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DYNASTEE

Introduction to LORD

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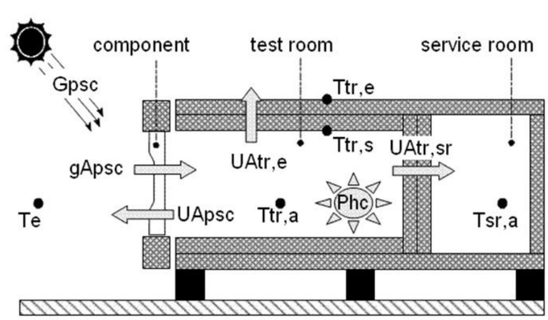
Origins

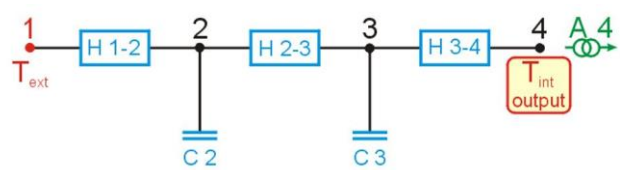
- LORD was developed for the PASLINK EEIG by Olaf Gutschker, BTU Cottbus, to analyse ***dynamic test cell data*** and deliver high quality performance characteristics for building components tested in real climates.



Purpose

- LORD can be used for components (walls, windows etc), whole rooms or more complicated systems;
- to obtain ***thermal transmittance values***, ***solar gain factors***, and possibly dynamic information (e.g. capacitances, time constants).
- A transient mathematical model is assumed. The parameters of the model (e.g. resistances, capacitances and heat flow admittances) essentially define the dynamic and steady-state thermal and solar properties of the system.

RC-networks



- Initial guesses of the parameter values are made.
- The ***output*** of the actual test (for instance, the test room temperature $\boldsymbol{T_{int}}$ as a function of time) is compared with the ***output*** which the model produces for the same ***input*** conditions.
- By statistical analysis of the deviations between the model and the measured outputs, the parameter values are progressively adjusted in order to improve the agreement.
- Read LORD Manual and other documents which will be provided.

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(Mostly) User friendly interface

Step 1 - Input data

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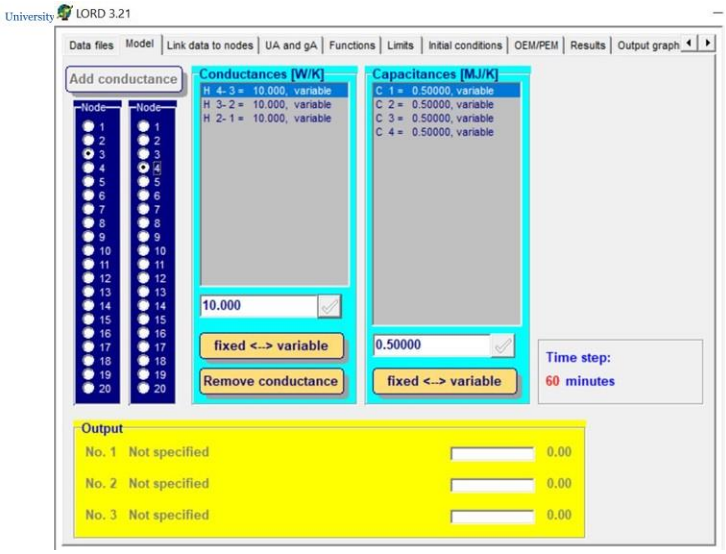
File formats – tab deliminated or CSV

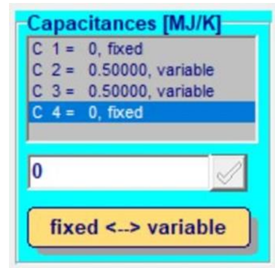
Headers must be enclosed in single quotation marks

	A	B	C	D	E	F	G
1	'timestamp'	'Tsi_glazing'	'Tsi_left'	'Tsi_back'	'Tsi_right'	'Tsi_celling'	'Tsi_floor'
2	41614	22.7454834	26.606781	26.6628572	27.2989349	26.4609832	28.63676
3	41614.00694	22.5884704	26.4465637	26.4946289	27.1242904	26.2911529	28.49256
4	41614.01389	22.4506836	26.2751311	26.3376159	26.9624634	26.134137	28.34516
5	41614.02083	22.3161011	26.1245224	26.1822051	26.7862244	25.9658966	28.19936
6	41614.02778	22.1959381	25.9626922	26.0299851	26.6083832	25.7912597	28.04554
7	41614.03472	22.0549438	25.7896576	25.8681641	26.4337463	25.6230316	27.91416
8	41614.04167	21.9043121	25.6278382	25.7063447	26.263916	25.4532013	27.77157

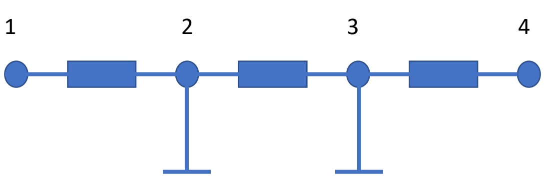
Step 2 – Create a model



Usually set capacitances at internal and external nodes to zero.

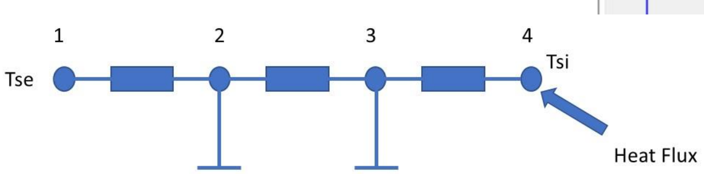


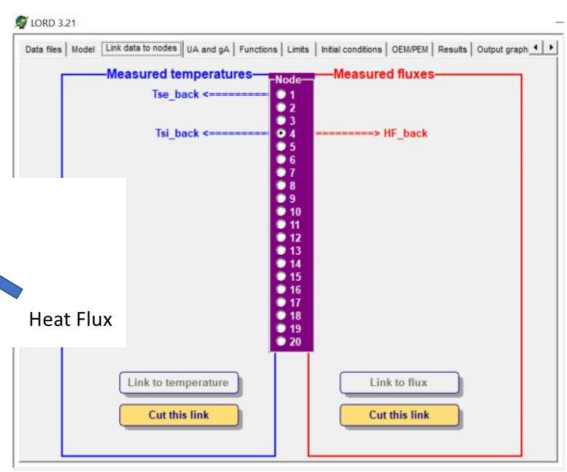
Check that time step is correct (note default is 60 minutes)



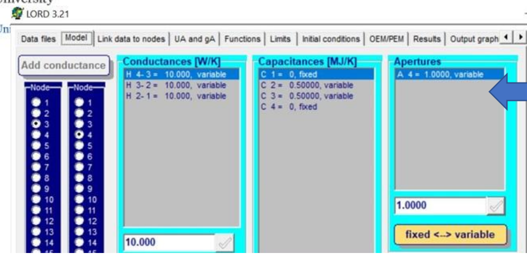
Step 3 – Link data to nodes

We now have a basic four node model which could be applied to heat flow measurements through a wall.

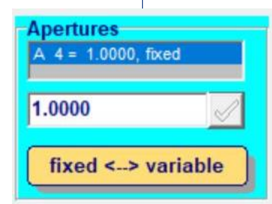




Step 4 – Go back to Model!

