The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2132-39

Winter College on Optics and Energy

8 - 19 February 2010

Intermittent technology for solar drying of crops

I. Farkas
Szent Istvan University
Hungary

Department of Physics and Process Control

INSTITUTE FOR ENVIRONMENTAL ENGINEERING SYSTEMS

FACULTY OF MECHANICAL ENGINEERING

SZENT ISTVÁN UNIVERSITY

Gödöllő, Páter K. u. 1. H-2103
Hungary

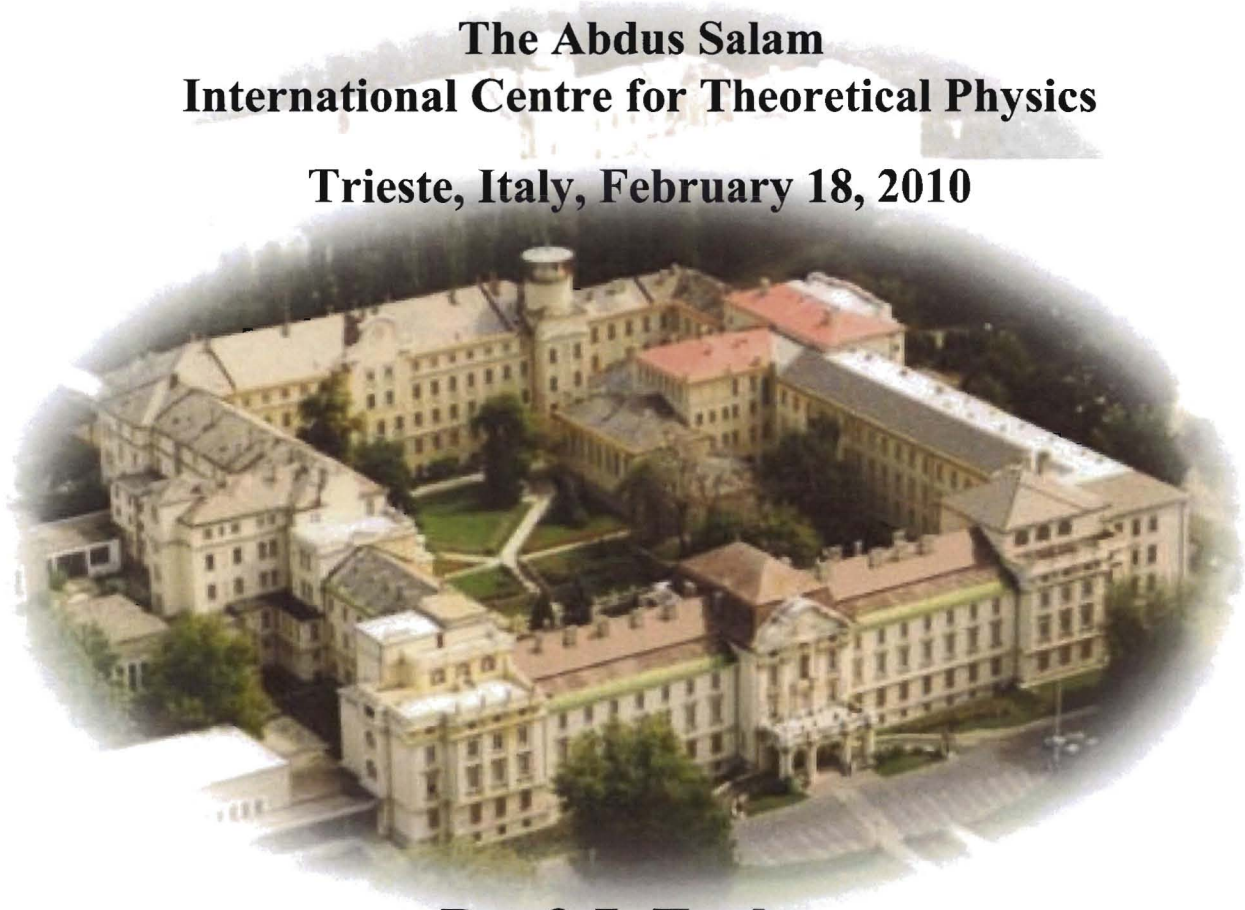
Tel: +36 28 522055
Fax: +36 28 410804
Fizika.Tanszek@gek.szie.hu
http://fft.szie.hu

TEMPERATURE AND MOISTURE CONTENT DISTRIBUTION DURING SOLAR DRYING OF FRUITS AND VEGETABLES

Winter College on Optics and Energy

The Abdus Salam
International Centre for Theoretical Physics

Trieste, Italy, February 18, 2010



Prof. I. Farkas
E-mail: Farkas.Istvan@gek.szie.hu

C O N T E N T S

- INTEGRATED SOLAR ENERGY/TECHNOLOGY SYSTEM
- EFFICIENCY OF SOLAR DRYES
- SORPTION ISOTHERMS MEASUREMENTS
- DIFFISION COEFFICIENT MEASUREMENTS
- OPTICAL MEASUREMENT OF MOISTURE CONTENT
- EXPERIMENTS WITH SOLAR DRYING
- CONCLUSIONS

Integrated solar energy/technology system

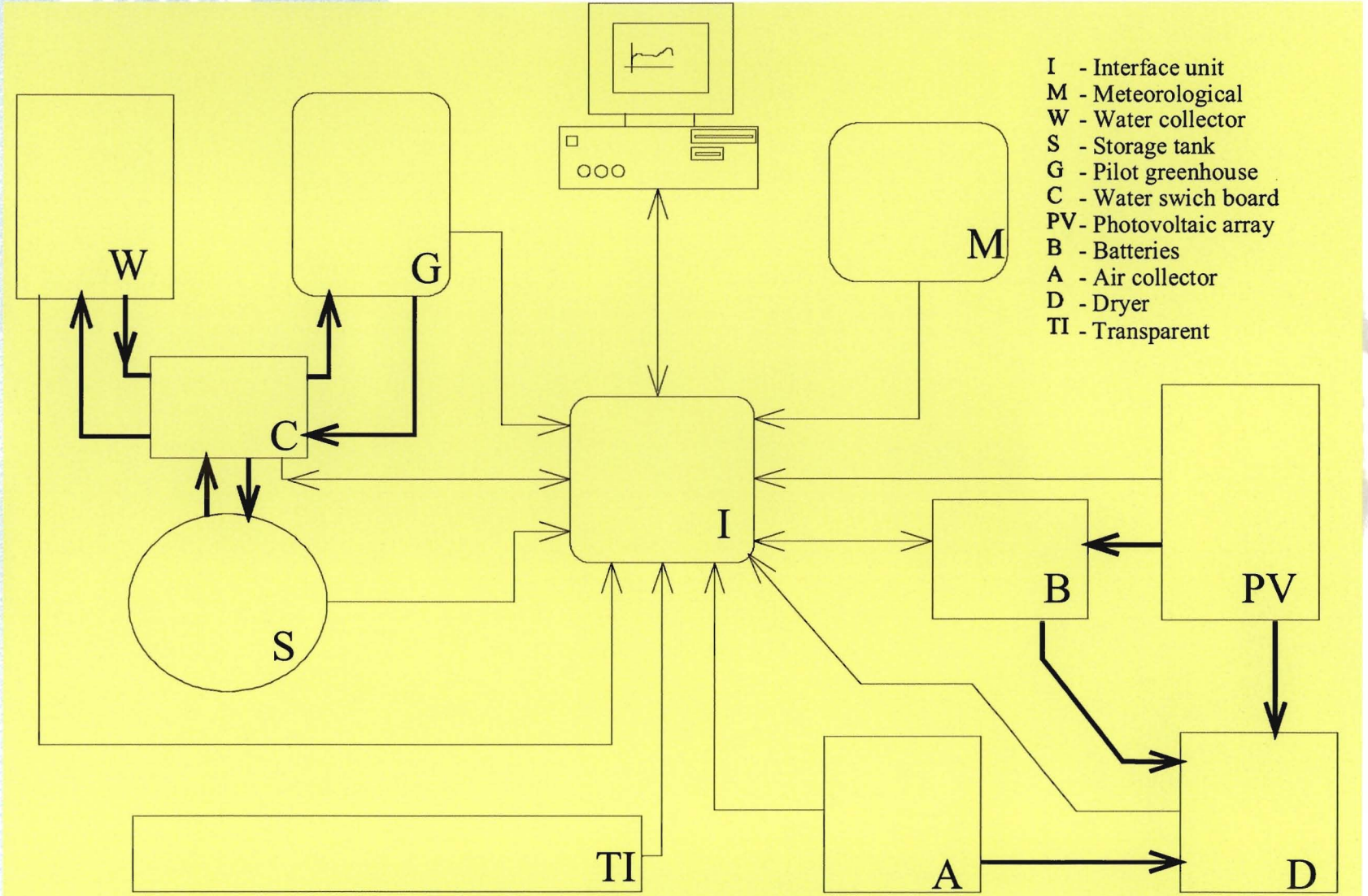
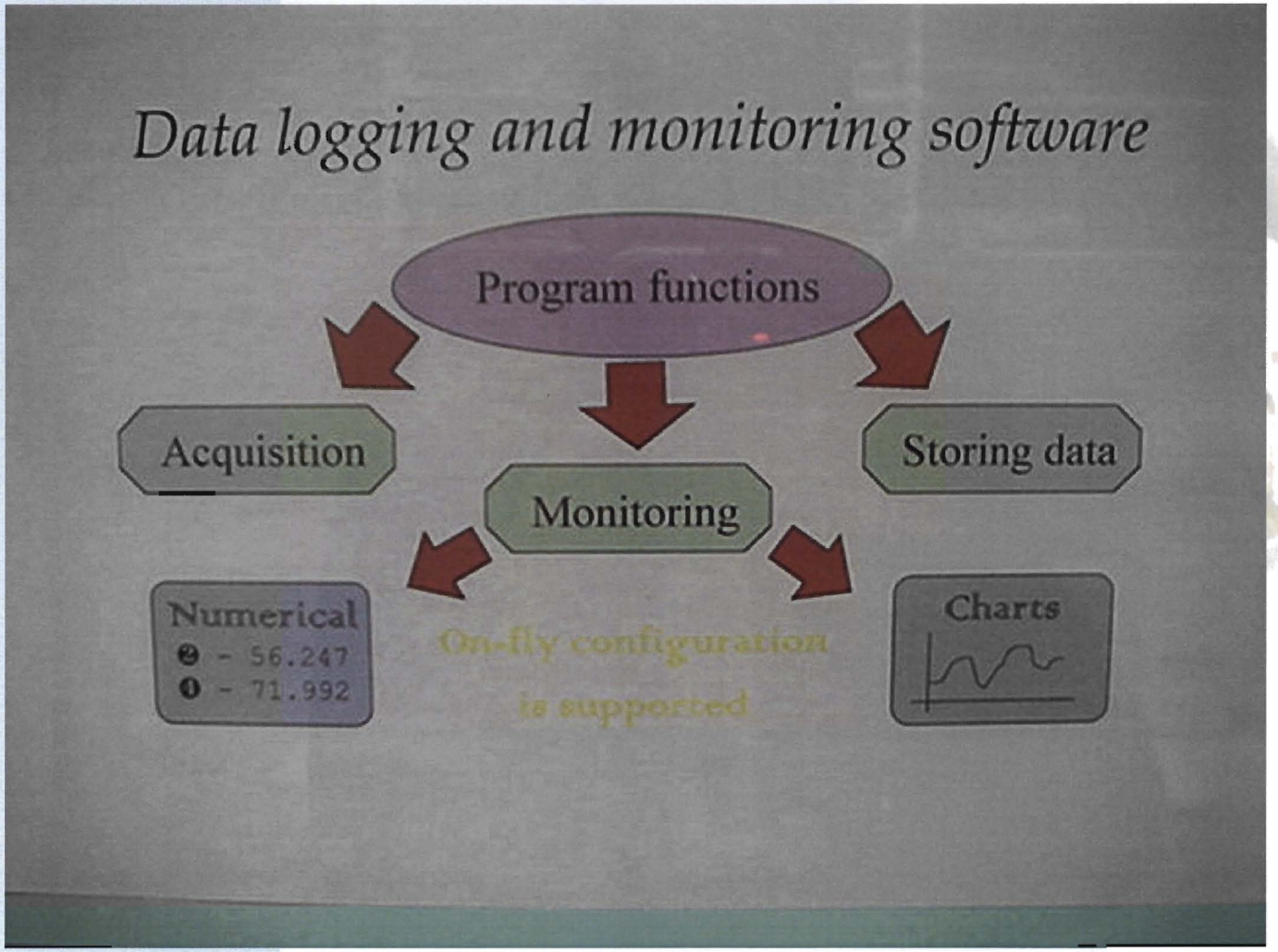
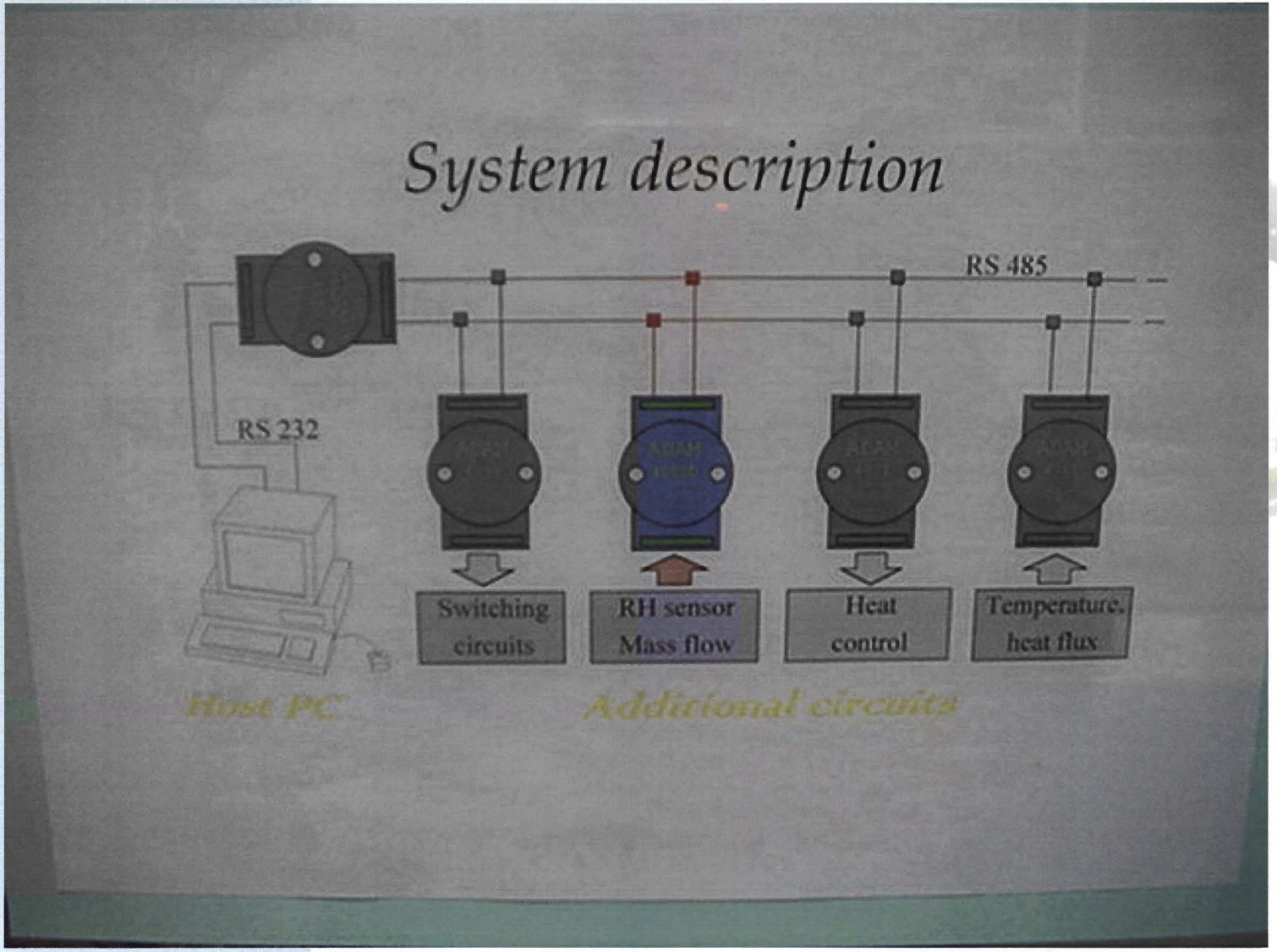


