Simulation of a 4th generation district heating network operating with renewable heat sources and TES technologies

LoT-NET project

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Low Temperature Heat recovery and Distribution Network Technologies (LoT-NET)

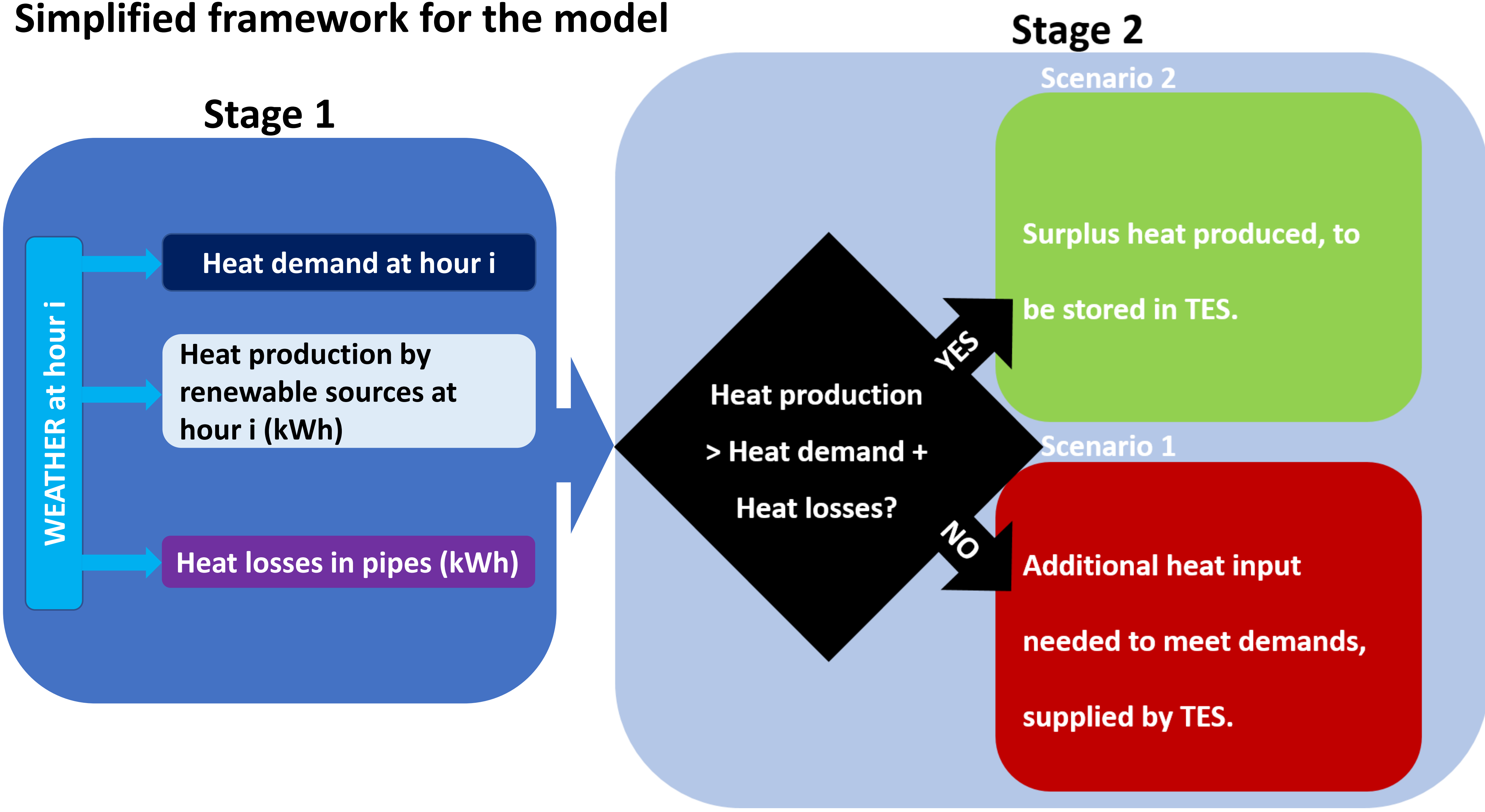
Main objectives:

- ✓ To develop a spatial and temporal simulation tool that can be used to simulate a smart thermal network interacting with storage and thermal transformation technologies, which will allow the adoption of **4th generation district heating** concept based on low/zero carbon heat sources.

  i. Determine and geographically map the heat demand and available heat resources and how they vary in time within an area. Obtain **heat demand time resolved data** (for different areas) and **heat production time resolved data** (for different heat resources, focusing in low carbon heat resources).
  ii. Develop a **model for a heat network based on low carbon heat sources.**
  iii. Apply the developed model to 3 selected regions: **Loughborough, Bunhill and Coleraine**.

- ✓ Prototype a range of alternative systems utilising chemical, phase change material or sensible heat for both the distribution and storage of energy.

Simplified framework for the model



Simplified framework for the model

Stage 1

Obtained with on-line tool [Renewables.ninja] developed by Staffell and Pfenninger[1-2]. The tool allows to obtain different historic hourly weather data for a given location:

i. **temperature (°C),**
ii. **precipitation (mm/h),**
iii. **snowfall (mm/h),**
iv. **snow mass (amount of snow per land area, kg/m^2),**
v. **ground-level solar irradiance (W/m^2),**
vi. **top of atmosphere solar irradiance (W/m^2),**
vii. **cloud cover fraction and air density (kg/m^3).**

The data are taken from the MERRA-2 reanalysis.

[1] S. Pfenninger, I. Staffell, Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data, Energy. 114 (2016) 1251–1265. doi:10.1016/J.ENERGY.2016.08.060.
[2] I. Staffell, S. Pfenninger, Using bias-corrected reanalysis to simulate current and future wind power output, Energy. 114 (2016) 1224–1239. doi:10.1016/J.ENERGY.2016.08.068.

Simplified framework for the model

Stage 1

The on-line tool Renewables.ninja can be used to directly estimate the hypothetical **hourly capacity factor** that could be achieved in a given location by using **Solar Photovoltaic (SPV) panels and Wind turbines.** Some variables can be modified also, such as :

i. **System loss fraction**
ii. **Tilt**
iii. **Azimuth angle**

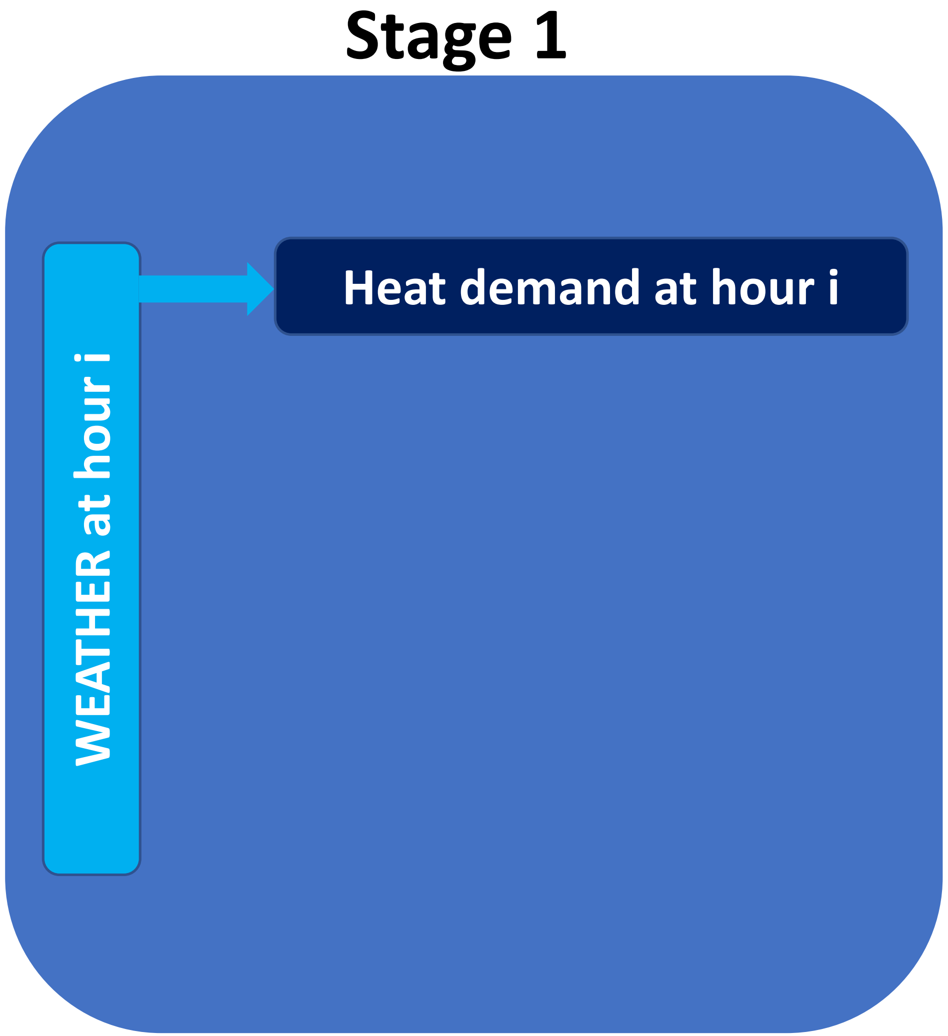
For the SPV panels and:

i. **Hub height**
ii. **Turbine model**

For the Wind.

[1] S. Pfenninger, I. Staffell, Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data, Energy. 114 (2016) 1251–1265. doi:10.1016/J.ENERGY.2016.08.060.
[2] I. Staffell, S. Pfenninger, Using bias-corrected reanalysis to simulate current and future wind power output, Energy. 114 (2016) 1224–1239. doi:10.1016/J.ENERGY.2016.08.068.

Simplified framework for the model



$$HD_i = \sum_{j=1}^{4} HL_{ij} + H_{hw_i} + HL_{v_i} - H_{G_i}$$

HL_{ij} are the **hourly heat losses through fabric** at *t* = *i* of the part of the dwelling *j* (where j = 1…4, being 1 = walls, 2 = floor, 3 = ceiling and 4 = glazing) (kWh)

H_{hw_i} is the **hourly heat demand originated from tap water heating** (kWh)

HL_{v_i} are the **hourly heat losses due to ventilation** (kWh)

H_{G_i} are the **hourly heat gains** due to:

1. **Occupancy**
2. **Solar heat gains**

Heat demand calculation. Heat losses through fabric and due to ventilation: Equations

Hourly heat losses through fabric	$$HL_{ij} = U_j \cdot A_j \cdot (T_{in} - T_{out_i})$$
Hourly heat losses due to ventilation	$$HL_{v_i} = \frac{\rho_{air} \cdot Cp_{air} \cdot HV \cdot (T_{in} - T_{out_i}) \cdot N_{air}}{3600}$$

HL_{ij} are the heat losses at *t = i* of the part of the dwelling *j* (where j = 1…4, being 1 = walls, 2 = floor, 3 = ceiling and 4 = glazing) (kWh)

U_j is the U-value or thermal transmittance of the part of the dwelling *j* (W/m^2 K)

A_j is the area of the part of the dwelling *j* (m^2)

T_{in} is the desired temperature inside the dwelling or the space heating control set point, and was assumed to be 21 °C (typical of that seen in UK housing [7])

T_{out_i} is the outdoors temperature at *t = i* (obtained with the on-line tool *Renewables.ninja*)

ρ_{air} is the density of the air inside the house (1.225 kg/m^3 at 20°C),

Cp_{air} is the specific heat capacity of the air (1 kJ/kg K),

***HV* is heated volume of the dwelling (which is obtained from the dimensions showed in Table 2 for every type of dwelling, m^3)**

N_{air} is the number of air changes per hour, which is taken from Table 1 for every type of dwelling.

