Introduction to LORD

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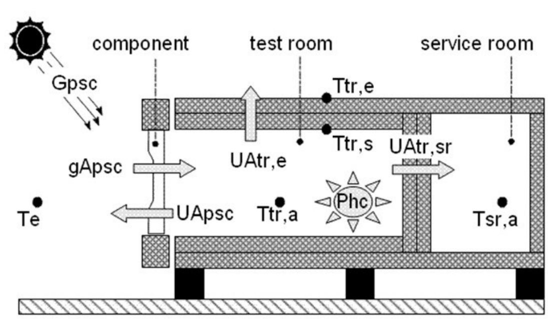
Origins

- 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.



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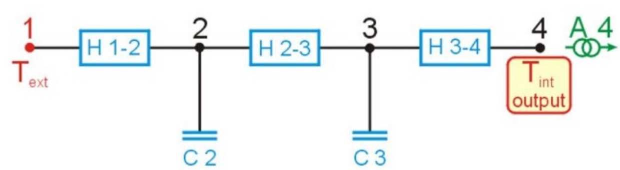
Purpose

- 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.

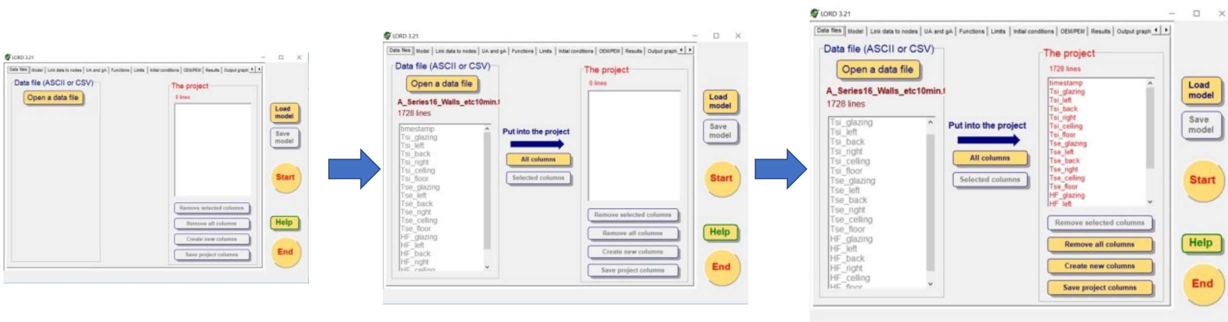
The user defines a RC-network



- 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.

(Mostly) User friendly interface

Step 1 - Input data: go to Data File tab.

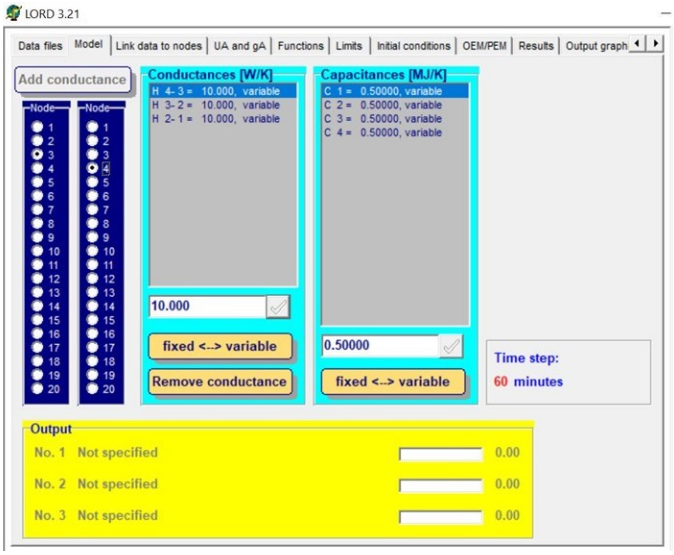


File formats – tab deliminated or CSV

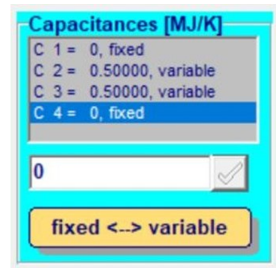
Headers must be enclosed in single quotation marks

	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

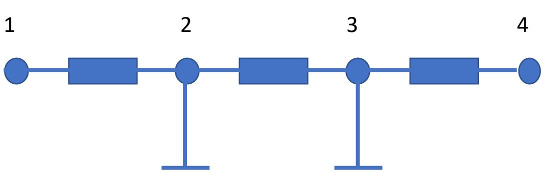
Step 2 – Create a model



Usually set capacitances at internal and external nodes to zero.

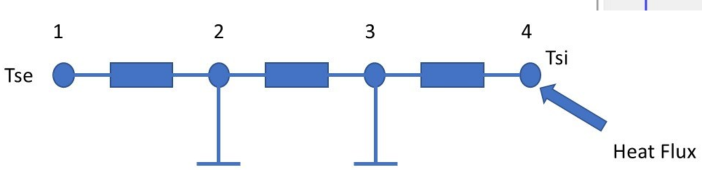


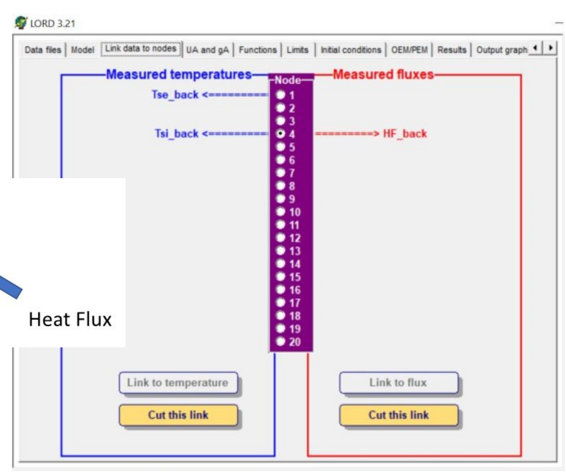
Check that time step is correct (note default is 60 minutes)



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

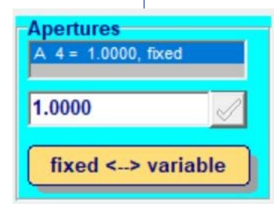
Step 3 – Link data to nodes





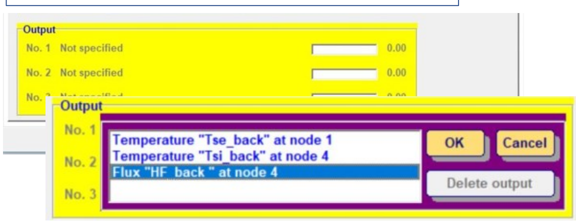
Step 4 – Go back to Model!