Fig.1 Scheme of the integrated agricultural solar system

Scheme of data logging and monitoring



Layout of data logging



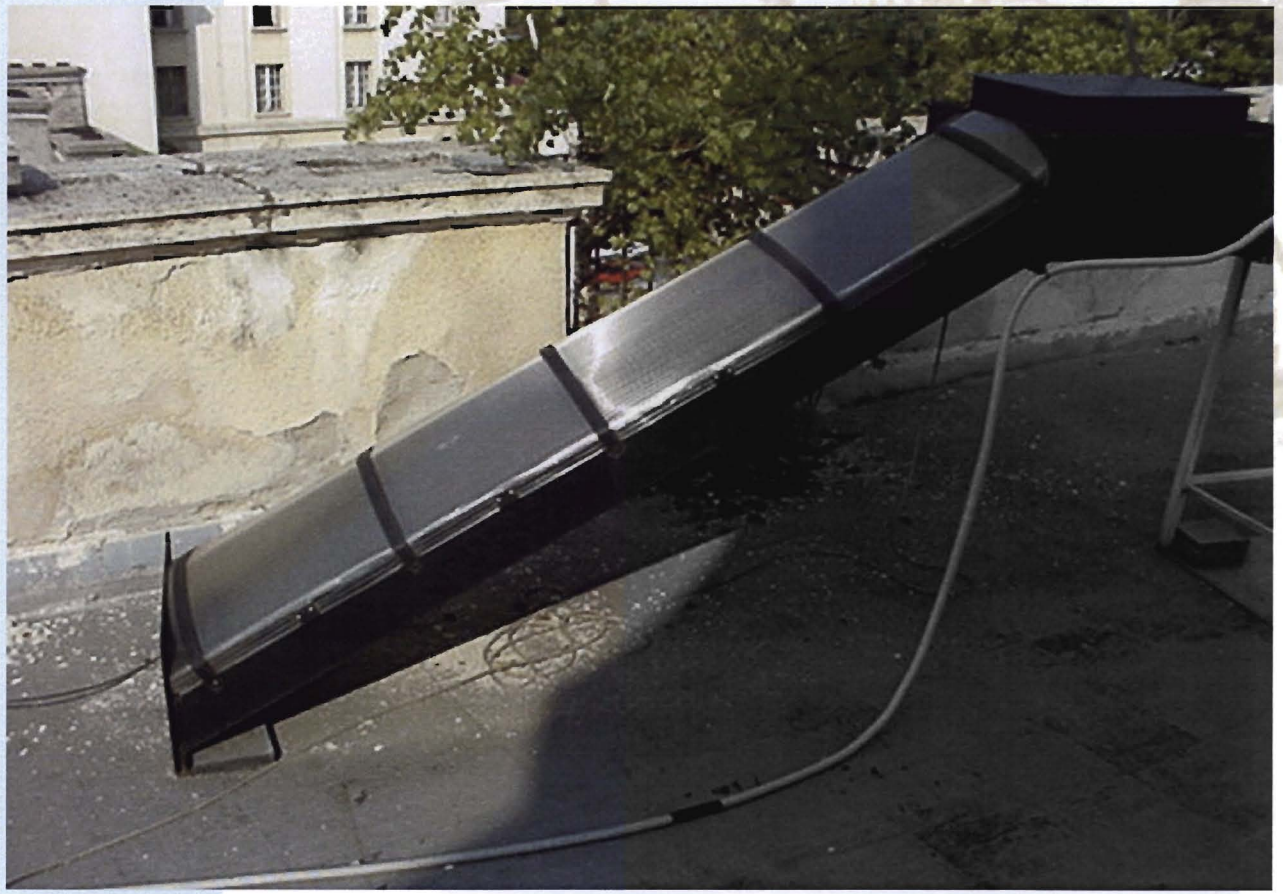
Modules of data logging and control

Modules of data logging and control in work

Solar dryer

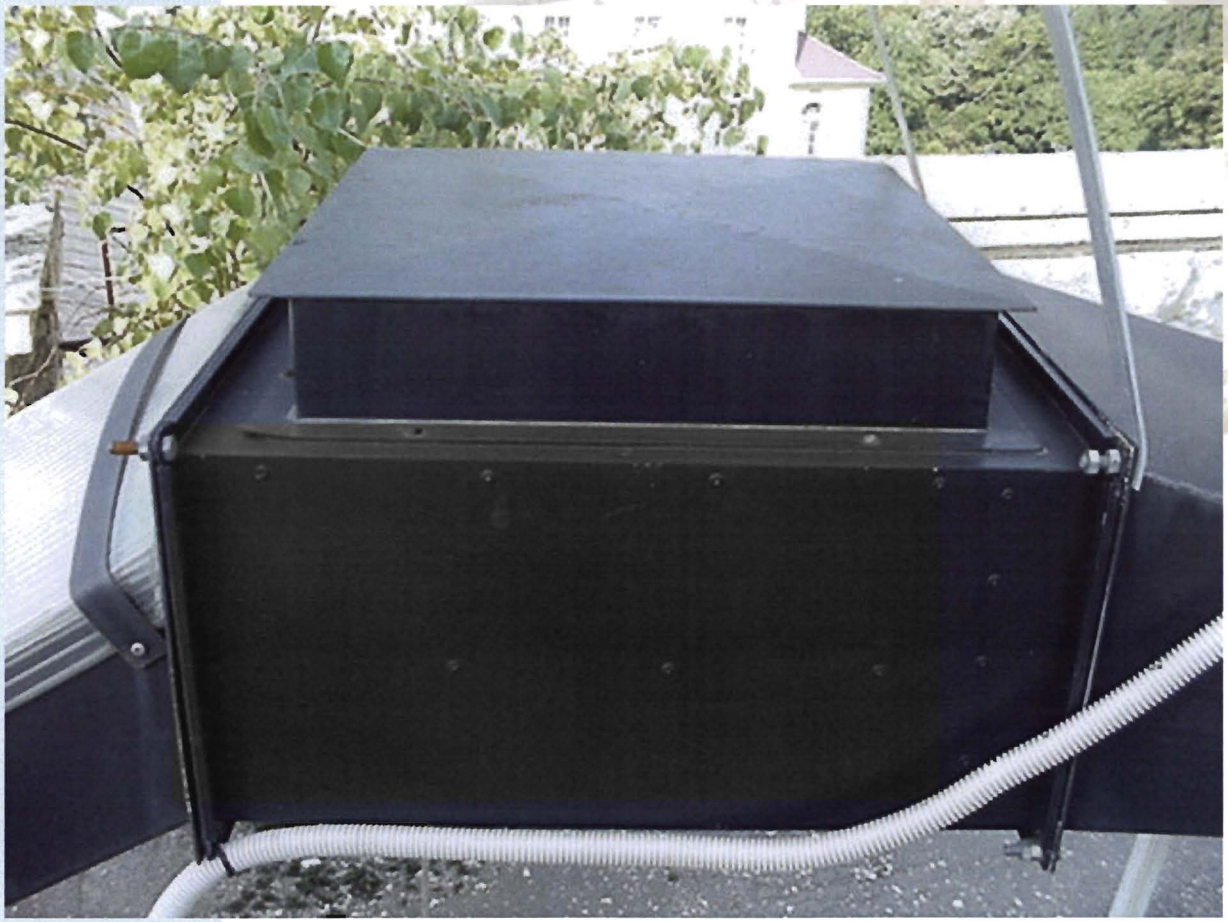
Air collector

can be connected to the drying chamber,
surface of the absorber is about 1,6 m^2



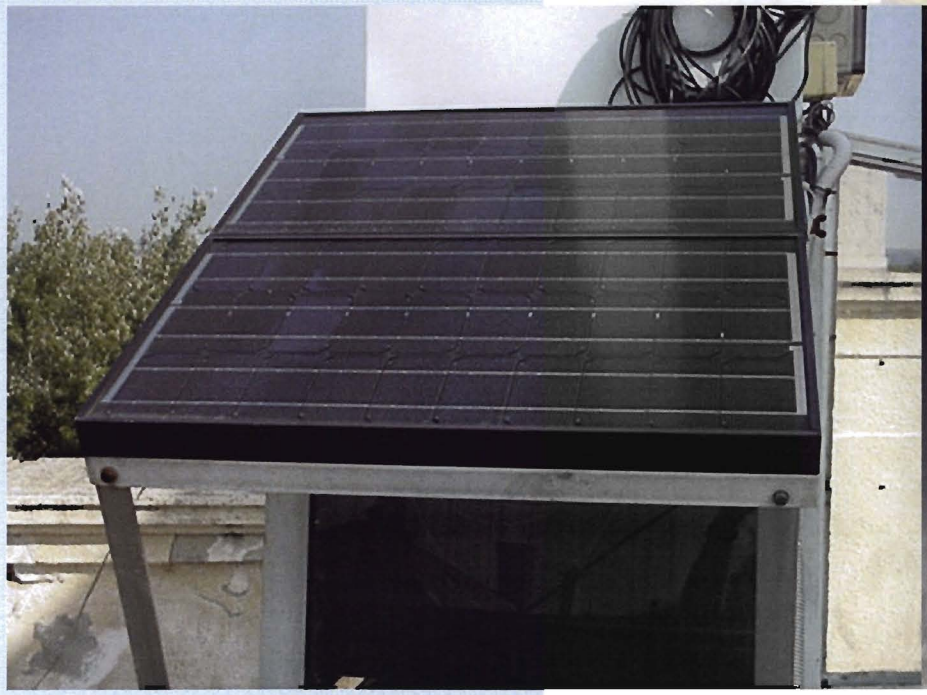
Electrical fan

Modularly applied,
grid connected,
it serves to adjust the required air flow rate



PV unit + fan

the fan is operated by the PV unit,
the power of the photovoltaic panel is about 40 W



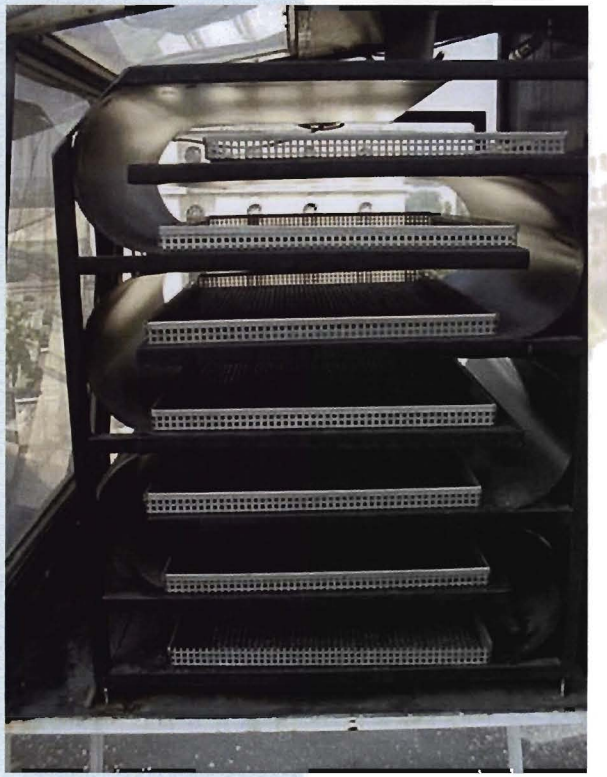
Chimney

the chimney is 2 m high
for the case of improving the natural ventilation

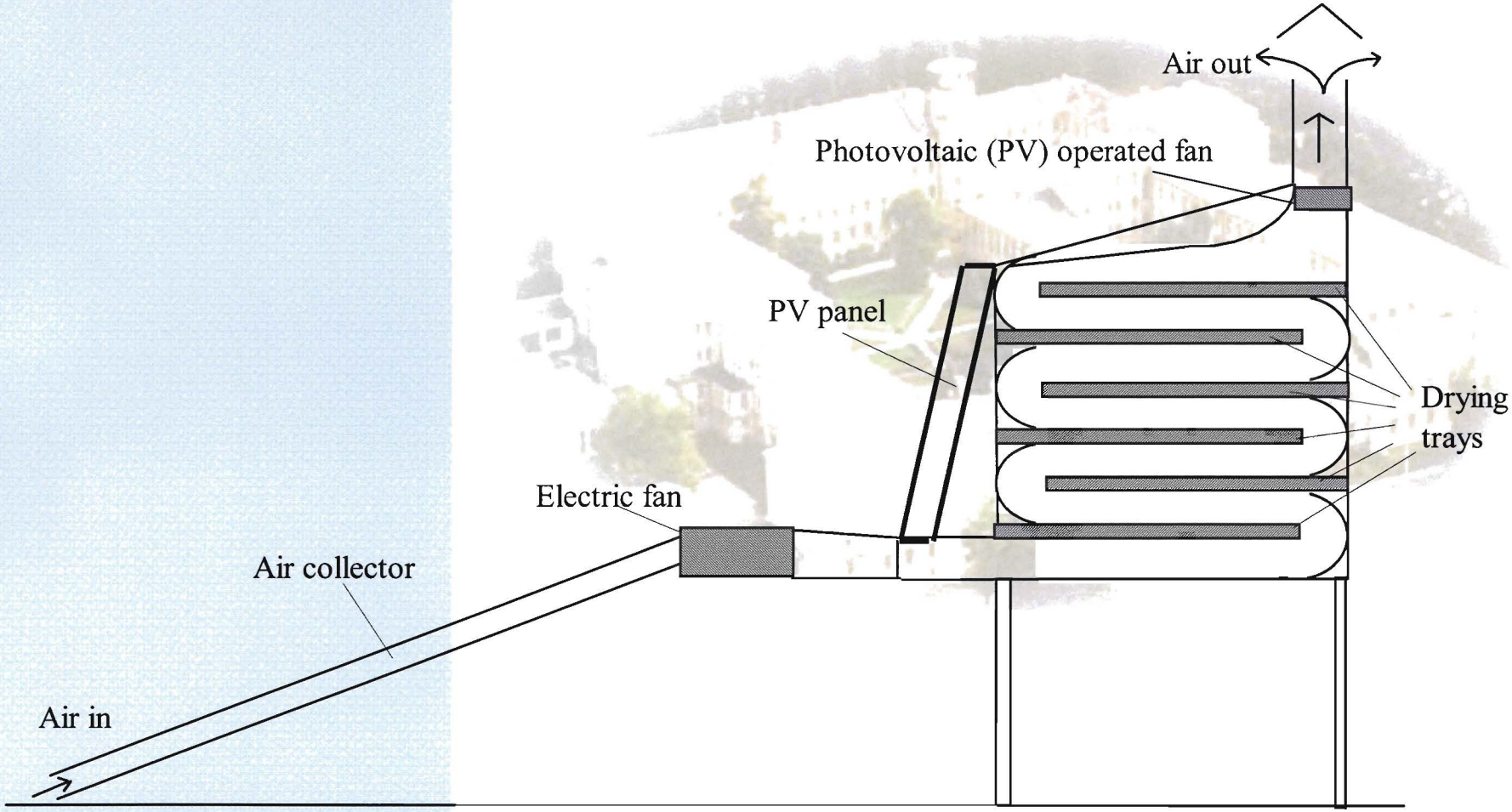
Drying chamber

Replaceable shelves

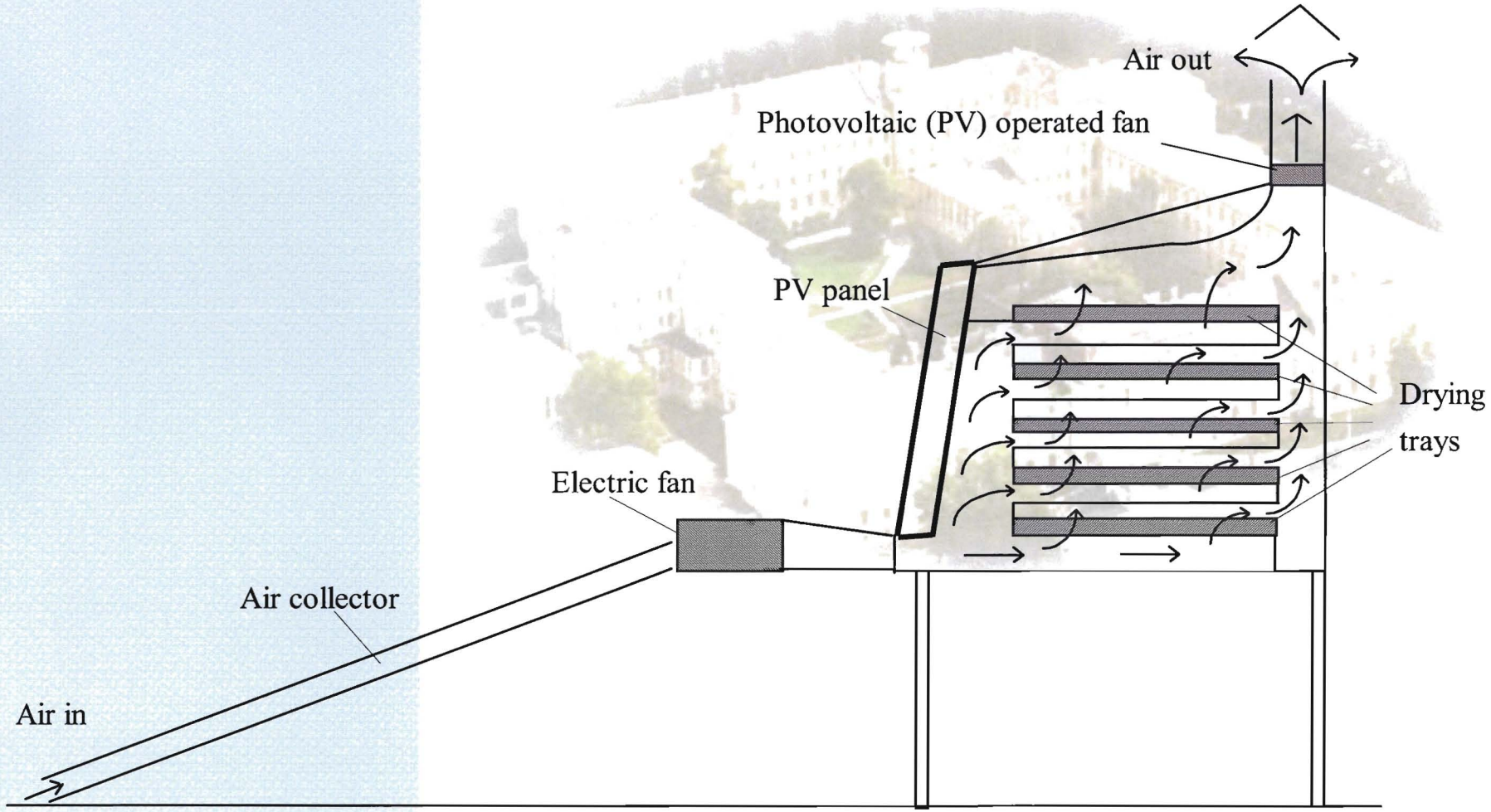
one serves for surface drying of small stuff,
the other one serves for cross flow drying of bigger size of stuff