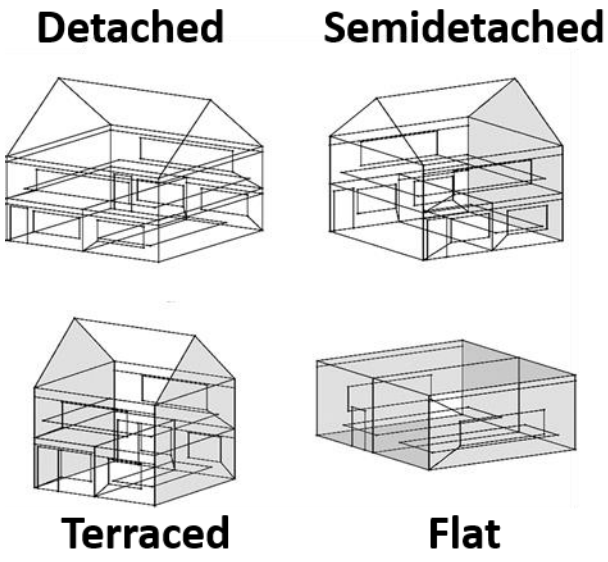
Heat demand calculation. Heat losses through fabric and due to ventilation: Assumptions

	Floor area (m^2)[1]	Heated volume (m^3)[1]	Total windows area (m^2)[1]	Width (m)[2]
Detached	136	286	34.00	10
Semi-detached	87	186	21.75	10
Terraced	57	142	14.25	10
Flat	56	140	14.00	10

[1] Assumed as a 25% of the floor area, according to [2]

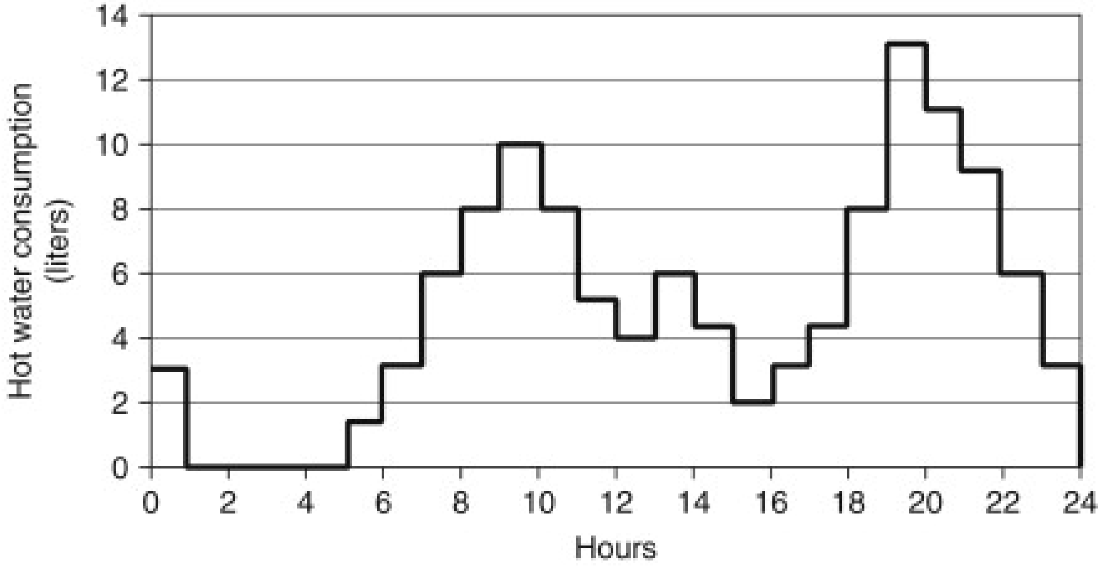
[2] Assumed values.

[1] J. Allison, K. Bell, J. Clarke, A. Cowie, A. Elsayed, G. Flett, G. Oluleye, A. Hawkes, G. Hawker, N. Kelly, M.M.M. de Castro, T. Sharpe, A. Shea, P. Strachan, P. Tuohy, Assessing domestic heat storage requirements for energy flexibility over varying timescales, Appl. Therm. Eng. 136 (2018) 602–616. doi:10.1016/J.APPLTHERMALENG.2018.02.104.
[2] UK goverment, Approved Document L1B: conservation of fuel and power in existing dwellings, 2010 edition (incorporating 2010, 2011, 2013, 2016 and 2018 amendments), n.d. https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l (accessed November 12, 2019).



	Basic U-value ($W/m^2 K$) [1]	Improved U-value (W/m^2K) [1]
External wall	0.45	0.11
Floor	0.60	0.10
Ceiling	0.25	0.13
Glazing	2.94	0.70
Infiltration (air changes per hour)	0.50	0.06

Heat demand calculation. Heat demand originated from tap water heating



Hot-water daily consumption profile. Adapted from [3].

[3] S.A. Kalogirou, S.A. Kalogirou, Solar Water Heating Systems, Sol. Energy Eng. (2009) 251–314. doi:10.1016/B978-0-12-374501-9.00005-4

$$H_{hw_i} = \frac{V_{hw_i}\,\rho_{water} Cp_{water}\left(T_{supply} - T_{return}\right) \; {}^{N_{occ}}/_{4}}{3600 \cdot 1000}$$

V_{hw_i} **is the volume of hot water consumed per 4 person and per hour at** ***t = i*** **(l/h per 4 person),**

ρ_{water} **is the density of water (kg/m³),**

Cp_{water} **is the specific heat of water (kJ/kg K),**

T_{supply} **temperature of the water in the supply pipe (°C),**

T_{return} **temperature of the water in the return pipe (°C) and**

N_{occ} **is the number of occupants.**

Heat demand calculation. Solar heat gains

$$H_{G,i} = A_w \alpha \overline{F_c} \left(\overline{f}_i \tau_b I_{b,i} \overline{R_b} + \tau_d F_{rs} I_{d,i} + \frac{\rho}{2} \tau_g I_{T,i} \right)$$

Dwelling orientation	South-facing windows (50%)
Lougborough latitude	52,8°
Ground reflectance (ρ)	0,20
Control function ($\overline{F_c}$)	1
Reflectance of the room surfaces (ι_R)	0,60
Transmittance for beam radiation (τ_b)	0,71
Transmittance for diffuse and ground-reflected (τ_d and τ_g)	0,64
Radiation view factor between receiver and sky (F_{rs})	Calculated from the dimensions of the window and overhang (using Tables at Duffie and Beckman, 1980)
Ratio of total beam radiation on a vertical surface during a month to that on a horizontal surface during the same month ($\overline{R}_b$)	Estimated for every month as a function of latitude from Figures at Duffie and Beckman, 1980.
Ratio of total beam radiation on the shaded receiver during a month to that on the unshaded receiver in same month ($\overline{f}_i$)	Calculated from dimensions of window and overhang (using Tables at Duffie and Beckman, 1980)
$I_{b,i}$, $I_{d,i}$ and $I_{T,i}$ are, respectively, the hourly daily beam, diffuse and total solar radiation per unit area on a horizontal surface (W/m²)	Obtained by *renawables.ninja*

Heat demand calculation. Solar heat gains

$$H_{G,i} = A_w \alpha \overline{F_c} \left(\bar{f}_i \tau_b I_{b,i} \overline{R_b} + \tau_d F_{rs} I_{d,i} + \frac{\rho}{2} \tau_g I_i \right)$$

	Detached	Semi-detached	Terraced	Flat
Relative width of window (width/height)	≈4,0	≈4,0	≈4,0	≈4,0
Relative projection of overhang (projection overhang/height window)	≈0,5	≈0,5	≈0,5	≈0,5
Overhang: position above the window (m)	0,4	0,4	0,4	0,4
Extensions (m)	0,0	0,0	0,0	0,0

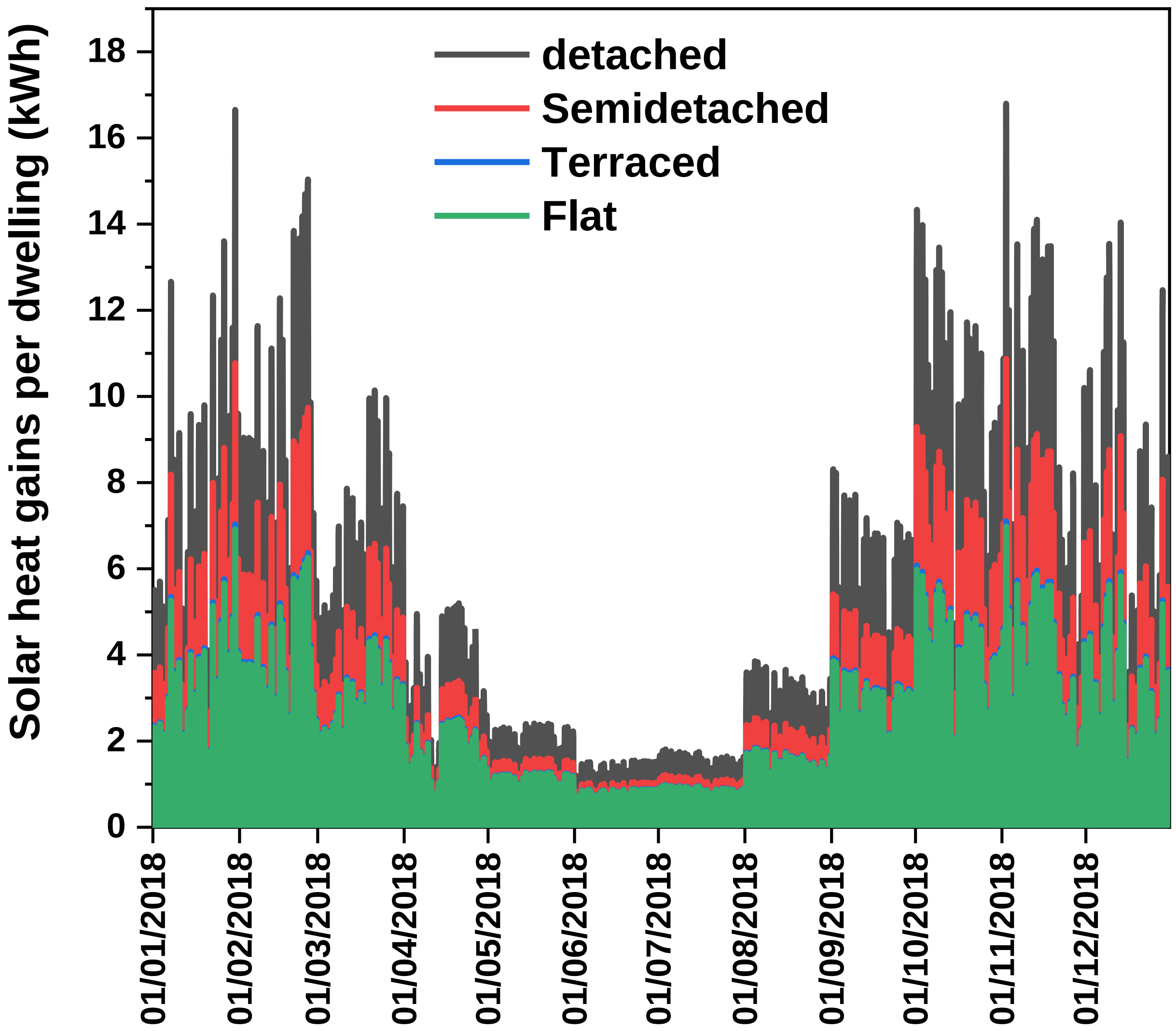
α is the effective absorptance of the window/room combination, calculated as $\alpha = 1 - \left[\frac{\frac{\tau_b \iota_R A_W}{A_R}}{1 - \iota_R \left(1 - \frac{A_W}{A_R} \right)} \right]$ **[where ι_R is the reflectance of the room surfaces, assumed as 0.6 (0.9 can be used for clean white surfaces, 0 for black surfaces) and A_R is the room surface area (walls, floor, ceiling)]**

$$\alpha = 1 - \left[\frac{\frac{\tau_b \iota_R A_w}{A_R}}{1 - \iota_R \left(1 - \frac{A_w}{A_R} \right)} \right]$$

Heat demand calculation. Solar heat gains

I. Solar heat gains higher in the winter due to a lower sun position in the sky and therefore lower incidence angle of the sun on south-facing windows.

