6. APPLICATION OF THE AVERAGE METHOD TO ALL CASES

J.J. Bloem

ABSTRACT

This chapter describes the application of the classical steady state method, also referred to as the average method. The method is a straightforward analysis technique which provides some quantitative and qualitative information about the measured data and is therefore very useful as a first step in the analysis process. However in general the disadvantage of the application of the average method is the long test duration to obtain a relative accurate result. Furthermore it does not give information about the dynamics of the physical system.

1.1. INTRODUCTION

The average method as applied to the 5 cases in the competition, uses measurements of three quantities over the whole test period. These quantities are the indoor temperature (T_{in} in K), the outdoor temperature (T_{out} in K) and the heat flow through the wall measured at one side of the wall (q in W/m^2). The time interval between successive measurements is usually one hour. The formula below gives the estimate of the average method of the heat resistance after N measurements (R_N in Km^2/W):

$$R_N = \frac{\sum\limits_{i=1}^{N}(T_{in,i} - T_{out,i})}{\sum\limits_{i=1}^{N}q_i} \qquad (6.1)$$

In the above formula, *i* stands for the index of an observation. Putting it in words, the estimate equals the average temperature difference divided by the average heat flow rate.

According to the CEN/TC89/WG8 N90 document, "Building components and elements - in-situ measurement of thermal resistance and thermal transmittance (ISO 9869)", the average method is accurate provided it fulfils the following five conditions:

1. the test duration has to exceed 72 hours (3 days);
2. the estimate at the end of the test period should not deviate by more than 2% from the estimate at 24 hours before;
3. the estimate corresponding to the first 2/3 part of the test period should not deviate by more than 2% from the estimate corresponding to the last 2/3 part of that period;
4. during the experiment duration the wall should not be exposed to solar radiation and rain penetration;
5. the change in internal energy of the wall has to be less than 2% of the heat passing through the wall over the test period. One should estimate that change by the difference

between the average temperature of the wall at the start of the test period (T_{start} in K) and that temperature at the end of that period (T_{end} in K), multiplied by a specific heat (C in J/kgK) of 1200 J/kgK and the wall's mass (m in kg/m^2).

These conditions reflects the need for quite stable and well controlled conditions during the measurement period, which is in practice not often the case. One could apply these conditions to the cases in the competition and come to the conclusion that it might be a time consuming and costly operation to obtain such data series from real experiments. Dynamic methods could provide the necessary means to obtain accurate estimates with even shorter periods of observations.

6.2. APPLICATION

The estimation of the thermal resistance by using the average method is defined in ISO 9869 and CEN/TC89/WG8 N90. This method assumes that the surface-to-surface thermal resistance can be obtained by dividing the mean temperature difference by the mean density of heat flow rate, the average being taken over a long enough time. The thermal resistance is obtained by ;

$$R_t = \frac{\sum_{j=1}^{m}\left(T_{sij} - T_{sej}\right)}{\sum_{j=1}^{m}q_j} \qquad (6.2)$$

where:

m is the number of observations, T_{sij} and T_{sej} are respectively the external and internal surface temperature at time point j and q_j is the internal density of heat flow rate at time j.

Disadvantages of the average method are:

- no estimation of thermal capacity
- long duration of time required
- difficulty in estimation when average heat flow or temperature difference is small or zero.

Instead of applying the average method on the whole length of the data series, the method will be applied on different parts of the data. In this way results for four consecutive parts are found by using the previously stated equation. To obtain better approximations of the real value longer periods of the data series could be used, which can be easily done by applying the methods on combinations of the four parts. In this test session the thermal resistance was estimated for the following periods;

1) a, first fourth part
2) b, second fourth part
3) c, third fourth part
4) d, last fourth part
5) a+b, first half
6) b+c, second half
7) c+d, third half
8) a+b+c, first three fourth parts
9) b+c+d, second three fourth parts
10) a+b+c+d, total length