Surface drying



Cross-flow drying



Efficiency of the solar air collector

Mass of air passing through: $m=\rho \cdot a \cdot b\ v\ t$

Amount of heat taken by the air: $Q = c_p\ m\ \Delta T$

$$P = \frac{Q}{t} = c_p\ \rho\ a\ b\ v\ \Delta T$$

Using the values of: $v = 5$ cm/s and $\Delta T = 18$ K:

Heat development in the air provided by collector:

$P = 115$ W

Efficiency of the solar air collector

Average solar density:

$P_s = 300\ W/m^2$,

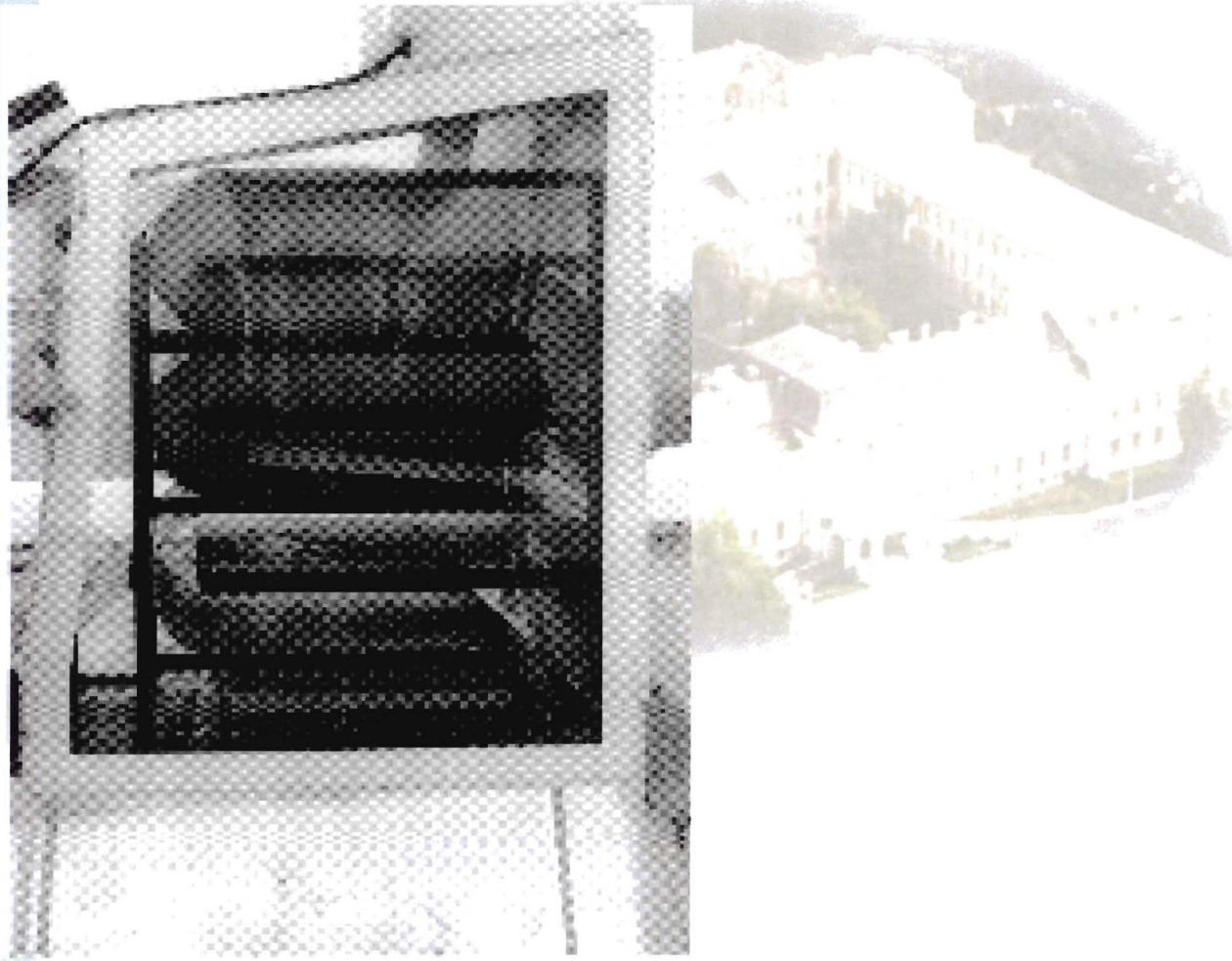
Power of the collector:

$P_{col} = P_s \cdot A = 324\ W$.

Efficiency of the collector:

$$\eta = \frac{P}{P_{col}} = 35.5\%$$

Making visible the air flow through the drying chamber

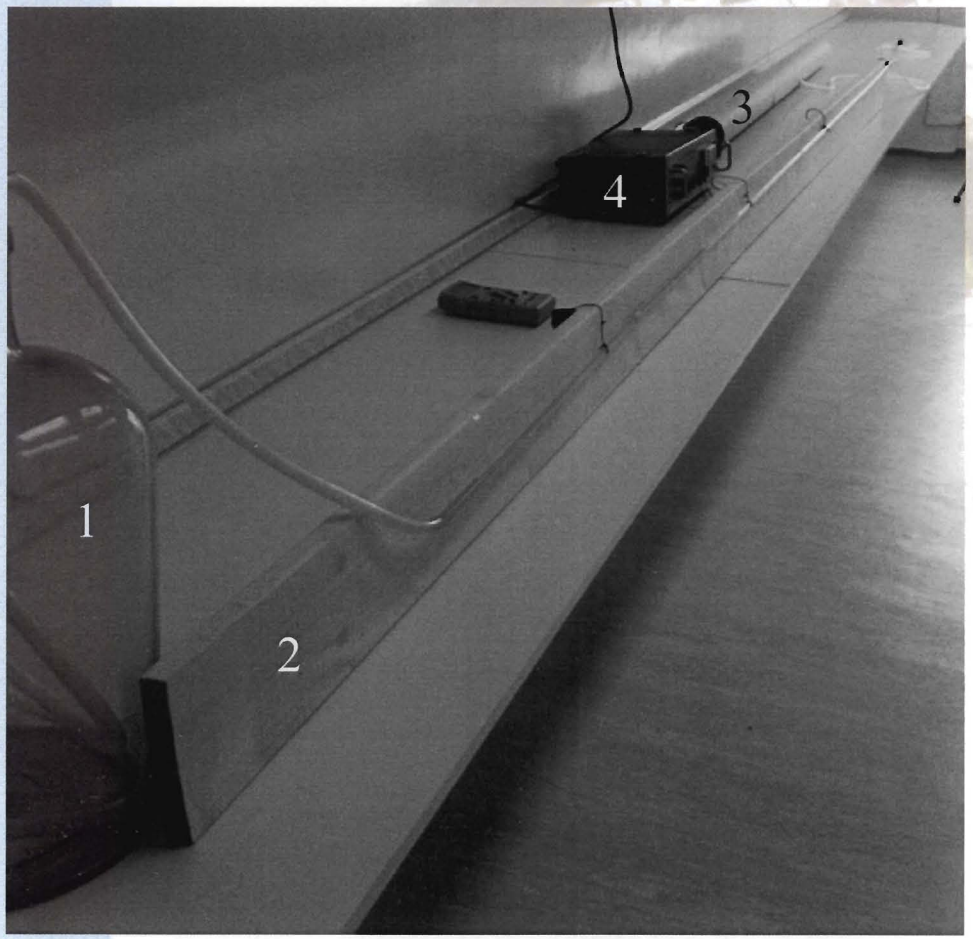


Measuring air flow rate by anemometer

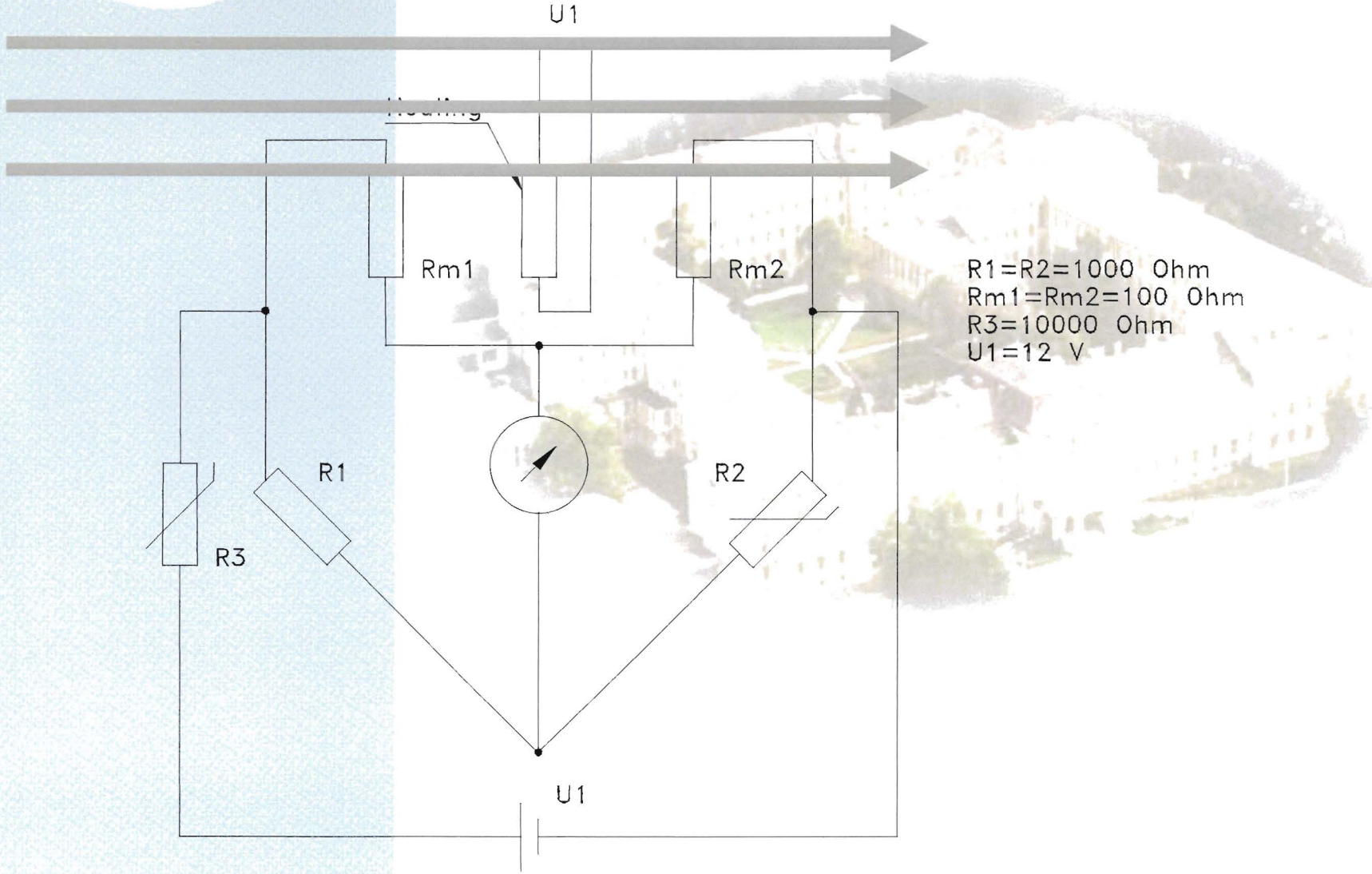
- the sensitivity is not good enough
- measures only the averag in an interval

Measuring the air flow rate by manometer based on Bernoulli law

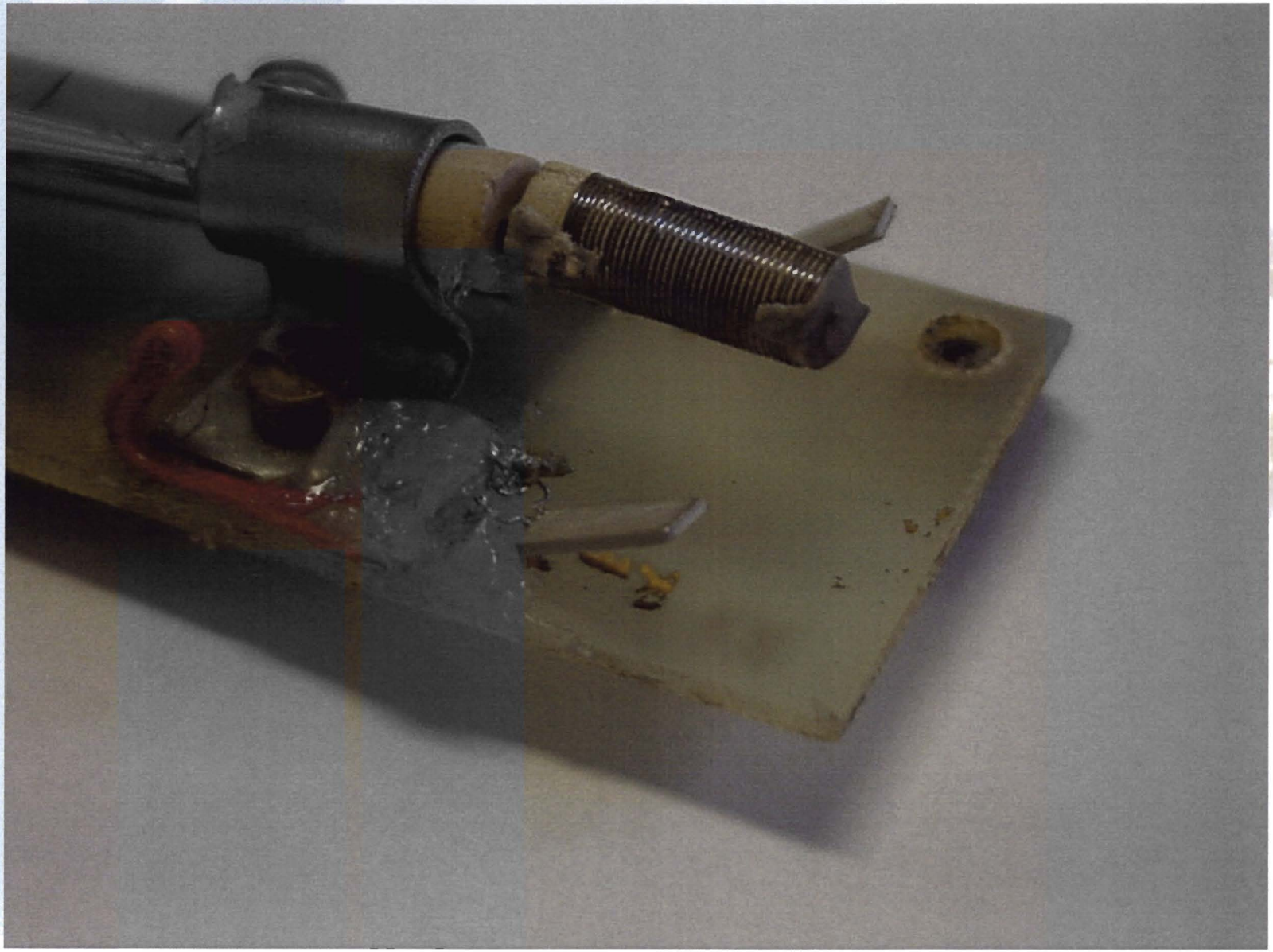
- the sensitivity is not good enough

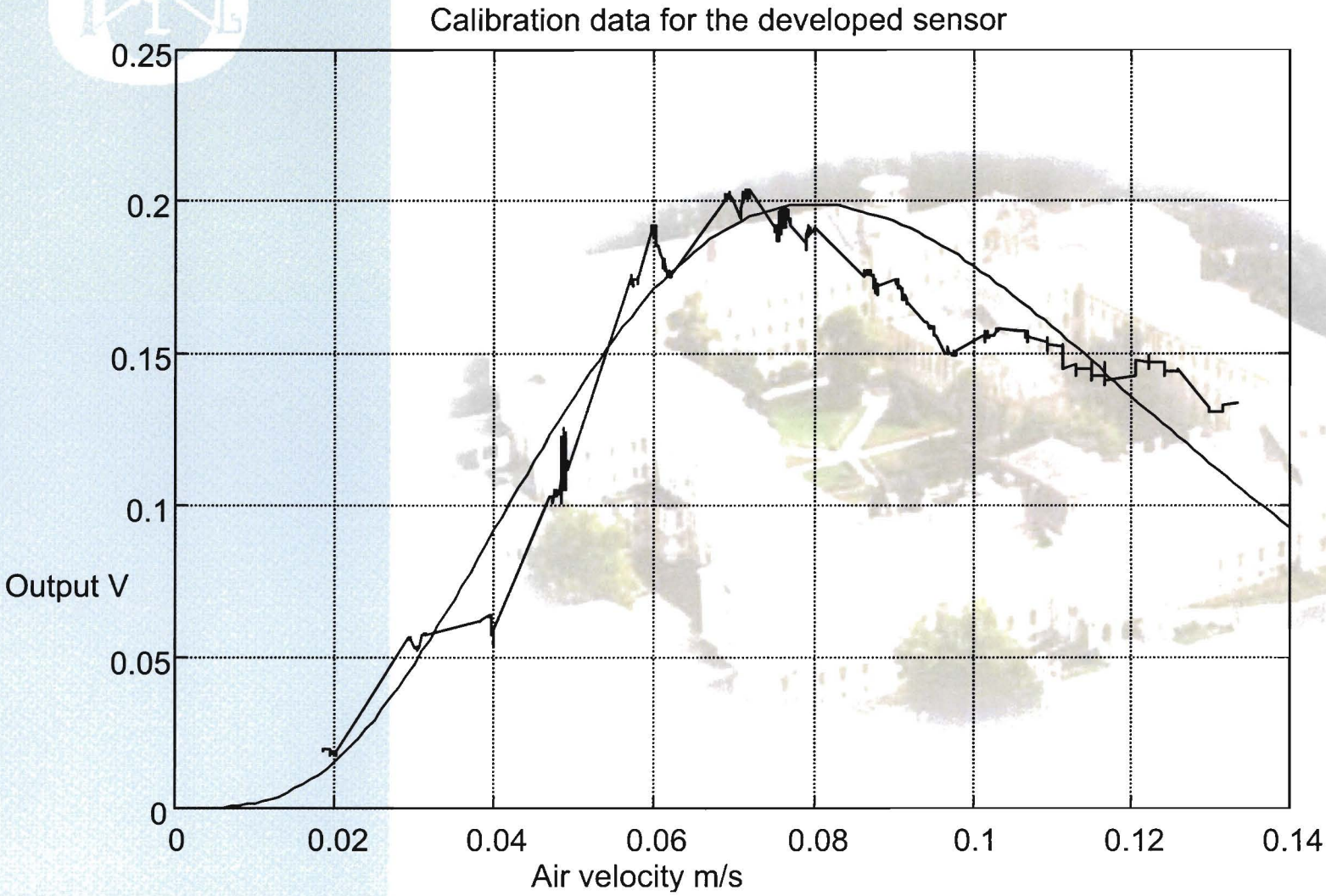


Measuring the air flow rate based on thermal behaviour



The developed sensor




Calibration data for the developed sensor
0.25
0.2
0.15
0.1
0.05
0
Output V
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Air velocity m/s

