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Developing simplified thermal model of buildings by means of thermal networks

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RESIZED
Research Excellence for Solution and Implementation of net Zero Energy city Districts

Outline

- Introduction and Objectives

- Steps to develop thermal networks
  - From 3R1C to 4R3C

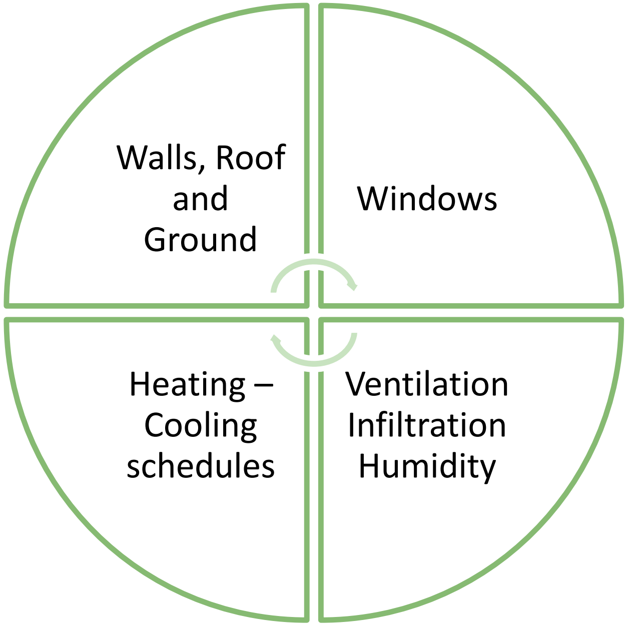
- System identification
  - System identification toolbox – MATLAB

- Results and discussion
  - Thermal networks
  - The accuracy of parameters
  - Radiation effects
  - Internal mass capacity