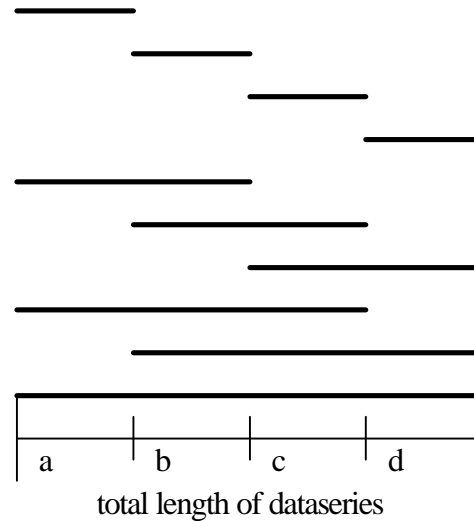total length of dataseries

For all different periods an estimate of the mean thermal resistance can be made. The results will show in a graphic the trend of the mean of the resistance. A simple control of the value gives the expected value from further (dynamic) analysis.

figure 6.1 : Dividing in four parts

A second and different way of applying the average method is to increase the length of observations with a fixed step. This step can be defined in a multiple number of observations, for example. 4 or 24 hours. Information than can be derived from the plotted data points as is illustrated for all cases in the figures on the following pages. Both ways have been applied to all five cases, respectively to the data series: Data11.txt, Data201.txt, Data301.txt, Data41.txt, Data51.txt.
This approach can be applied also, starting at different times in the data set.

6.3. AVERAGE METHOD APPLIED

The obtained range of possible estimate values then can be used in the second step of the analysis process. One may even decide to split the data set to obtain two series for cross validation of the applied model.

Dynamic analysis compared to the average method, requires less observations. One might conclude from the first application of the average method, which part of the data set could be taken as being the most stable period. The second application of the average method could indicate the length that should be used of the available data and if cross validation might be applied.

The next five pages give graphical information for each of the individual cases. As it becomes clear from the graphs, the results depends on the length of the data series as well as the part that is taken for analysis.

Case 1:

Period	Length	Estimate
1	336	7.880
2	336	8.927
3	336	10.456
4	336	9.832
5	672	8.398
6	672	9.555
7	672	10.088
8	1008	8.926
9	1008	9.658
10	1344	9.171