II. Solar heat gains higher in detached houses due to a bigger windows area in these dwellings.



Heat demand calculation. Heat gains due to occupancy

Table 6.1 Heat emission (W) from an adult male body (of surface area 2 m^2) and average heat emission per person for a mixture of men, women and children typical of the stated application

Activity	Typical application	Occupancy density (m^2/person)	Total, sensible and latent heat emission (W) for stated application and dry bulb temperature (C) for adult male (and average for mixture of men, women and children)										
			Total	15		20		22		24		26	
				Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent
Seated, inactive	Theatre, cinema matinee	0.75–1.0[2,3]	115 (100)	100 (87)	15 (13)	90 (78)	25 (22)	80 (70)	35 (30)	75 (65)	40 (35)	65 (57)	50 (43)
Seated, inactive	Theatre, cinema evening	0.75–1.0[2,3]	115 (105)	100 (91)	15 (14)	90 (82)	25 (23)	80 (73)	35 (32)	75 (68)	40 (37)	65 (59)	50 (46)
Seated, light work	Restaurant	1.0–2.0[2,3]	140 (126)	110 (99)	30 (27)	100 (90)	40 (36)	90 (81)	50 (45)	80 (72)	60 (54)	70 (63)	70 (63)
Seated, moderate work	Office	8–39[4–6], 14[4,7]*	140 (130)	110 (102)	30 (28)	100 (93)	40 (37)	90 (84)	50 (46)	80 (74)	60 (56)	70 (65)	70 (65)
Standing, light work, walking	Department store	1.7–4.3[2,3]	160 (141)	120 (106)	40 (35)	110 (97)	50 (44)	100 (88)	60 (53)	85 (75)	75 (66)	75 (66)	85 (75)
Standing, light work, walking	Bank	—	160 (142)	120 (107)	40 (35)	110 (98)	50 (44)	100 (89)	60 (53)	85 (76)	75 (66)	75 (66)	85 (76)
Light bench work	Factory	—	235 (209)	150 (133)	85 (76)	130 (116)	105 (93)	115 (102)	120 (107)	100 (89)	135 (121)	80 (71)	155 (138)
Medium bench work	Factory	—	265 (249)	160 (150)	105 (99)	140 (132)	125 (117)	125 (117)	140 (132)	105 (99)	160 (150)	90 (85)	175 (164)
Heavy work	Factory	—	440 (440)	220 (220)	220 (220)	190 (190)	250 (250)	165 (165)	275 (275)	135 (135)	305 (305)	105 (105)	335 (335)
Moderate dancing	Dance hall	0.5–1.0	265 (249)	160 (150)	105 (99)	140 (132)	125 (117)	125 (117)	140 (132)	105 (99)	160 (150)	90 (85)	175 (164)

* Recommended

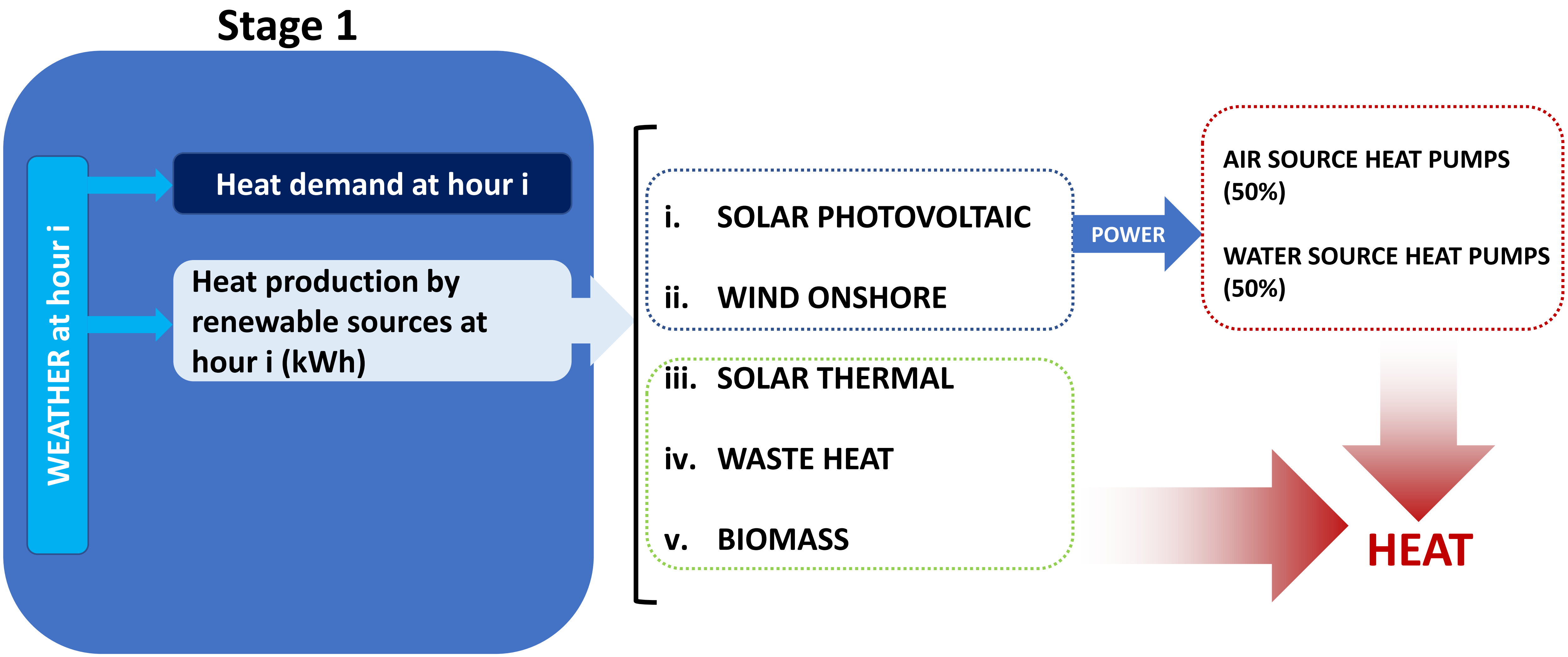
Notes:

(1) Figures in parenthesis are adjusted heat gains based on normal percentage of men, women and children for the applications listed. This is based on the heat gain for women and children of 85% and 75% respectively of that of an adult male.

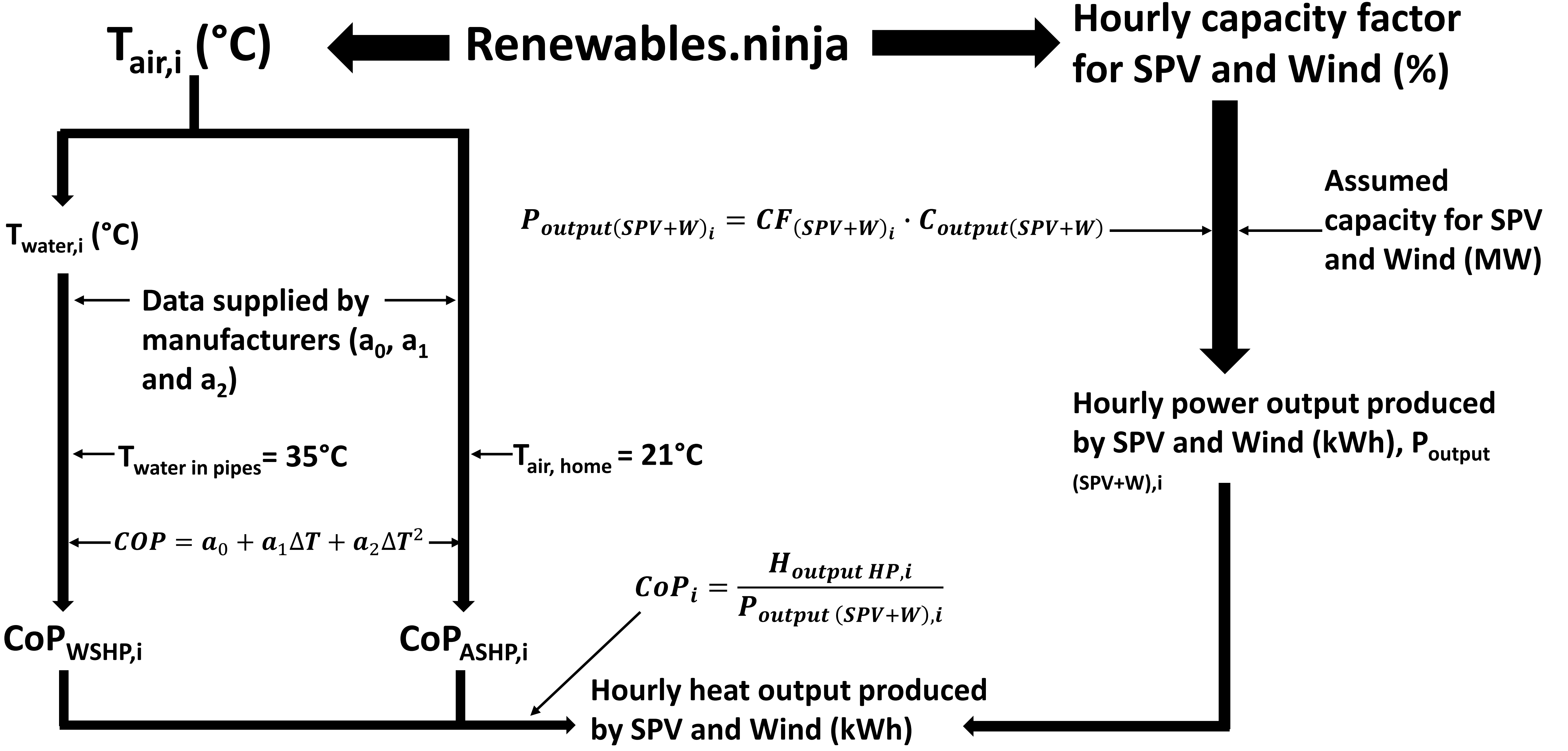
(2) For restaurant serving hot meals add 10 W sensible and 10 W latent for food per individual.

SOURCE: Chartered Institution of Building Services Engineers (CIBSE), *http://www.cibse.org/getattachment/Knowledge/CIBSE-Guide/CIBSE-Guide-A-Environmental-Design-NEW-2015/Guide-A-presentation.pdf.aspx*

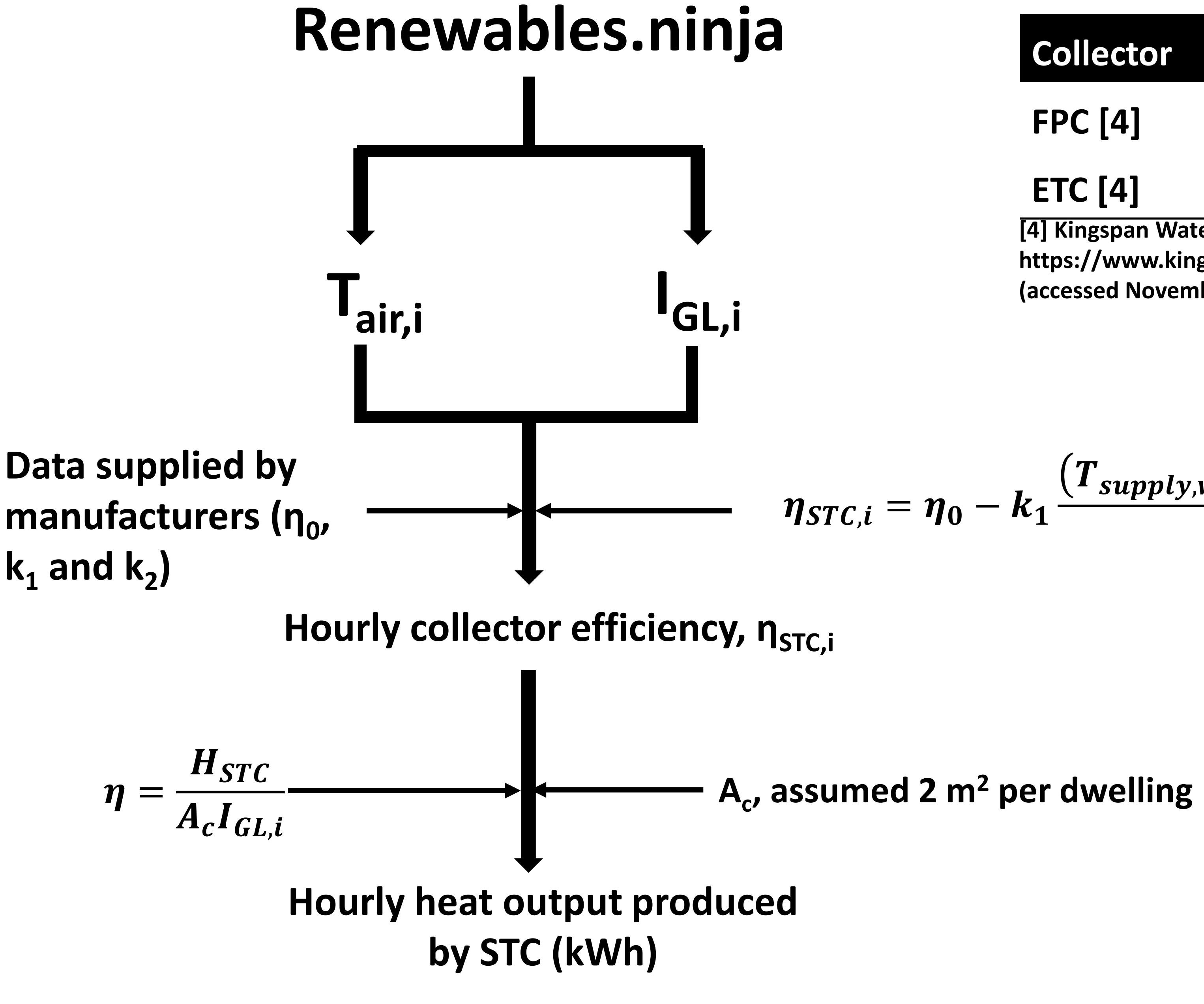
Simplified framework for the model



Heat output produced by heat pumps powered by SPV and Wind turbines



Heat output produced by Solar thermal Collectors



Collector	η_0	k_1	k_2
FPC [4]	0.775	3.73	0.0152
ETC [4]	0.75	1.18	0.0095

[4] Kingspan Water & Energy | Home | Kingspan | Great Britain, (n.d.). https://www.kingspan.com/gb/en-gb/about-kingspan/kingspan-water-energy (accessed November 12, 2019).

