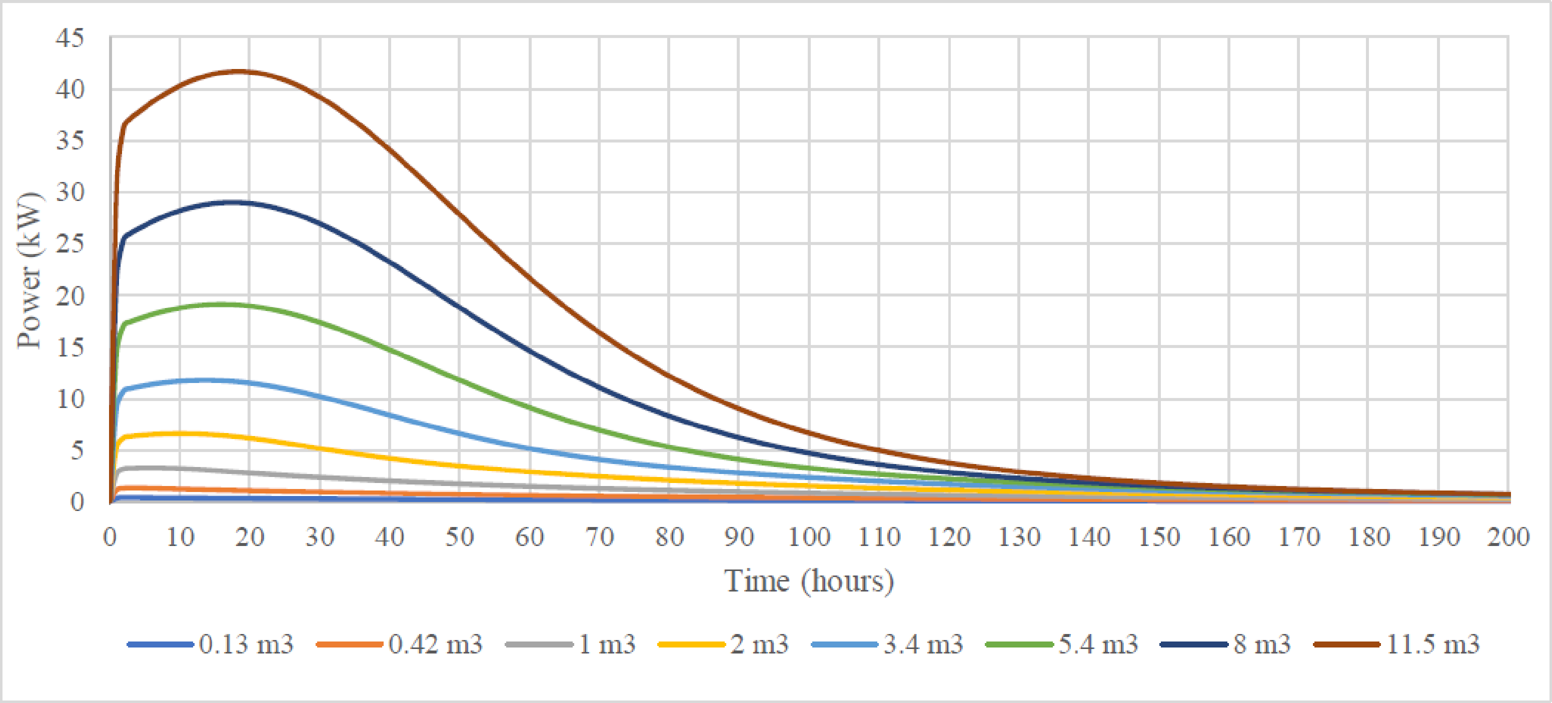
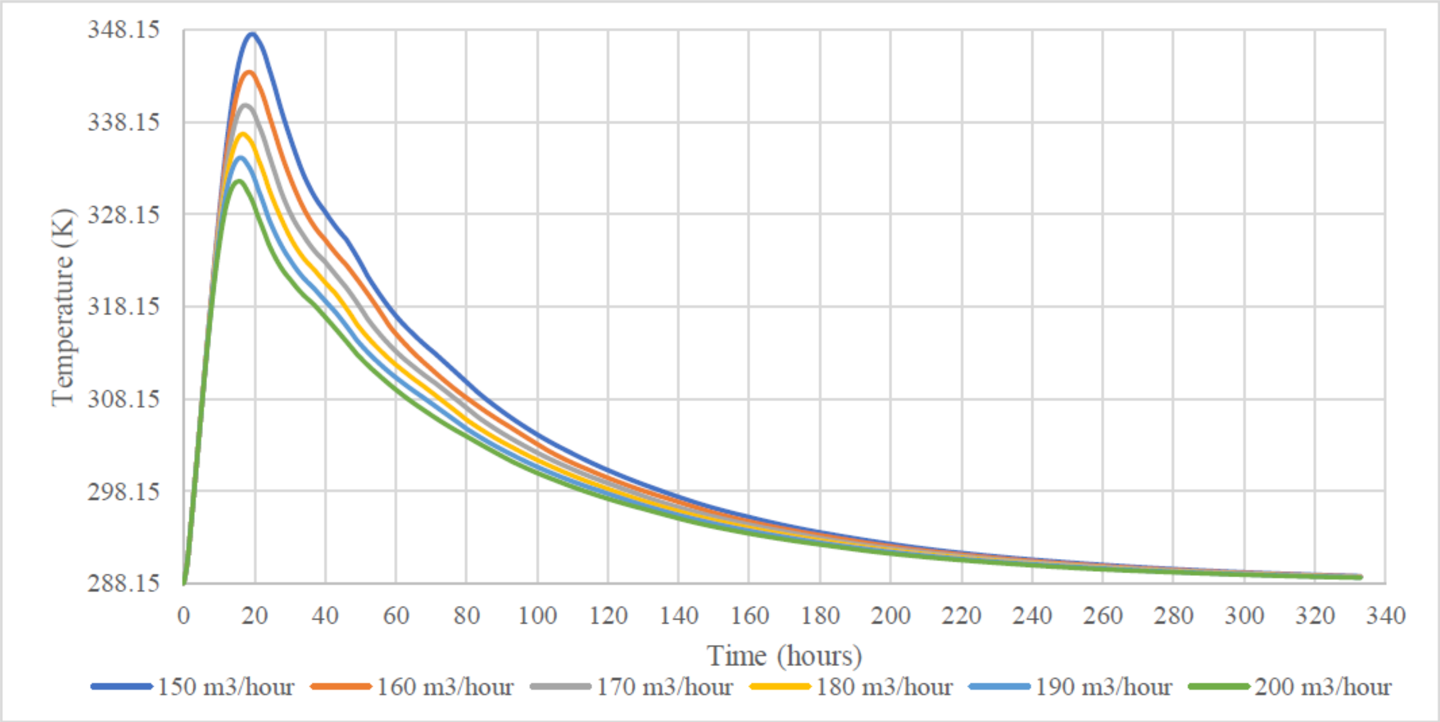
Calculated power output with time for packed beds of different volumes. Relative humidity of the moist air entering the reactor is 60% and the inlet temperature is 288.15K for an air mass flow rate of 170m3/hour.



A 1m3 store can store 254kWh

An 8m3 store can store over 2 MWh

Predicted air temperatures at outlet for mass flow rates from 150-200 m3/hour for a 1m3 store



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Predicted temperatures in the packed bed at 18 hours of discharge