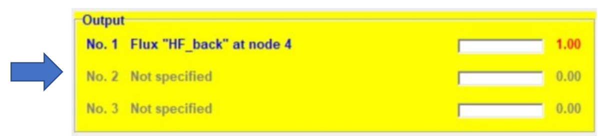
Fix Aperture = 1
for measured *Heat Flux or Heating Power*



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

Select Output

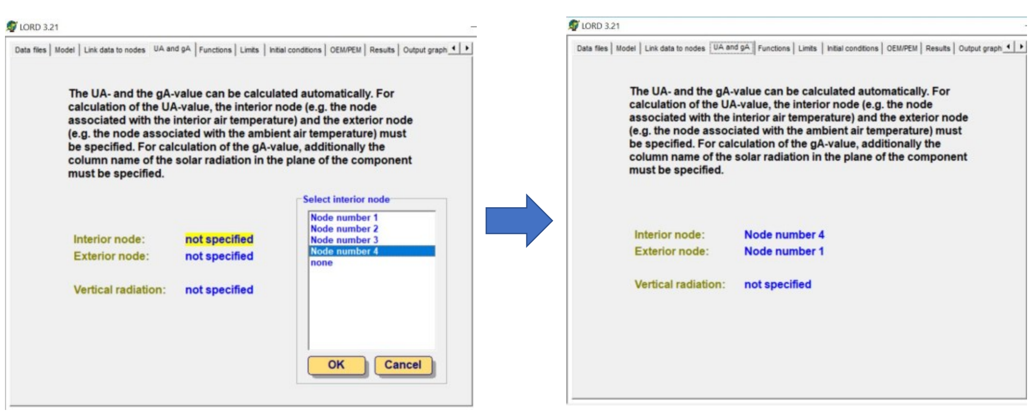




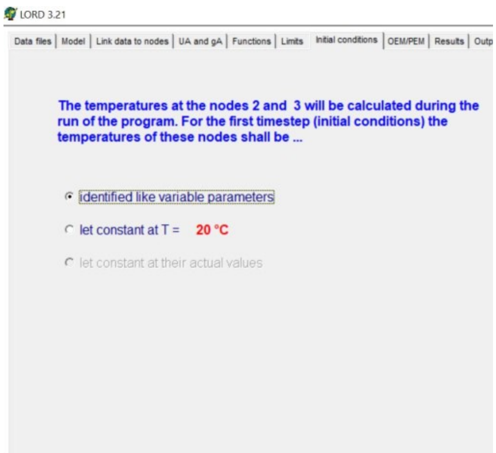
Step 5 - UA & gA

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

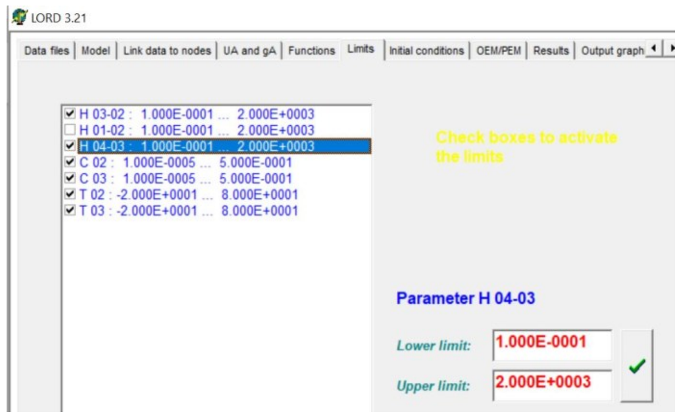
For our 4-node model we need to specify interior & exterior nodes:



Step 6 – Initial Conditions



Step 7 – Limits

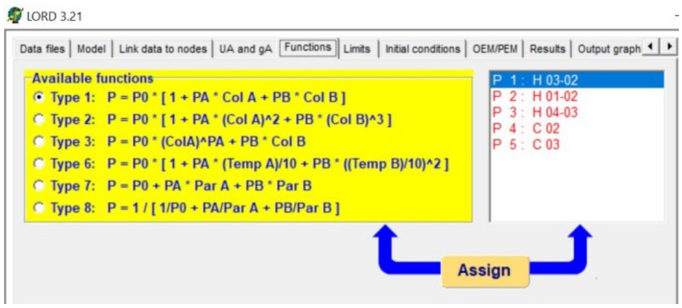


Step 8 – OEM/PEM

Recommend →

- LORD originally developed using OEM. PEM added later.
- 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!

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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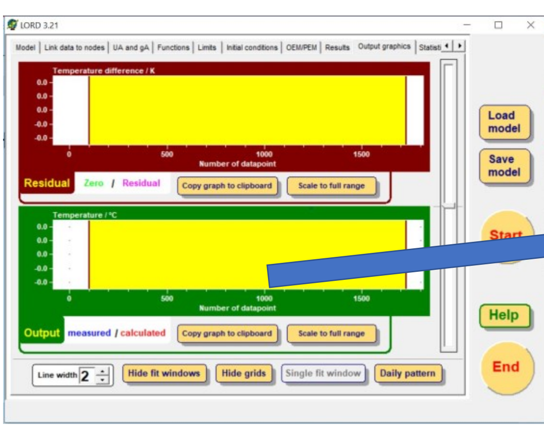
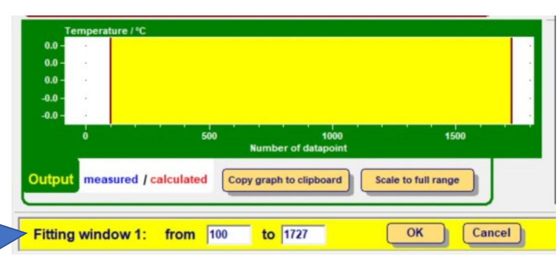
Other Options – Output Graphics & 'Fitting Windows'