$$\eta_{STC,i} = \eta_0 - k_1 \frac{\left(T_{supply,water} - T_{air,i}\right)}{I_{GL,i}} - k_2 \frac{\left(T_{supply,water} - T_{air,i}\right)^2}{I_{GL,i}}$$

SUMMARY RENEWABLES (and non renewables) AVAILABLE NEAR LOUGHBOROUGH (30 KM RADIUS).

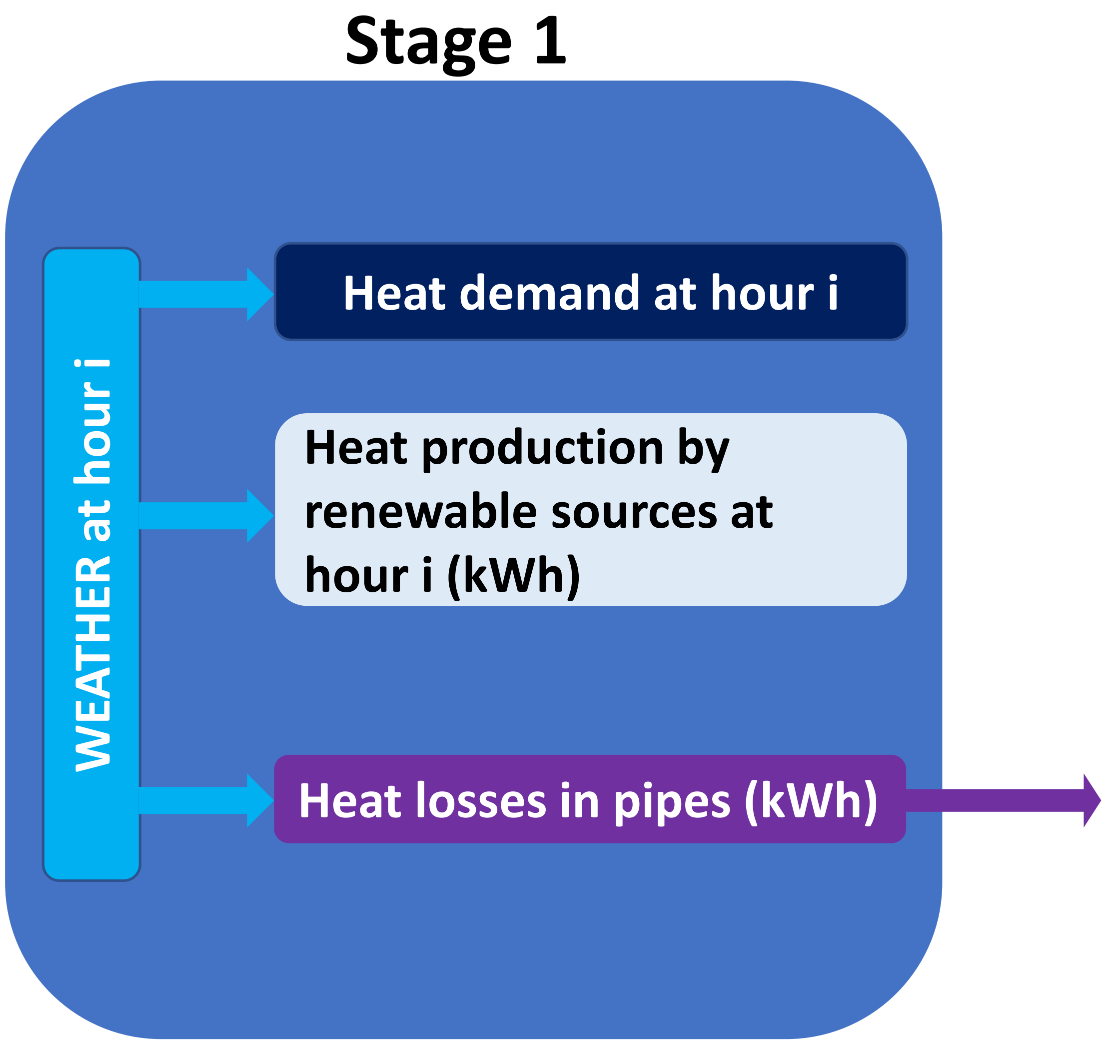
SOURCE: https://www.carbonbrief.org/mapped-how-the-uk-generates-its-electricity

Name	Technology	Capacity (MW)	Date operational	Totals (MW)
A C Shropshire (Farm AD)	Anaerobic Digestion	2	14/05/2013	
Colwick Industrial Estate (Farm and Food waste)	Anaerobic Digestion	2	30/09/2014	
Stoke Bardolph energy crop (Farm AD)	Anaerobic Digestion	2	10/07/2010	**6**
Green's Lodge Farm	Biomass (dedicated)	2	14/05/2013	**2**
Mountsorrel Landfill Site	Landfill gas	1.6	01/05/1996	
Enderby Warren Phase II	Landfill gas	4.9	01/06/1999	
Narborough Landfill	Landfill gas	2.7	11/03/2005	
Bradgate Quarry Landfill Gas Scheme	Landfill gas	2.5	01/08/1998	
Lount/Smoile	Landfill gas	1.1	21/07/2003	
Bretby Power	Landfill gas	1.6	01/09/2001	
Dorket Head	Landfill gas	2.8	01/02/2005	
Burntstump Landfill Scheme	Landfill gas	1.8	15/04/1999	**19**
Beeston Weir Hydro Scheme	Small hydro	1.7	01/02/2000	**1.7**
East Midlands Distribution Centre	Solar photovoltaics	6.1	02/03/2015	
Walnut Yard (Phase 1)	Solar photovoltaics	1.8	31/03/2015	
Radcliffe Solar Farm	Solar photovoltaics	4.2	13/06/2015	
Wymeswold Airfield	Solar photovoltaics	34	28/03/2013	
Six Hills Solar Farm	Solar photovoltaics	18.7	24/03/2015	
Prestop Park Farm	Solar photovoltaics	16	21/03/2015	
Packington Solar Farm	Solar photovoltaics	13.9	16/03/2015	
Toyota Solar Farm	Solar photovoltaics	4.6	25/07/2011	
Atherstone	Solar photovoltaics	14.7	31/03/2015	
The Stables	Solar photovoltaics	1.8	22/08/2014	
Gedling Solar Farm	Solar photovoltaics	5.6	15/03/2015	**121.4**
East Midlands Airport	Wind Onshore	1	10/05/2011	
Severn Trent STW	Wind Onshore	2.5	26/02/2014	
Newthorpe Wind Turbine	Wind Onshore	2.5	08/04/2014	
Low Spinney Wind Farm	Wind Onshore	8	29/09/2011	**14**
			TOTAL	**164.1**

NO RENEWABLES

Ratcliffe	Coal	2000	1968	
TOTAL	2000 **MW**			
			TOTAL (OVERALL)	**2164.1**

Simplified framework for the model

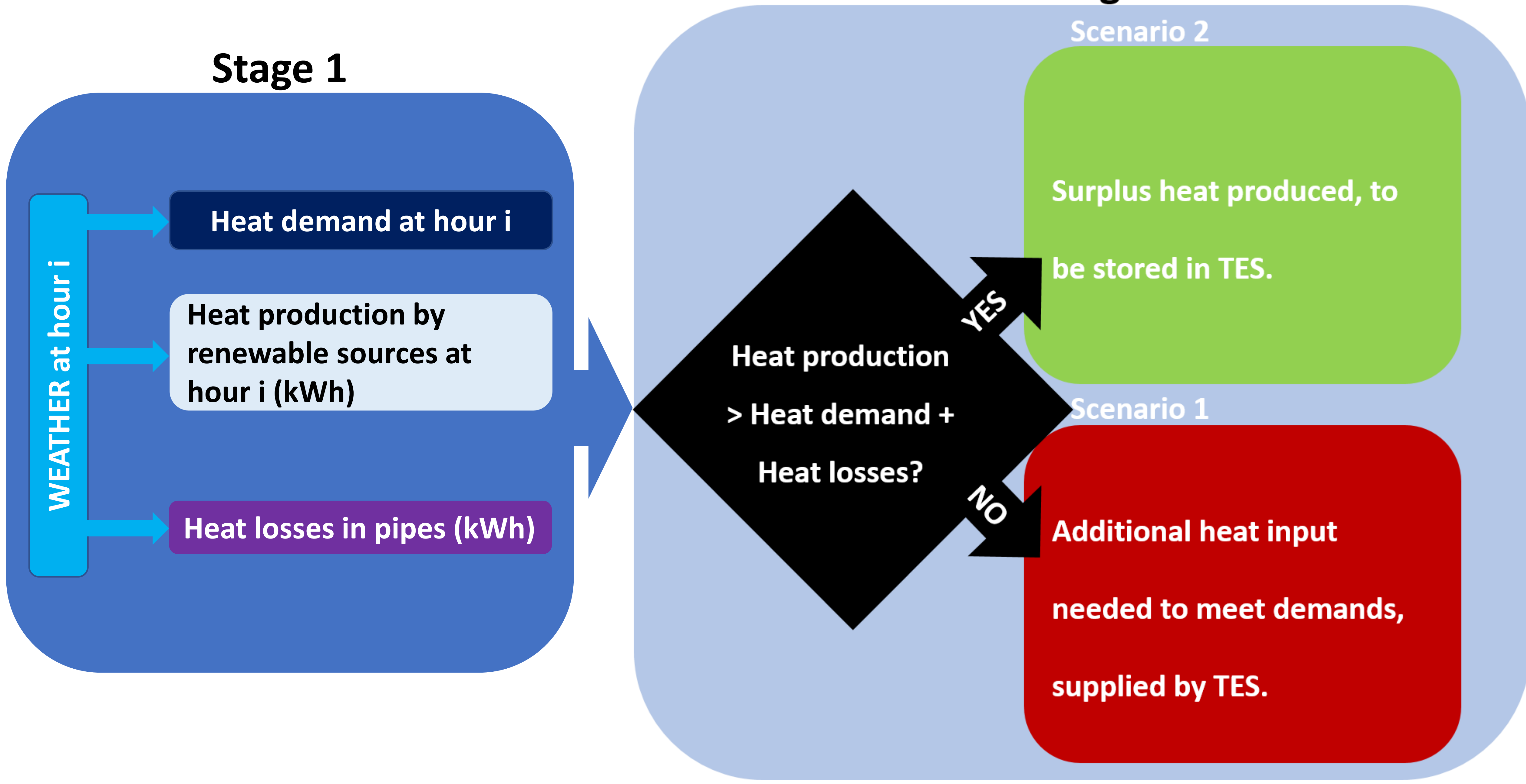


$$HL_{p,x\ to\ y,i} = 2 \cdot \pi \cdot \lambda \cdot L_{x\ to\ y} \cdot \frac{(T_{in} - T_{out,i})}{ln\left(\frac{r_{out}}{r_{in}}\right)}$$

Pipes characteristics	
D_{in} (m)	0.009[1]
D_{out} (m)	0.01[1]
Insulation material	AluFlex[2]
λ (W/m K)	0.023[2]
T_{supply} (°C)	50
T_{return} (°C)	35
Length (m)	To be decided

[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). doi:10.1016/j.energy.2012.02.061.