The true value of the resistance is 8.651

The highest value found for the estimate is 10.456 and the smallest 7.880 both from the shortest periods. One may assume the estimate should fall somewhere between these extremes. One might decide to split into two data sets, each half of the size of the provided set, for cross validation purposes.
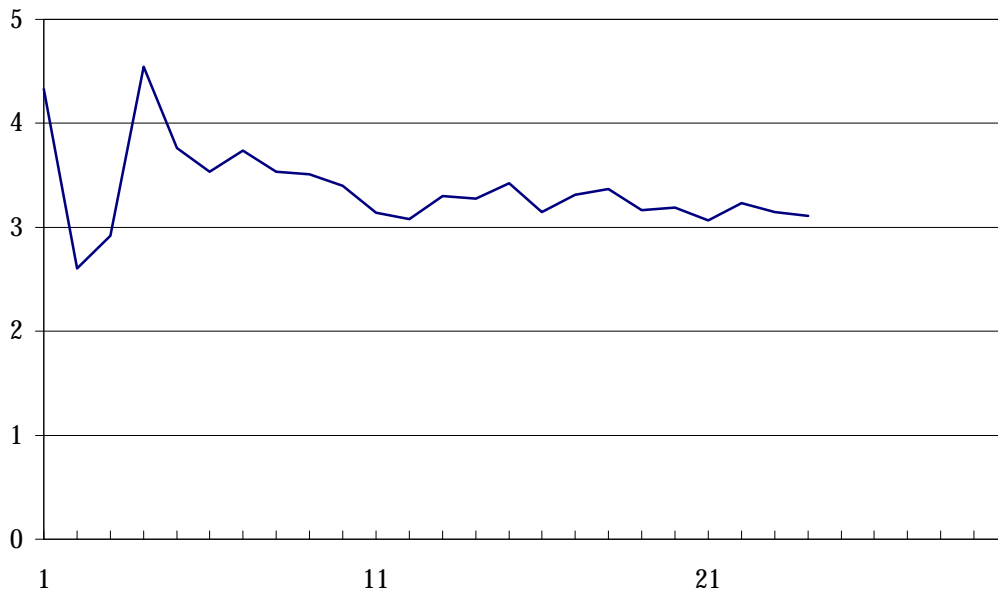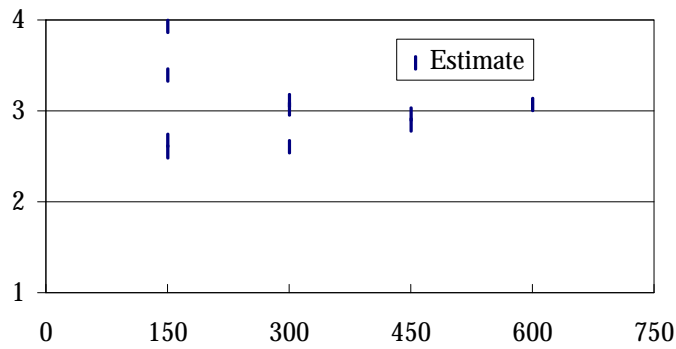
Average method applied on case 1
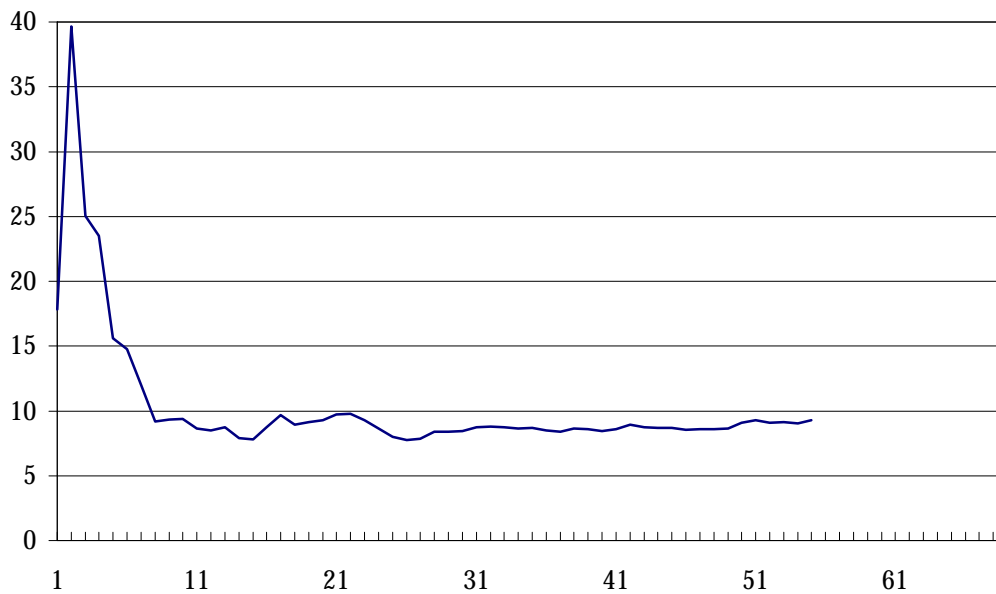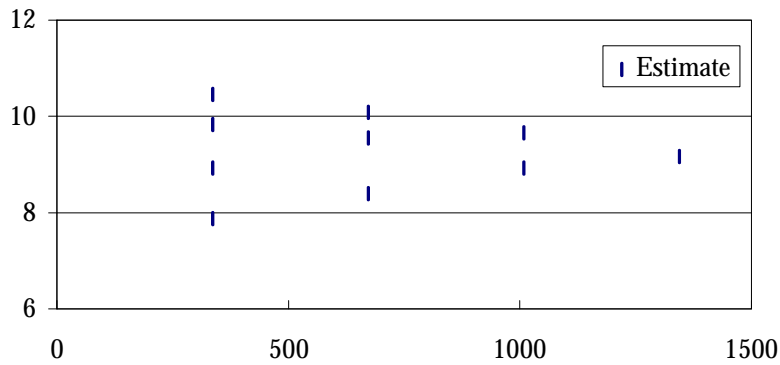
Case 2:

Number	Length	Estimate
1	150	3.927
2	150	2.550
3	150	2.675
4	150	3.391
5	300	3.115
6	300	2.608
7	300	3.022
8	450	2.967
9	450	2.845
10	600	3.069

The true value of the resistance is 3.229

Although it looks as a stable data set, it shows variation for the R from different periods. It is more difficult compared to case 1.