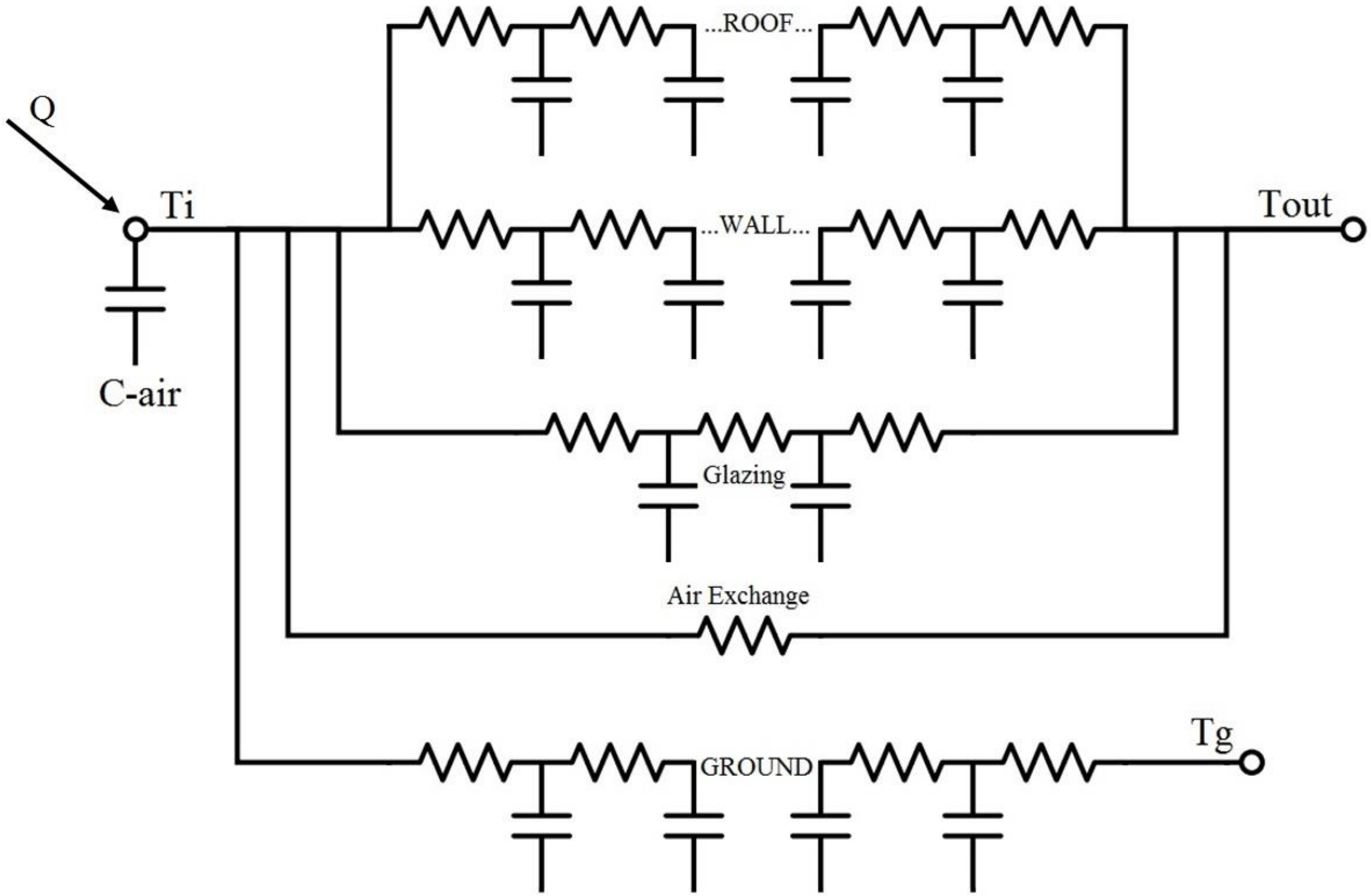
- Conclusion and future works

Introduction – Literature review

- Simplified models
- Early works 1990 – 2000
- Commercial software
- System identification
- Thermal networks structure
- Load calculation



Introduction – Simplified thermal network Scheme

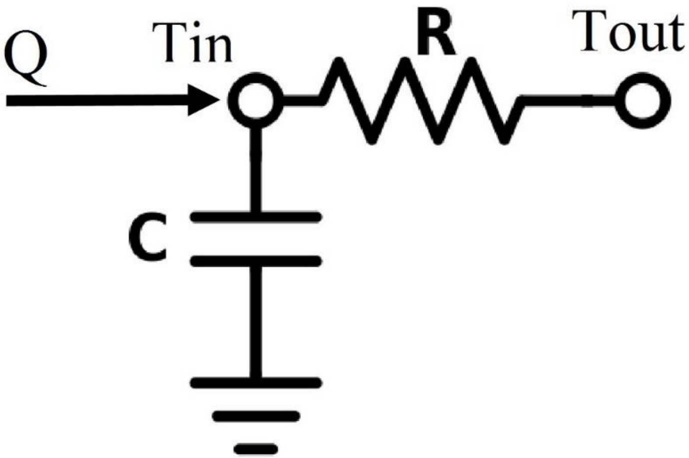


Introduction – Simplified thermal network Scheme

$$C\dot{T}_{in} = \frac{T_{out} - T_{in}}{R} + Q$$

$$\frac{dT}{dt} = \frac{T(t + \Delta t) - T(t)}{\Delta t}$$

$$\begin{cases} \dot{\boldsymbol{X}} = A \times \boldsymbol{X} + B \times \boldsymbol{u} \\ \boldsymbol{y} = C \times \boldsymbol{X} + D \times \boldsymbol{u} \end{cases}$$

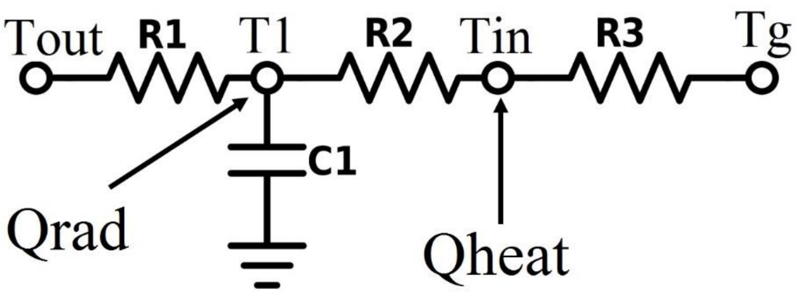


Aims of the research

- To develop a simple RC model (as simple as possible)
- R and C are deducted from limited knowledge of the building
- Studying the smallest amount of thermal information which can confirm the accuracy of parameters in the thermal network
- RE-SIZED Project: developing a simplified model of district by means of thermal network

3R1C model – A building without windows, ventilation and infiltration

- $$\begin{cases} C_1 \frac{dT_1}{dt} = \frac{T_{out} - T_1}{R1} - \frac{T_1 - T_{in}}{R2} + Q_{rad} \\ Q_{heat} + \frac{T_1 - T_{in}}{R2} - \frac{T_{in} - T_g}{R3} = 0 \end{cases}$$



- $$\begin{cases} T_1(k+1) = \left[1 - \frac{\Delta t}{R1C1} - \frac{\Delta t}{R2C1}\right] \times T_1(k) + \left[\frac{\Delta t}{R1C1} \quad 0 \quad \frac{\Delta t}{C1} \quad \frac{\Delta t}{R2C1}\right] \times \begin{bmatrix} T_{out}(k) \\ T_g(k) \\ Q_{rad}(k) \\ T_{in}(k) \end{bmatrix} \\ Q_{heat}(k) = \left[-\frac{1}{R2}\right] \times T_1(k) + \left[0 \quad -\frac{1}{R3} \quad 0 \quad \frac{1}{R2} + \frac{1}{R3}\right] \times \begin{bmatrix} T_{out}(k) \\ T_g(k) \\ Q_{rad}(k) \\ T_{in}(k) \end{bmatrix} \end{cases}$$