Simplified framework for the model



THERMAL ENERGY STORAGE

Main properties of TES materials.

PCM: Sodium acetate trihydrate[1]		TCS: $MgSO_4$ + zeolite[2]		Sensible: Water	
Density (kg/m^3)	1450	Density (kg/m^3)	1453	Density (kg/m^3)	1000
Latent heat (h, kJ/kg)	180	Reaction enthalpy (ΔH_r, KJ/Kg)	708	Specific heat (kJ/kg K)	4.18
Specific heat of liquid (kJ/kg K)	3.35	Conversion achieved (x_r %)	1[3]	Cost (£/kg)	
Specific heat of solid (kJ/kg K)	1.97	Cost (£/kg)			
Temperature of solid (cold) (°C)	30[3]				
Temperature of liquid (hot) (°C)	70[3]				
Melting/freezing point (°C)	58				
Cost (£/kg)	0.081				

[1] M. Kenisarin, K. Mahkamov, Salt hydrates as latent heat storage materials: Thermophysical properties and costs, Sol. Energy Mater. Sol. Cells. 145 (2016) 255–286. doi:10.1016/J.SOLMAT.2015.10.029.

[2] D. Mahon, P. Henshall, G. Claudio, P.C. Eames, Feasibility study of $MgSO_4$ + zeolite based composite thermochemical energy stores charged by vacuum flat plate solar thermal collectors for seasonal thermal energy storage, Renew. Energy. 145 (2020) 1799–1807. doi:10.1016/J.RENENE.2019.05.135.

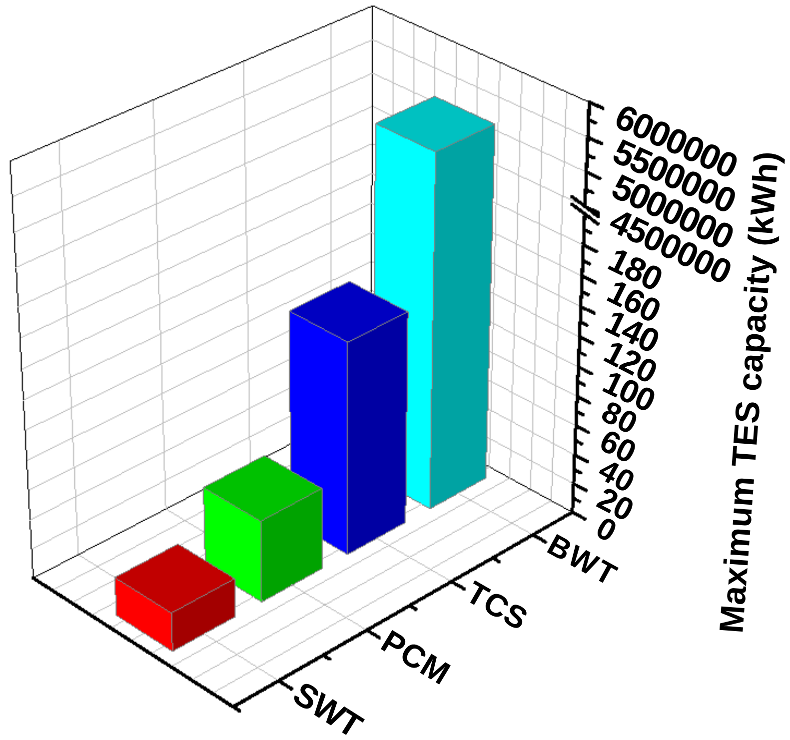
[3] Assumed values.

THERMAL ENERGY STORAGE

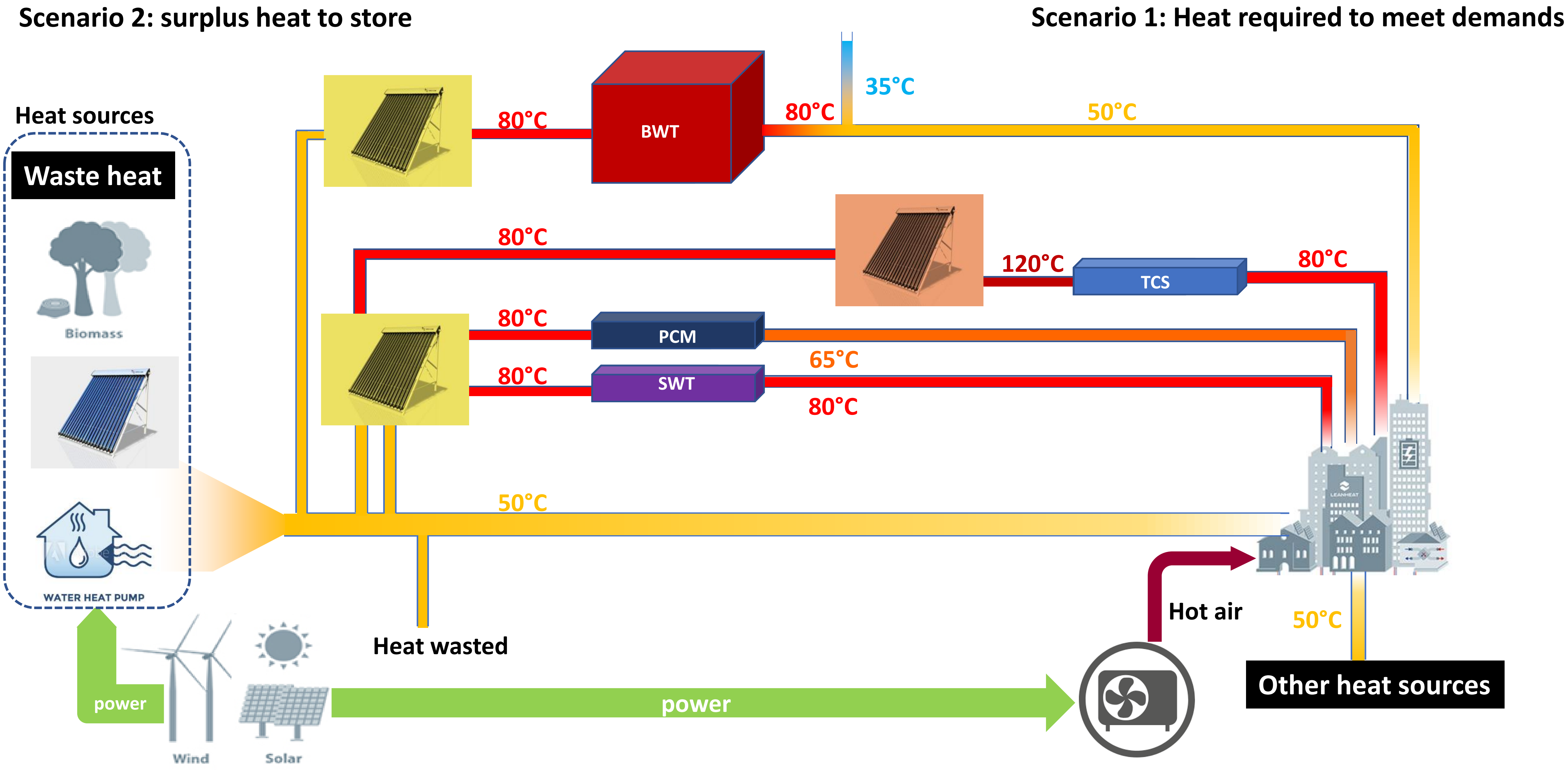
Main assumptions referred to TES devices.

	Sensible	**Latent**	**Sensible**	**Thermochemical storage**
	Small Water Tanks (SWT)	Phase Change Materials (PCM)	Big Water Tank (BWT)	Thermochemical Storage (TCS)
Maximum volume allowed (m^3)[1]	1	1	500000	1
Temperature charging (°C)	80	80	80	120
Temperature discharging (°C)	80	T range available	80	T range available
Storage capacity (kWh)[1]	26	55	52250000	143
Initial energy stored (kWh)	0	0	[illegible]	[illegible]

[1] The maximum volume allowed when referring to SWT, PCM and TCS is the <u>volume per every 2 dwellings</u>, whereas when referring to BWT the maximum volume is the volume of the whole single unit.

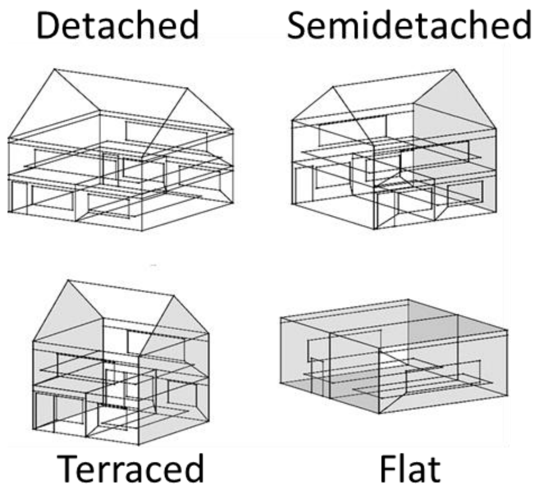


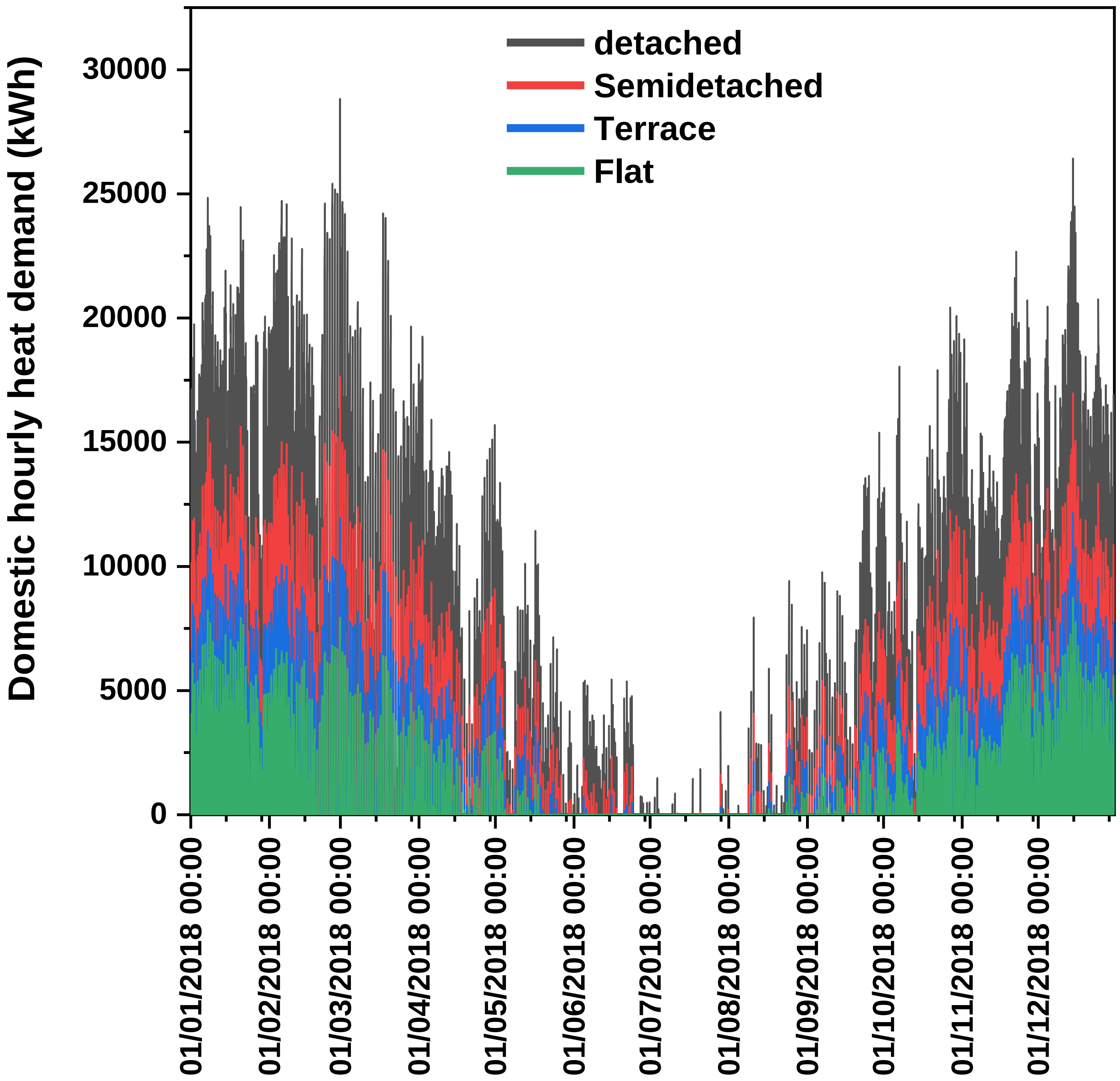
Proposed operating mode for the heating district