- 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

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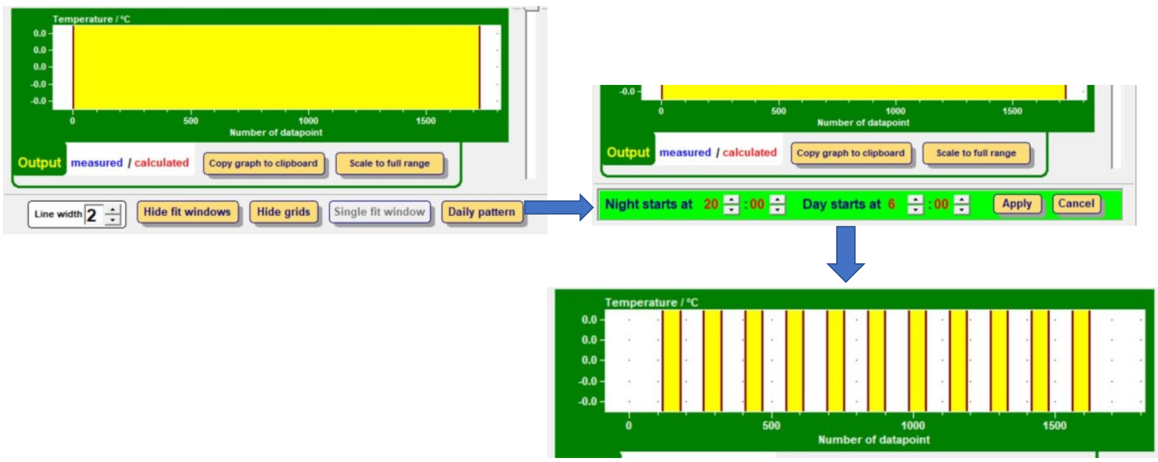
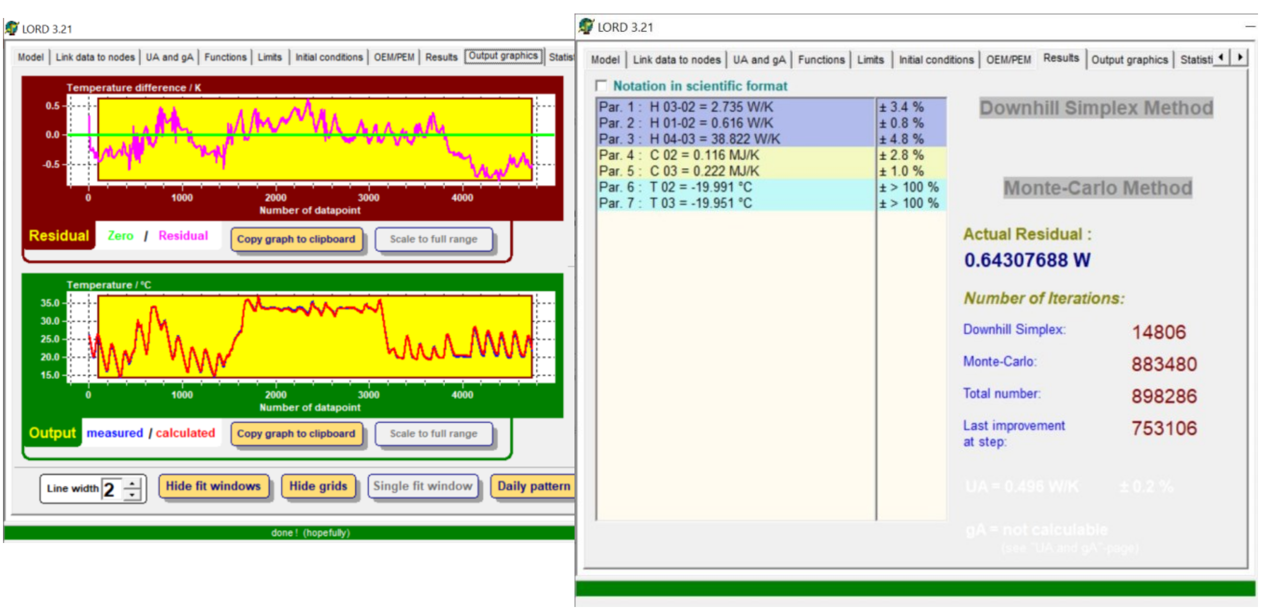
Daily Pattern – useful, for example, for excluding daytime data for heat flow measurements through windows.



SS21 15

Run!



SS21 16

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.
```

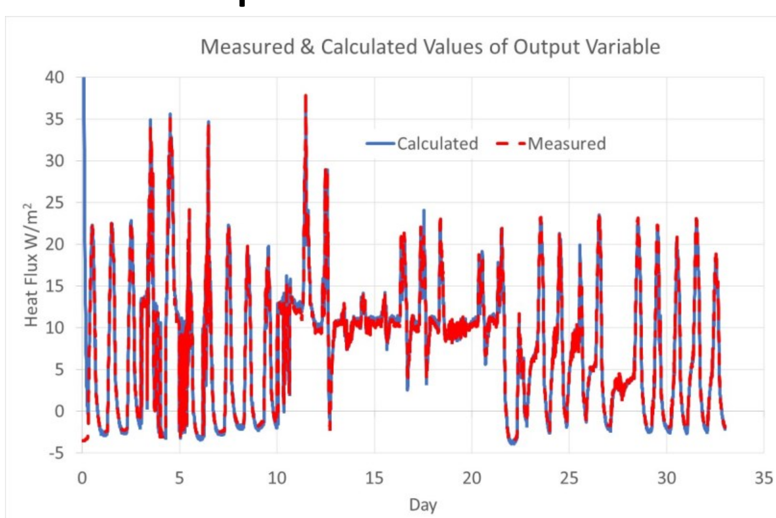
```
=======
Results
=======