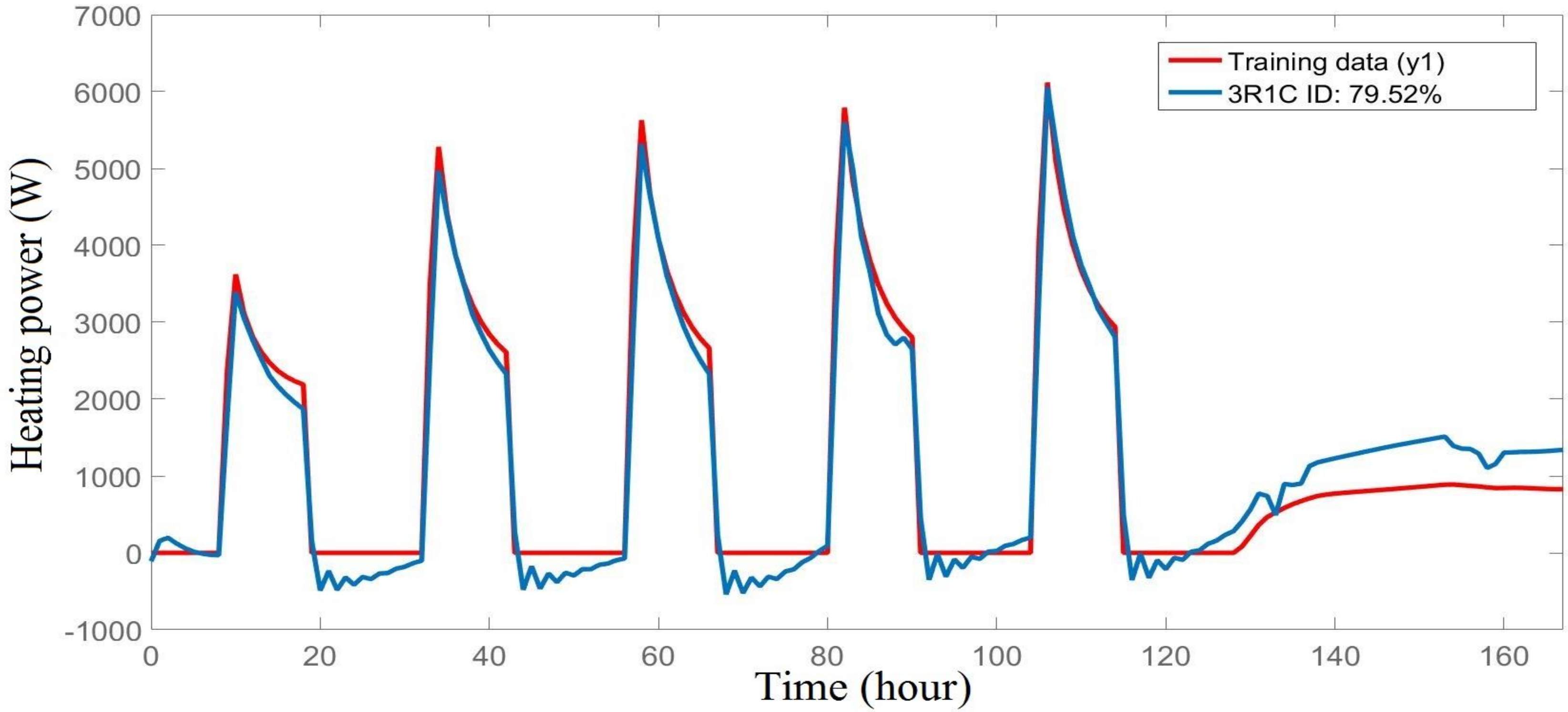
System identification – Training data and specifications

- System identification toolbox – Matlab
- Training Data – Insufficient or Sufficient
  - TRNSYS software – Office building – Belgium, Uccle meteonorm
  - 50 m^2 - 4 facades – south faced – 6 m^2 windows – Heavy structured
  - Occupied hours : 9:00 – 17:00, Minimum temperature 22°C
  - Unoccupied hours : Minimum temperature 15°C
  - Training data for 150 hours, 1500 hours, 3000 hours, containing: $T_{in}, Q_{heat}, T_{out}, T_g, Q_{rad}, Q_{vent}, Q_{inf}$
- Constraints
  - Resistances > 0 K/W
  - Capacitance ≥ 1000 Wh/K
- Fixed initial conditions:
  - Resistances = 0.1 K/W
  - Capacitance = 1000 Wh/K

