Twomes: Digital Twins for the Home Heating Transition

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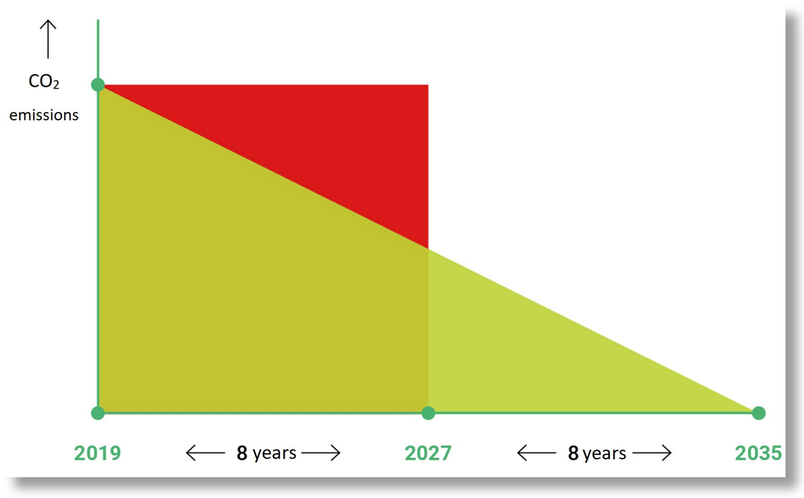
Which home heating model parameters of specific homes can we learn automatically from energy monitoring data in order to provide better advice to specific households about their home heating transition?

WHY?

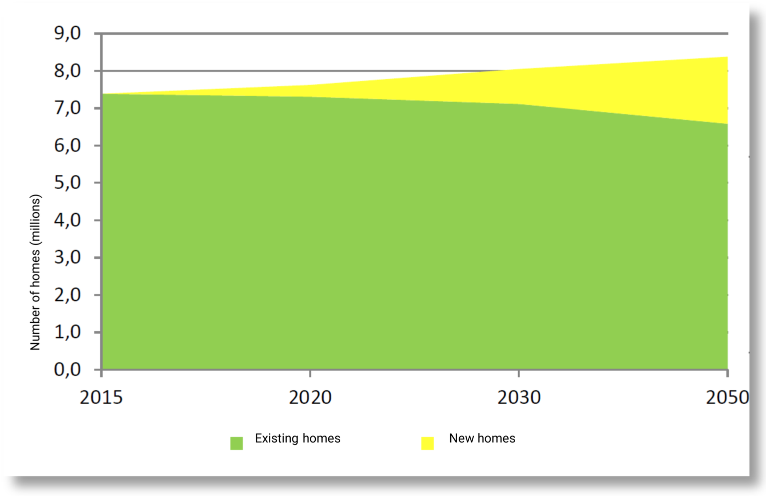
edu.nl/xghje

Scan for short Twomes movie

Paris agreement: limit temperature < 1.5 °C above pre-industrial levels.



Implies CO_2-emission budget; start reducing soon helps avoid cliff.



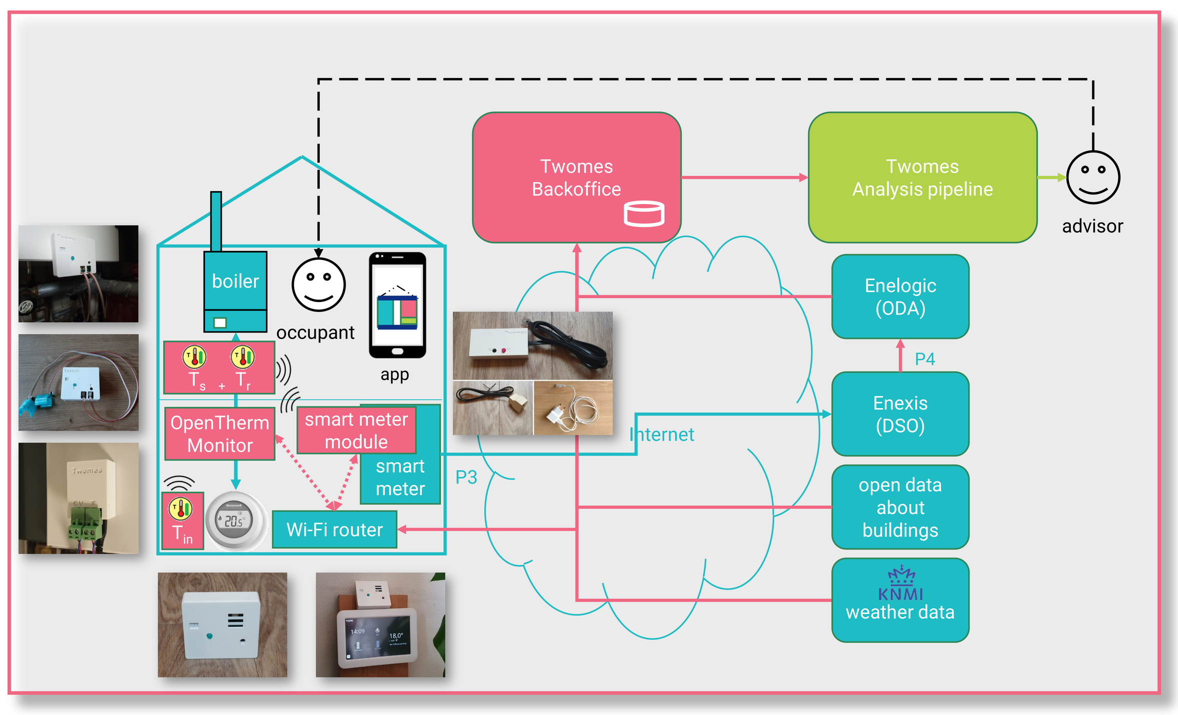
In NL, most homes in 2030 & 2050 were built before 2015.