RESULTS

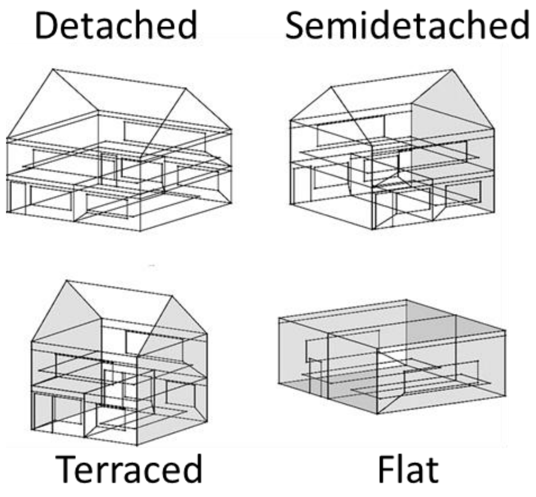
- ✓ Number of dwellings of each type with similar characteristics: 10000;
- ✓ Number of person living in the dwelling: 4;
- ✓ Heating hours: 7 am - 9 am, 5 pm - 9 pm;
- ✓ Working hours: 8 am to 5 pm;
- ✓ No heat demand originated from tap water heating considered here.
- ✓ Temperature inside dwelling = 21°C
- ✓ Assuming improved U-vales for the fabric.

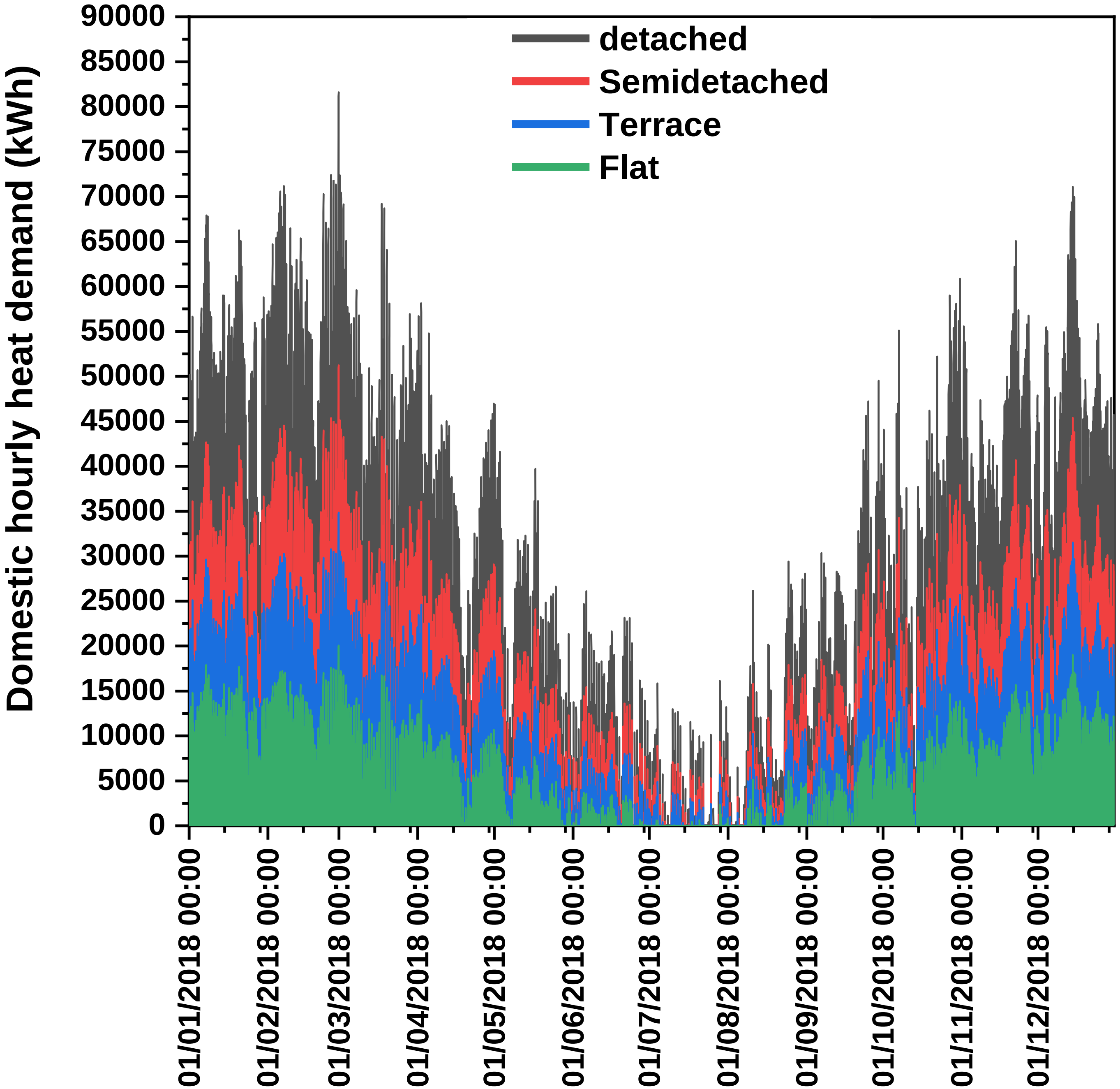




RESULTS

- **Number of dwellings of each type with similar characteristics:** 10000;
- **Number of person living in the dwelling:** 4;
- **Heating hours:** 7 am - 9 am, 5 pm - 9 pm;
- **Working hours:** 8 am to 5 pm;
- **No heat demand originated from tap water heating considered here.**
- **Temperature inside dwelling = 21°C**
- **Assuming basic U-vales for the fabric.**





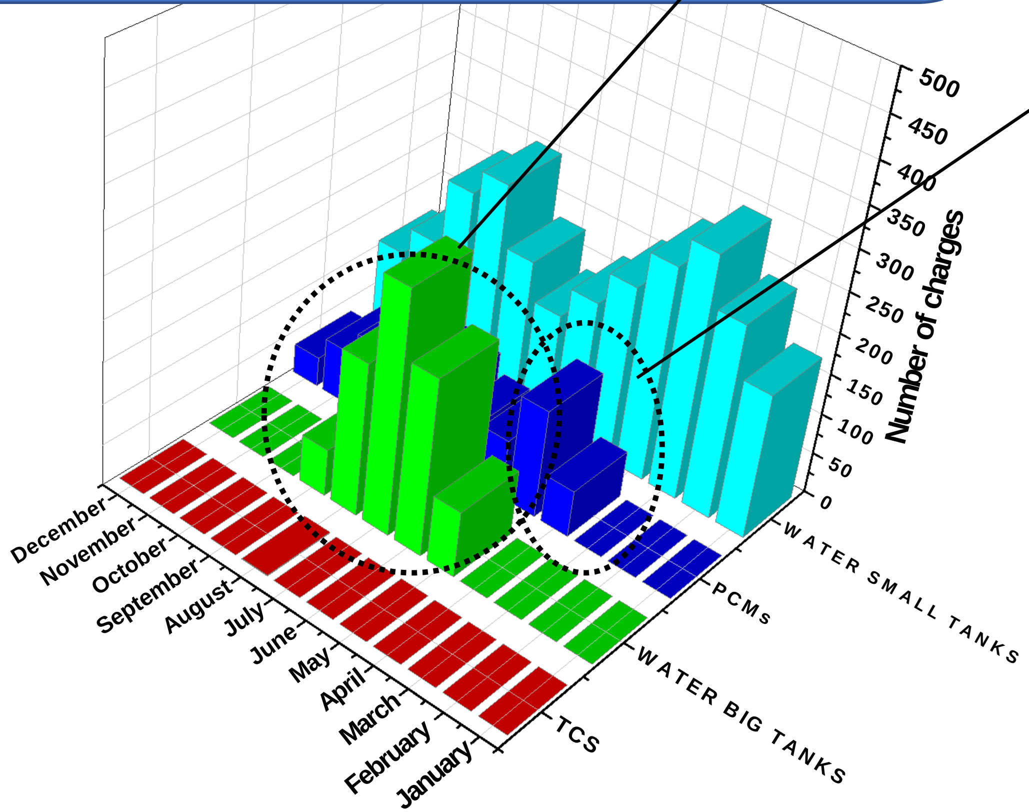
RESULTS

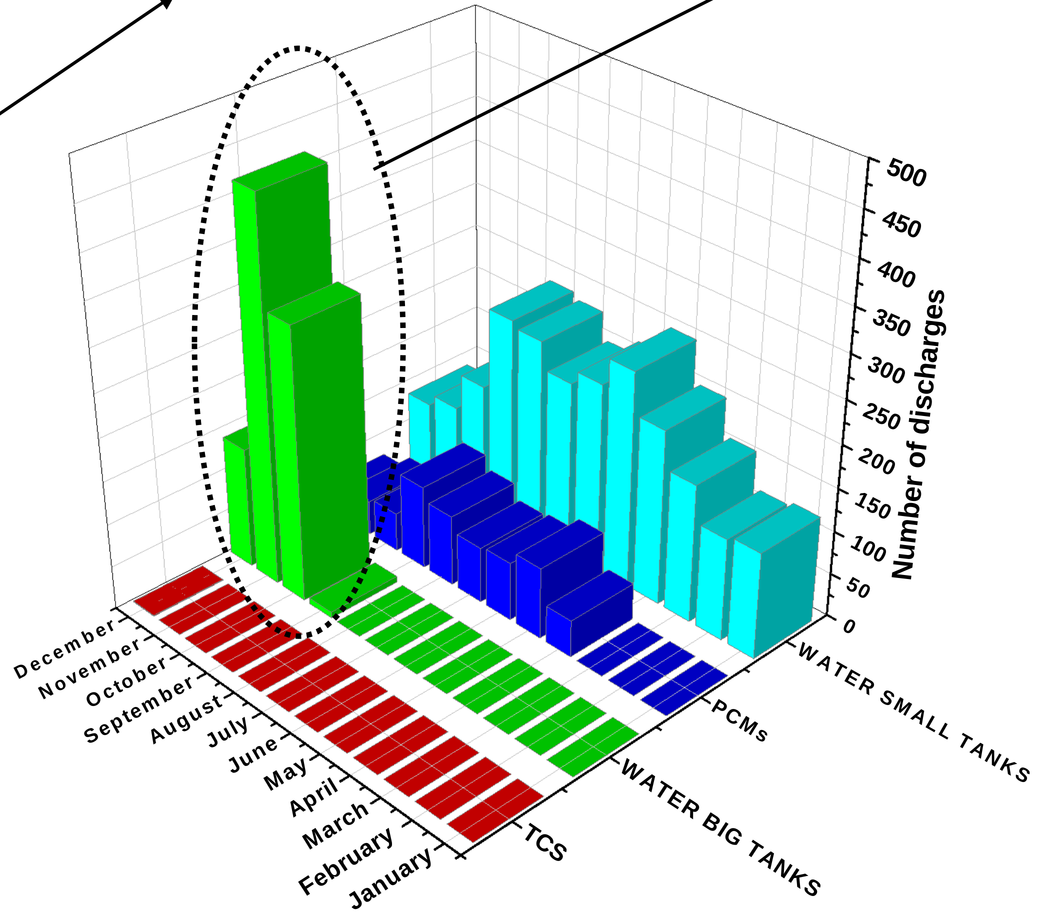
Type of dwelling: detached
Number of dwelling with same characteristics: 10000
Number of person living in the dwelling: 4
Heating hours: 7 am - 9 am, 5 pm - 9 pm
Working hours: 8 am to 5 pm
No heat losses in pipes considered for SWT, PCM and TCS
Distance from BWT to dwellings (pipes above the ground): 1000 m
No heat losses in stores considered yet
Temperature inside dwelling = 21°C.
Just ETSTC considered.