Average method applied on case 2

Case 3

Number	Length	Estimate
1	180	16.958
2	180	8.021
3	180	24.205
4	180	7.846
5	360	11.288
6	360	11.341
7	360	13.737
8	540	13.307
9	540	10.437
10	720	12.016

The true value of the resistance is 11.111

A difficult case as the graphs below indicate. The used thermal network, apparently is a stiff system. Although one might assume the R to be around 12 with a possible error of roughly 20%. Probably the thermal capacity is big.

Average method applied on case 3
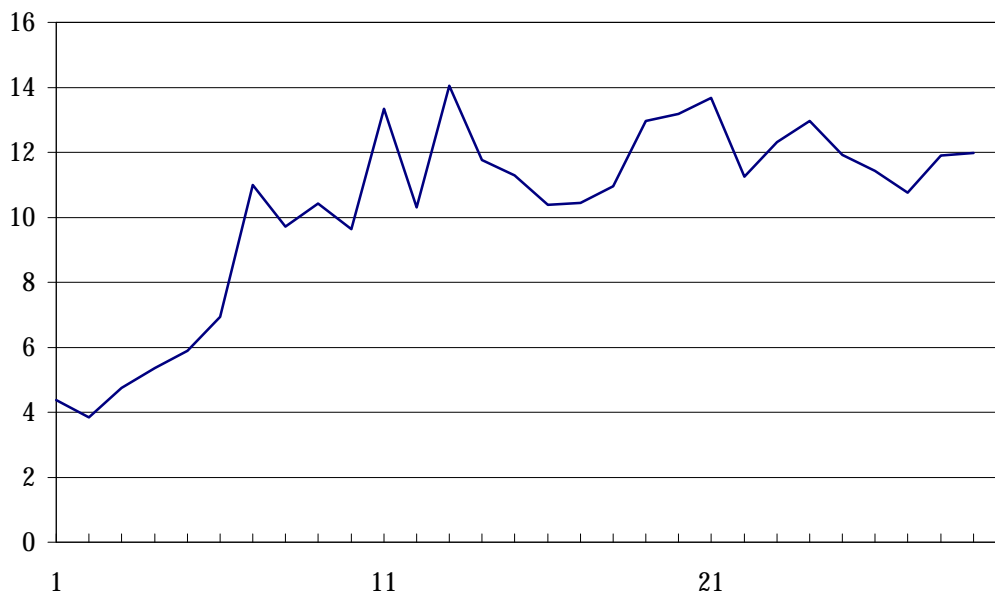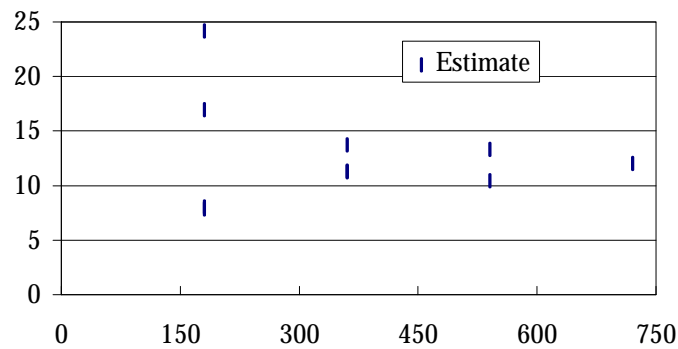
Case 4

Number	Length	Estimate
1	420	3.180
2	420	3.103
3	420	3.090
4	420	3.094
5	840	3.140
6	840	3.097
7	840	3.092
8	1260	3.124
9	1260	3.096
10	1680	3.117

The true value of the resistance is 3.140

The values found for all periods do not differ that much; within 3%. One might conclude that it is an easy case to estimate R and C and to obtain a reliable model for prediction.