Homes and heating transition may vary.

DATA COLLECTION

edu.nl/demr9

Scan for open source software and hardware on GitHub



Measurement devices (cost including PCB, enclosure, power supply, cabling)

Device	Module	Cost	QR	Set A	Set B	Set C	Set D
OpenTherm monitor	OpenTherm monitor	€ 25	✓	✓		✓	✓
smart meter module	smart meter module	€ 15	✓	✓			
smart meter module + boiler module + room monitor	smart meter module	€ 15	✓		✓	✓	✓
	boiler module	€ 25			✓	✓	✓
	room monitor	€ 20			✓		✓
	room monitor incl. CO_2-sensor	€ 50				✓	
Total per home				**€ 40**	**€ 60**	**€ 115**	**€ 85**

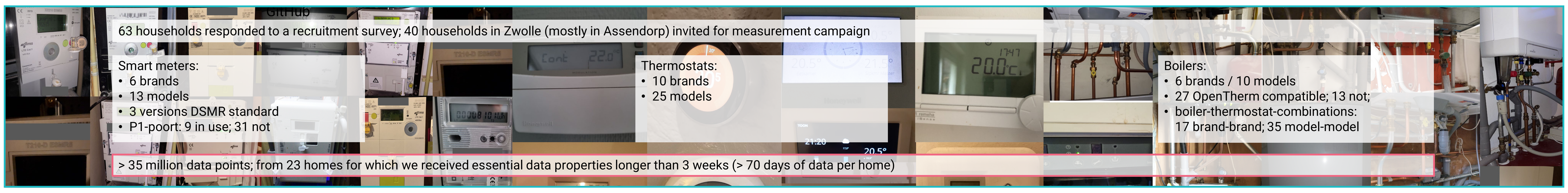
Data collected

Category	Measured data	Symbol	Unit	API	Sensor
comfort	setpoint	T_{set}	°C		✓
weather	outdoor temperature	T_{out}	°C	KNMI	
	wind	U	m/s		
	global horizontal irradiation	I	W/m^2		
indoor	indoor temperature	T_{in}	°C		✓
installation	supply temperature	T_s	°C		✓
	return temperature	T_r	°C		✓
heating energy	electricity	E	kWh	Enelogic	✓
	gas	G	m^3		
occupancy/ ventilation	CO_2 concentration	CO_2	ppm		✓
	Bluetooth presence	BT_{pres}	#pp		✓