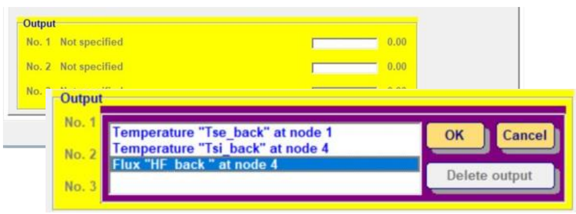


Fix Aperture = 1
for measured *Heat Flux or Heating Power*



For *Solar Radiation* **Aperture is variable.**

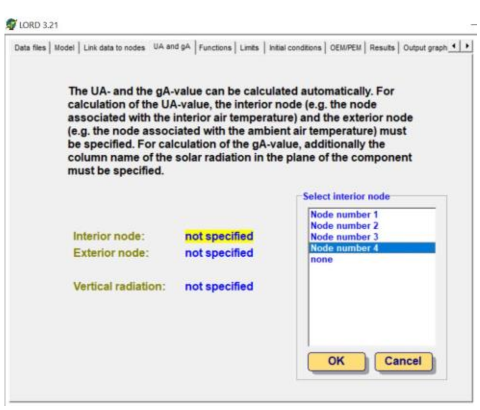
Select Output



Step 5 - UA & gA

Note for 1-D heat flux measurements = U- & g-values

For our 4-node model we need to specify interior & exterior nodes:



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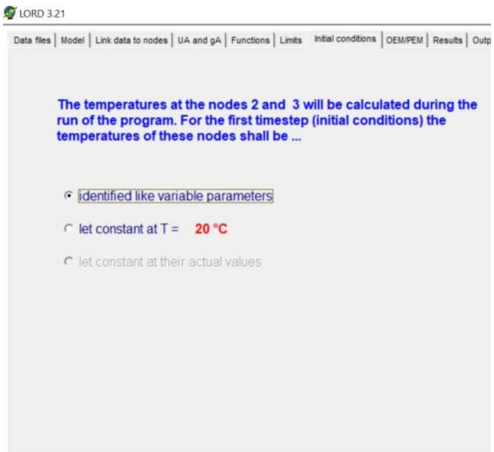
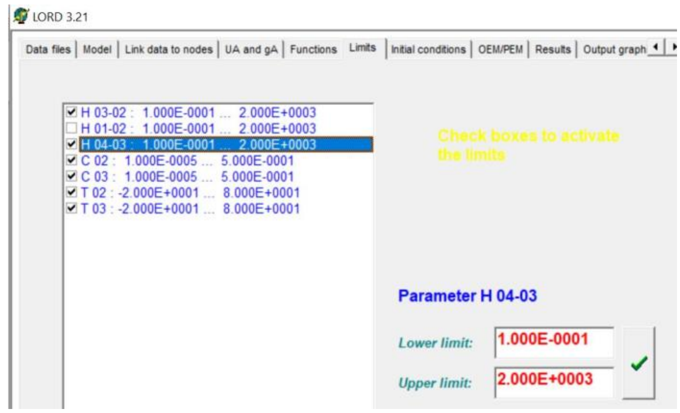
Step 6 – Initial Conditions



Step 7 – Limits



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Step 8 – OEM/PEM

- In general, the residuals using PEM are smaller than using OEM.
- The identification process takes much longer using PEM.
- PEM can only be used if the outputs are measured temperatures.
- Ask a statistician to explain!

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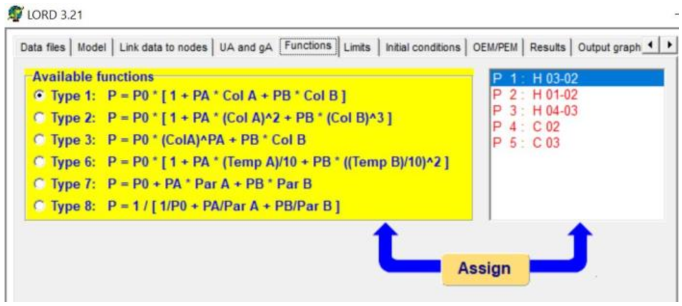
Other Options - Functions



For example, it is possible to create a variable resistance dependent on a measured parameter such as wind speed.

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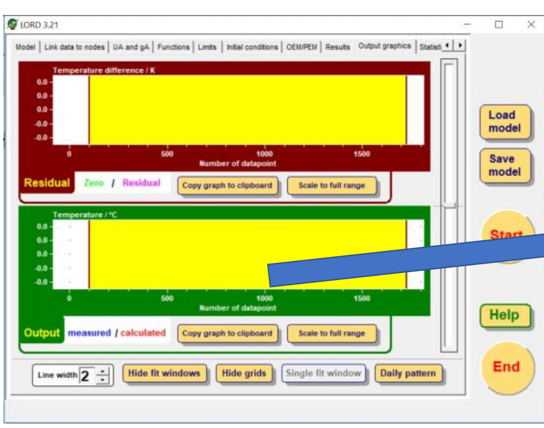
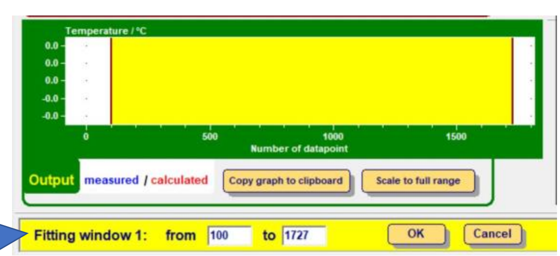
Options – Output Graphics & 'Fitting Windows'

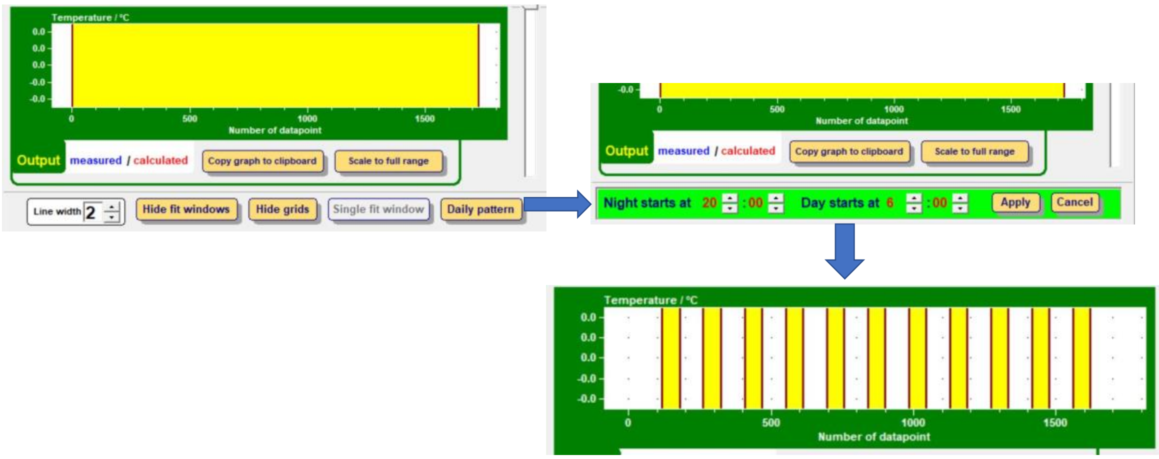
- Fitting windows can be used to select only part of the data for analysis.
- See LORD help for instructions.



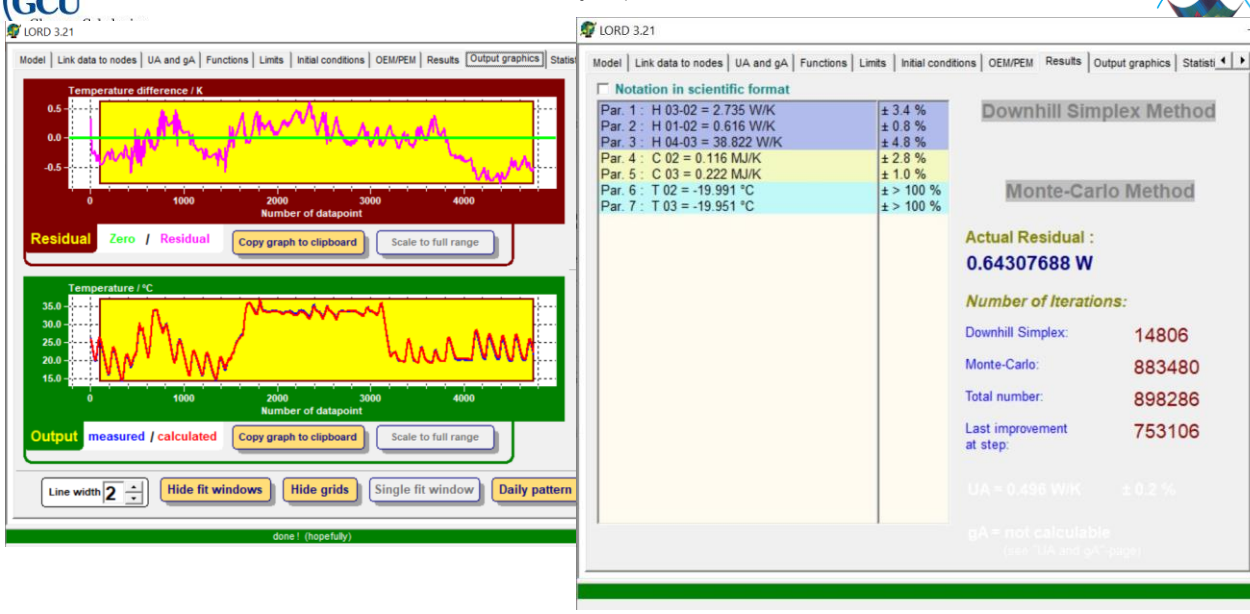


Right Click on Yellow Window to change Fitting Window

Daily Pattern



Run!