### Average method applied on case 4
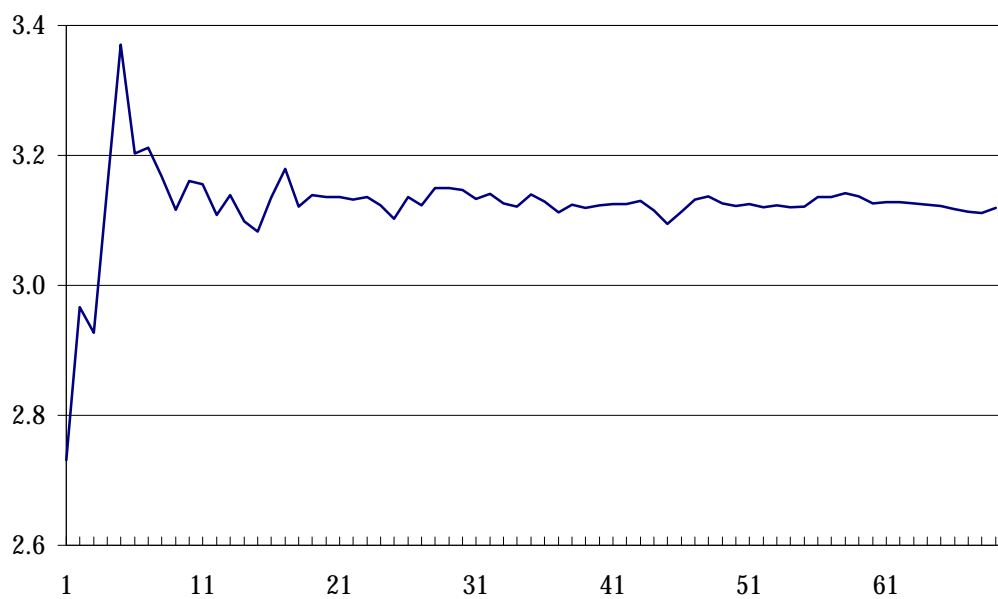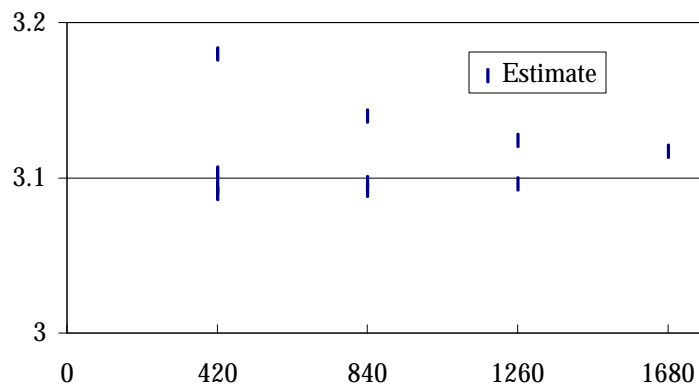
Case 5

Number	Length	Estimate
1	168	2.237
2	168	2.309
3	168	2.149
4	168	2.313
5	336	2.268
6	336	2.228
7	336	2.205
8	504	2.232
9	504	2.246
10	672	2.243

The true value of the resistance is 2.268

An accurate estimate for R should be achievable. Its variation for the different periods is about 8%. Since less data is available the prediction might become more difficult.