System identification – Algorithm in the toolbox

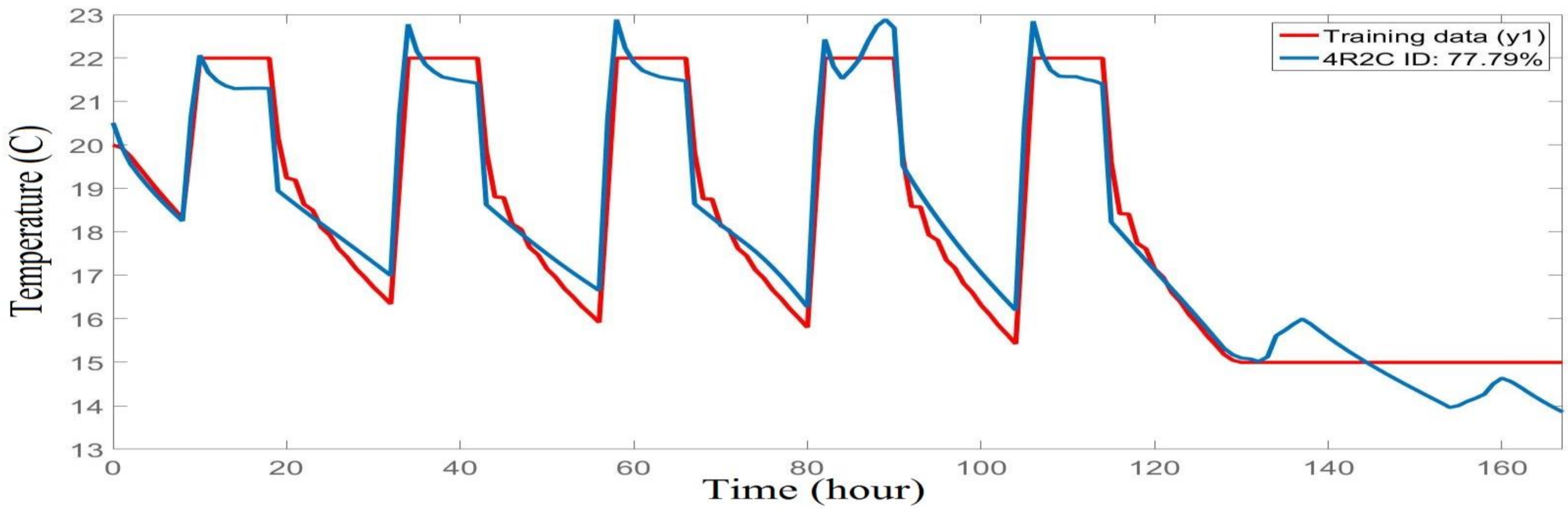
1. Time step
2. Load Training data
3. Initial conditions
   Resistances = 0.1 K/W
   Capacitances = 1000 Wh/K
4. Make the state space matrices (A, B, C, D) with initial values
5. Put constraints on the model
   Resistances > 0
   Capacitances ≥ 1000
6. Run the identification algorithm to identify the model's parameters
7. Make the state space matrices (A, B, C, D) with identified parameters
8. Compare the model with training data
9. Report the identified parameters

System identification – 3R1C identification



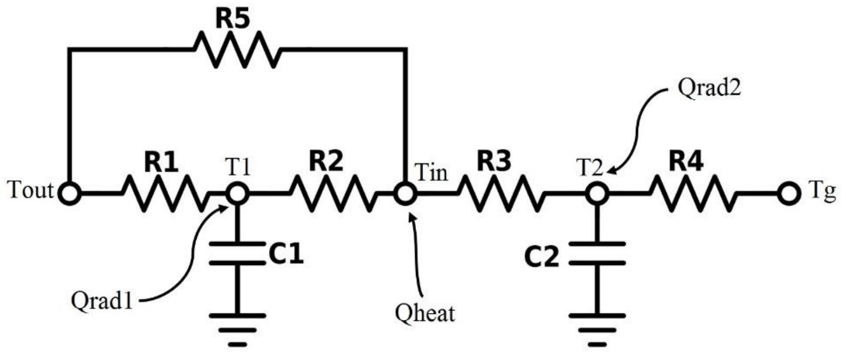
	TRNSYS Data	24h identification	168h Identification	8760h identification
$R1$ (K/W)		0.006546	0.007952	0.008115
$R2$ (K/W)		0.001101	0.001107	0.001173
$R1 + R2$ (K/W)	0.0151	0.007647	0.009059	0.009288
$R3$ (K/W)	0.0067	22.022	62.62	135000
$C1$ (Wh/K)	10066.66	5843.9	5770	5741

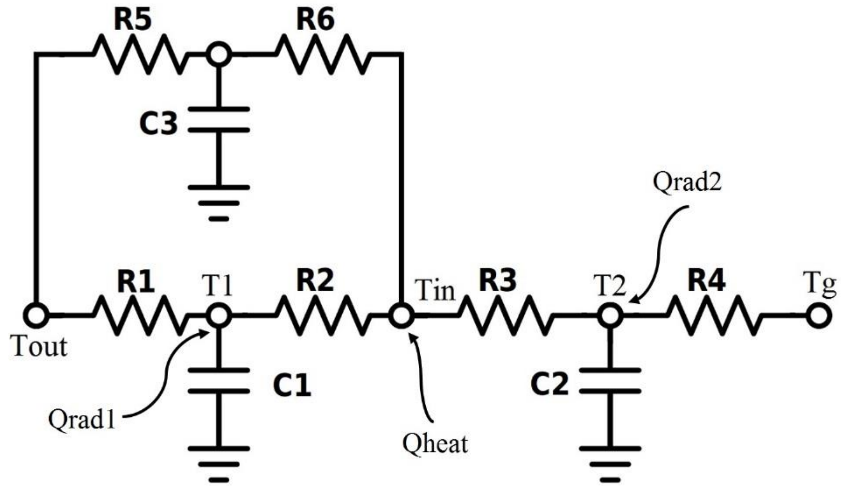
4R2C model – Stabilizing the parameters of the ground resistance