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Results - Output File *. log gives all input and output information

```
Back_10min-5 - Notepad
File Edit Format View Help
Log-File, created by LORD
================================

Date: 17/08/2020
Time: 14:39:33

Time step: 10.00 minutes

Fitting window:
number 1 -  from 100 to 4751

======================
Model and start values
======================

-------------------
Conductances [W/K]
-------------------
H  4- 3 =   38.822,  variable, limited between 0.10 and 2000.00
H  3- 2 =    2.7352,  variable, limited between 0.10 and 2000.00
H  2- 1 =    0.61610,  variable

-------------------
Capacitances [MJ/K]
-------------------
C  1 =   0, fixed
C  2 =   0.11647, variable, limited between 0.000 and 0.500
C  3 =   0.22201, variable, limited between 0.000 and 0.500
C  4 =   0, fixed

---------
Apertures
---------
A  4 =  1.0000, fixed

-------------------
Parameter functions
-------------------
not specified

---------------------------------------------
Columns in the data file and links to nodes
---------------------------------------------
Node number 1 ----> temperature "Tse_back"
Node number 4 ----> temperature "Tsi_back"

Node number 4 ----> flux "HF_back "

-------
Outputs
-------
No.1: Flux "HF_back " at node 4, weight = 1.00
No.2: Not specified
No.3: Not specified

------------------
Initial conditions
------------------
Initial temperatures were identified.
```

```
=======
Results
=======

----------
Iterations
----------
Downhill Simplex Method: 31800
Monte Carlo Method: 972710
Total number of iterations: 1004510
Last improvement at step: 943995

---------------------------------------------
Residual at end of calculation : 0.64307645 W
---------------------------------------------

----------
Parameters
----------
Par. 1 :  H 03-02 = 2.722 W/K ± 3.4 %
Par. 2 :  H 01-02 = 0.617 W/K ± 0.8 %
Par. 3 :  H 04-03 = 38.762 W/K ± 4.8 %
Par. 4 :  C 02 = 0.0194 MJ/K ± 2.8 %
Par. 5 :  C 03 = 0.0370 MJ/K ± 1.0 %
Par. 6 :  T 02 = -19.996 °C ± > 100 %
Par. 7 :  T 03 = -19.952 °C ± > 100 %

---------
UA and gA
---------
Interior node: Node number 4
Exterior node: Node number 1
Column with vertical radiation: not specified

---------
UA and gA
---------
Interior node: Node number 4
Exterior node: Node number 1
Column with vertical radiation: not specified

UA = 0.496 W/K ± 0.1 %
gA = not calculable

------------------
Cross - Correlation
------------------

           | H 03-02   H 01-02   H 04-03   C 02      C 03
-----------+-----------------------------------------------
H 03-02    | 1.0000    -0.6792   0.0133    0.0285    -0.3329
H 01-02    | -0.6792   1.0000    -0.0808   -0.0098   0.3028
H 04-03    | 0.0133    -0.0808   1.0000    0.2362    -0.2504
C 02       | 0.0285    -0.0098   0.2362    1.0000    -0.4843
C 03       | -0.3329   0.3028    -0.2504   -0.4843   1.0000
```


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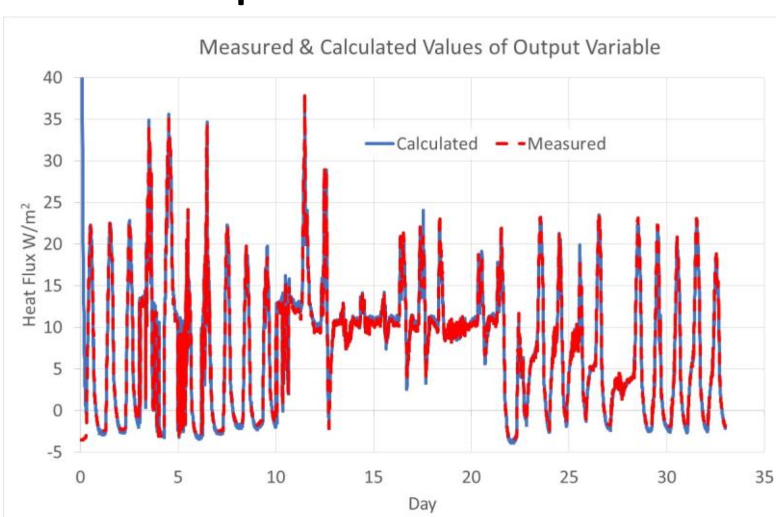
Results - Output File *.res gives measured & calculated values of output variable

Back_10min-5 - Notepad

File Edit Format View Help

Day	Calc. 1	Meas. 1
0.0069444	1122.4832	-3.5312
0.0138889	710.7753	-3.5433
0.0208333	461.6966	-3.5464
0.0277778	309.8872	-3.5555
0.0347222	216.0325	-3.5646
0.0416667	157.2057	-3.5706
0.0486111	119.2652	-3.5676
0.0555556	94.4965	-3.5433
0.0625000	77.8772	-3.5585
0.0694444	65.5455	-3.5706
0.0763889	56.3539	-3.5494
0.0833333	49.1957	-3.5585
0.0902778	43.4346	-3.5555
0.0972222	38.9503	-3.5525
0.1041667	34.7030	-3.5494
0.1111111	31.0022	-3.5433
0.1180556	27.7674	-3.5191
0.1250000	24.9462	-3.5100
0.1319444	22.8053	-3.5009
0.1388889	20.2331	-3.4888
0.1458333	17.9165	-3.4888
0.1527778	16.0493	-3.4676
0.1597222	14.3594	-3.4646
0.1666667	12.9064	-3.4465



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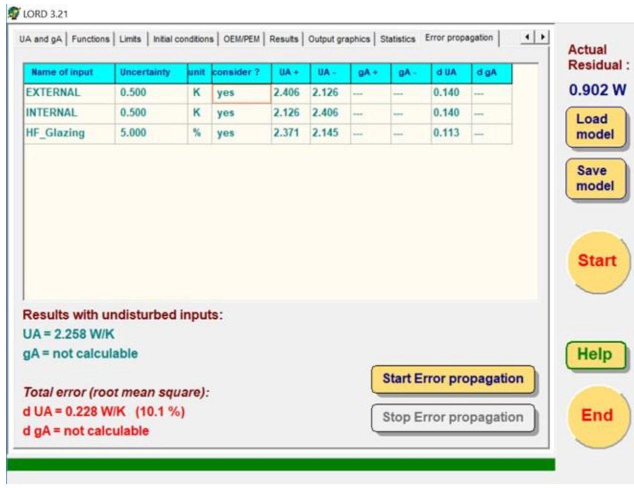
Save Model

A final option is to run an Error Propagation:



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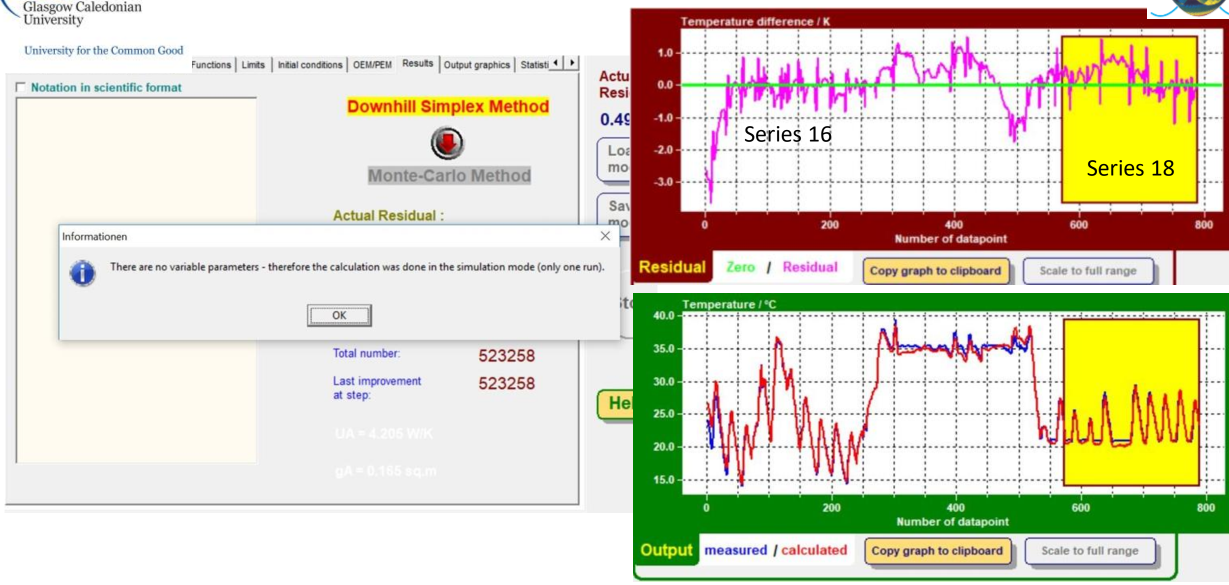
Using LORD for Simulation/Validation

- Example: validate results from one part of a data series on another part – identify model on Series 16 and apply to Series 18.
- Run LORD for Series 16 only.
- Obtain results & save model.
- Fix all parameters.
- Set initial conditions.