Determination of drying parameters

Modelling of drying, optimization

⇓

drying properties:

- Sorption isotherm
- Diffusion coefficient

moisture content

Sorption isotherm measurement

Solar dryer

$\Rightarrow$ 40 °C (thermostat)

Relative humidity control:
saturated salt solution
(at 60 °C over-saturated,
then cooled back)

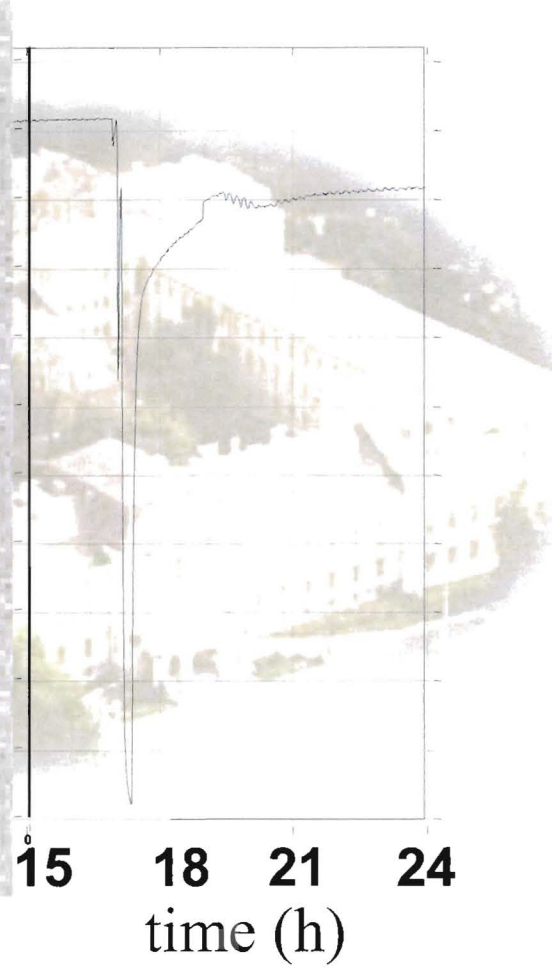
Sorption isotherm measurement

Saturated salt sol.	Relative humidity
$MgCl_2$	33 %
NH_4NO_3	49 %
NaCl	74 %
Na_2CO_3	86 %

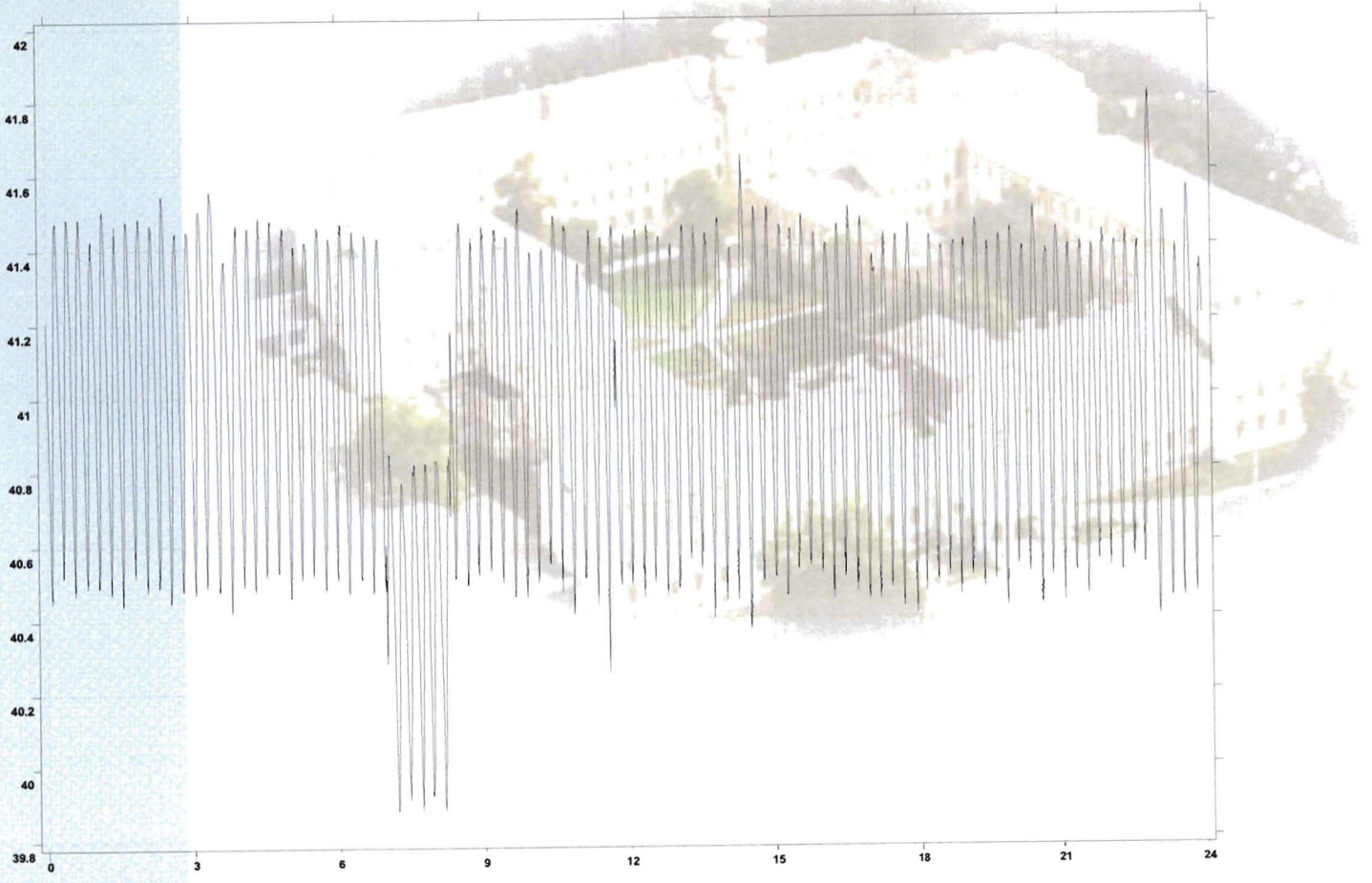
Sorption isotherm measurement

Sorption isotherm measurement

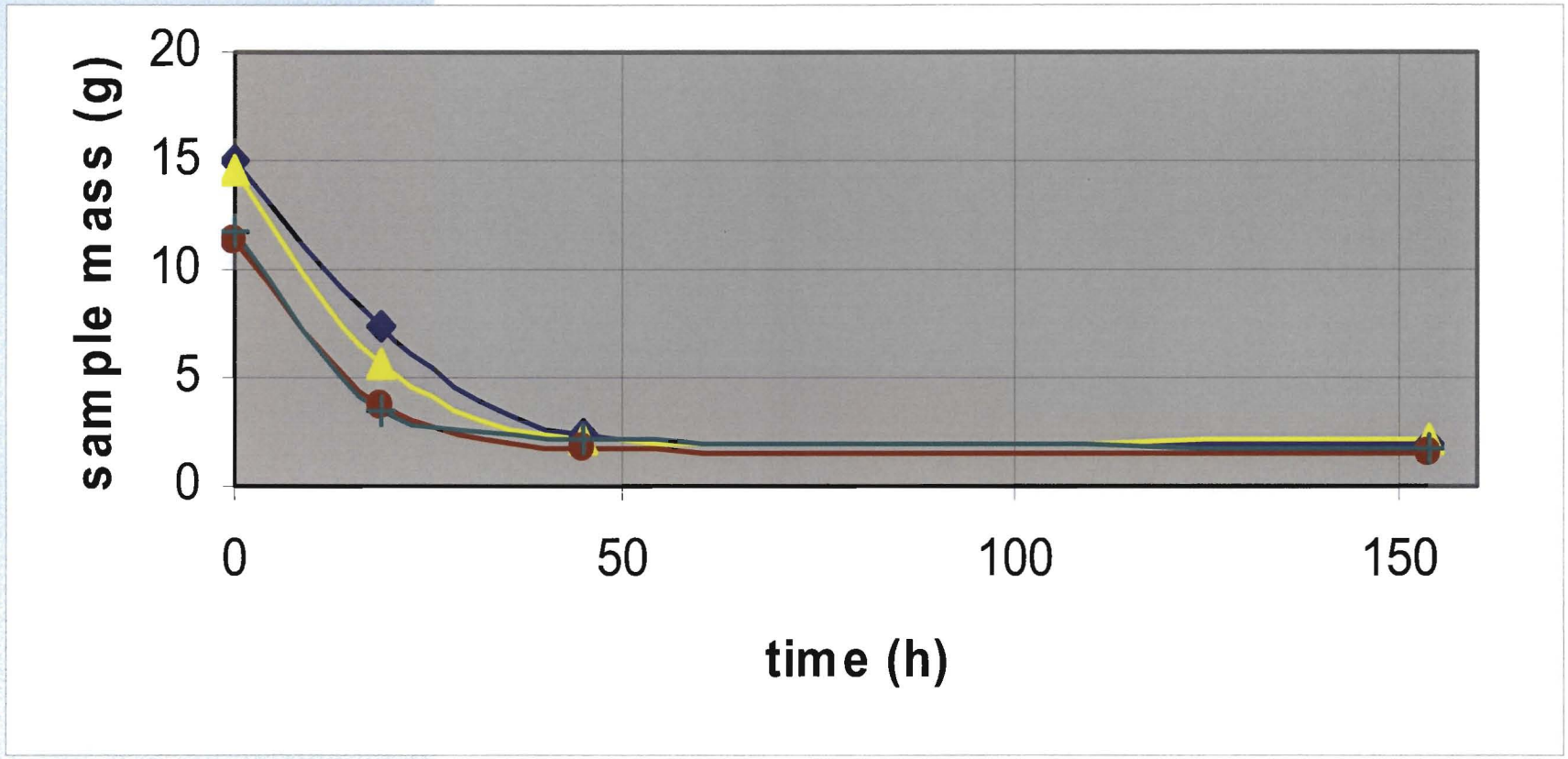
The effect of the measurement on the thermostat temperature