----------
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
```


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

Back_10min-5 - Notepad

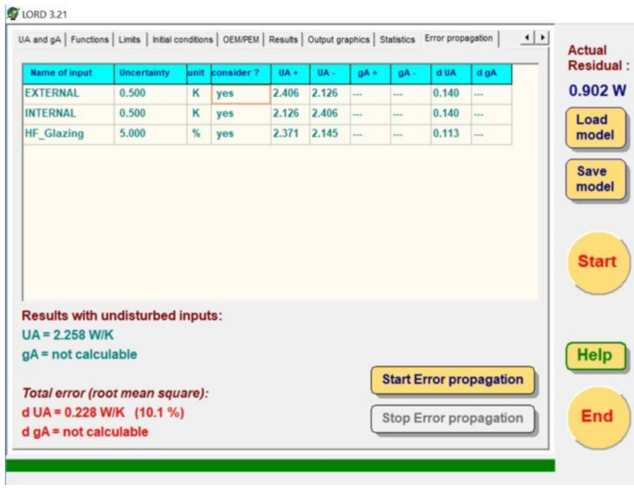
File Edit Format View Help

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



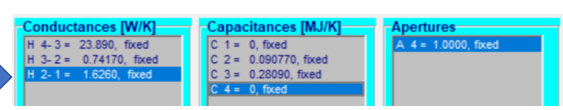
Save Model

A final option is to run Error Propagation:

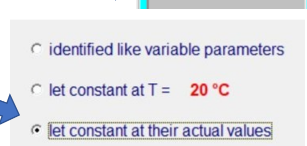


Using LORD for Simulation/Validation

- 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.

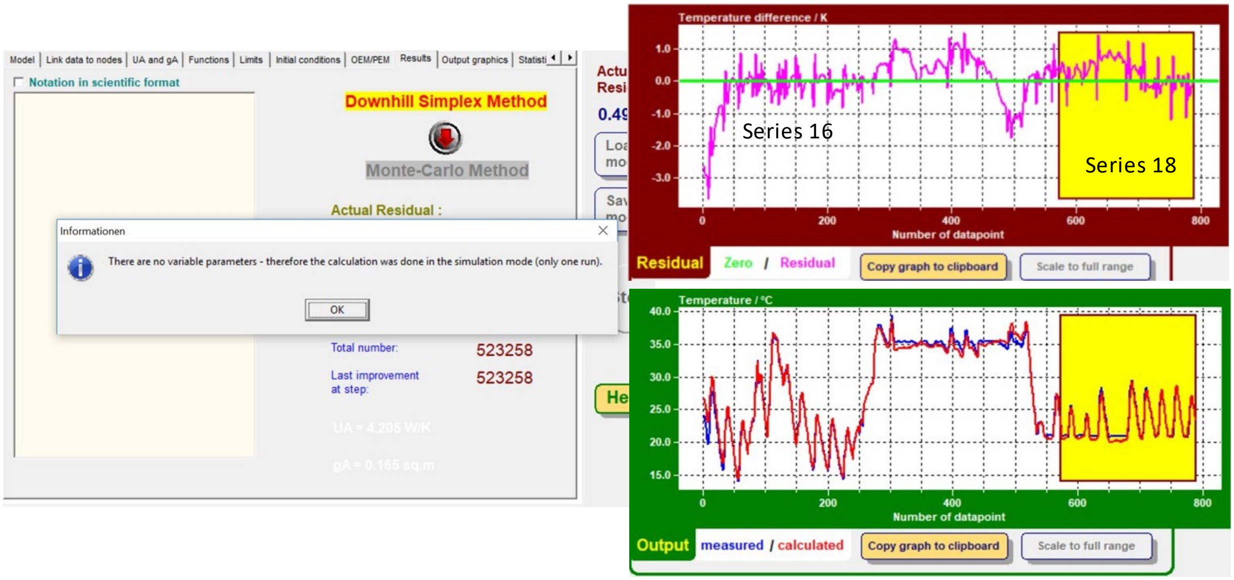


- Set initial conditions.



- Move window over Series 18.
- Run LORD.

Using LORD for Simulation/Validation



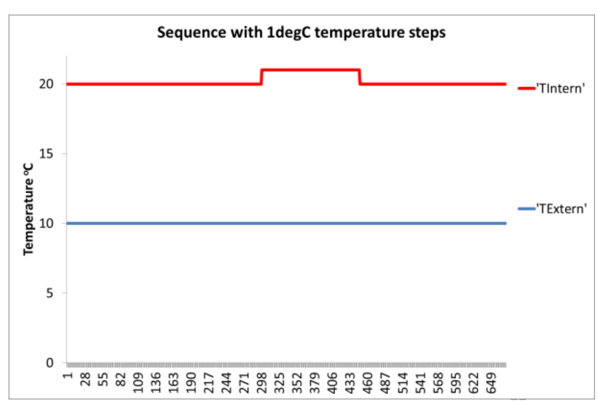
Simulation mode – time constants

- Run LORD with data set
- Save model when satisfied with results
- Create simulated data file:

➢heat flux as original file (which is not used in next step using LORD in simulation mode)

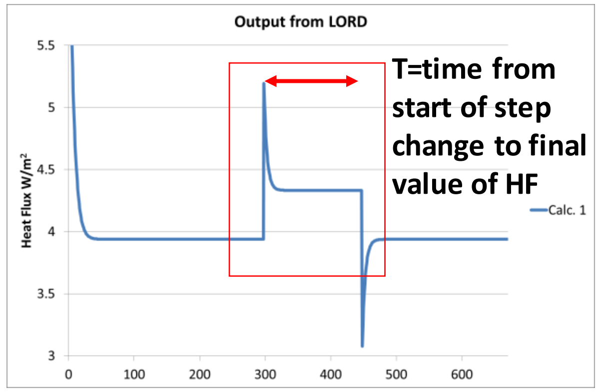
➢**with fixed external temperature**

➢**fixed internal temperature with a 1degC step change....**



Simulation mode – time constants

- Open the simulated data file.