- Move window over Series 18.
- Run LORD.

Using LORD for Simulation/Validation

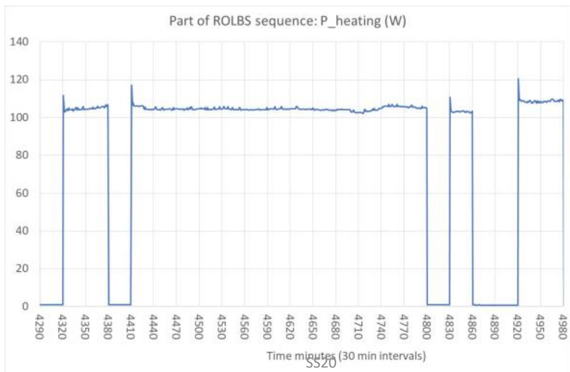


Application of LORD to Real Data

- Firstly the data must be processed for input in LORD
  - ❑Check integrity of data – plots!
    - ➢Missing data?
    - ➢Anomalies?
  - ❑What data interval to use? *Example of PSA Series 16-18 data follows.*
  - ❑Etc.

What is the optimum data interval in order *not* to loose dynamic information?

- Data are provided at 1 minute intervals (too much information – too long computation time?)
- The ROLBS sequence in Series 16 is based on 30 minute periods:



- Maximum interval to include all dynamic information is 30 minutes,
- Maybe better to use 10 minute averages.
- Check data to identify start of ROLBS:

A	B	AA	AY	AZ
		P_heating		P_heating
09/12/2013 01:21	4402	1.075042		
09/12/2013 01:22	4403	1.060033		
09/12/2013 01:23	4404	1.075042		
09/12/2013 01:24	4405	1.044998		
09/12/2013 01:25	4406	1.014981		
09/12/2013 01:26	4407	1.075042		
09/12/2013 01:27	4408	1.044998		
09/12/2013 01:28	4409	1.044998		
09/12/2013 01:29	4410	1.044998		
09/12/2013 01:30	**4411**	**117.2594**	09/12/2013 01:30	105.7771495
09/12/2013 01:31	4412	106.6699		
09/12/2013 01:32	4413	107.7513		
09/12/2013 01:33	4414	106.2493		
09/12/2013 01:34	4415	106.2343		
09/12/2013 01:35	4416	106.2343		
09/12/2013 01:36	4417	106.2493		
09/12/2013 01:37	4418	106.024		
09/12/2013 01:38	4419	106.039		

Inspect data: Sequence changes on the hour or half hour.

Therefore start averaging at the beginning of Series 16 at 6/12/13 00:00

This captures all the dynamic information.

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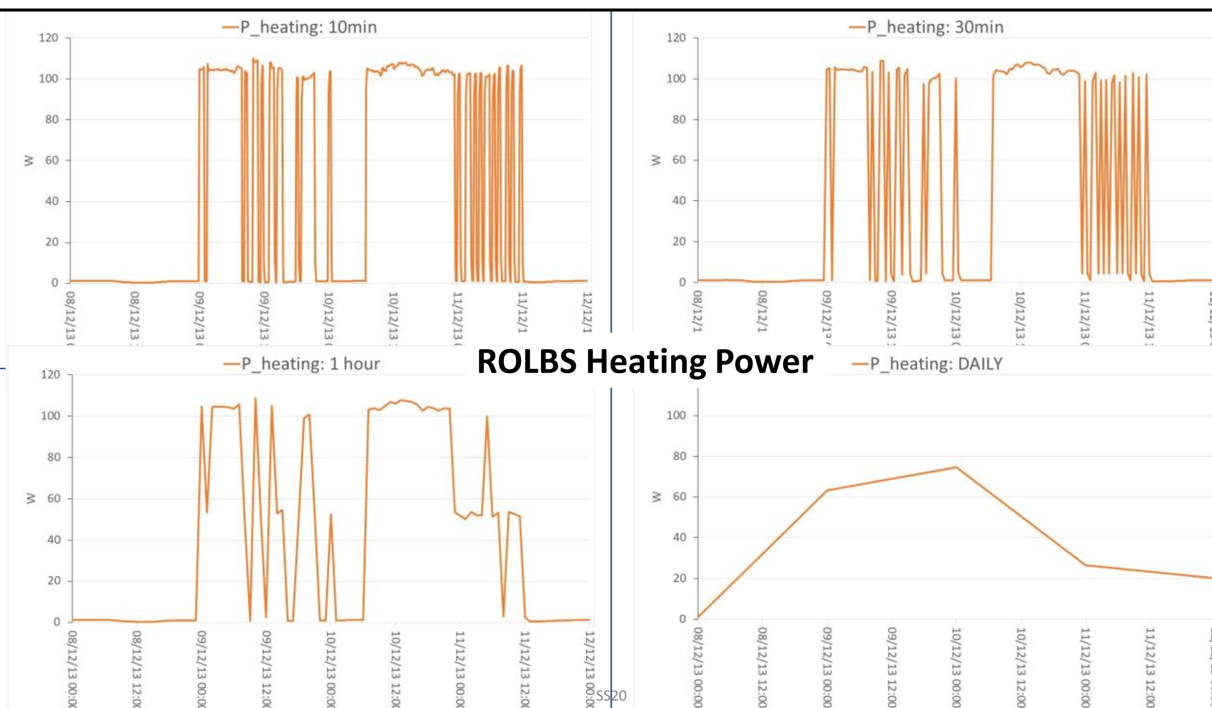
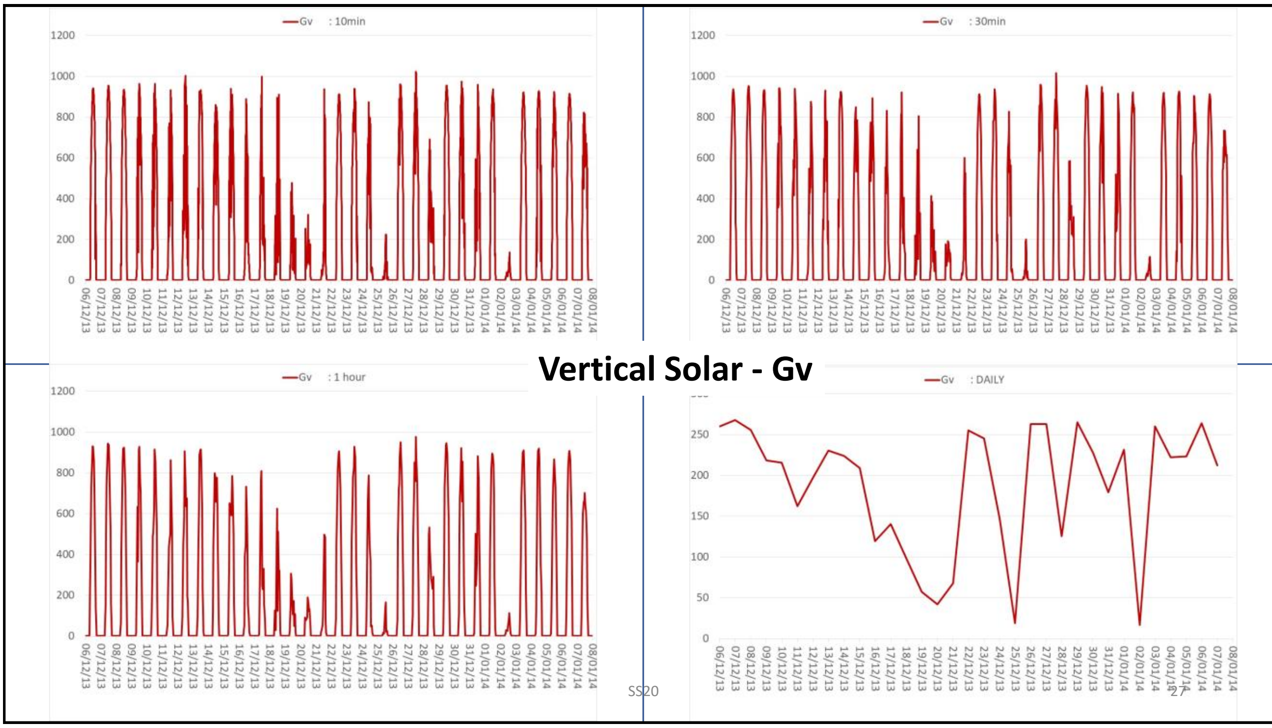
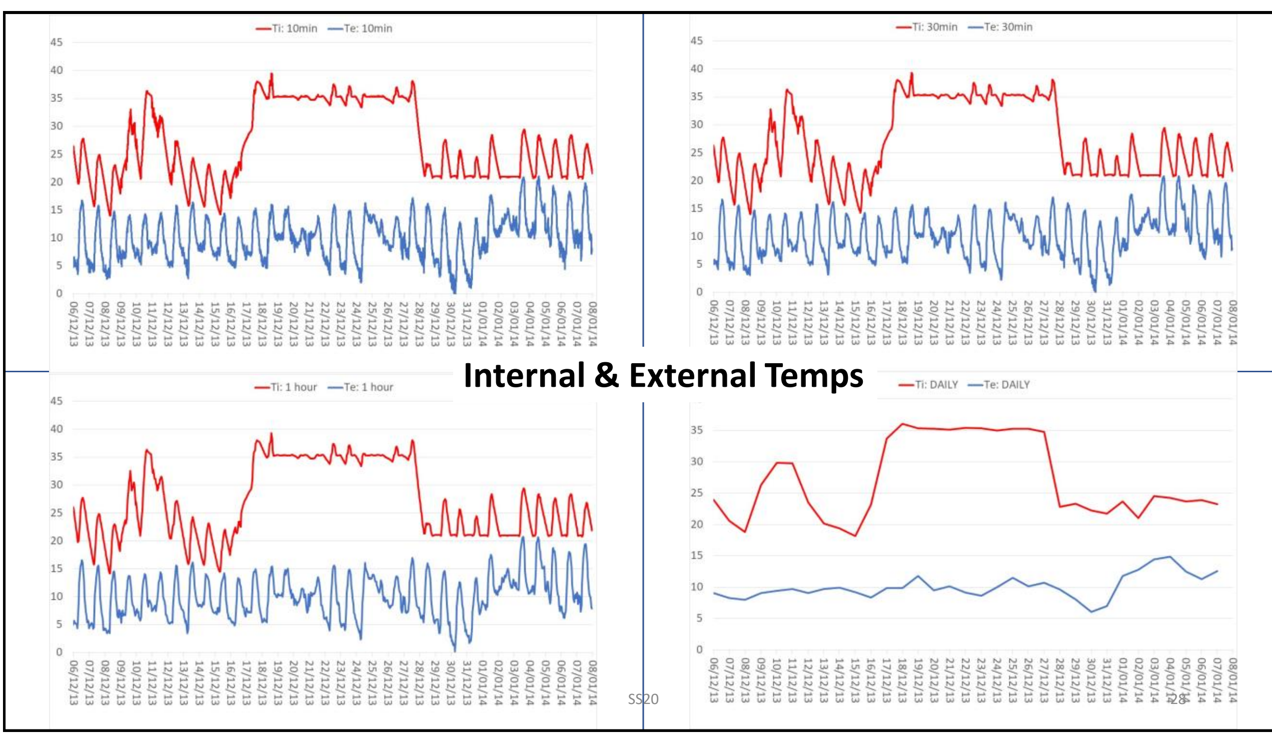
The following figures show the effect of different averaging periods….