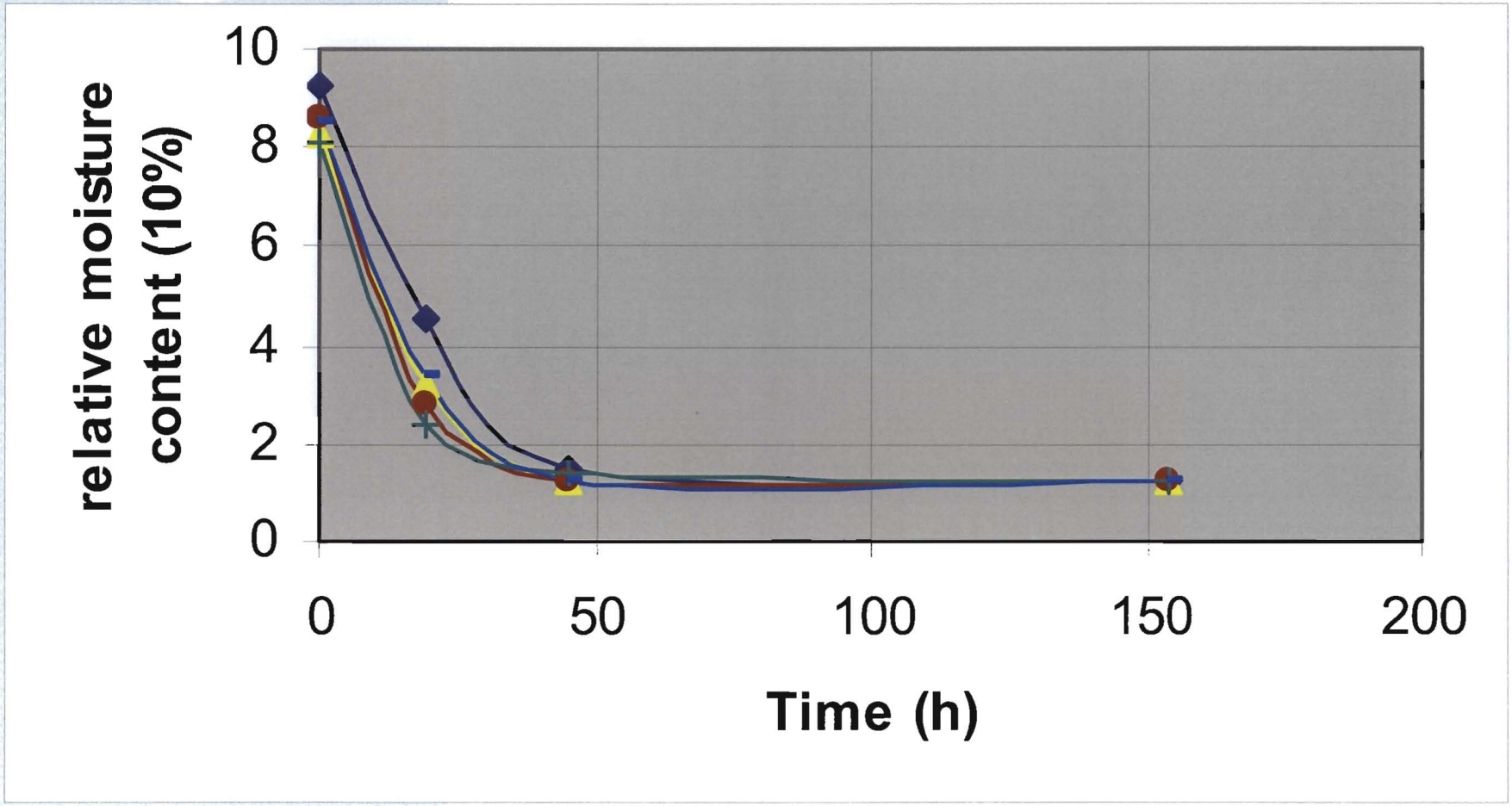
Sorption isotherm measurement



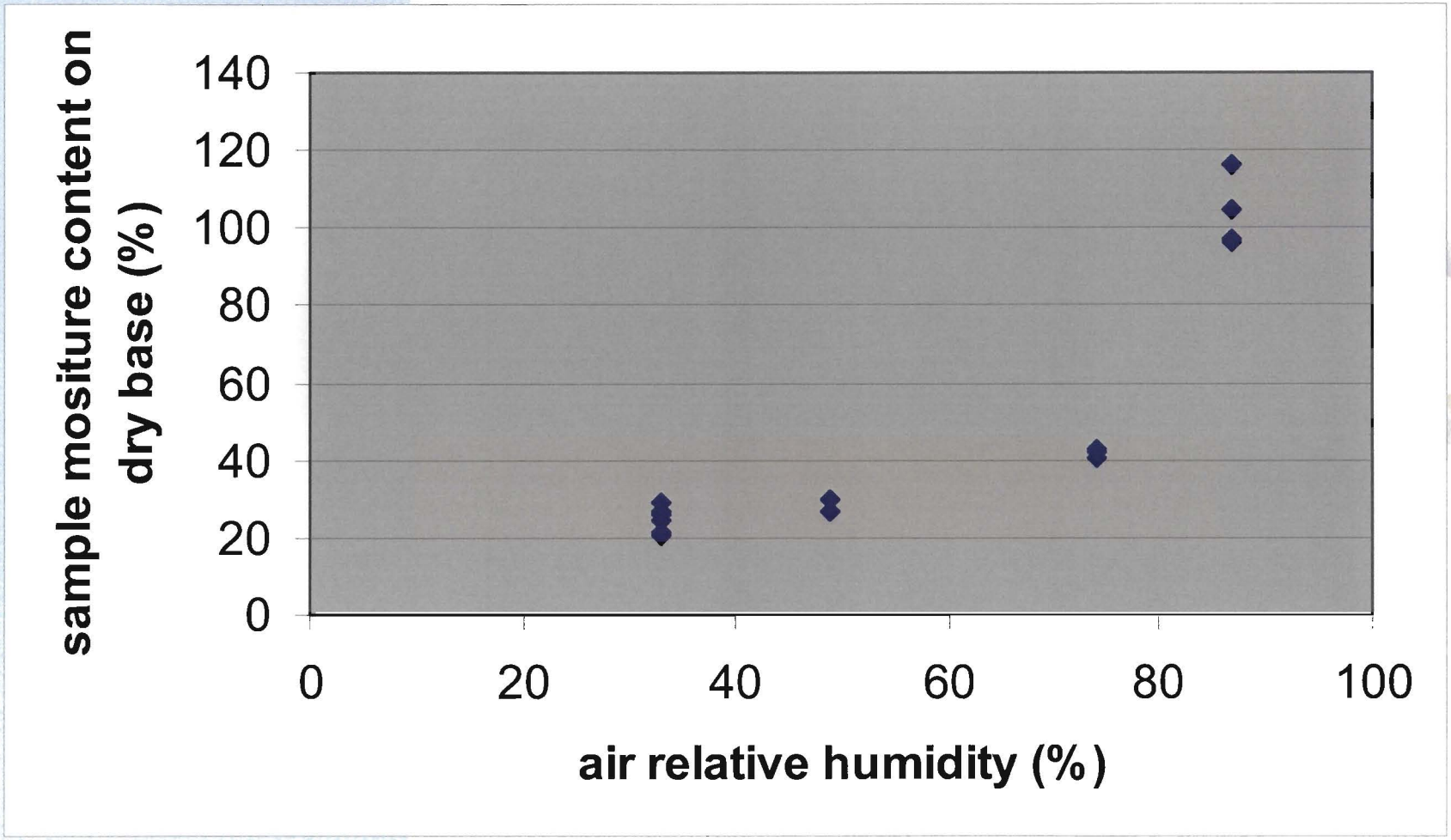
Sorption isotherm measurement



Sorption isotherm measurement



Sorption isotherm measurement

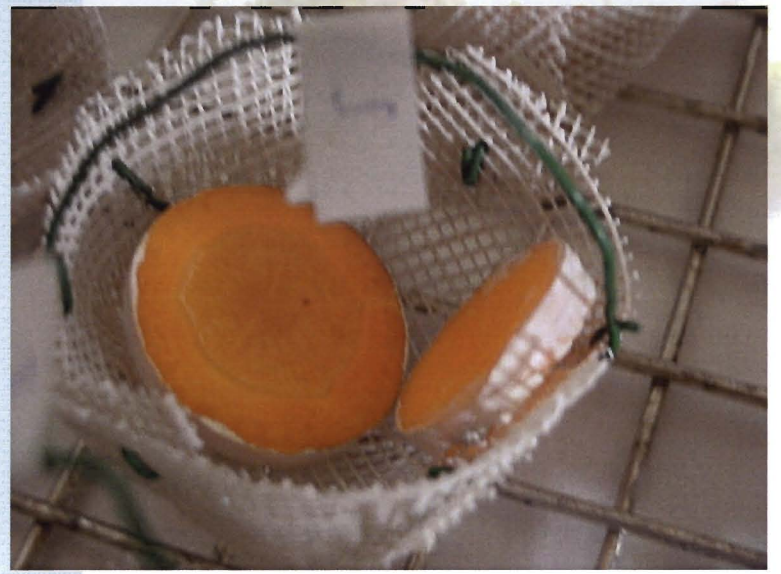


Diffusion coefficient measurement

One dimensional diffusion with insulation

With the same environmental properties (e.g.equilibrium mositure content), the drying curves of the different size sample differs because of the diffusion coefficient.

Diffusion coefficient measurement



Diffusion coefficient measurement

Environmental parameters:

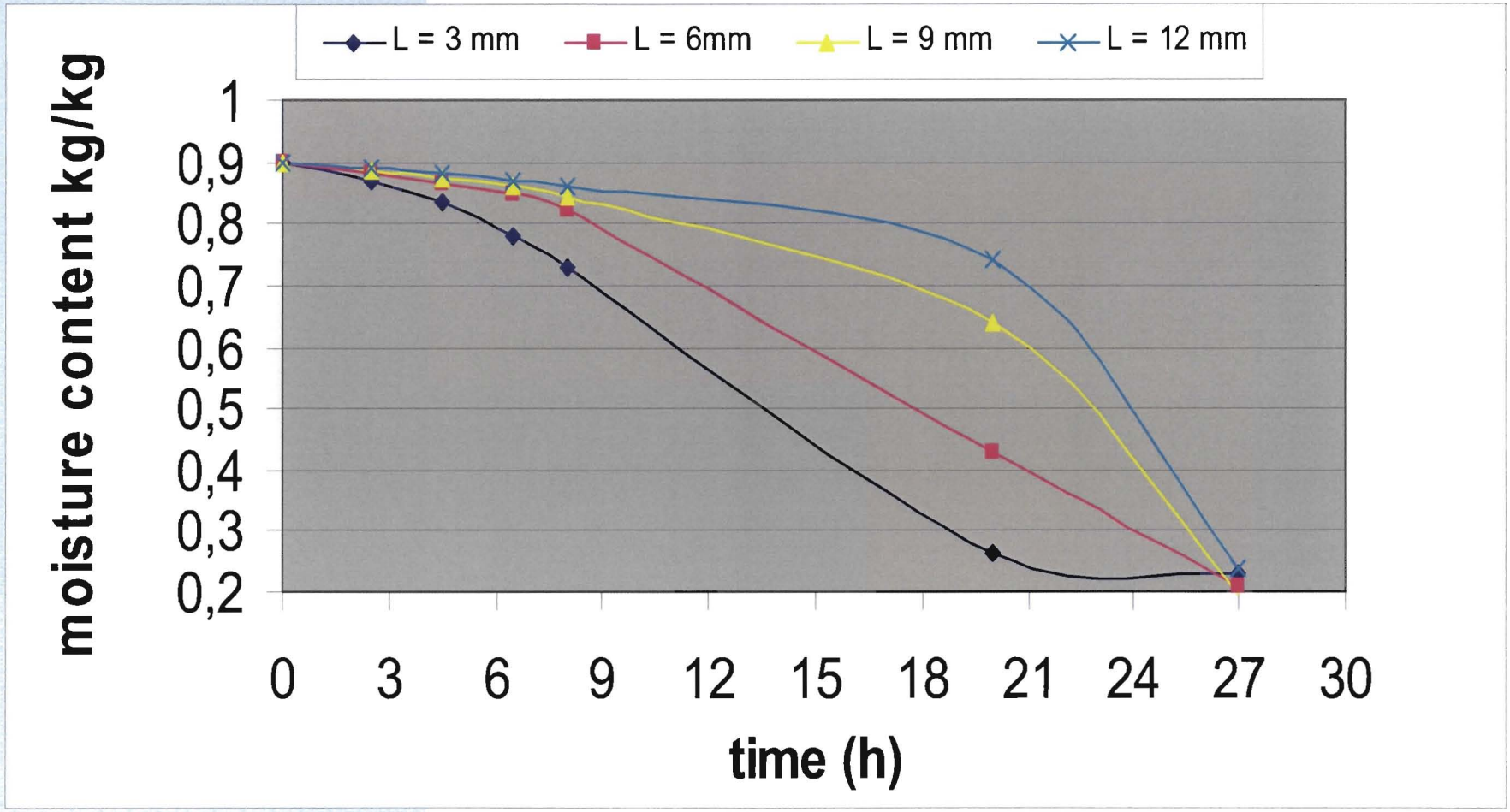
air relative humidity 33%

ambient temperature 40 °C

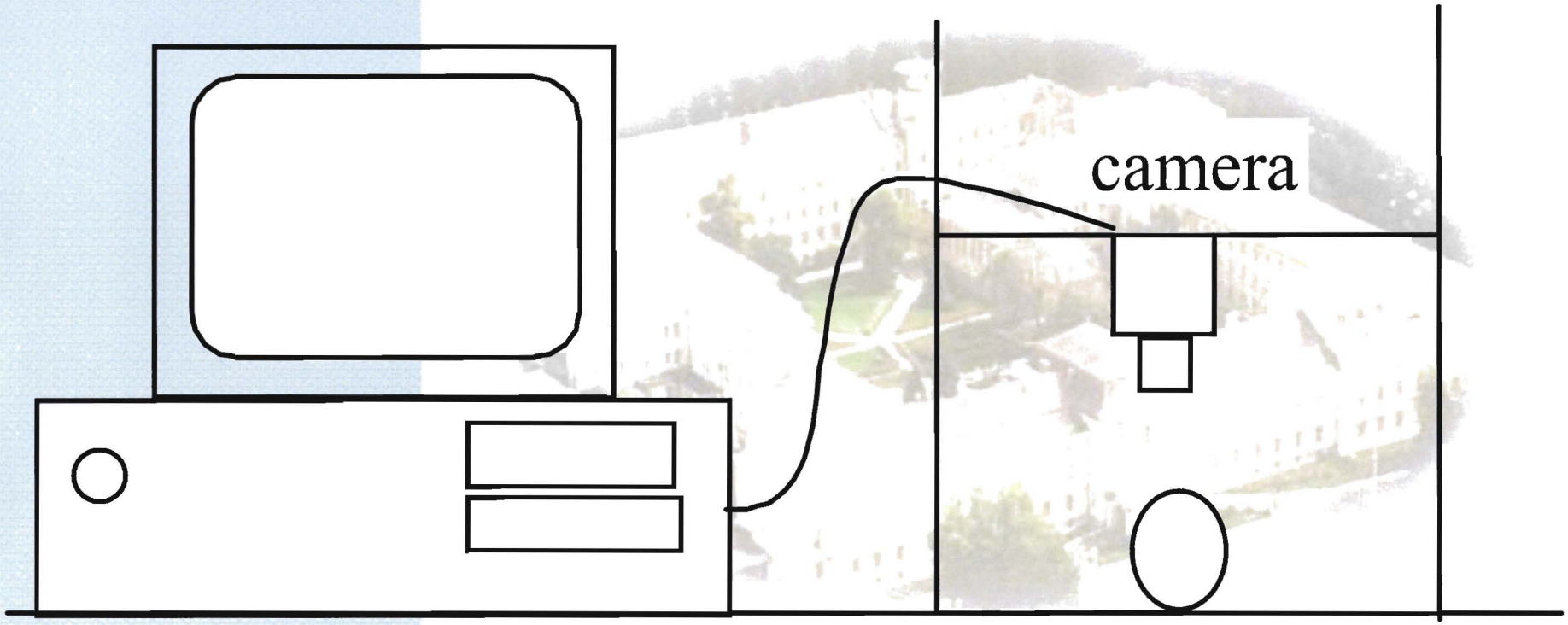
Sample size in the direction of diffusion :