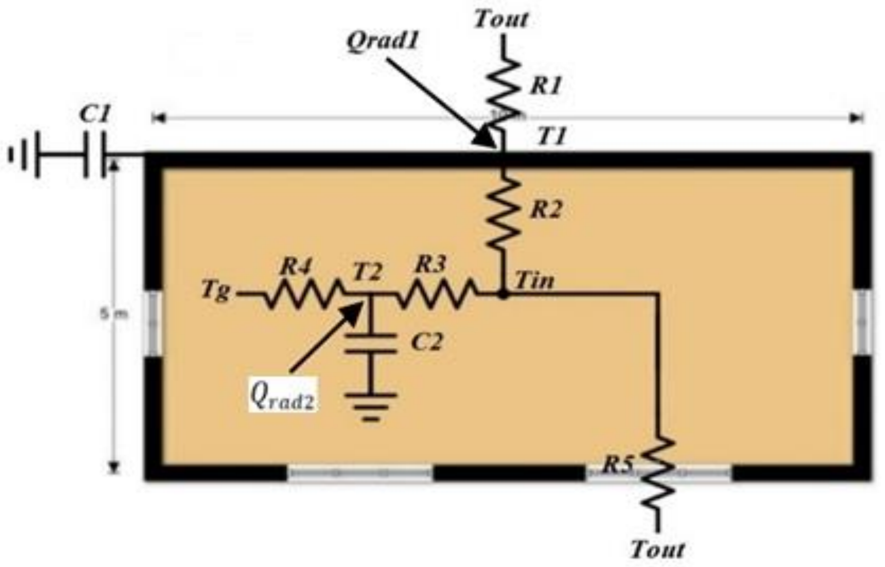


	TRNSYS	24h ID	168h ID	720h ID	8760h ID
$R1$ **(K/W)**		0.0069	0.0126	0.000139	0.000044
$R2$ **(K/W)**		0.0119	0.012	0.0154	0.0159
$R1 + R2$ **(K/W)**	0.0151	0.0188	0.0146	0.0155	0.0159
$R3$ **(K/W)**		0.0017	0.3932	0.0011	0.0011
$R4$ **(K/W)**		0.536	3.865	0.0043	0.0047
$R3 + R4$ **(K/W)**	0.0067	0.537	4.258	0.0054	0.0058
$C1$ **(Wh/K)**	6738.67	5234.9	3626.9	29930	99460
$C2$ **(Wh/K)**	2846.67	1583.9	1006.5	4752.3	4816.8

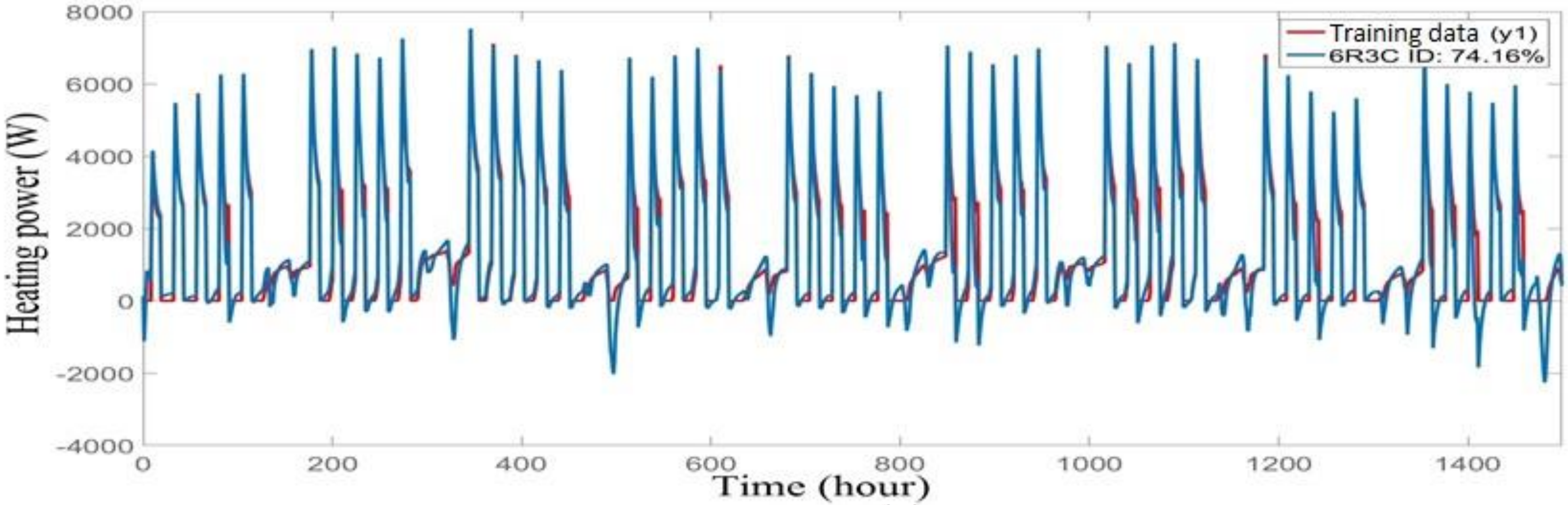
5R2C and 6R3C models – Adding windows to the building's model