10 min	**30 min**
1 hour	**24 hour**

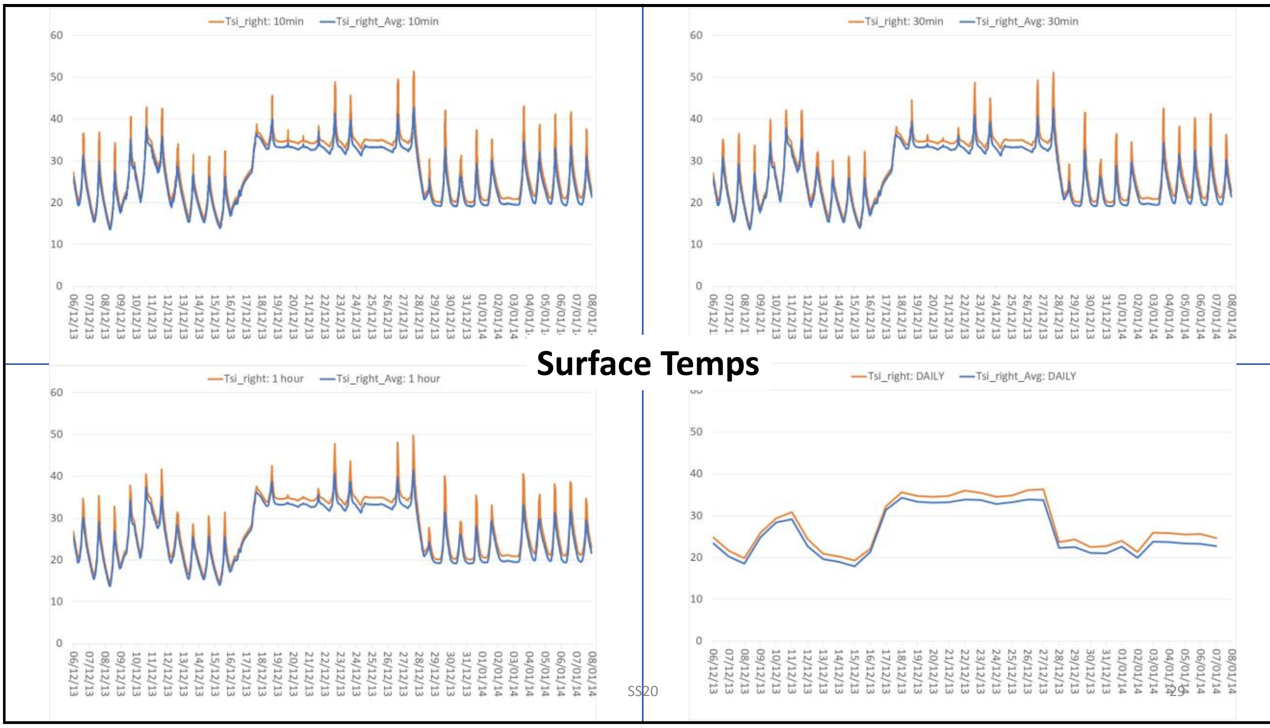
ROLBS Heating Power



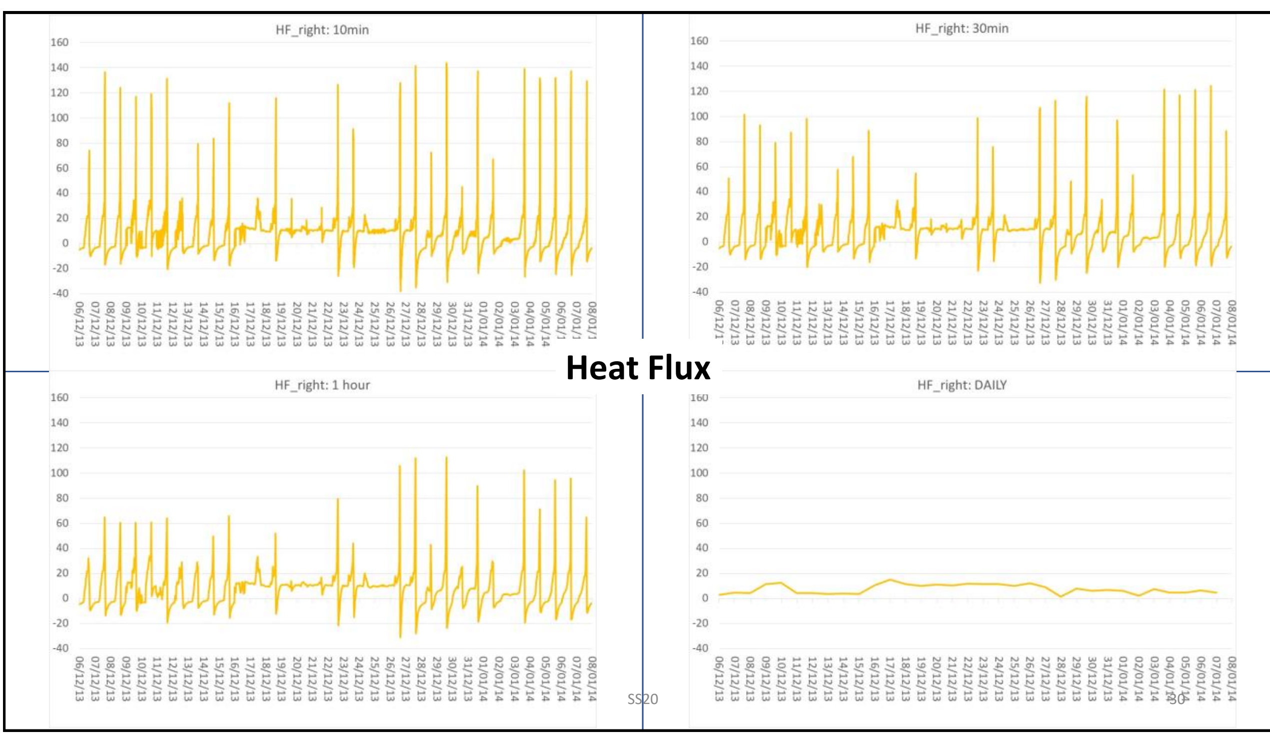

Vertical Solar - Gv
Gv : 10min
Gv : 30min
Gv : 1 hour
Gv : DAILY
SS20
27


Internal & External Temps
Ti: 10min
Te: 10min
Ti: 30min
Te: 30min
Ti: 1 hour
Te: 1 hour
Ti: DAILY
Te: DAILY
SS20
28

Surface Temps



Heat Flux



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Applying LORD to Heat Flux Measurements from PSA data

- Firstly it is helpful to estimate results by *simple averaging* before running LORD on data.
- I've tried three approaches using the different temperatures available…….
- These give a good idea of the U-value result(s) you should be aiming for by identification.

	U-value based on Tsi, Tse & HF				
	Left	*Back*	*Right*	*Ceiling*	*Floor*
ALL Data	**0.44**	**0.46**	**0.41**	**0.45**	**0.53**
Series 16	**0.47**	**0.48**	**0.42**	**0.48**	**0.57**
Series 17	**0.45**	**0.45**	**0.42**	**0.45**	**0.48**
Series 18	**0.41**	**0.43**	**0.37**	**0.42**	**0.55**
	U-value based on Ti, Te & HF				
	Left	*Back*	*Right*	*Ceiling*	*Floor*
ALL Data	**0.46**	**0.45**	**0.44**	**0.52**	**0.55**
Series 16	**0.49**	**0.49**	**0.46**	**0.56**	**0.61**
Series 17	**0.45**	**0.44**	**0.44**	**0.49**	**0.47**