3mm, 6 mm, 9 mm és 12 mm

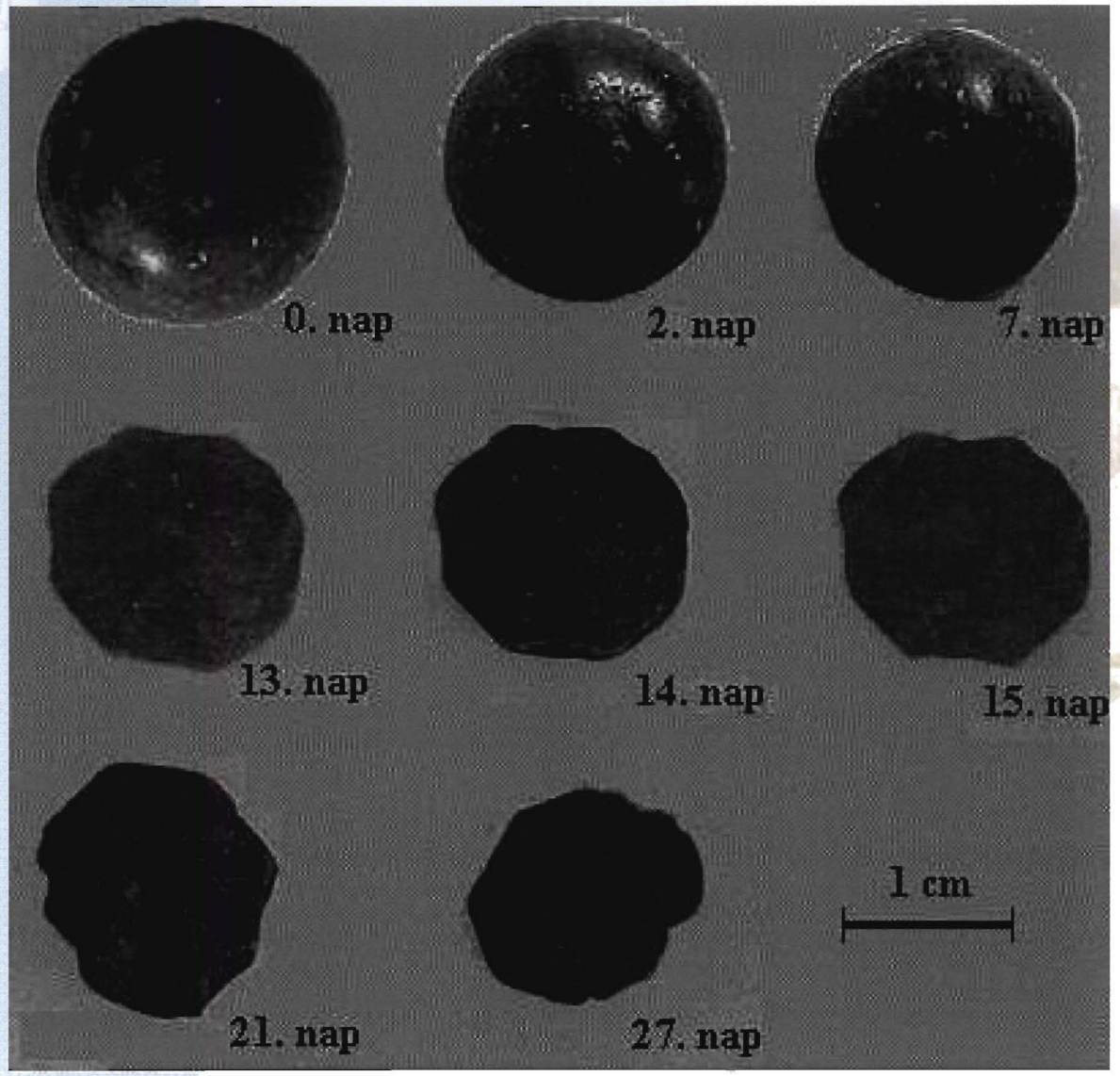
Diffusion coefficient measurement



Optical measurement of moisture content



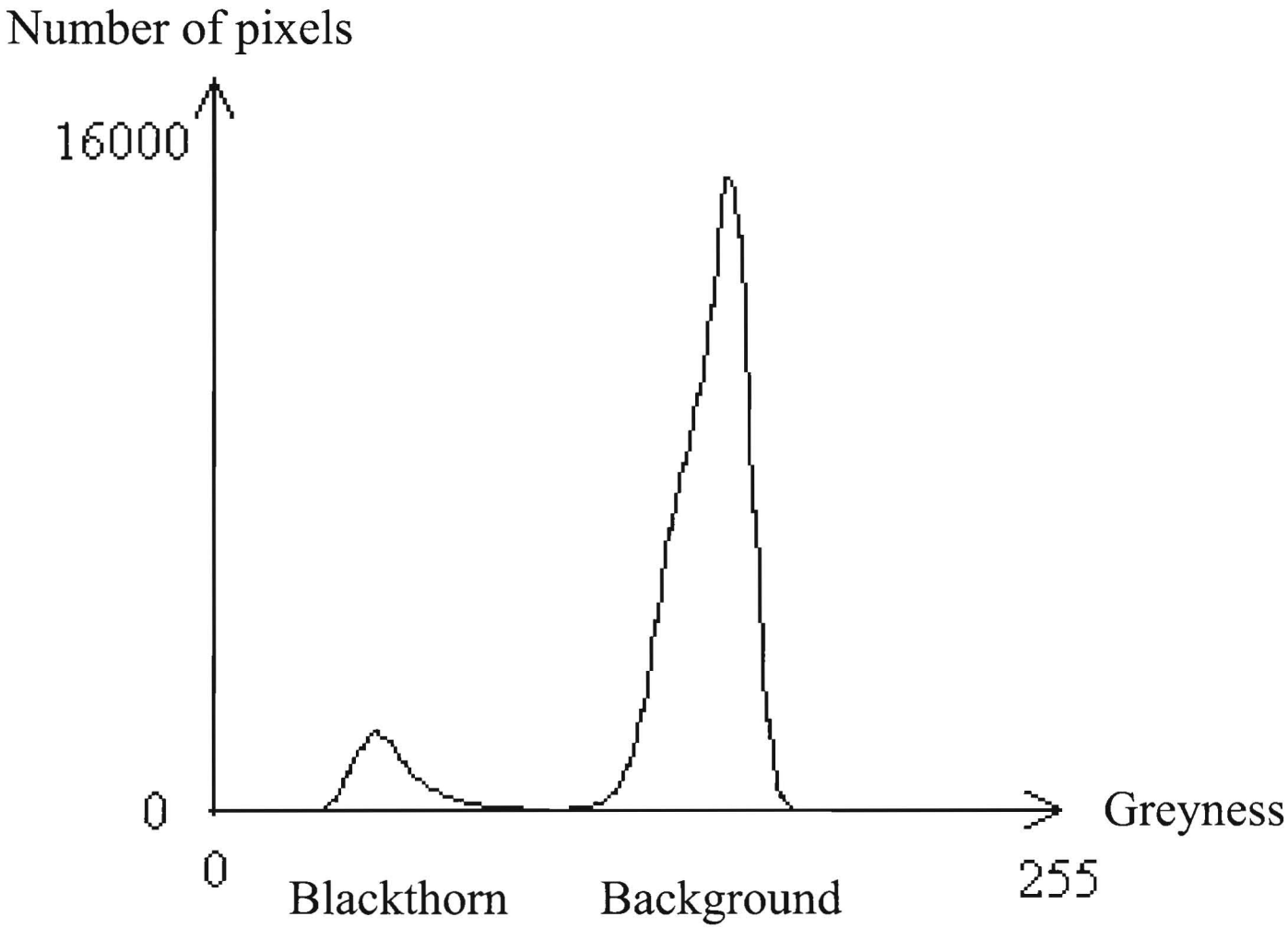
Drying experiment with blackthorn

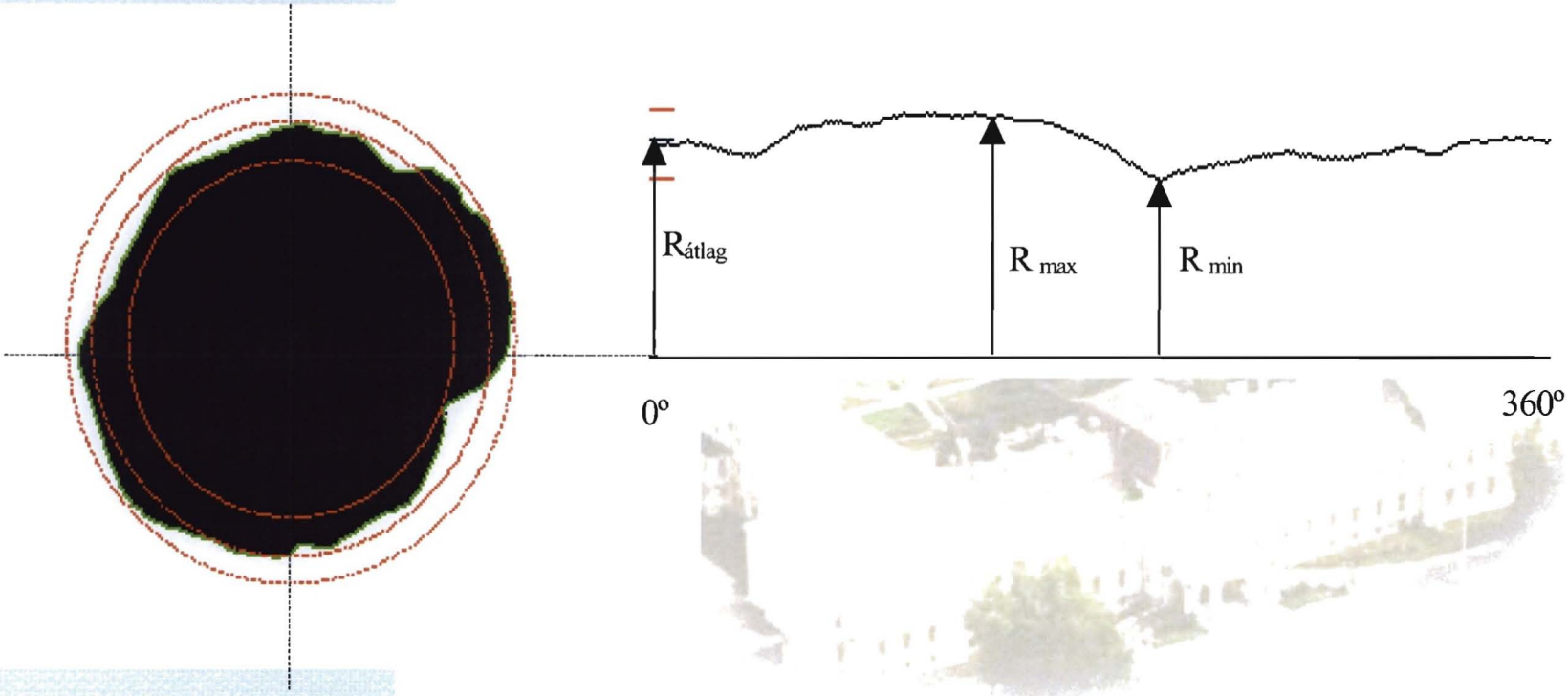


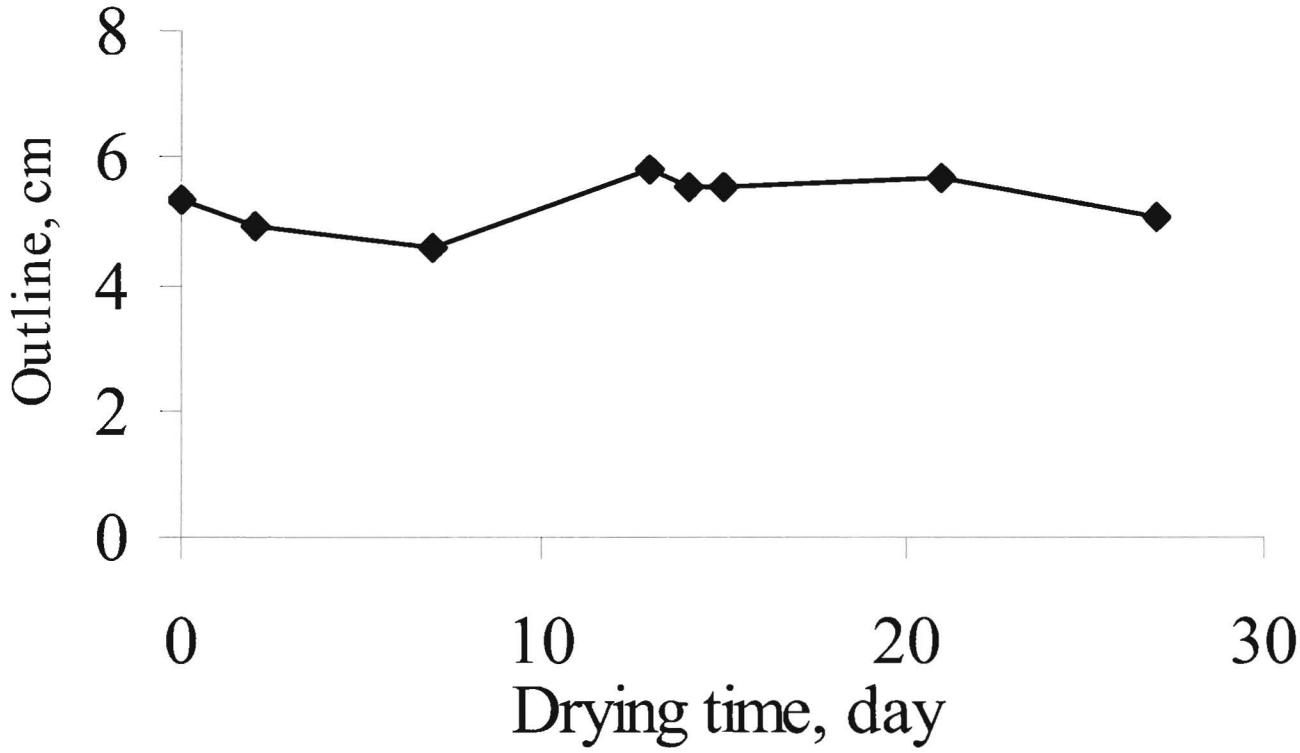
The image analysis system

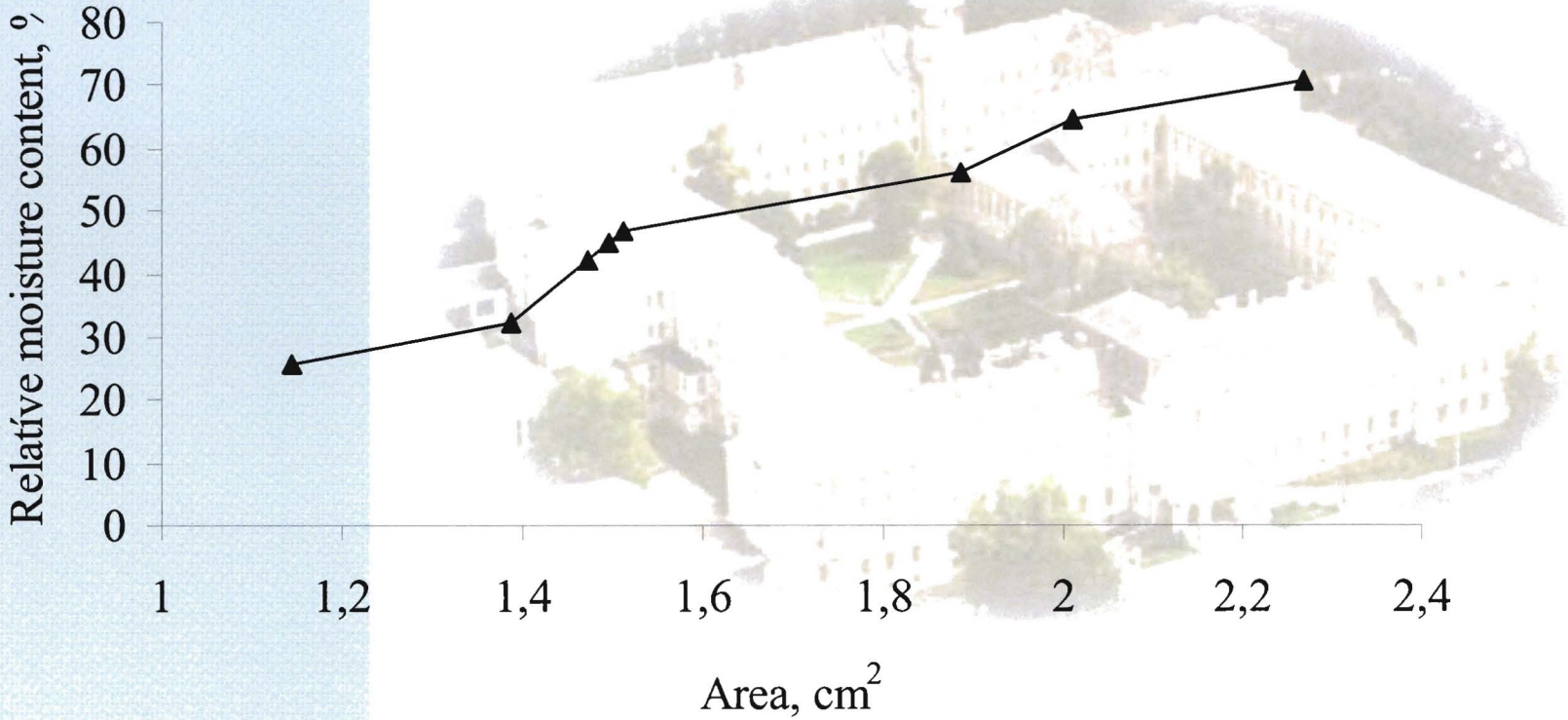
The methods of analysis:

- Colour --- grey scale conversion
- Histogram
- Segmentation
- Outline, area and volume calculation
- Contour search


Number of pixels
16000
0
0
Greyness
255
Blackthorn
Background


Rátlag
R max
R min
0º
360º


8
6
4
2
0
Outline, cm
0
10
20
30
Drying time, day


Relative moisture content, %
80
70
60
50
40
30
20
10
0
1
1,2
1,4
1,6
1,8
2
2,2
2,4
Area, cm2

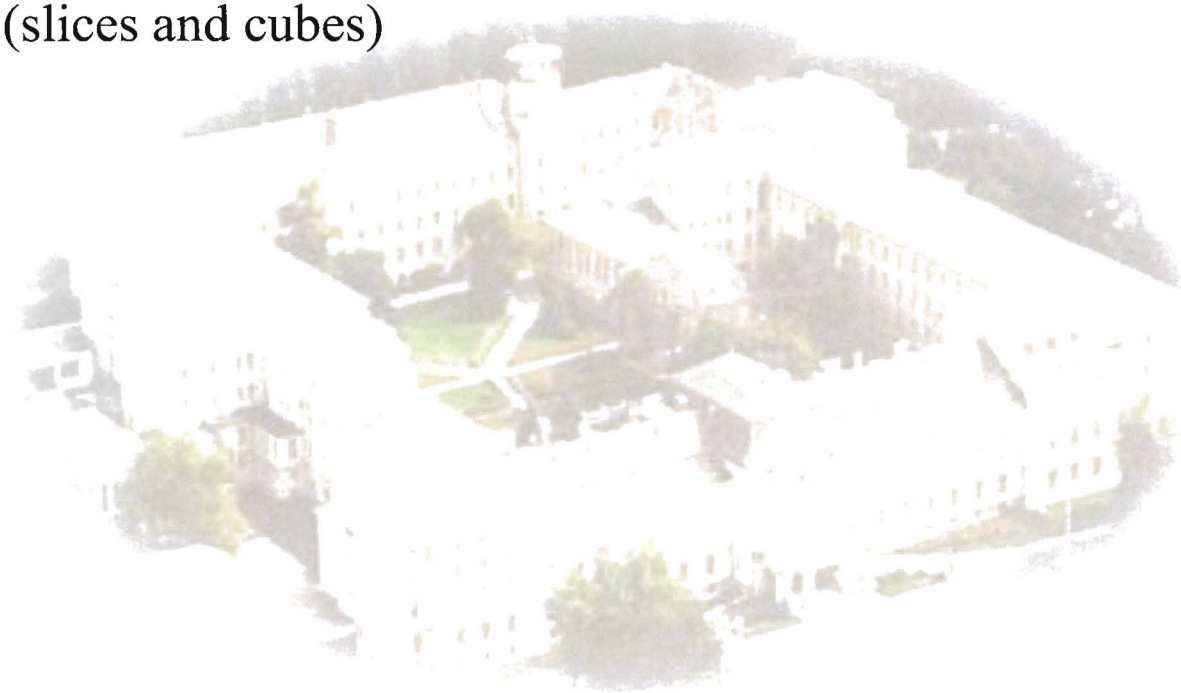
PREPARATION OF MATERIALS FOR MEASUREMENTS

The products were cut into:

1) Two different shapes (slices and cubes)

for carrot:

- slices 2 mm
- slices 1 cm
- cubic 1 cm



for apple:

- slices 0,4 mm
- slices 0,8 mm
- cubic 1 cm

2) Two different shapes (slice and cubes)

for potato:

- slice 4 mm
- cubic 1 cm

PREPARATION OF MATERIALS FOR MEASUREMENTS

The products were cut into:

3) Normal shape

for strawberry:

- 2 cm

4) One shape for the other fruits

for pineapple:

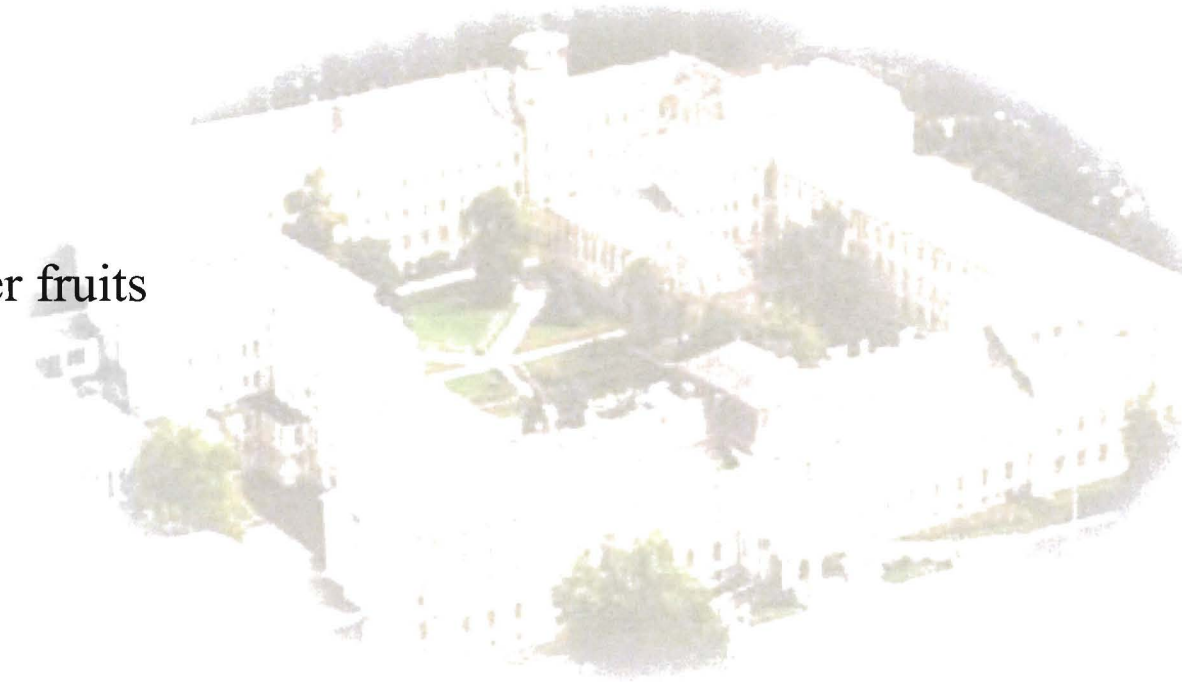
- slices 6 mm

for kiwi:

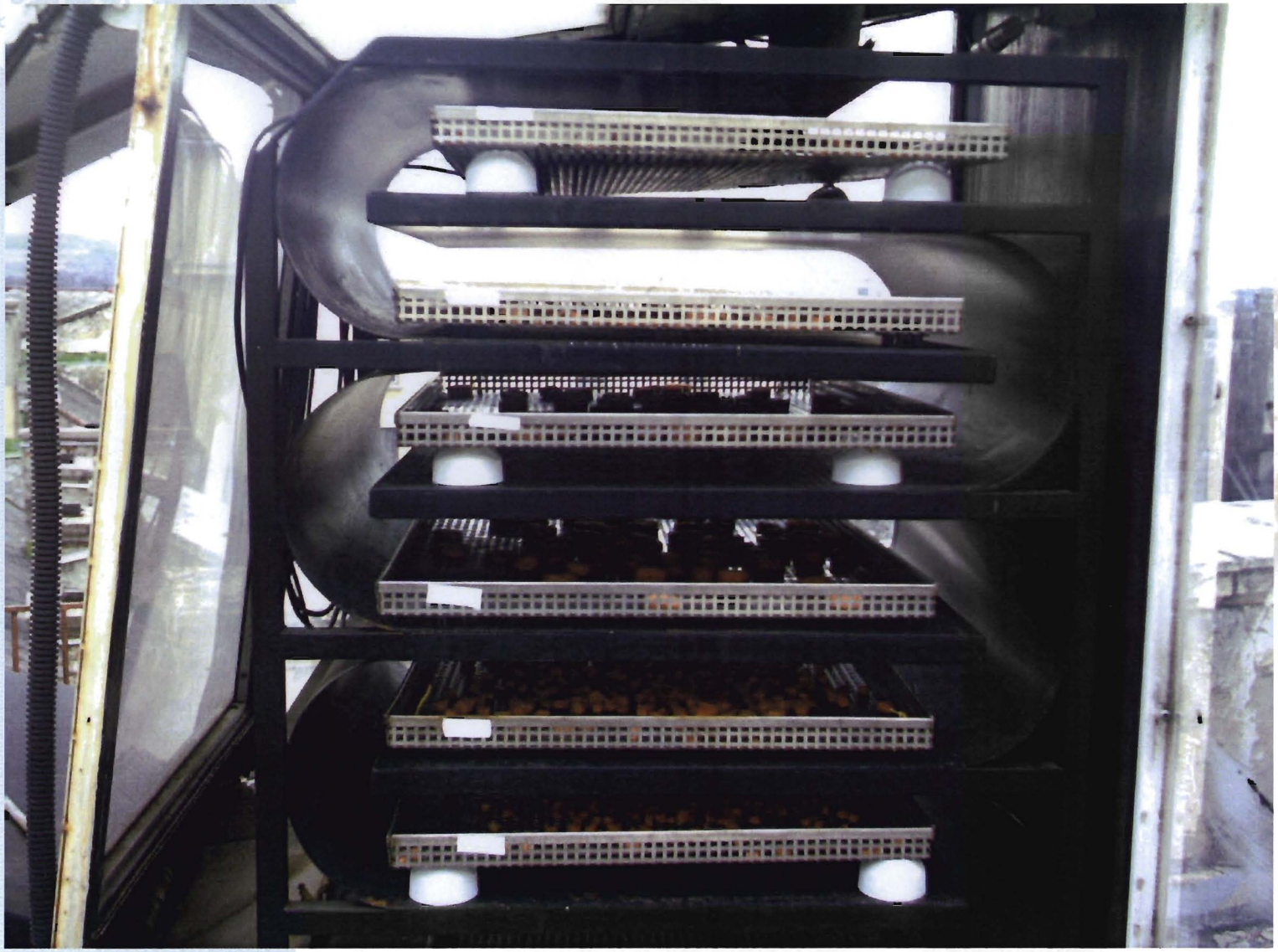
- slices 4 mm

for pear:

- slices 8 mm

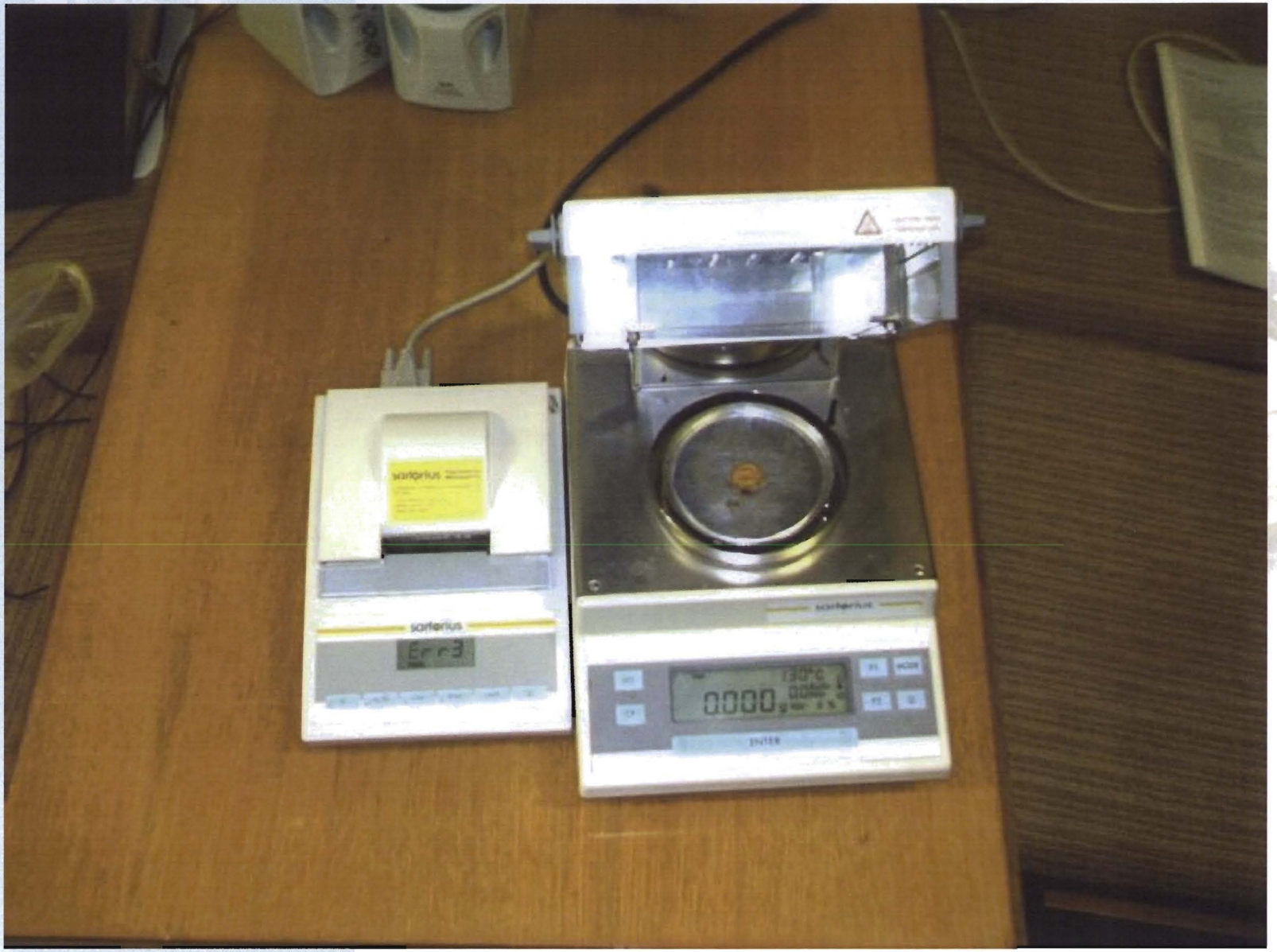


DRYING CHAMBER WITH TRAYS



ENVIRONMENT MEASURING INSTRUMENT

MOISTURE ANALYZER INSTRUMENT



ANALYSIS OF DATA

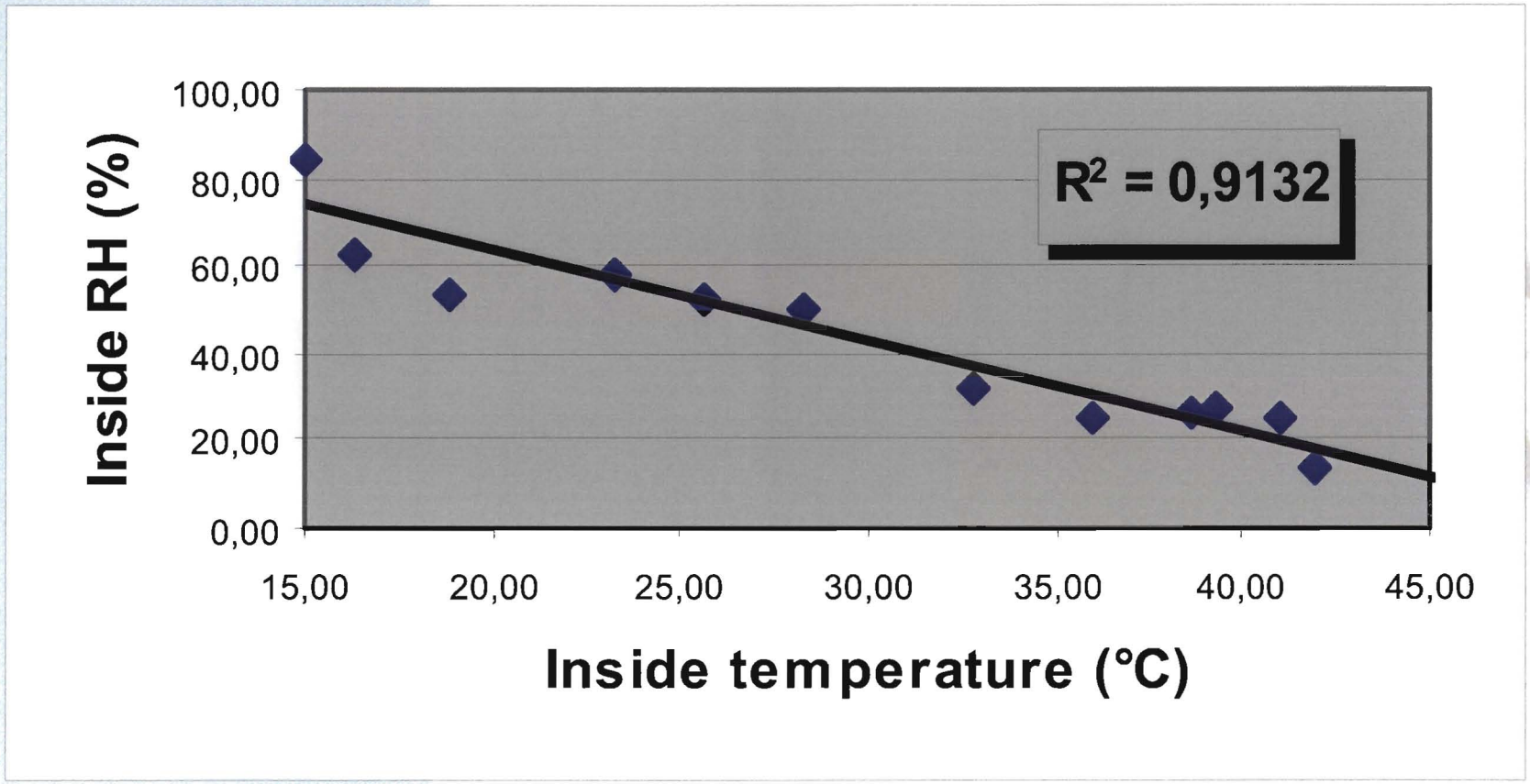
RH AND AVERAGE TEMPERATURE DURING THE DRYING PERIOD FOR THE CARROTS

Trays	RH-outside, %	Temperature-outside, °C
	30,88	18,12
	RHs-inside	Temperature-inside
1	30,25	20,29
2	29,97	20,45
3	30,13	20,45
4	30,36	20,44
5	30,29	20,16
6	30,92	20,23

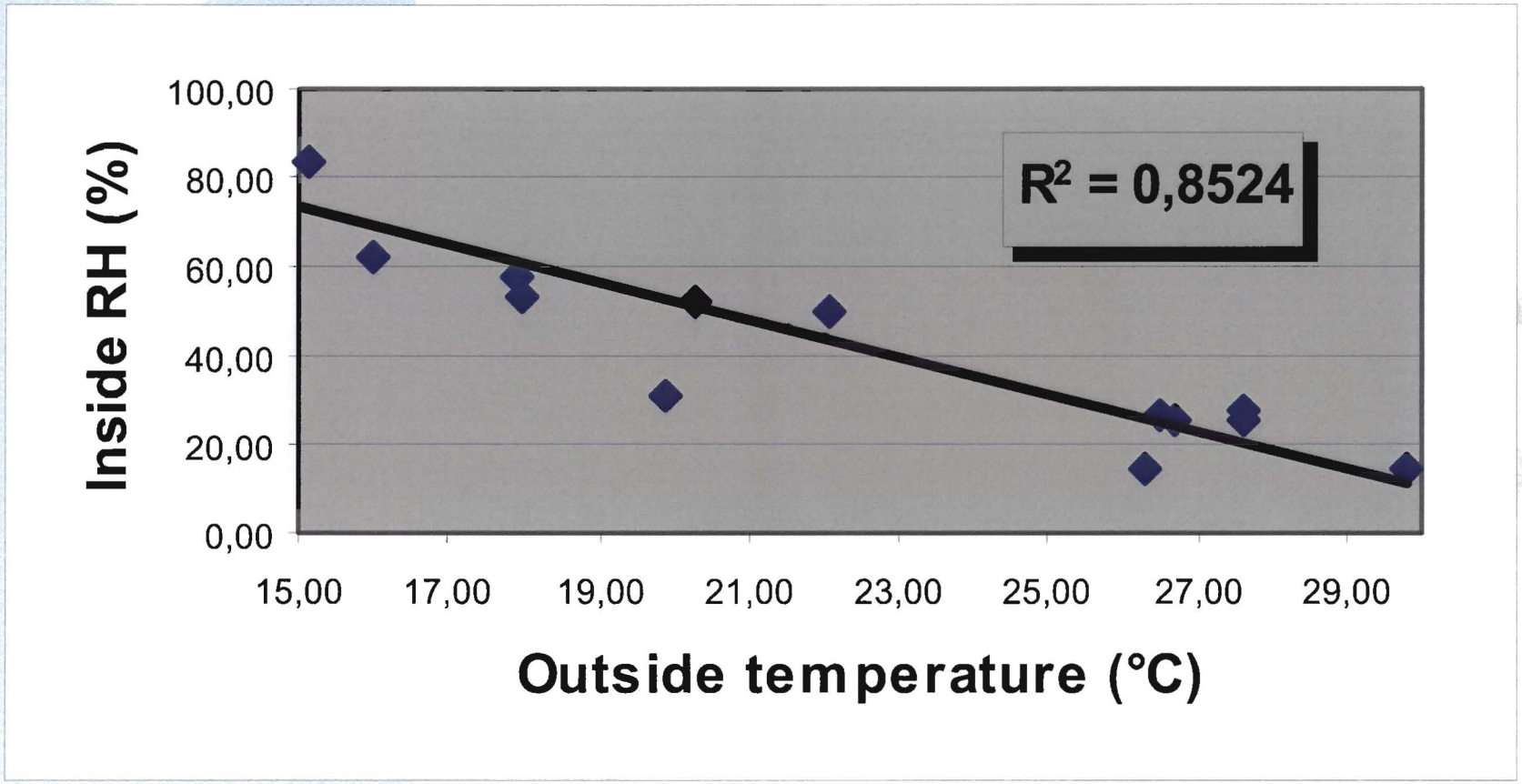
RH AND AVERAGE TEMPERATURE DURING THE DRYING PERIODS FOR THE APPLES

Trays	RH-outside, %	Temperature-outside, °C
	42,64	22,02
	RHs-inside	Temperature-inside
1	41,82	30,26
2	42,20	30,03
3	43,06	30,14
4	43,72	29,95
5	45,74	29,58
6	45,54	28,32

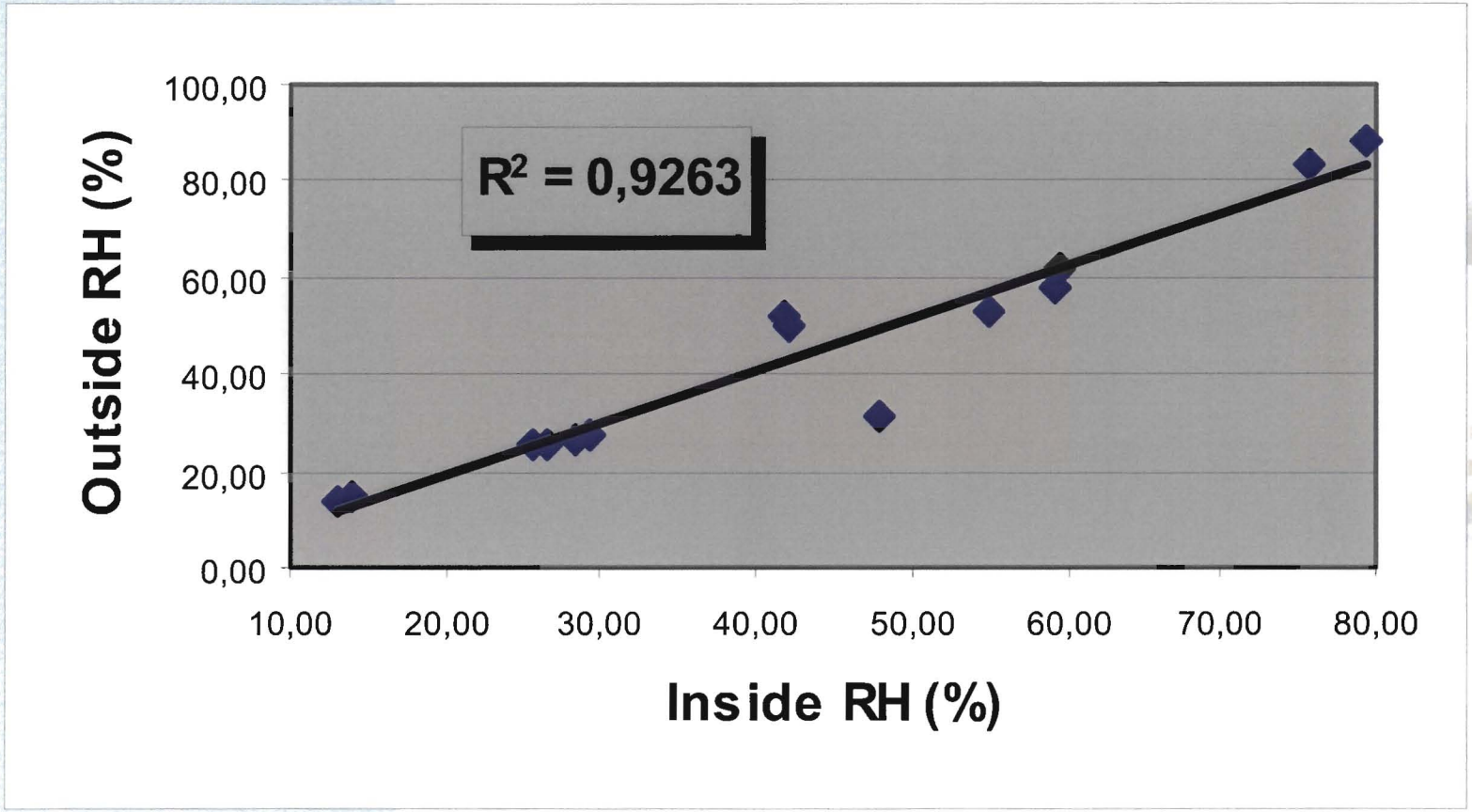
RH VS AVERAGE TEMPERATURE INSIDE THE DRYING CHAMBER