- Load the model used previously.
- Fix the parameters in the model.
- Fix the initial conditions.
- Set the output to Heat Flux.
- Run LORD
  - it will run in simulation mode.
- Open ***.res file in Excel
- Find period corresponding to step change..



Time Constants and Capacitance

T = 47 hours

Time constant = τ or 3τ

τ = 63.212% x T = 29.7 hours 3τ = 95% x T = 44.6 hours

The Resistance of the model =2.54 m^2K/W

Capacitance = Time Constant/R

For τ: Capacitance = **11.7** Wh/Km^2

For 3τ: Capacitance = **17.6** Wh/Km^2

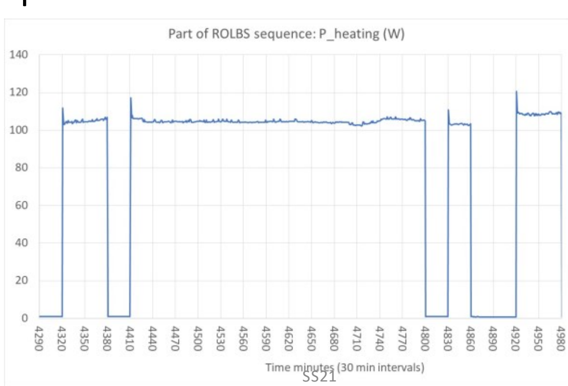
There are other methods of obtaining the capacitance

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		

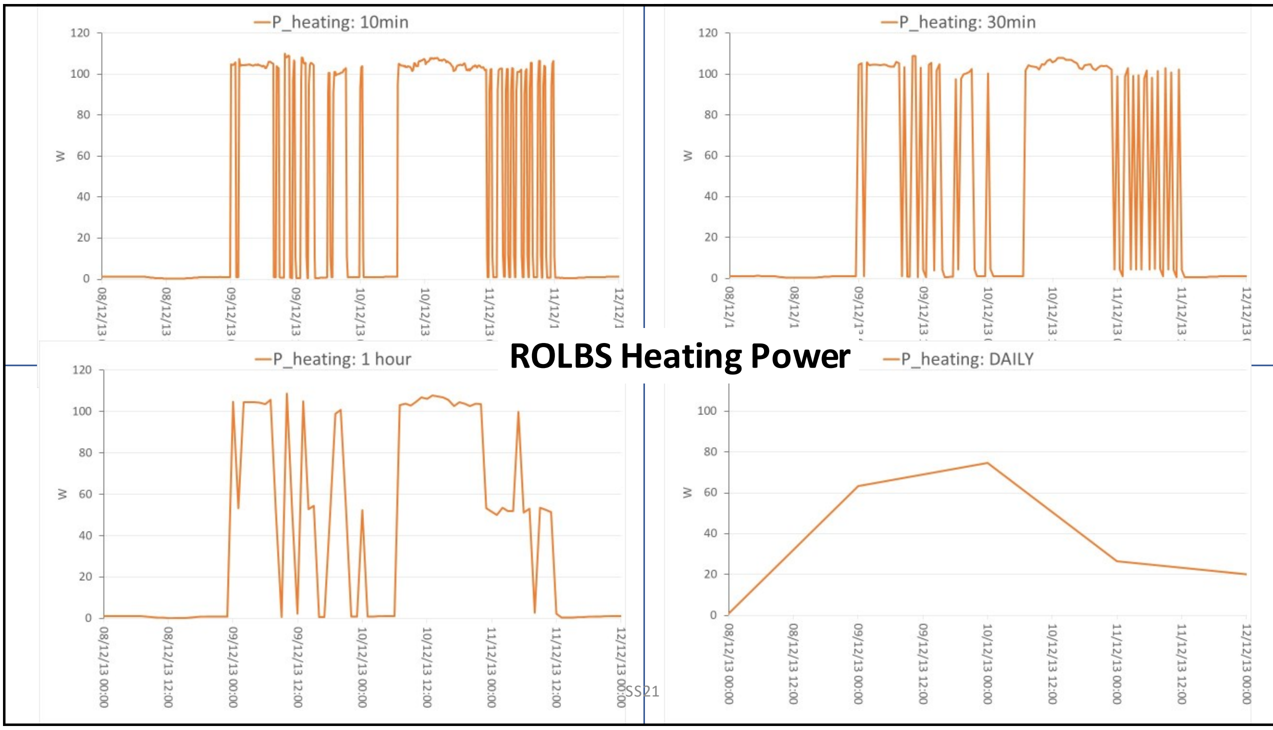
Inspect data: Sequence changes on the hour or half hour.

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

This captures all the dynamic information.

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

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


ROLBS Heating Power
P_heating: 10min
P_heating: 30min
P_heating: 1 hour
P_heating: DAILY
W
SS21