Series 18	**0.44**	**0.44**	**0.43**	**0.50**	**0.59**
	U-value based on Tsi_Avg, Tse & HF				
	Left	*Back*	*Right*	*Ceiling*	*Floor*
ALL Data	**0.47**	**0.46**	**0.44**	**0.48**	**0.60**
Series 16	**0.51**	**0.49**	**0.46**	**0.52**	**0.67**
Series 17	**0.46**	**0.45**	**0.45**	**0.49**	**0.52**
Series 18	**0.45**	**0.44**	**0.42**	**0.45**	**0.65**

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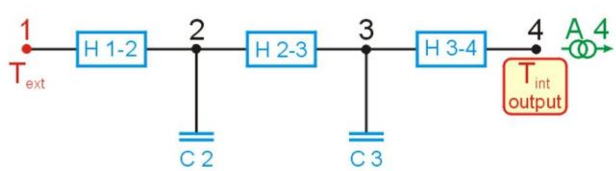
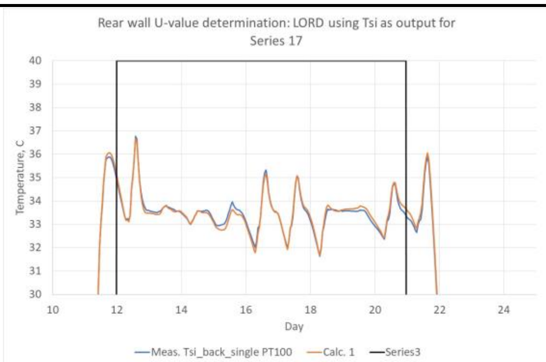
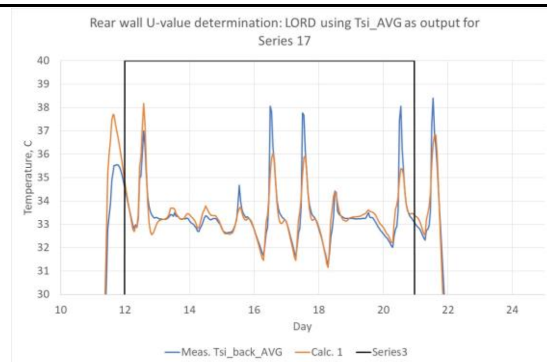
Using LORD

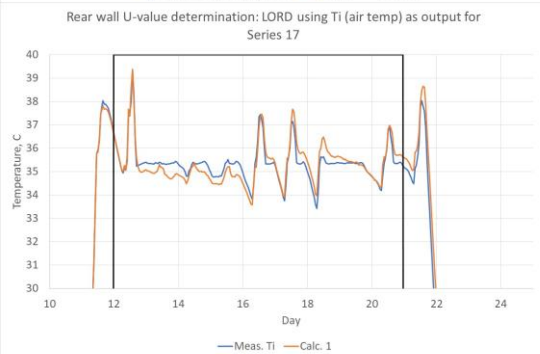
- The rear wall is used as an example.
- Use the basic 4 node model.



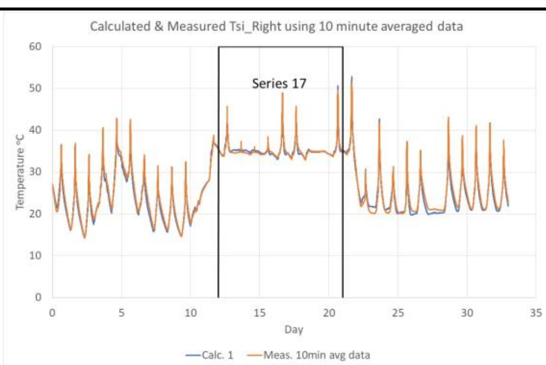
- I've used the external surface temperature Tse and the PT100 internal temperature Tsi because it is more local to heat flux sensor.
- I tried Tsi_Avg and Ti, however Tsi produced better results – lower residuals.

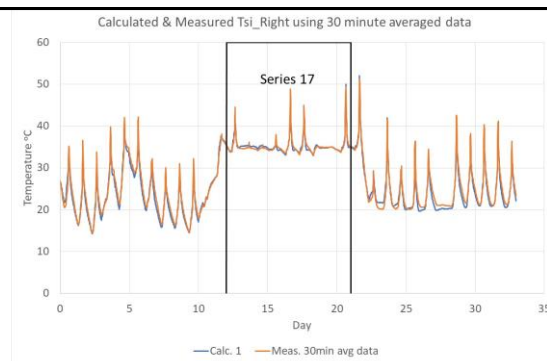


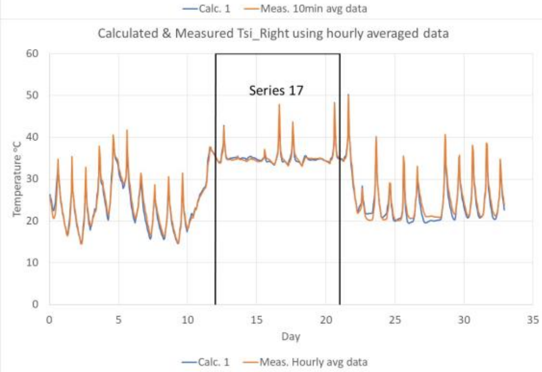




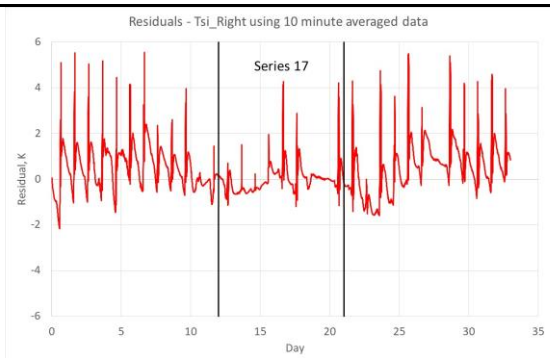
Tsi appears to give best fit

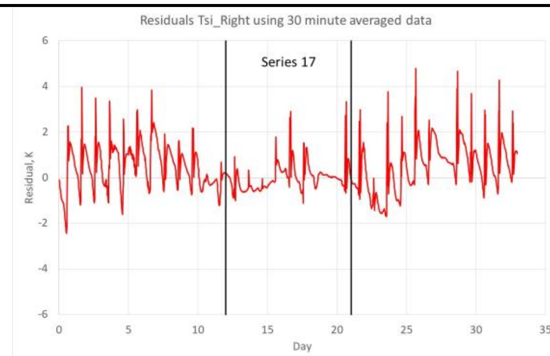


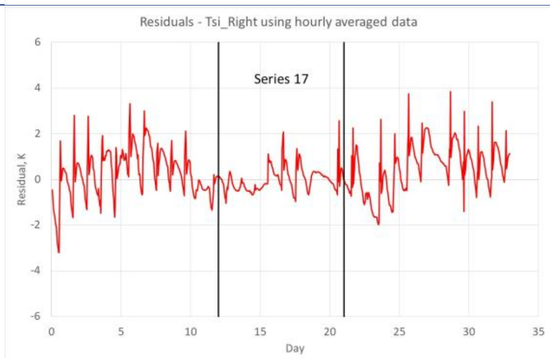




	Averaging Period	U-value, W/m^2K
LORD	10 min	0.42
LORD	30 min	0.42
LORD	Hourly	0.42
Averaging Method		0.42