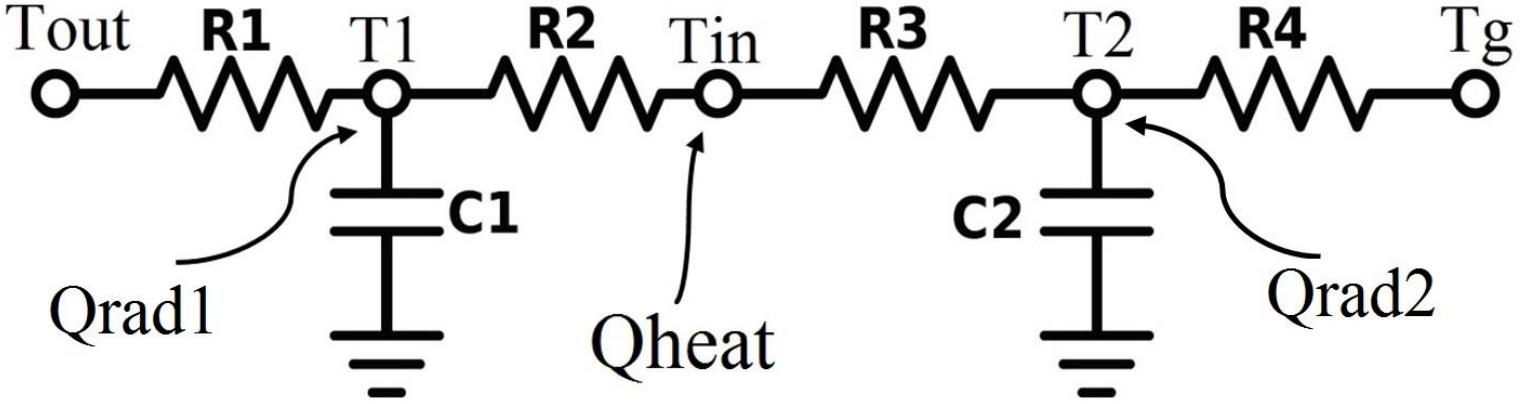
System identification – 5R2C and 6R3C models



	TRNSYS Data	168h ID	1500h ID	3000h ID
$R1$ (K/W)		0.00125	0.000191	0.0005686
$R2$ (K/W)		0.0062	0.0127	0.01532
$R1 + R2$ (K/W)	0.016	0.00745	0.0128	0.0158
$R3$ (K/W)		10	0.0048	0.001157
$R4$ (K/W)		0.1208	0.0012	0.0001854
$R3 + R4$ (K/W)	0.0067	10.12	0.006	0.00133
$R5$ (K/W)		0.6024	2.586	10
$R6$ (K/W)		0.0048	0.0052	0.00188
$R5 + R6$ (K/W)	0.143	0.607	2.591	10.002
$C1$ (Wh/K)	6738.67	5167	5989	9369
$C2$ (Wh/K)	2846.67	1177	4337	1000
$C3$ (Wh/K)	-	1004	95.31	1376

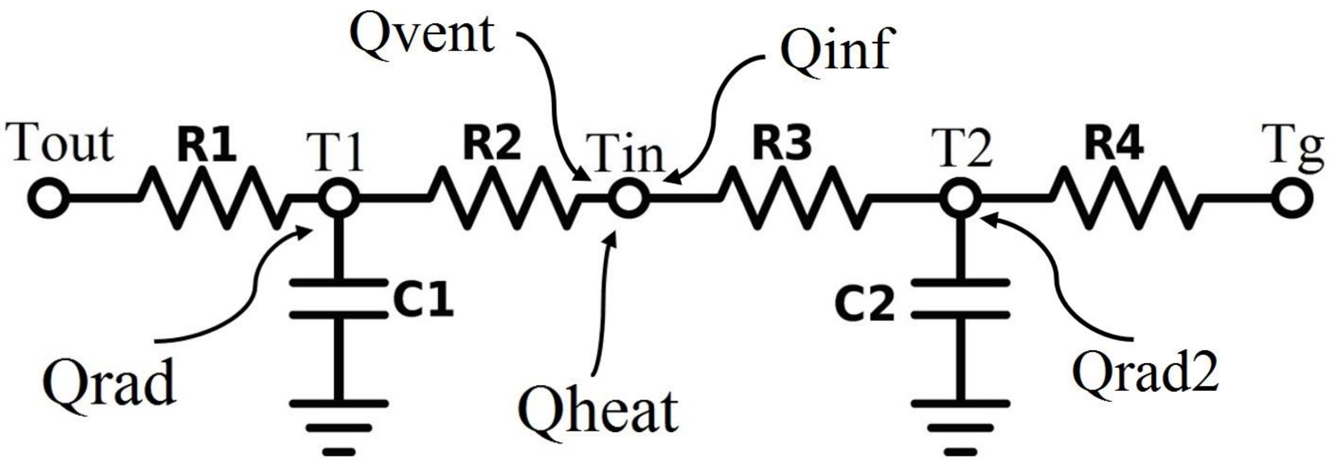
System identification – A brief discussion on identification