High number of heat charges to Big Water Tanks in summer months, due to both lower demand and higher heat production in these months

PCMs start being charged in the spring months, due to SWT reaching maximum capacity

The Big Water Tank help to meet heat demands in winter and autumn months.



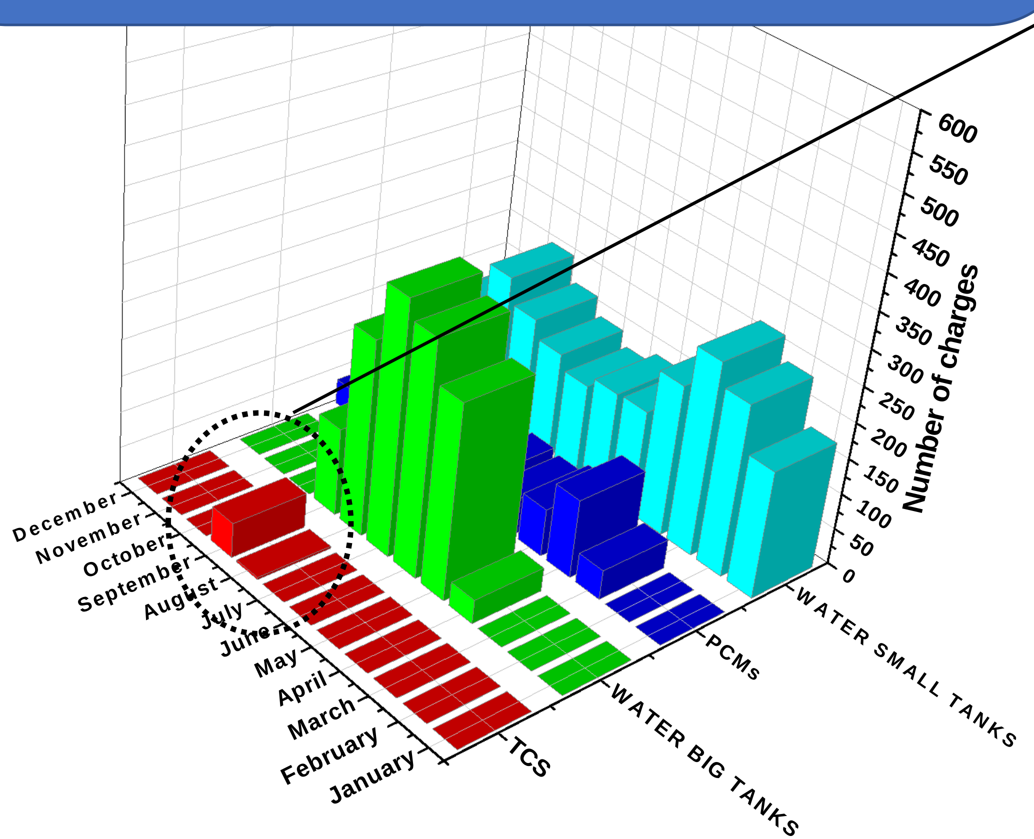


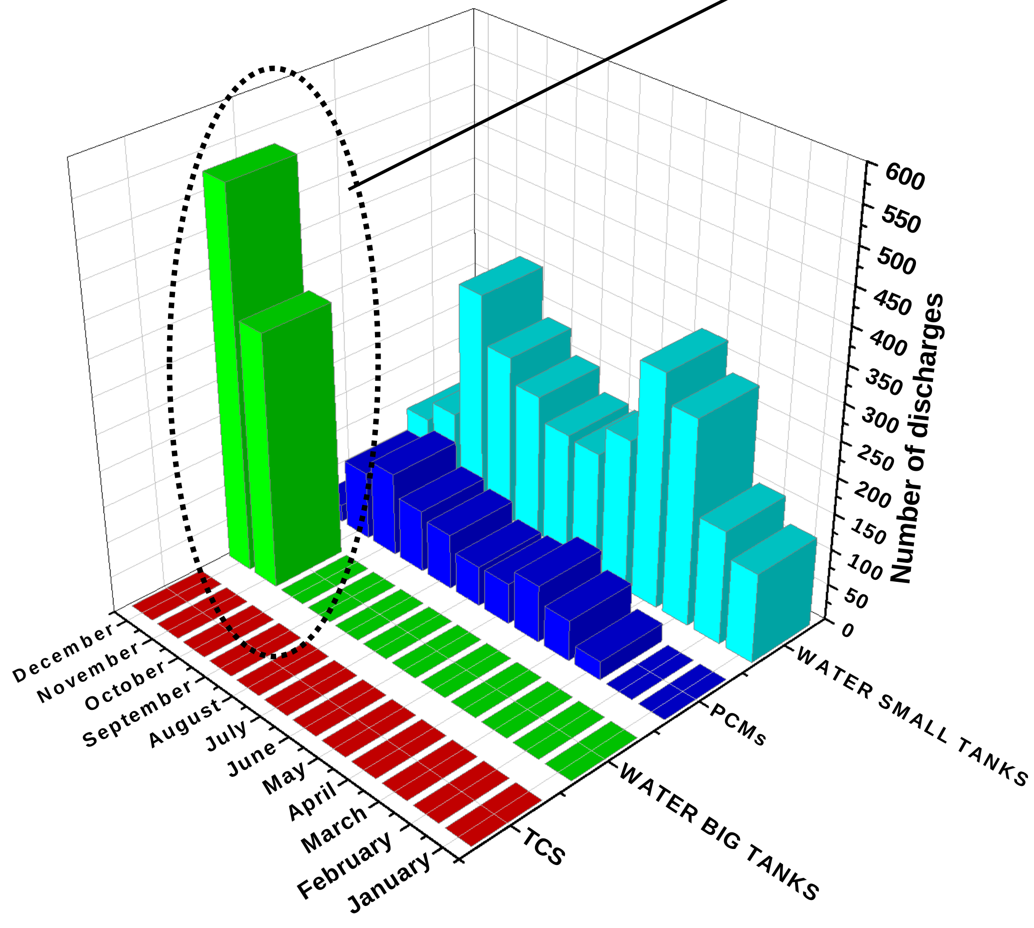
RESULTS

Type of dwelling: flat
Number of dwelling with same characteristics: 10000
Number of person living in the dwelling: 4
Heating hours: 7 am - 9 am, 5 pm - 9 pm
Working hours: 8 am to 5 pm
No heat losses in pipes considered for SWT, PCM and TCS
Distance from BWT to dwellings (pipes above the ground): 1000 m
No heat losses in stores considered yet
Temperature inside dwelling = 21°C.
Just ETSTC considered.

The low heat demand in flats leads to maximum capacity reached in SWT, PCM and BWT in summer months and therefore TCS are started to being charged.

The Big Water Tank help to meet heat demands in winter and autumn months.





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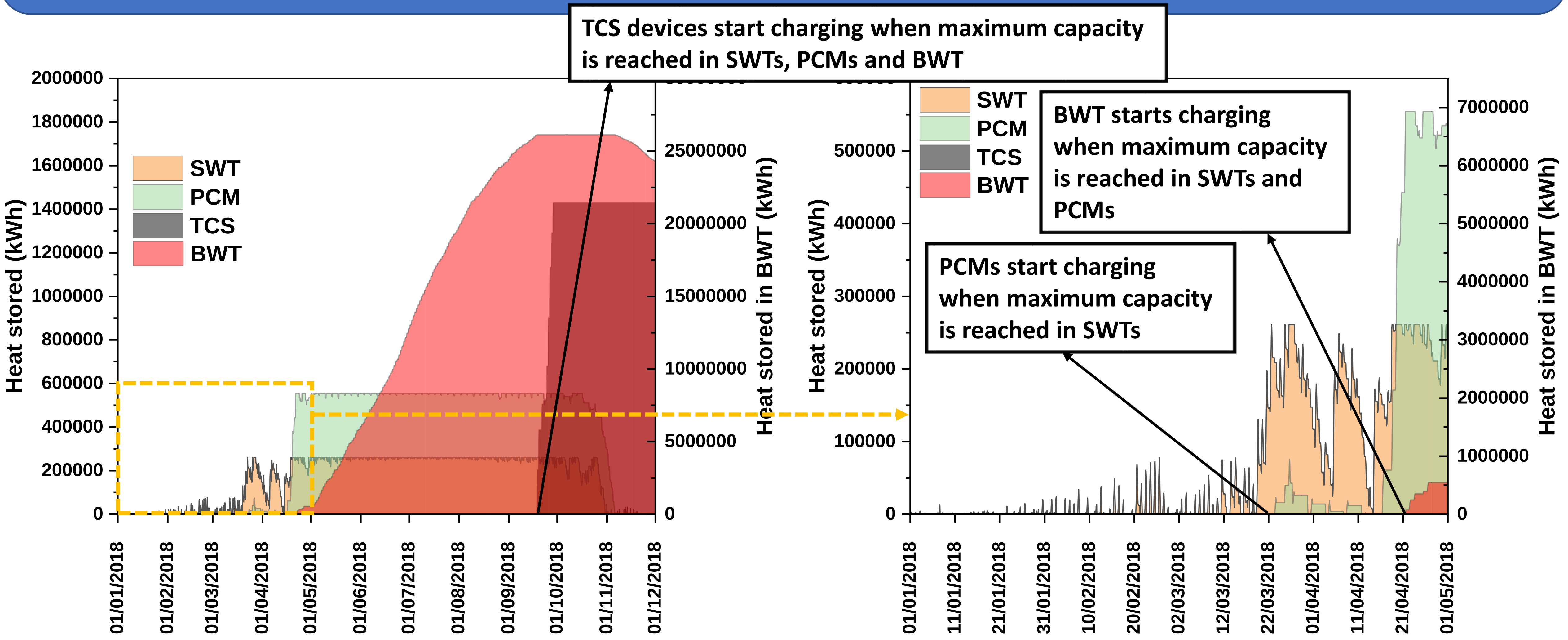


FUTURE WORK

i. Identify possible sources of waste heat near Loughborough.

ii. Assume biomass-source heat production capacity (MW).

iii. Introduce heat losses in stores (kWh).

iv. Find a detailed profile for domestic hot water consumption.

v. Calculate friction losses in pipes.

vi. Consider profiles when discharging some TES materials (PCMs).

vii. Find cost of the different materials and technologies in order to carry out a proper study.

viii. Decide lengths of pipes for the different sections of the District Heating. Decide if pipes will be underground or above the ground.

ix. Include different profiles for dwellings.

House type	Occupancy level	Number of occupants	Occupant characteristics	Mean appliance gains (W)	Mean active occupancy as % of day	Mean hot water use (litres/day)
Terrace	Low	1 adult	Part-time employment	160.4	35.8%	51.4
Terrace	High	3 adults	2 x full-time employment + 1 x non-working	503.8	54.0%	125.7
Detached	Low	2 adults/2 children	1 x full-time employment + 1 x non-working	272.0	48.2%	50.0
Detached	High	2 adults/3 children	1 x full-time + 1 x part-time employment	456.0	55.8%	251.6
Semidetached	Low	1 adult/1 child	Non-working	199.1	45.0%	85.5
Semidetached	High	2 adults	Both retired	582.2	54.8%	146.9
Flat	Low	1 adult	Non-working	115.4	41.2%	42.3
Flat	High	2 adults/1 child	1 x full-time employment + 1 x non-working	228.2	46.2%	82.7

[1] J. Allison, K. Bell, J. Clarke, A. Cowie, A. Elsayed, G. Flett, G. Oluleye, A. Hawkes, G. Hawker, N. Kelly, M.M.M. de Castro, T. Sharpe, A. Shea, P. Strachan, P. Tuohy, Assessing domestic heat storage requirements for energy flexibility over varying timescales, Appl. Therm. Eng. 136 (2018) 602–616. doi:10.1016/J.APPLTHERMALENG.2018.02.104.

FUTURE WORK

x. Detailed spatial/temporal model for district heating networks including thermal storage.