- Using hourly average data improves residuals as smoothed out more extreme spikes – but maybe also need to improve model.
- For example: try using Heat Flux as output.

UA- & gA-values for whole test cell from Series 16-18 or 'Co-heating' test of a building

- For the heat flux measurements we can easily get an idea of the U-value by the averaging method, however this is not possible for UA- & gA-values.
- For steady state conditions, the electrical heat input to maintain a constant internal temperature within the test cell or building, will increase when the outside temperature falls and decrease when the solar radiation rises (in actuality these are always fluctuating, but dampened by the thermal inertia). However, neither the heat loss coefficient, nor the solar heat gain factor of the building envelope can be measured directly.

UA & gA

- But estimates can be made using the daily average data with ***Siviour Analysis*** for Series 16-18……

What is Siviour Analysis?

Daily averages (or longer) are produced.

$$P\_heating = UA \times \Delta T \; - gA \times Gv$$

Dividing by ΔT gives

$$\frac{P\_heating}{\Delta T} = \mathrm{UA} - \mathrm{gA} \times \frac{Gv}{\Delta T}$$

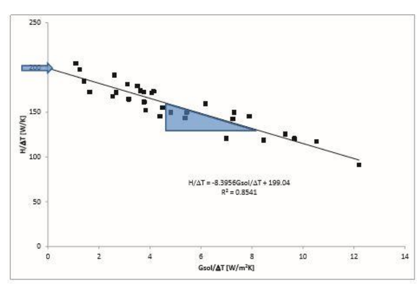


Figure A2: Example of X-Y plot of co-heating test data (Siviour analysis). The intercept of the linear regression line is the whole house heat loss coefficient and the slope is the solar gain factor

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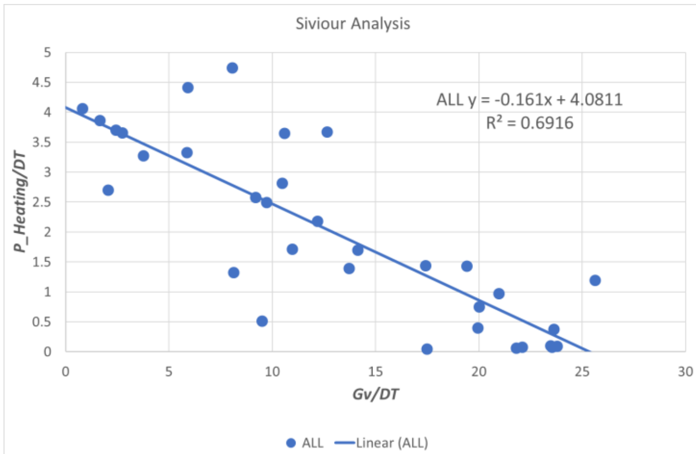
All data Series 16-18



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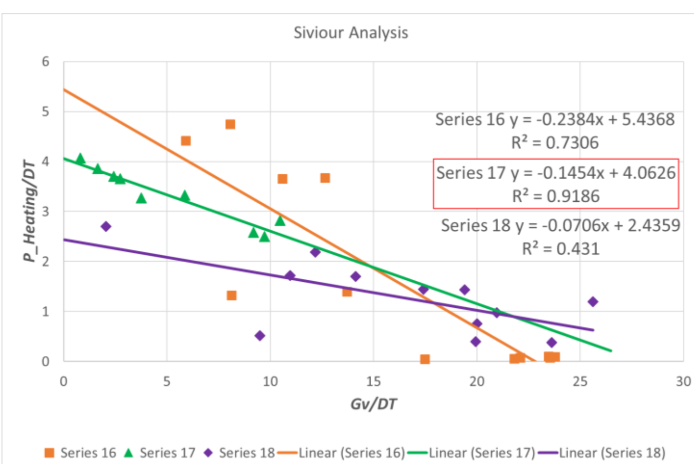
DYNASTEE

Divide into 3 series



Series 17 gives the best fit:
UA= 4.06 W/K
gA= 0.145 m^2

Best 'steady state' data series with high ΔT

This suggest that the data series would *possibly* give good results for steady state parameters using LORD, etc.

Research Papers

FIRST EVIDENCE FOR THE RELIABILITY OF BUILDING CO-HEATING TESTS

Richard Jack, Dennis Loveday, David Allinson and Kevin Lomas

Building Energy Research Group, School of Civil & Building Engineering, Loughborough University.

Building Research & Information Vol. 46, 2018.

The energy balance is typically carried out using measurements that are averaged over a 24 hour period:

- Electrical Heating + Solar Heating = Fabric Heat Loss + Infiltration Heat Loss

Co-heating Test Methodologies

In November 2013, NHBC report NF54, Review of Co-heating Test Methodologies, was produced, which contained a background to co-heating testing and an initial analysis of the results (Butler & Dengel, 2013).

It concluded that variable weather conditions, in particular heat gain resulting from **solar irradiance**, were the largest cause of **uncertainty** in the test results.

- *Google also: QUB/e: U-values in-situ*

Multiple Regression Analysis

As an alternative to Siviour Analysis use MRA treating ΔT & Gv as independent variables with the heating power H as the dependent variable.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9686565
R Square	0.938295416
Adjusted R Squar	0.904046881
Standard Error	13.78066775
Observations	33

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	89520.88797	44760.44399	235.6968952	4.50956E-19
Residual	31	5887.110913	189.9068036		
Total	33	95407.99889			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Gv'	-0.16674958	0.0210204	-7.932750068	5.90481E-09	-0.209620968	-0.123878191	-0.209620968	-0.123878191
DT	4.207991683	0.234685402	17.93035122	6.40728E-18	3.72934765	4.686635716	3.72934765	4.686635716

gA = 0.17
UA = 4.208

Multiple Regression Analysis

The gA-value result is used to adjust daily values of the heating power for solar gains:

$$\text{Hsol} = H + \boldsymbol{gA} * Gv = UA \times \Delta T$$

Plot Hsol (heating power + solar gains) vs. ΔT

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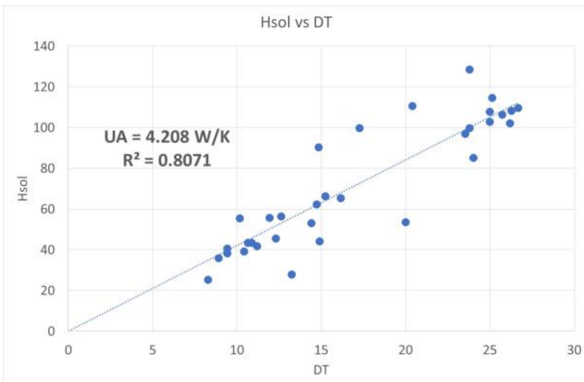

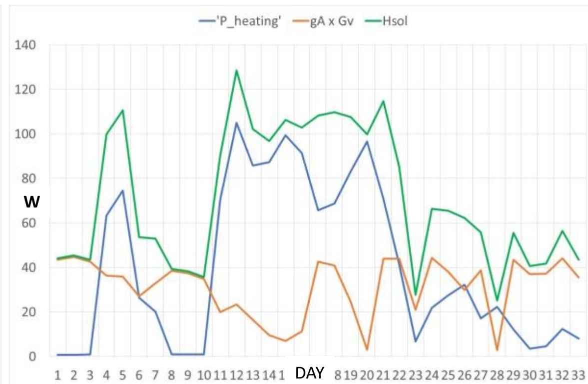

Maybe useful if you're only interested in UA-value.