- Richness of training data
- Same training data – More complicated models
- Accurate fitness – Inaccurate parameters
- Merging windows branch with the envelope branch

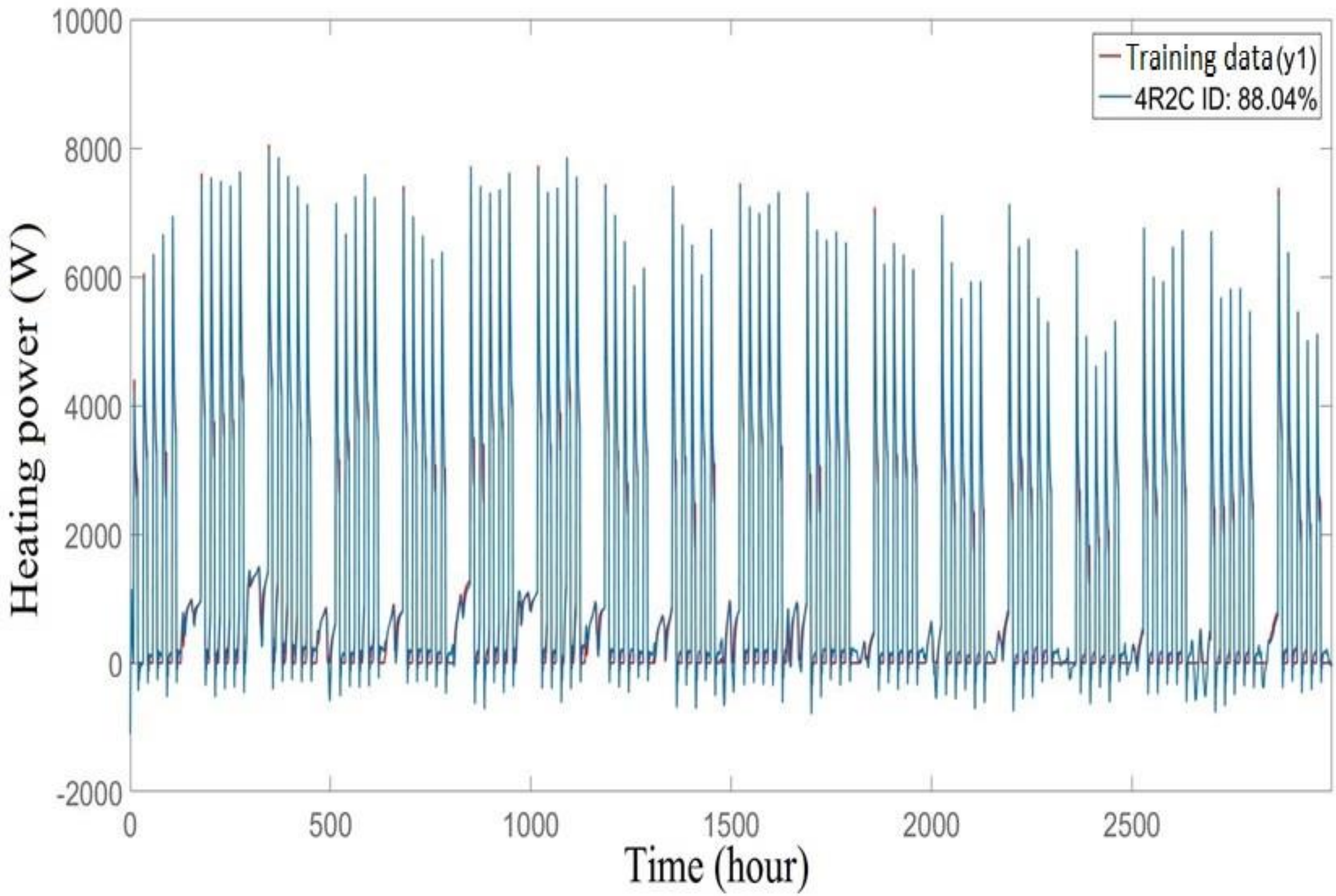


Modified 4R2C model – The model to consider windows, ventilation, and infiltration