Average method applied on case 5
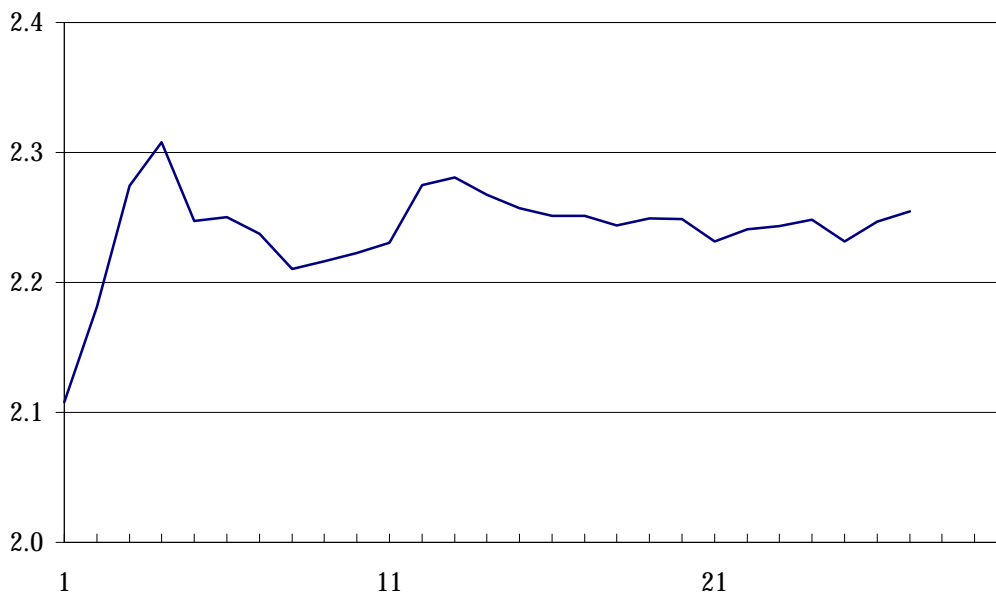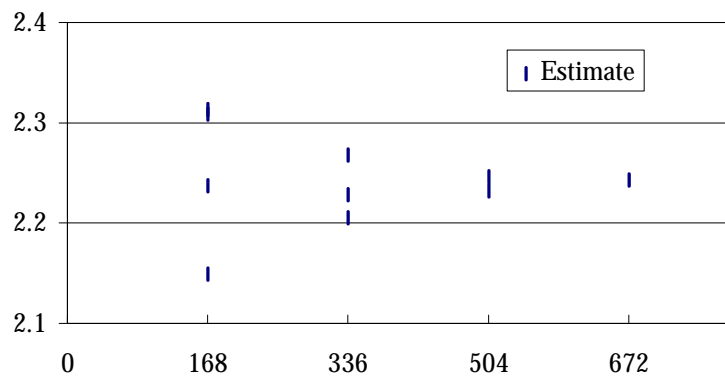
6.7. THE AVERAGE M-FILE

```
function [table]=average2(z)

% function table=avrg(z)
% This function calculates the statistics of the SysIdCom data file
% which is assumed to contain 3 columns Tout, Tin and q resp.
% The mean, maximum, minimum are calculated as well as variance.
% It calculates the value for the thermal resistance using the length
% of the dataset as a base for 10 shorter periods
% table format: size days  R4
% start         R1  R2  R3
% end           R3  R2  R1
% mid           R1  R2  R1

table=zeros(1); %initial settings
table1=zeros(1);

q=z(:,3) ; Tin=z(:,2) ; Tout=z(:,1) ;

table(1,1:4)=[min(q) mean(q) max(q) std(q)];
table(2,1:4)=[min(Tin) mean(Tin) max(Tin) std(Tin)];
table(3,1:4)=[min(Tout) mean(Tout) max(Tout) std(Tout)];

Rtot=(mean(Tin)-mean(Tout))/mean(q) ;

en=size(q) ; leng=en/100 ;
table1(1,1)=leng(1,1) ; % gives datapoints divided by 100
aa=size(q)/24 ; % gives number of days, based on hourly observations
table1(1,2)=aa(1,1) ;
table1(1,3)=Rtot(1,1) ; %is the total Ravrg

st=en/4 ;
for stp=1:3,
R=(mean(Tin(st:en))-mean(Tout(st:en)))/mean(q(st:en)) ;
table1(3,stp)=R(1,1) ;
st=st+en/4 ; %starts later and goes to end
end ;

aa=en/4 ; en=aa ;
st=1 ;

for stp=1:3,
R=(mean(Tin(st:en))-mean(Tout(st:en)))/mean(q(st:en)) ;
table1(2,stp)=R(1,1) ;
en=en+aa ; % starts at beginning and increases length
end ;

en=size(q) ;
st=en/4 ;
en=st+st ;
for stp=1:2,
R=(mean(Tin(st:en))-mean(Tout(st:en)))/mean(q(st:en)) ;
table1(4,stp)=R(1,1) ;
en=st+en ; %starts later and steps short
end ;
```

```
stp=3 ;
en=en-st ;
st=st+st ;
R=(mean(Tin(st:en))-mean(Tout(st:en)))/mean(q(st:en)) ;
table1(4,stp)=R(1,1) ;

days=size(q)/24 ;
for tel=1:(days-1),
de=24*tel ;
Rmov(tel,1)=(mean(Tin(1:de))-mean(Tout(1:de)))/mean(q(1:de)) ;
end

save Rmoving.txt Rmov -ascii
plot(Rmov(1:tel,1));

table1

end,
```

REFERENCES

CEN/TC89/WG8 N90, Building components and elements - in-situ measurement of thermal resistance and thermal transmittance (ISO 9869), working draft, (November 1994).