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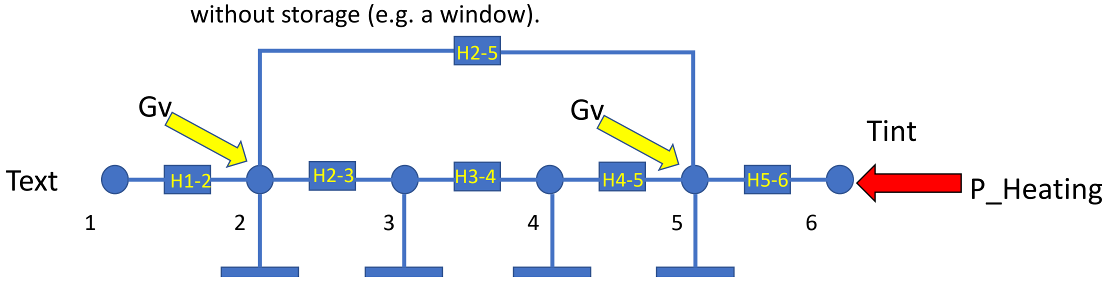
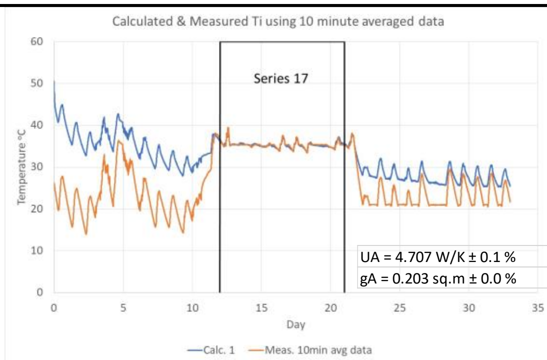
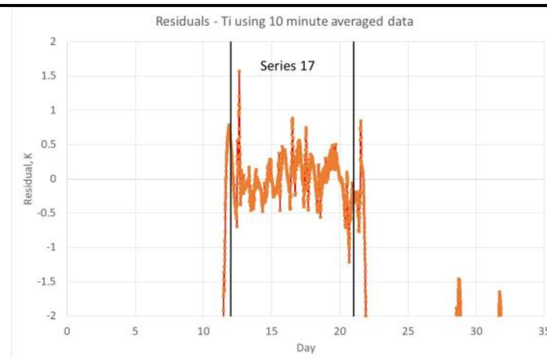
'Whole Building' model

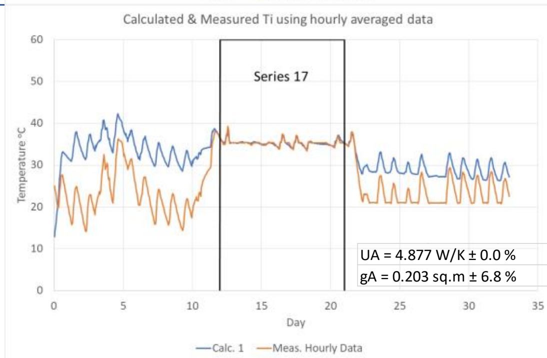
- Represent in LORD with six nodes (could be less!):

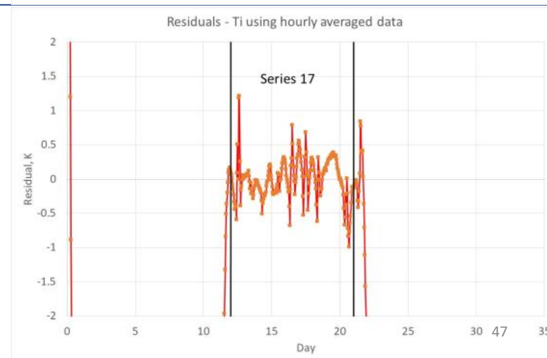
The additional parallel conductance H2-5 connected between node 2 and 5 allows for thermal conduction without storage (e.g. a window).

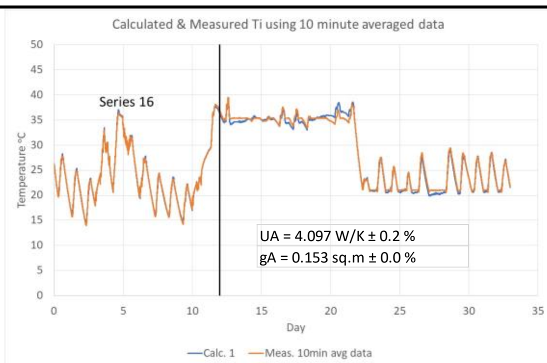


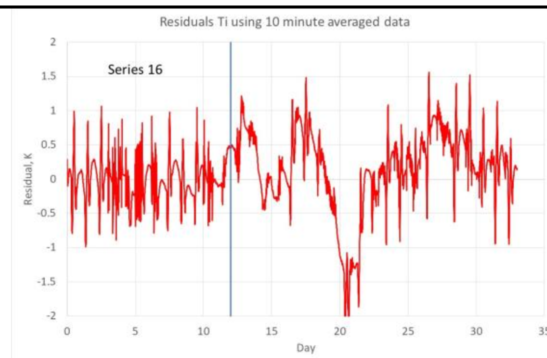

Calculated & Measured Ti using 10 minute averaged data
Series 17
UA = 4.707 W/K ± 0.1 %
gA = 0.203 sq.m ± 0.0 %
Temperature °C
Day
Calc. 1
Meas. 10min avg data

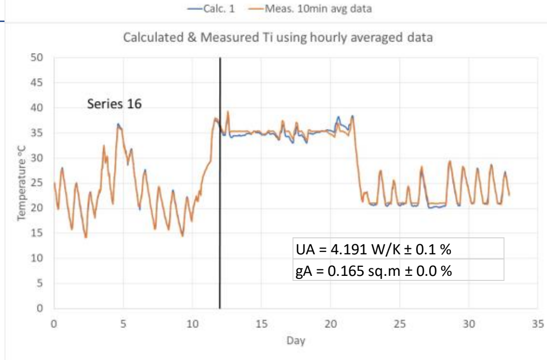

Residuals - Ti using 10 minute averaged data
Series 17
Residual, K
Day

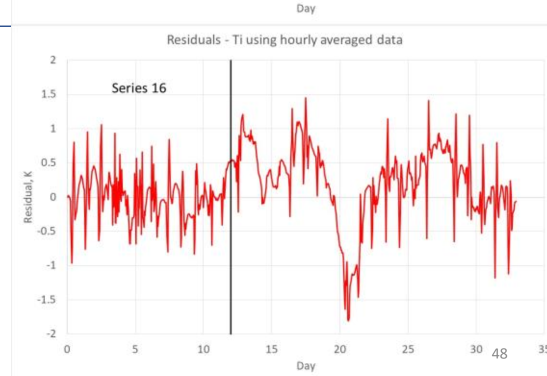

Calculated & Measured Ti using hourly averaged data
Series 17
UA = 4.877 W/K ± 0.0 %
gA = 0.203 sq.m ± 6.8 %
Temperature °C
Day
Calc. 1
Meas. Hourly Data


Residuals - Ti using hourly averaged data
Series 17
Residual, K
Day


Calculated & Measured Ti using 10 minute averaged data
Series 16
UA = 4.097 W/K ± 0.2 %
gA = 0.153 sq.m ± 0.0 %
Temperature °C
Day
Calc. 1
Meas. 10min avg data


Residuals Ti using 10 minute averaged data
Series 16
Residual, K
Day


Calculated & Measured Ti using hourly averaged data
Series 16
UA = 4.191 W/K ± 0.1 %
gA = 0.165 sq.m ± 0.0 %
Temperature °C
Day
Calc. 1
Meas. Hourly Data


Residuals - Ti using hourly averaged data
Series 16
Residual, K
Day

Results

- Expected the more steady state Series 17 would give good results,
- However UA- & gA-values using Series 17 are high.
- Also the model fit to the rest of the data (Series 16 & 18) is poor.

- Series 16 gives better results and overall a better fit to *all* data.

- Do we use 10min or hourly data?
- Are there problems with high frequency data using LORD?
- Try different model?

Comments & Conclusions

- Important to understand the physical system, for example, the construction of the PSA test cell and sensor locations.
- Plot the data – check for integrity.
- Use simple averaging or Siviour analysis to estimate results prior to using identification techniques.
- Select suitable data averaging period, particularly for dynamic test sequences.
- Compare different parts of test sequences.
- Note: I've not mentioned Capacitance!

Thank You!