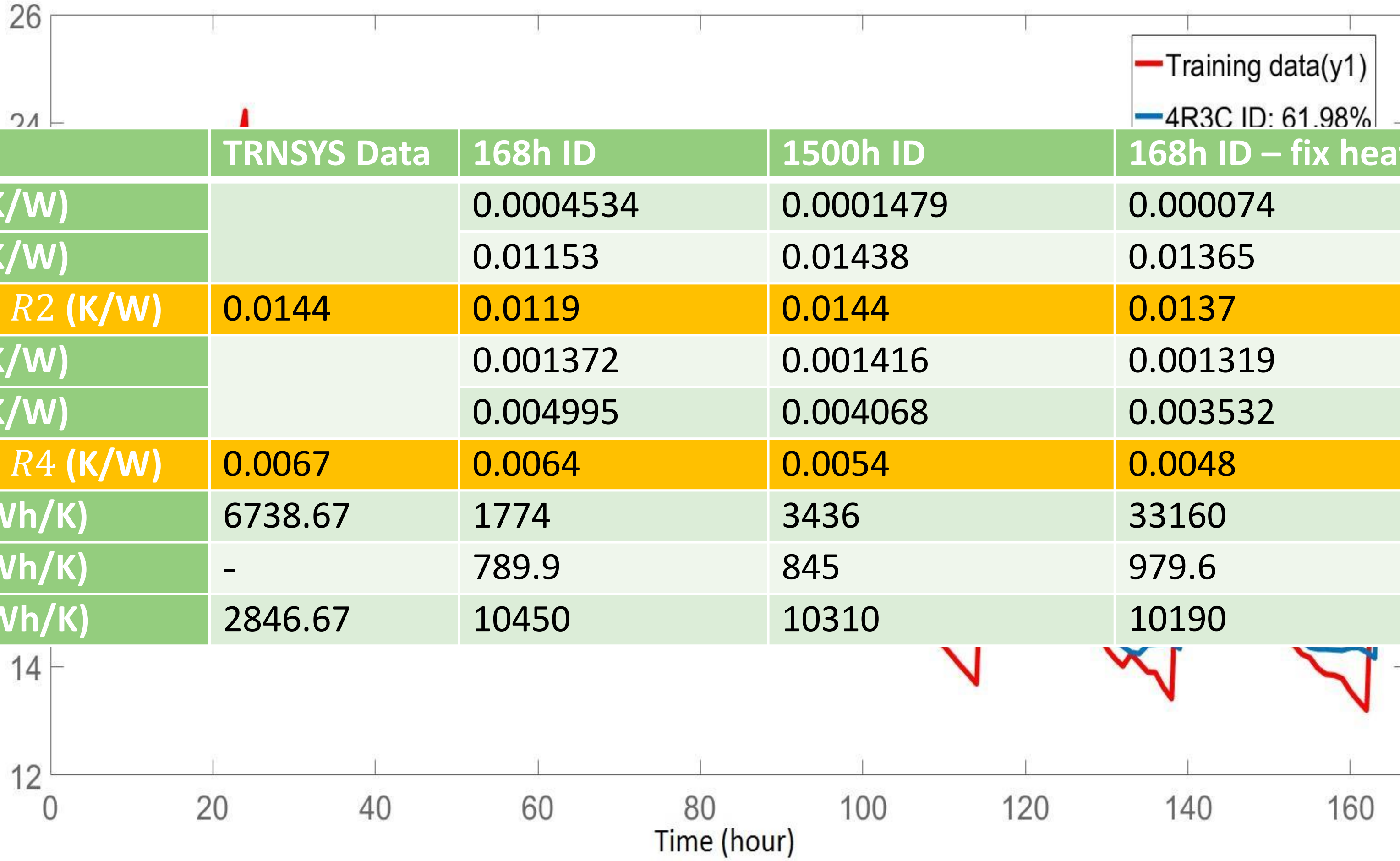
	TRNSYS Data	168h ID	1500h ID	3000h ID
$R1$ **(K/W)**		0.0001446	0.000136	0.000071
$R2$ **(K/W)**		0.01203	0.01455	0.01375
$R1 + R2$ **(K/W)**	0.0144	0.0121	0.0146	0.0138
$R3$ **(K/W)**		0.00123	0.001159	0.00117
$R4$ **(K/W)**		0.00694	0.00389	0.004112
$R3 + R4$ **(K/W)**	0.0067	0.00817	0.00504	0.0053
$C1$ **(Wh/K)**	6738.67	4158	4228	222100
$C2$ **(Wh/K)**	2846.67	4676	4575	4218



Modified 4R2C model – Studying radiation



4R3C Model – Studying the internal mass effect



	TRNSYS Data	168h ID	1500h ID	168h ID – fix heating
$R1$ (K/W)		0.0004534	0.0001479	0.000074
$R2$ (K/W)		0.01153	0.01438	0.01365
$R1+R2$ (K/W)	0.0144	0.0119	0.0144	0.0137
$R3$ (K/W)		0.001372	0.001416	0.001319
$R4$ (K/W)		0.004995	0.004068	0.003532
$R3+R4$ (K/W)	0.0067	0.0064	0.0054	0.0048
$C1$ (Wh/K)	6738.67	1774	3436	33160
$C2$ (Wh/K)	-	789.9	845	979.6
$C3$ (Wh/K)	2846.67	10450	10310	10190

Conclusion and future works

- Conclusion

➢ Thermal networks are reliable, accurate, and physical

➢ System identification – inaccurate parameters for complicated models

- Future Work

➢ The mathematical background for system identification will be studied. The main goals will be to discover: the problems related to initial conditions, parameter sensitivity, and minimum required data.

➢ Light building construction will be studied.

➢ Different types of buildings will be considered (attached, detached, semi-attached, and terraced) – Inputs from a master thesis

➢ Small neighborhoods will be simulated.

Thank You for Your Attention

Questions??