SUBJECTS & DATA

edu.nl/aqnhv

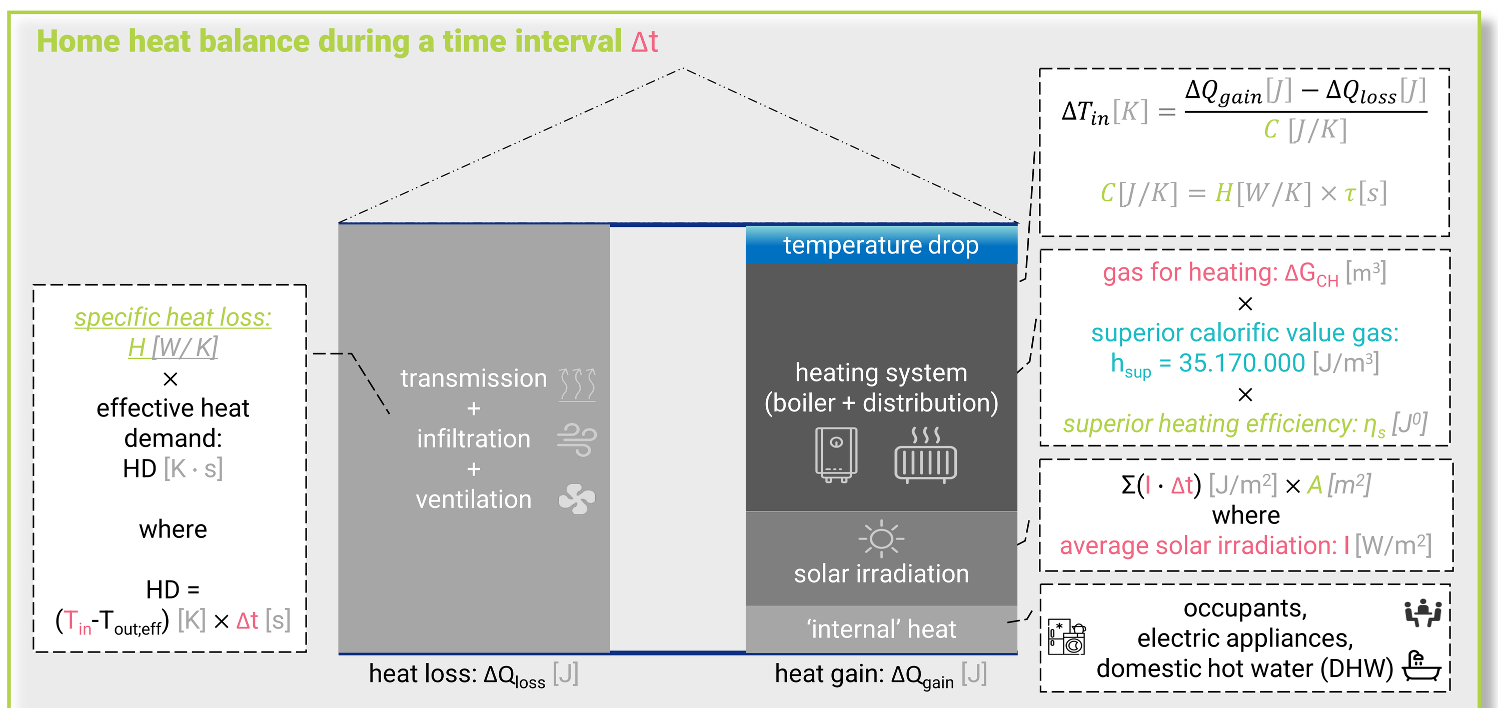
Scan for dataset

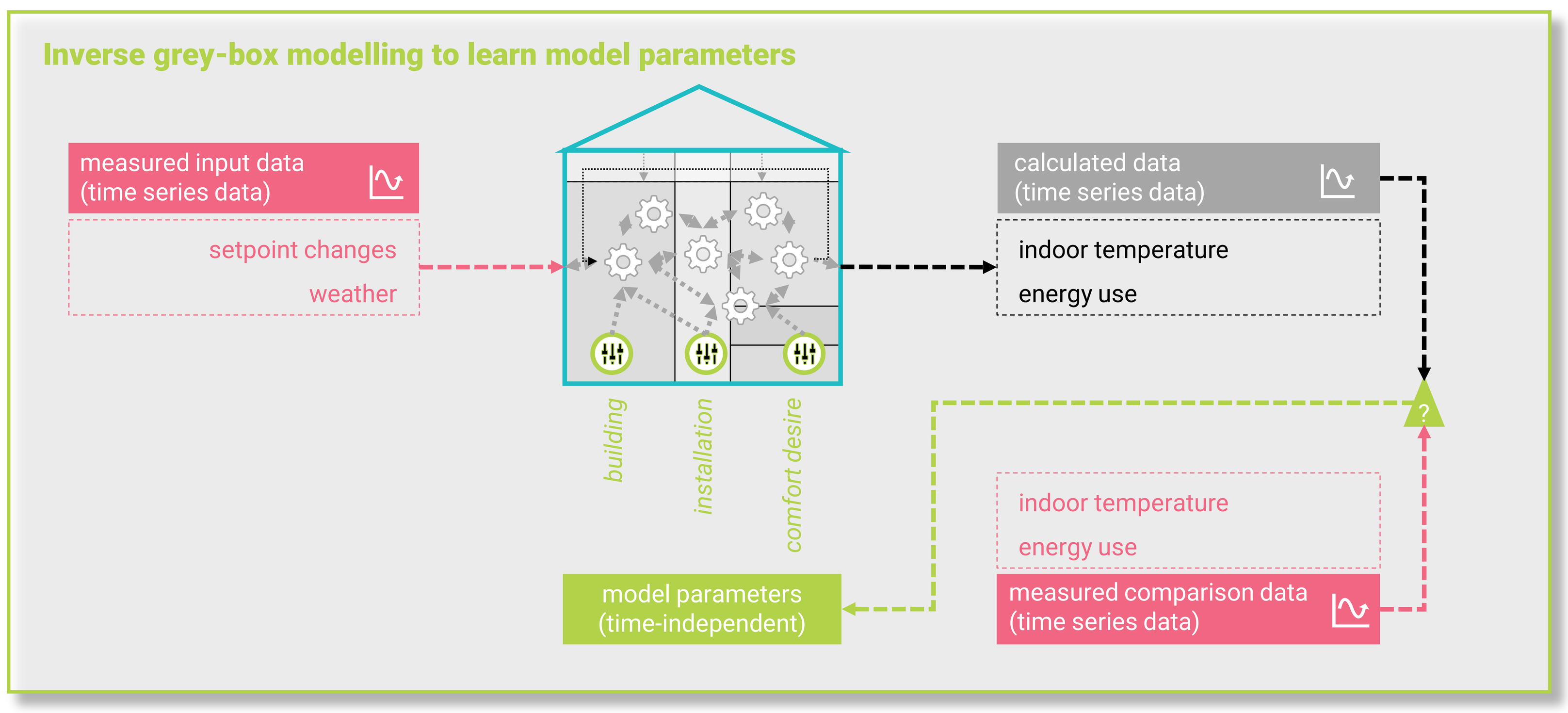


DATA ANALYSIS

edu.nl/kttbe

Scan for GEKKO Python heat balance model






```
##########################################
# Gekko Model - Initialize
##########################################

# initialize gekko
m = GEKKO(remote=False)
m.time = np.arange(0, duration_s, step_s)
```

```
##########################################################
# Gekko Model - Model Parameters
##########################################################

# Model parameter: H [W/K]: specific heat loss
H_W_p_K = m.FV(value=300.0, lb=0, ub=1000)
H_W_p_K.STATUS = 1; H_W_p_K.FSTATUS = 0

# Model parameter: tau [s]: effective thermal inertia
tau_s = m.FV(value=(100 * s_p_h), lb=(10 * s_p_h), ub=(1000 * s_p_h))
tau_s.STATUS = 1; tau_s.FSTATUS = 0
```

```
##########################################################
# Equation - Q_gain_sol_avg_W: : heat gain from solar irradiation
##########################################################

# Model parameter/fixed value: A [m^2]: Effective area of the solar aperture
if np.isnan(iterator_A_m2):
    A_m2 = m.FV(value=5, lb=1, ub=100); A_m2.STATUS = 1; A_m2.FSTATUS = 0
else:
    A_m2 = m.Param(value=iterator_A_m2)

irradiation_hor_avg_W_p_m2 = m.MV(value=irradiation_hor_avg_W_p_m2_array)
irradiation_hor_avg_W_p_m2.STATUS = 0; irradiation_hor_avg_W_p_m2.FSTATUS = 1

Q_gain_sol_avg_W = m.Intermediate(irradiation_hor_avg_W_p_m2 * A_m2)
```

```
##########################################################