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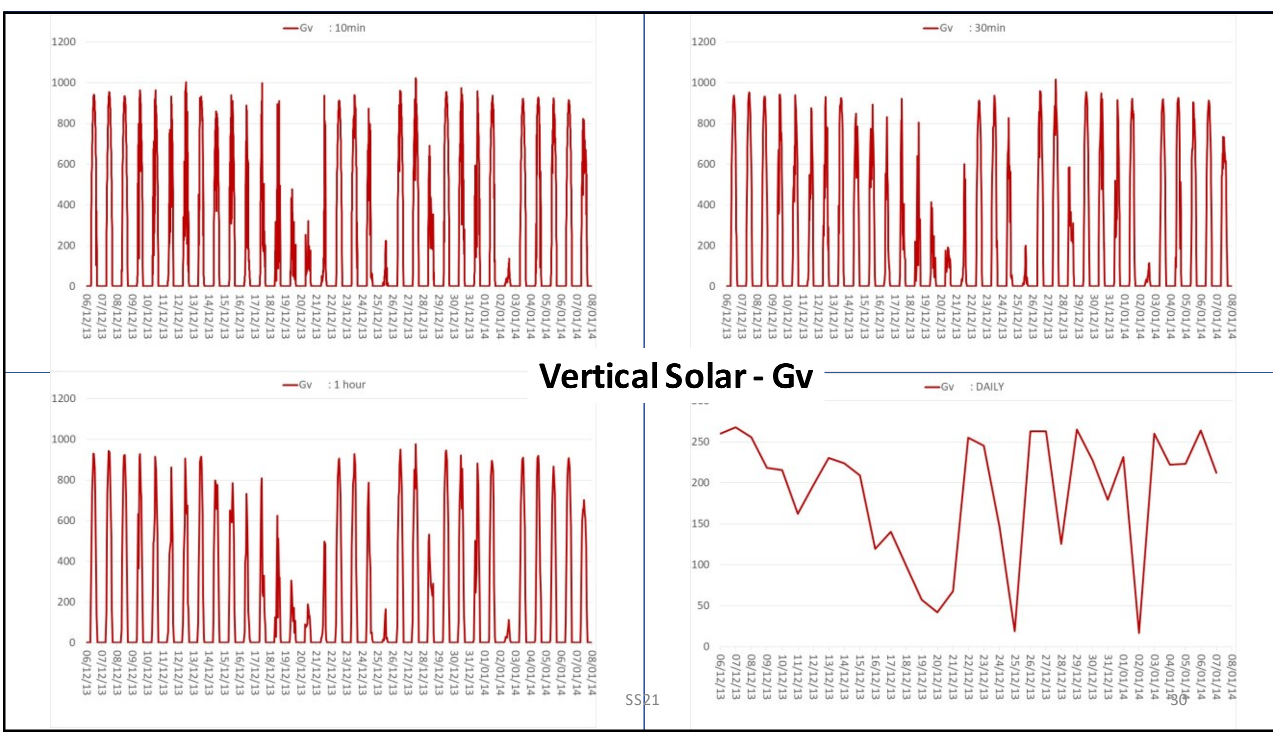
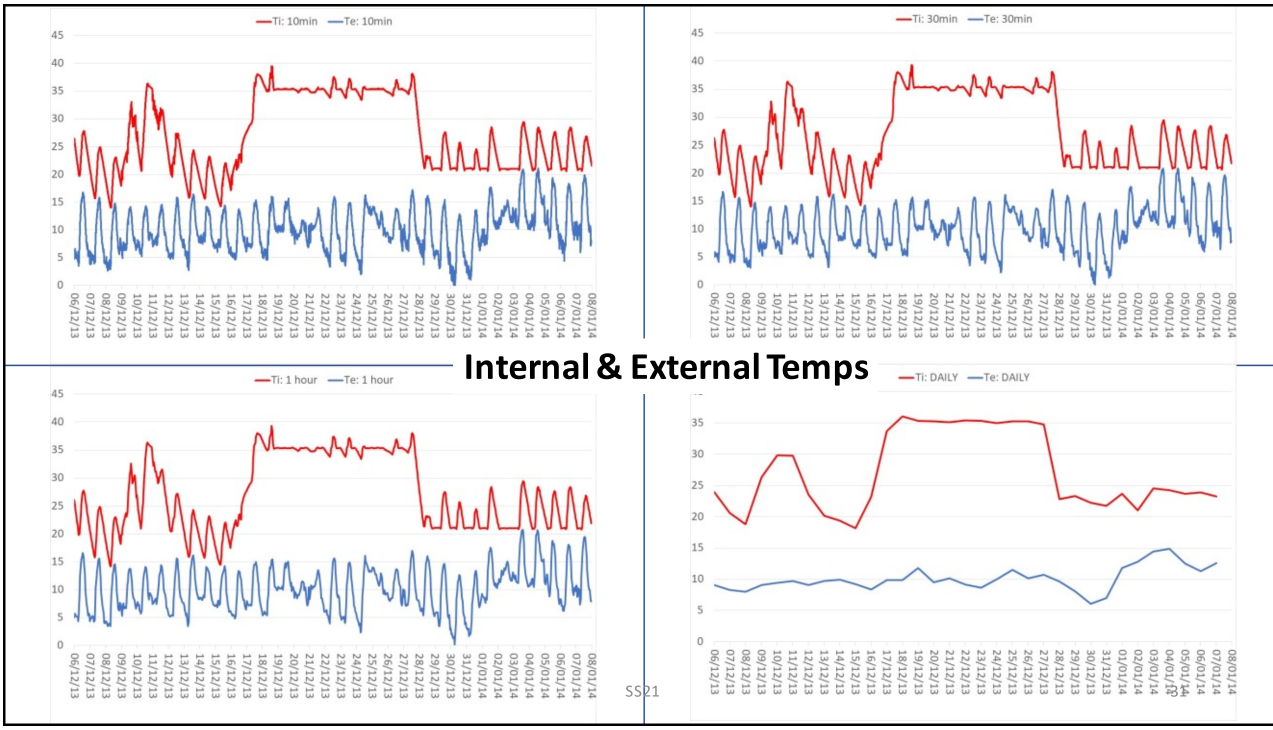

Vertical Solar - Gv
Gv : 10min
Gv : 30min
Gv : 1 hour
Gv : DAILY
SS21

30

Internal & External Temps



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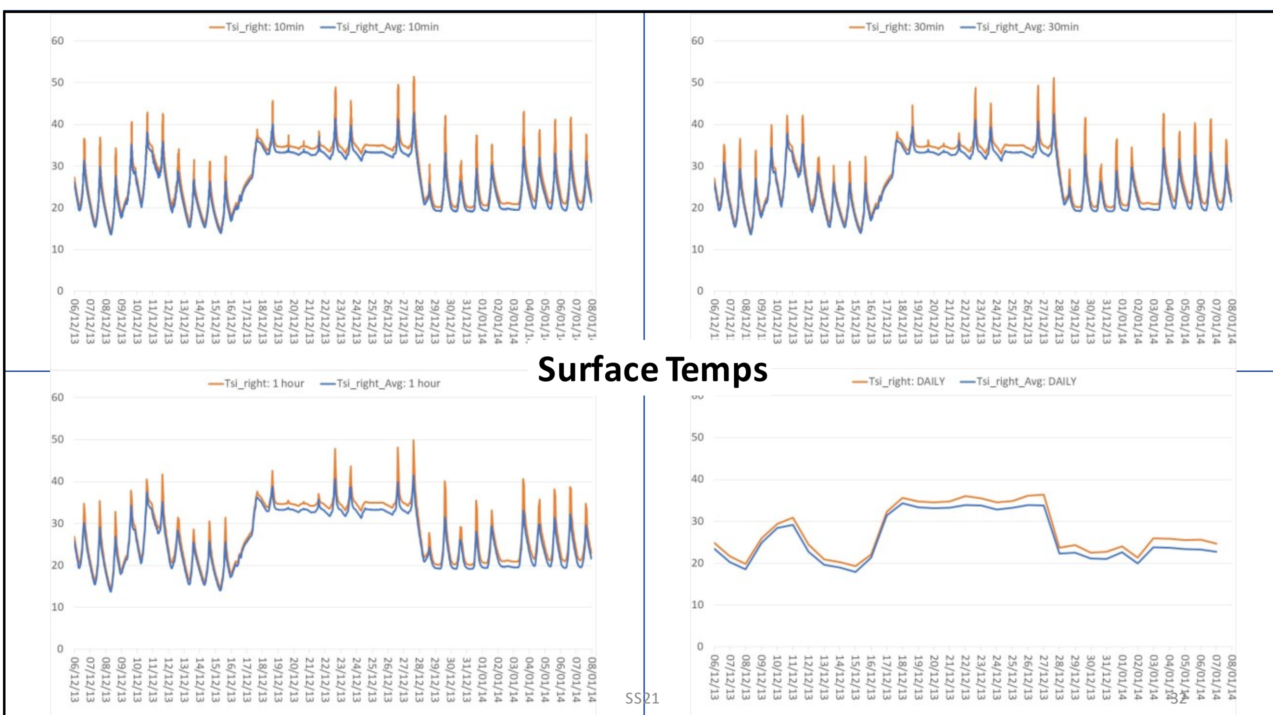
Surface Temps



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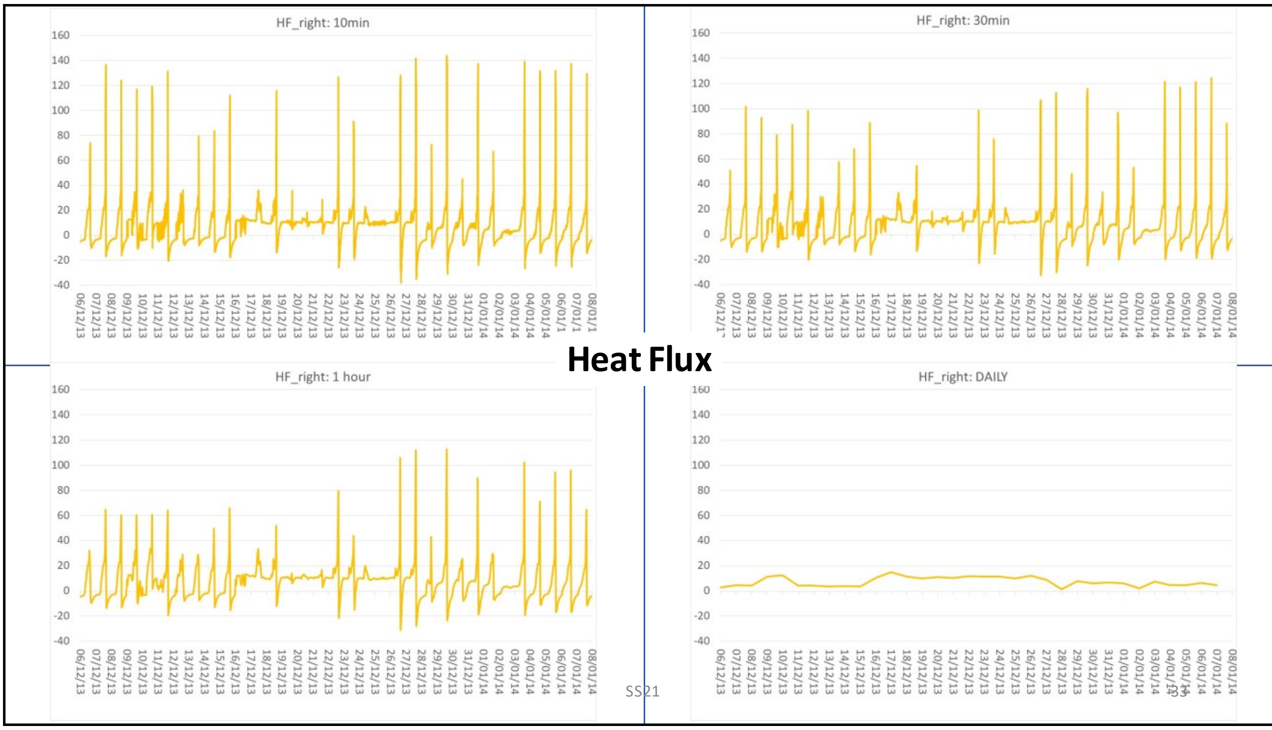
Heat Flux



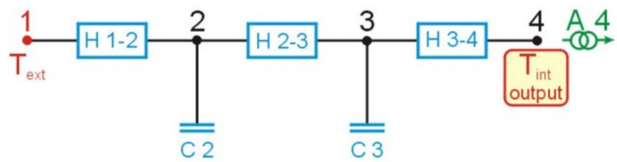
Applying LORD to Heat Flux Measurements from PSA data

- 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.

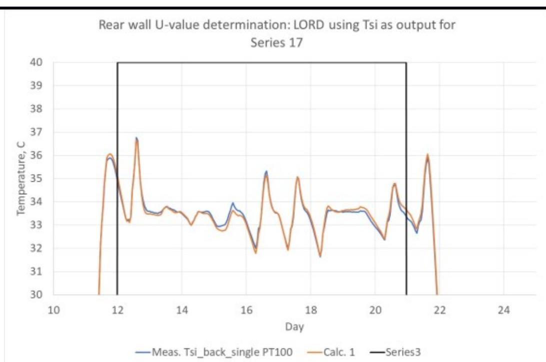
	U-value based on Tsi, Tse & HF				
	Left	*Back*	*Right*	*Ceiling*	*Floor*
ALL Data	0.44	0.46	0.41	0.45	0.53
Series 16	0.47	0.48	0.42	0.48	0.57
Series 17	0.45	0.45	0.42	0.45	0.48
Series 18	0.41	0.43	0.37	0.42	0.55
	U-value based on Ti, Te & HF				
	Left	*Back*	*Right*	*Ceiling*	*Floor*
ALL Data	0.46	0.45	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

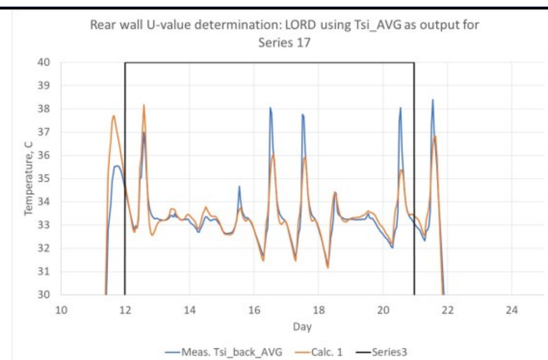
Using LORD

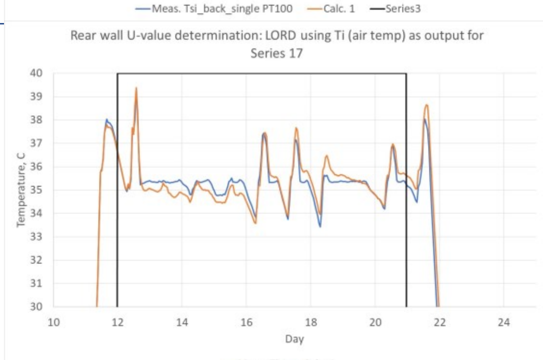
- The rear wall is used as an example.
- Use the basic 4 node model.