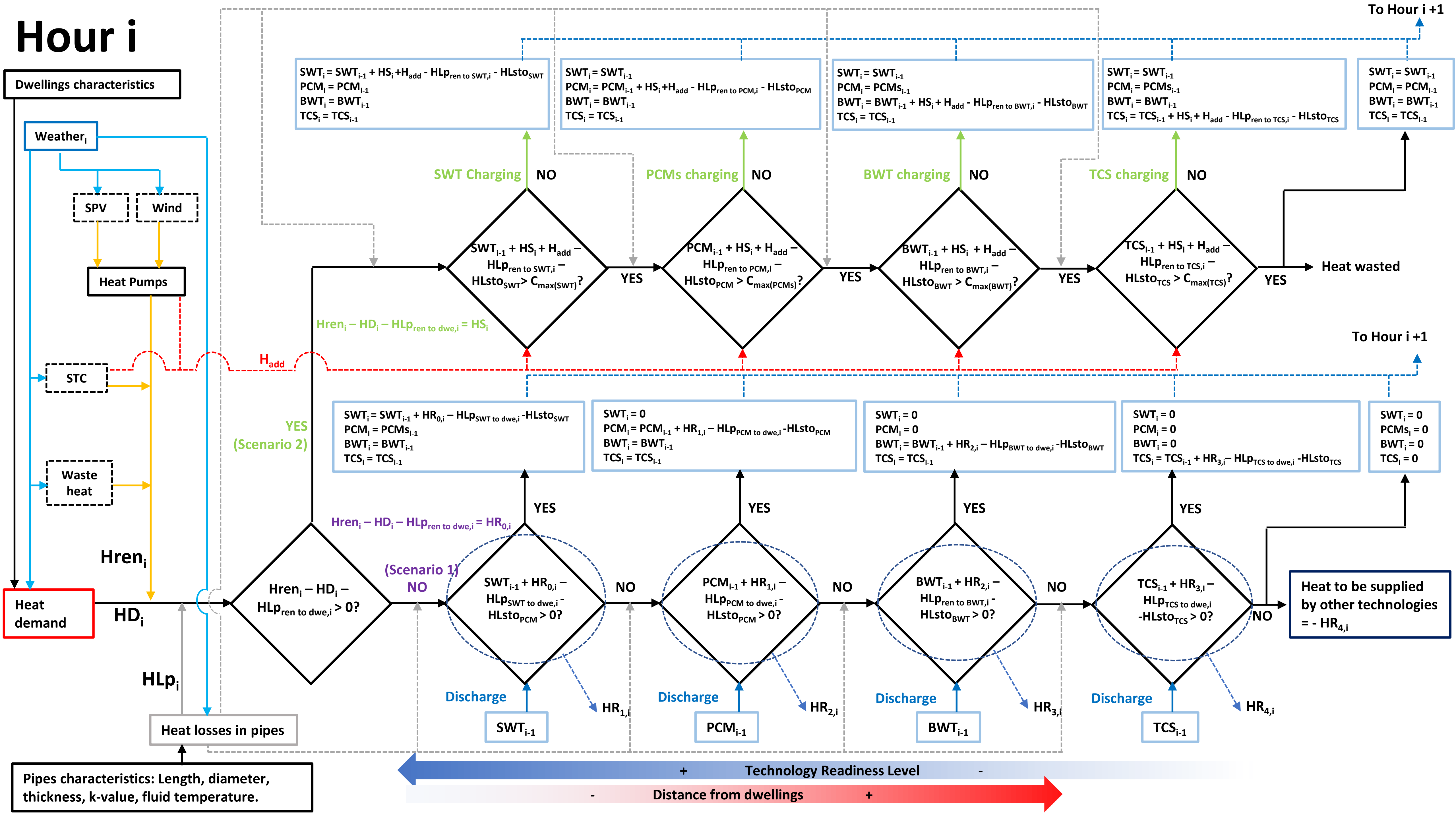
xi. Produce results and validate the model.

Simulation of a 4th generation district heating network operating with renewable heat sources and TES technologies

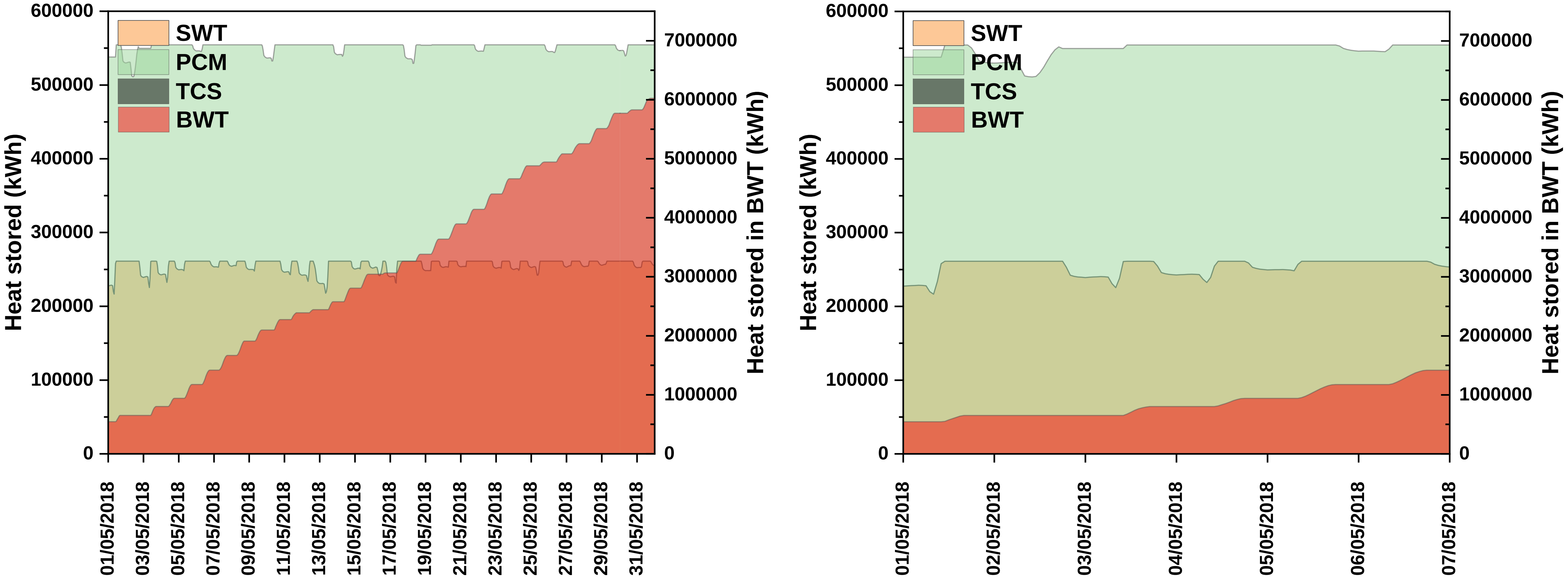
LoT-NET project

Miguel Angel Pans Castillo
Philip Eames

13-12-2019



Hour i
Dwellings characteristics
$Weather_i$
SPV
Wind
Heat Pumps
STC
Waste heat
$Hren_i$
Heat demand
HD_i
HLp_i
Heat losses in pipes
Pipes characteristics: Length, diameter, thickness, k-value, fluid temperature.
H_{add}
$Hren_i - HD_i - HLp_{ren\ to\ dwe,i} > 0?$
YES (Scenario 2)
$Hren_i - HD_i - HLp_{ren\ to\ dwe,i} = HS_i$
(Scenario 1) NO
$Hren_i - HD_i - HLp_{ren\ to\ dwe,i} = HR_{0,i}$
$SWT_{i-1} + HS_i + H_{add} - HLp_{ren\ to\ SWT,i} - HLsto_{SWT} > C_{max(SWT)}?$
SWT Charging
NO
YES
$PCM_{i-1} + HS_i + H_{add} - HLp_{ren\ to\ PCM,i} - HLsto_{PCM} > C_{max(PCMs)}?$
PCMs charging
NO
YES
$BWT_{i-1} + HS_i + H_{add} - HLp_{ren\ to\ BWT,i} - HLsto_{BWT} > C_{max(BWT)}?$
BWT charging
NO
YES
$TCS_{i-1} + HS_i + H_{add} - HLp_{ren\ to\ TCS,i} - HLsto_{TCS} > C_{max(TCS)}?$
TCS charging
NO
YES
Heat wasted
To Hour i +1
$SWT_i = SWT_{i-1} + HS_i + H_{add} - HLp_{ren\ to\ SWT,i} - HLsto_{SWT}$
$PCM_i = PCM_{i-1}$
$BWT_i = BWT_{i-1}$
$TCS_i = TCS_{i-1}$
$SWT_i = SWT_{i-1}$
$PCM_i = PCM_{i-1} + HS_i + H_{add} - HLp_{ren\ to\ PCM,i} - HLsto_{PCM}$
$BWT_i = BWT_{i-1}$
$TCS_i = TCS_{i-1}$
$SWT_i = SWT_{i-1}$
$PCM_i = PCMs_{i-1}$
$BWT_i = BWT_{i-1} + HS_i + H_{add} - HLp_{ren\ to\ BWT,i} - HLsto_{BWT}$
$TCS_i = TCS_{i-1}$
$SWT_i = SWT_{i-1}$
$PCM_i = PCMs_{i-1}$
$BWT_i = BWT_{i-1}$
$TCS_i = TCS_{i-1} + HS_i + H_{add} - HLp_{ren\ to\ TCS,i} - HLsto_{TCS}$
$SWT_i = SWT_{i-1}$
$PCM_i = PCM_{i-1}$
$BWT_i = BWT_{i-1}$
$TCS_i = TCS_{i-1}$
To Hour i +1
$SWT_{i-1} + HR_{0,i} - HLp_{SWT\ to\ dwe,i} - HLsto_{PCM} > 0?$
YES
NO
Discharge
SWT_{i-1}
$HR_{1,i}$
$PCM_{i-1} + HR_{1,i} - HLp_{PCM\ to\ dwe,i} - HLsto_{PCM} > 0?$
YES
NO
Discharge
PCM_{i-1}
$HR_{2,i}$
$BWT_{i-1} + HR_{2,i} - HLp_{ren\ to\ BWT,i} - HLsto_{BWT} > 0?$
YES
NO
Discharge
BWT_{i-1}
$HR_{3,i}$
$TCS_{i-1} + HR_{3,i} - HLp_{TCS\ to\ dwe,i} - HLsto_{TCS} > 0?$
YES
NO
Discharge
TCS_{i-1}
$HR_{4,i}$
$SWT_i = SWT_{i-1} + HR_{0,i} - HLp_{SWT\ to\ dwe,i} - HLsto_{SWT}$
$PCM_i = PCMs_{i-1}$
$BWT_i = BWT_{i-1}$
$TCS_i = TCS_{i-1}$
$SWT_i = 0$
$PCM_i = PCM_{i-1} + HR_{1,i} - HLp_{PCM\ to\ dwe,i} - HLsto_{PCM}$
$BWT_i = BWT_{i-1}$
$TCS_i = TCS_{i-1}$
$SWT_i = 0$
$PCM_i = 0$
$BWT_i = BWT_{i-1} + HR_{2,i} - HLp_{BWT\ to\ dwe,i} - HLsto_{BWT}$
$TCS_i = TCS_{i-1}$
$SWT_i = 0$
$PCM_i = 0$
$BWT_i = 0$
$TCS_i = TCS_{i-1} + HR_{3,i} - HLp_{TCS\ to\ dwe,i} - HLsto_{TCS}$
$SWT_i = 0$
$PCMs_i = 0$
$BWT_i = 0$
$TCS_i = 0$
Heat to be supplied by other technologies $= - HR_{4,i}$
+ Technology Readiness Level -
- Distance from dwellings +


Heat stored (kWh)
Heat stored in BWT (kWh)
SWT
PCM
TCS
BWT
0
100000
200000
300000
400000
500000
600000
0
1000000
2000000
3000000
4000000
5000000
6000000
7000000
01/05/2018
03/05/2018
05/05/2018
07/05/2018
09/05/2018
11/05/2018
13/05/2018
15/05/2018
17/05/2018
19/05/2018
21/05/2018
23/05/2018
25/05/2018
27/05/2018
29/05/2018
31/05/2018
02/05/2018
03/05/2018
04/05/2018
05/05/2018
06/05/2018
07/05/2018