# Main Equations & Solver
##########################################################
Q_gain_W = m.Intermediate(Q_gain_gas_CH_avg_W + Q_gain_sol_avg_W + Q_gain_int_avg_W)
Q_loss_W = m.Intermediate(H_W_p_K * (T_in_avg_C - T_out_e_avg_C))
C_J_p_K  = m.Intermediate(H_W_p_K * tau_s)
m.Equation(T_in_avg_C.dt() == ((Q_gain_W - Q_loss_W) / C_J_p_K))

m.options.IMODE = 5
m.options.EV_TYPE = ev_type # specific objective function (L1-norm vs L2-norm)
m.solve(False)
```

RESULTS & CONCLUSIONS

edu.nl/jw9j3

Scan for more results

Model parameters to learn

symbol	scope	parameter	unit
H	building	specific heat loss	W/K
τ	building	thermal inertia	s (h)
C	building	thermal mass (C = H × τ)	J/K (Wh/K)
A	building	apparent horizontal window area	m^2
P	installation	maximum heating system power	W
η_s	installation	superior heating system efficiency	J^0
CD	behaviour	comfort desire (thermostat setpoints)	K·s

Initial results

Building parameters can be learned:

- specific heat loss: **H** [W/K],
- thermal mass: **C** [W/K] (or [Wh/K])
- thermal inertia: **τ** [s] (or [h])

What was challenging

- outlier removal (in particular for smart meter data)
- interpolation (in particular for smart meter timestamps)
- GEKKO Python model (validated with virtual home data)
- 10 to 50-fold increased analysis speed after switch to RMSE (i.e., using EV_TYPE=2, instead of EV_TYPE=1)

What's next

- assess increased precision over calculating parameters based on public building data
- learn installation parameters
- learn infiltration and ventilation parameters
- assess utility for occupant and advisor
- use to assess real effect of interventions

SBE22
DELFT