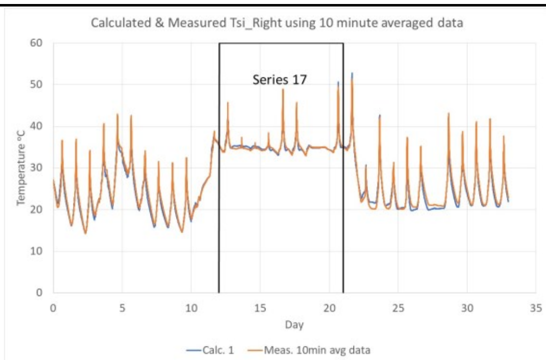
- I've used the external surface temperature Tse and the PT100 internal temperature Tsi because it is more local to heat flux sensor.
- I tried Tsi_Avg and Ti, however Tsi produced better results – lower residuals.

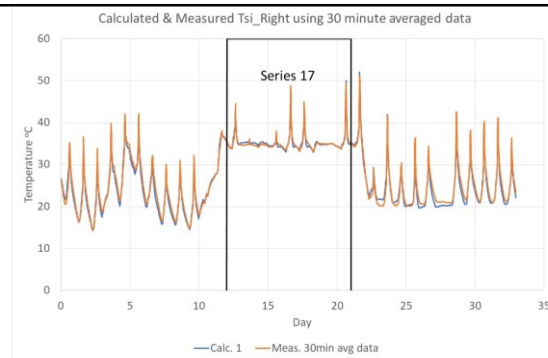


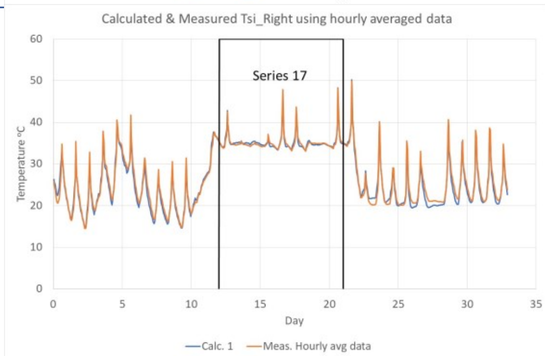




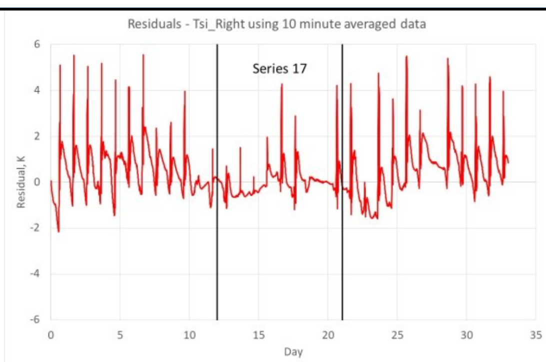
Tsi appears to give best fit

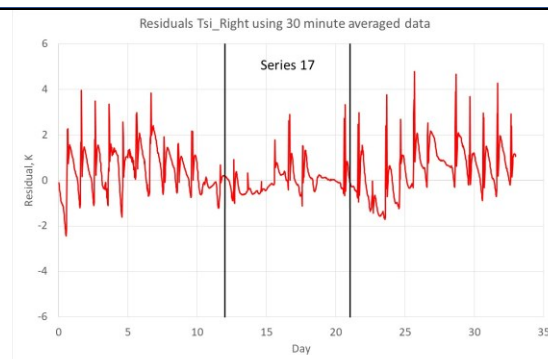


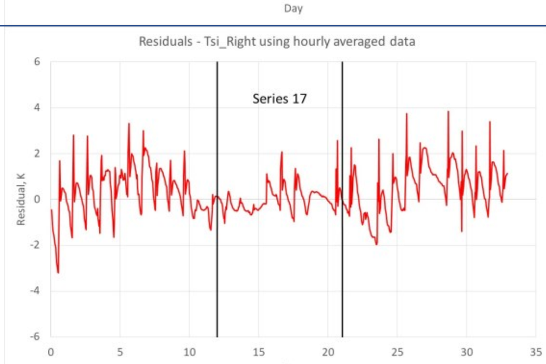




	Averaging Period	U-value, W/m^{2}K
LORD	10 min	0.42
LORD	30 min	0.42
LORD	Hourly	0.42
Averaging Method		0.42







- 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

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

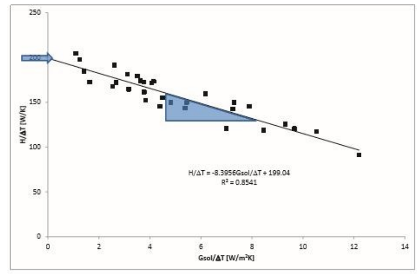
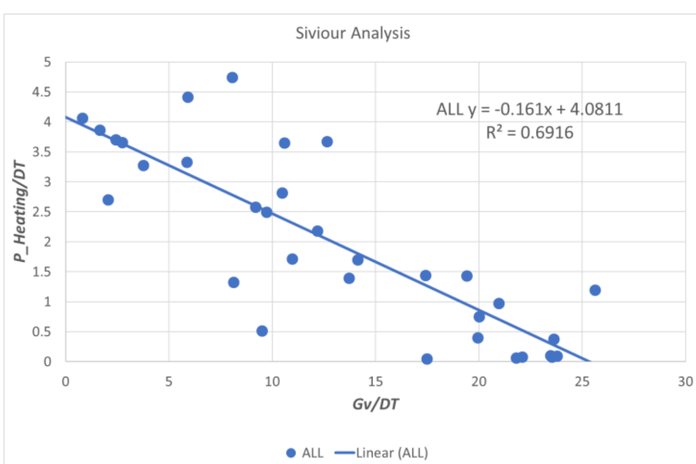


Figure A2: Example of X-Y plot of co-heating test data (Siviour analysis). The intercept of the linear regression line is the whole house heat loss coefficient and the slope is the solar gain factor

All data Series 16-18



Divide into 3 series

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

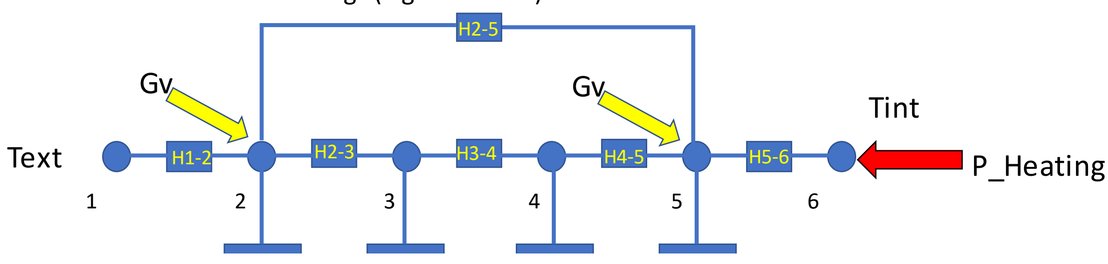
Best 'steady state' data series with high ΔT

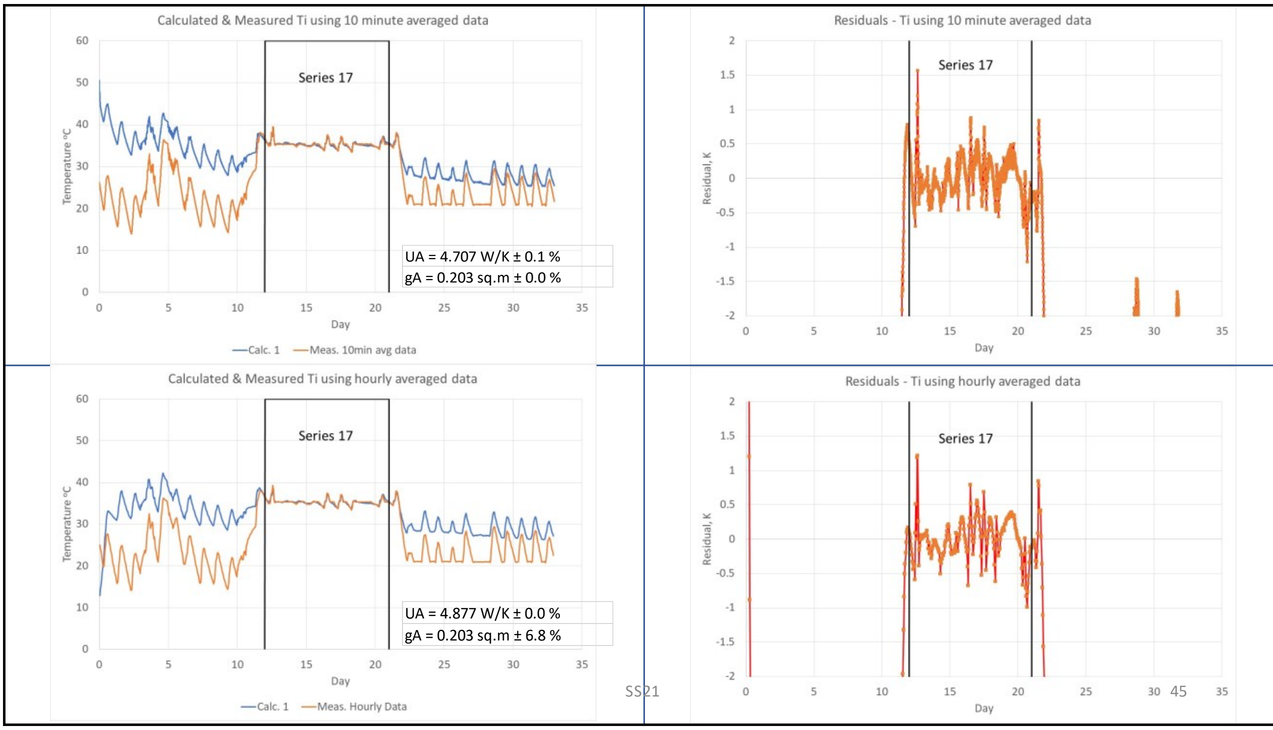
This suggest that the data series would *possibly* give good results for steady state parameters using LORD, etc.

'Whole Building' model

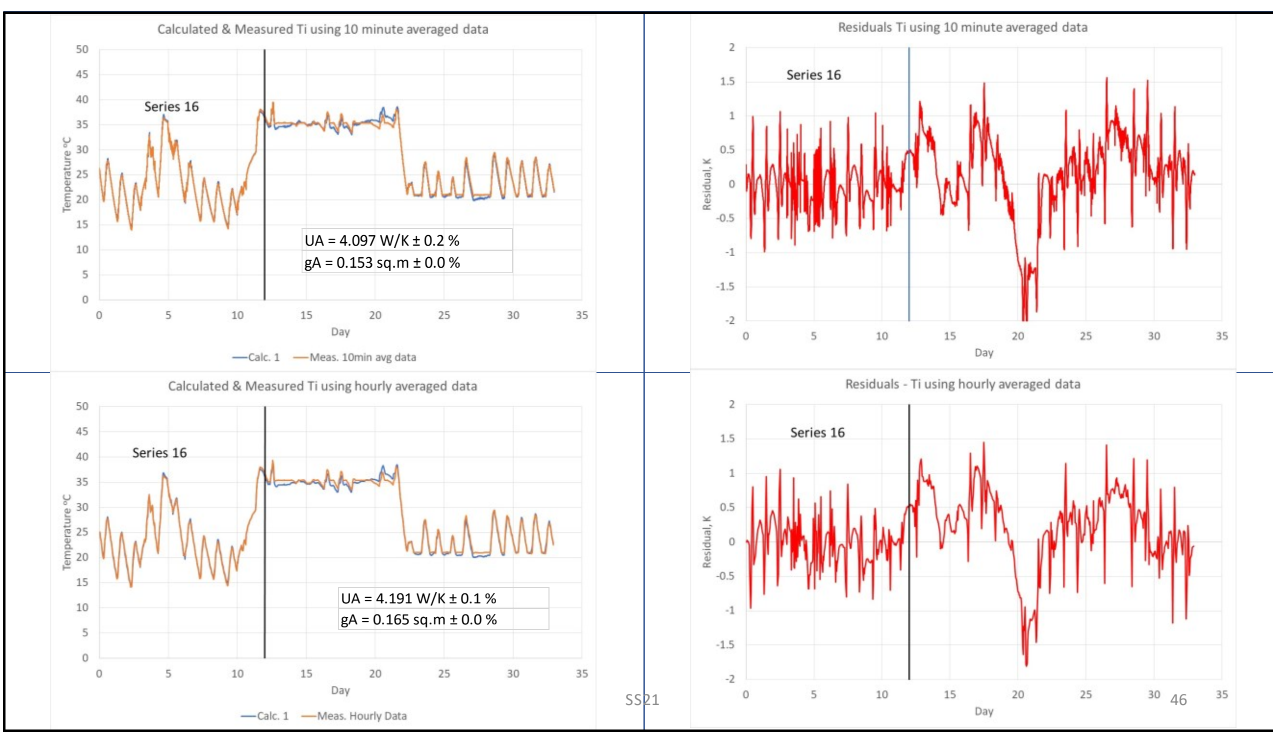
- Represent in LORD with six nodes (could be less!):

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
SS21
45

45


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
SS21
46

46

Results

- Expected the more steady state Series 17 would give good results.
- However UA- & gA-values using Series 17 are high.
- Also the fit of the model 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.
- Possible to estimate time constants using 'simulation' mode.

Useful Reference

- Baker P.H. and van Dijk H.A.L. PASLINK and dynamic outdoor testing of building components. Building and Environment Vol.43 pp143–151, 2008

Thank you Maria for your presentation

Thank you all for attending today's webinar

You can send further questions you might have, via email to

Hans Bloem at: hans.bloem@inive.org

The Webinar will now close.