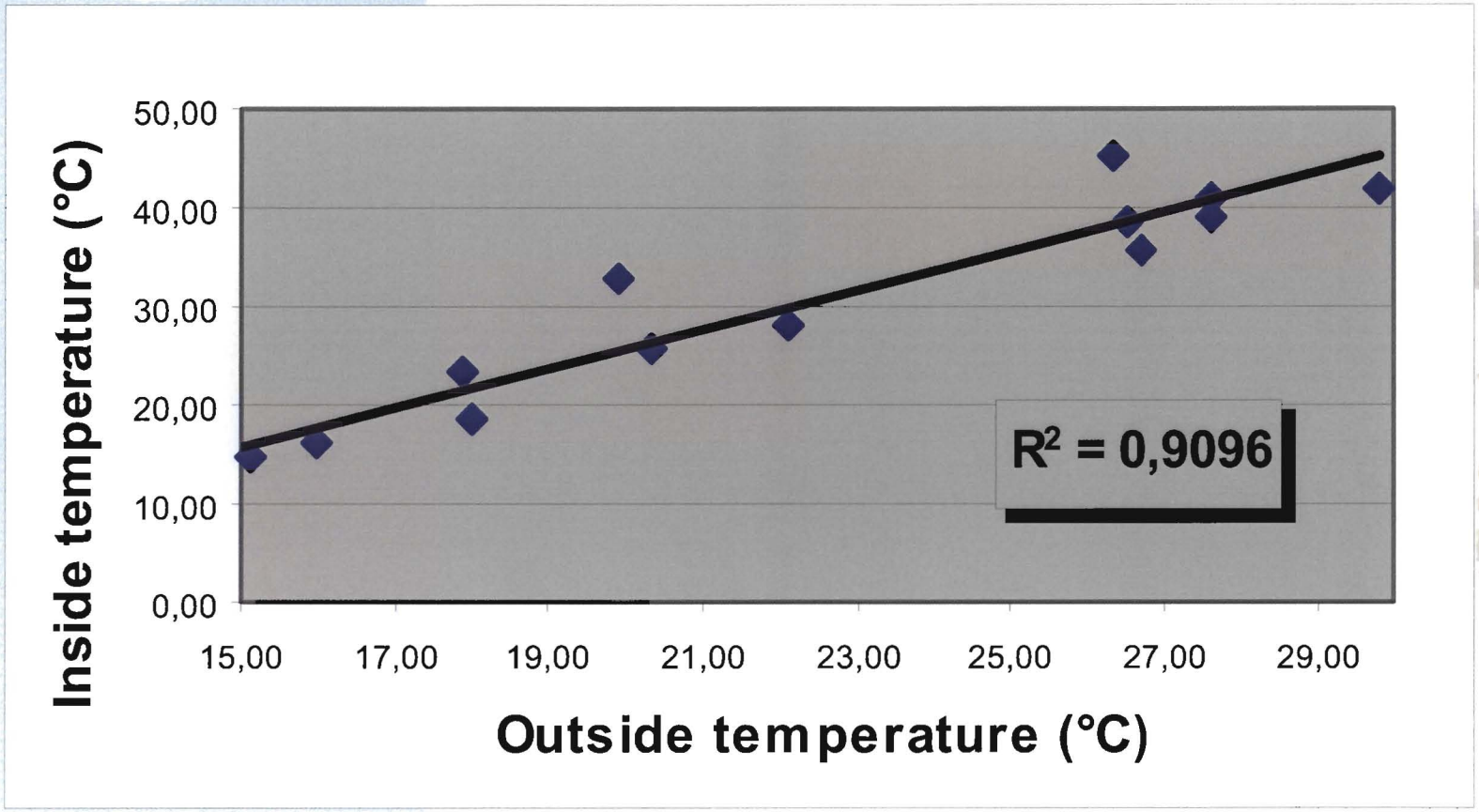
INSIDE CHAMBER RH VS OUTSIDE TEMPERATURE



AVERAGE OF RHS OUTSIDE VS INSIDE THE DRYING CHAMBER



AVERAGE OF TEMPERATURES INSIDE VS OUTSIDE OF THE DRYING CHAMBER



RH AND AVERAGE TEMPERATURE DURING THE DRYING PERIOD FOR THE POTATOES

Trays	RH-outside, %	Temperature-outside, ºC
	32,27	27,13
	RHs-inside	Temperature-inside
1	27,26	42,78
2	27,41	41,20
5	27,44	40,00
6	27,58	39,54

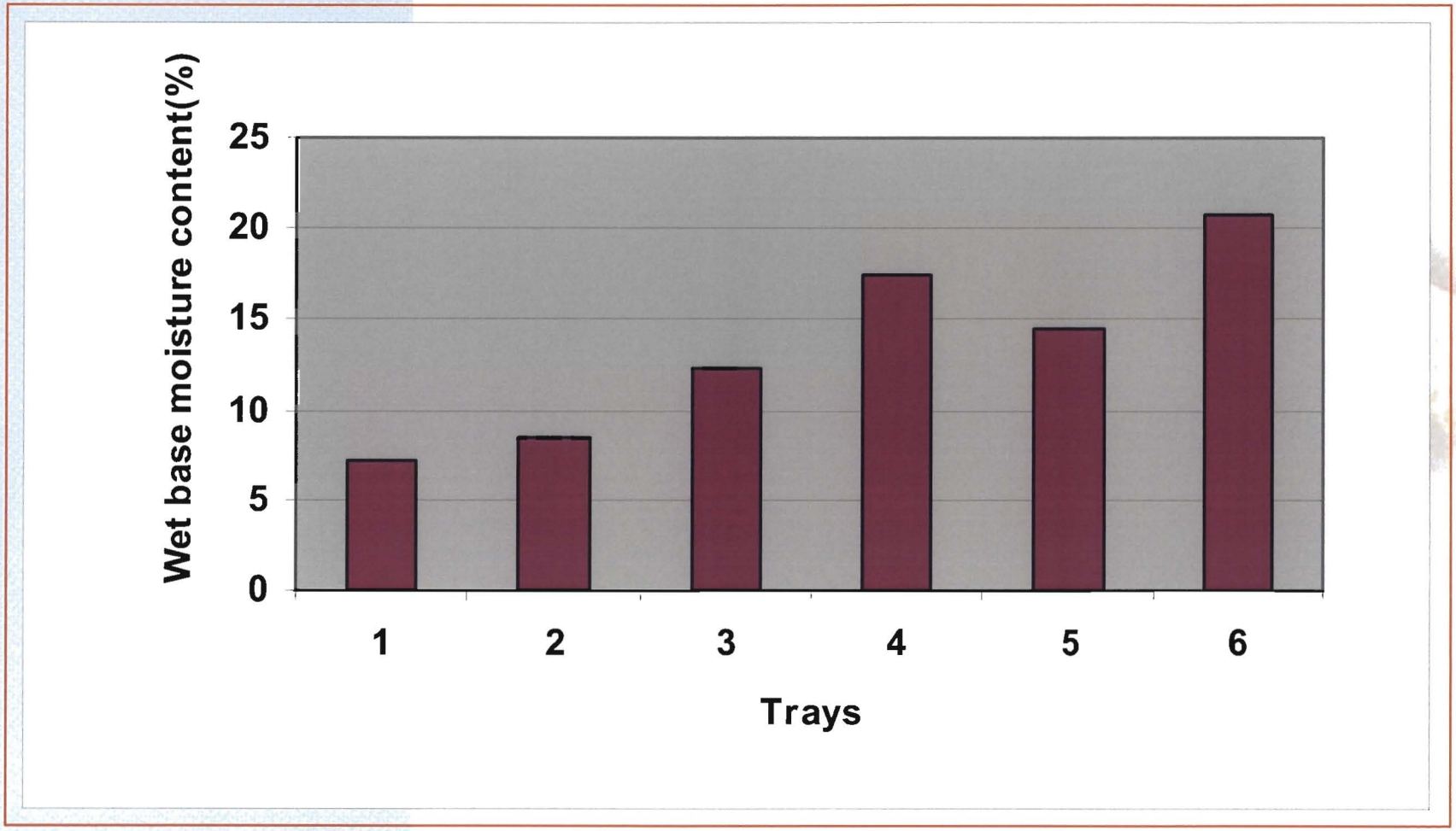
RH AND AVERAGE TEMPERATURE FOR STRAWBERRY AND PINEAPPLE

Trays	RH-outside, %	Temperature-outside, °C
	54,00	24,10
	RHs-inside	Temperature-inside
1	41,67	34,65
2	42,60	34,10
5	38,24	33,50
6	44,41	33,43

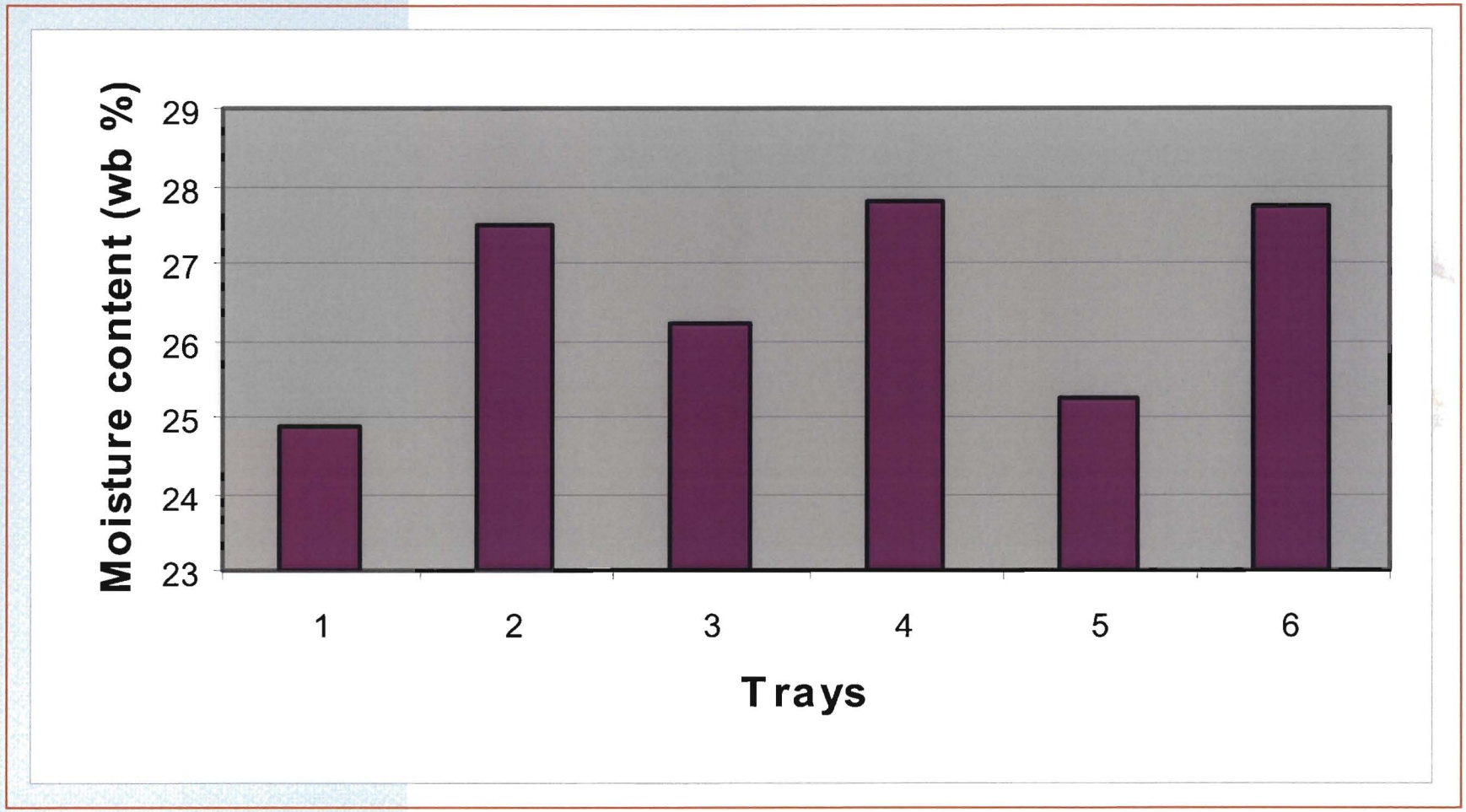
RH AND AVERAGE TEMPERATURE DURING THE DRYING PERIOD FOR PEAR AND KIWI

Trays	RH-outside, %	Temperature-outside, °C
	49,30	20,20
	RHs-inside	Temperature-inside
1	39,90	30,30
2	40,40	29,00
5	40,80	28,60
6	41,00	28,20

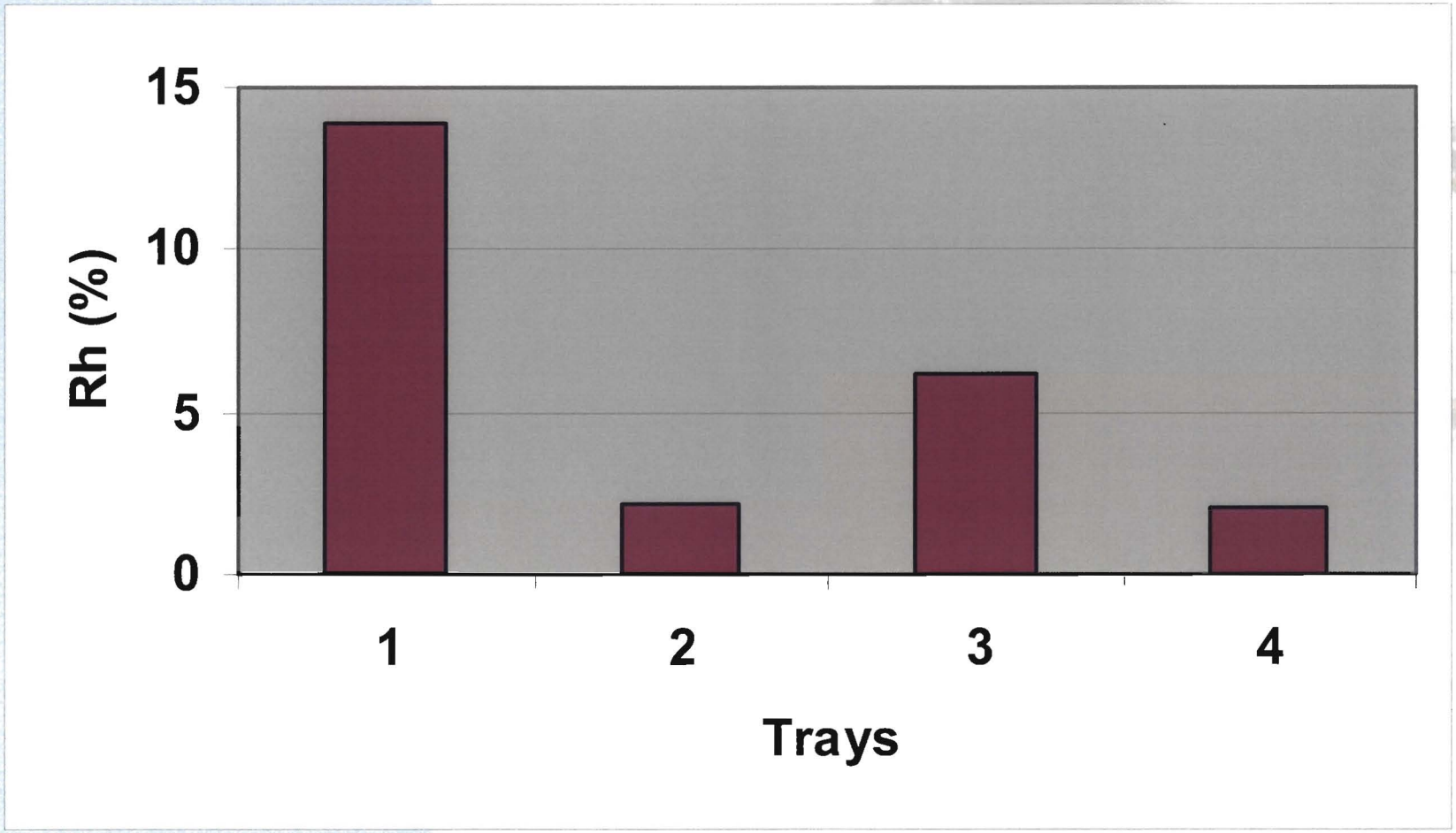
WET BASE MOISTURE CONTENT IN THE DIFFERENT TRAYS FOR THE CARROTS



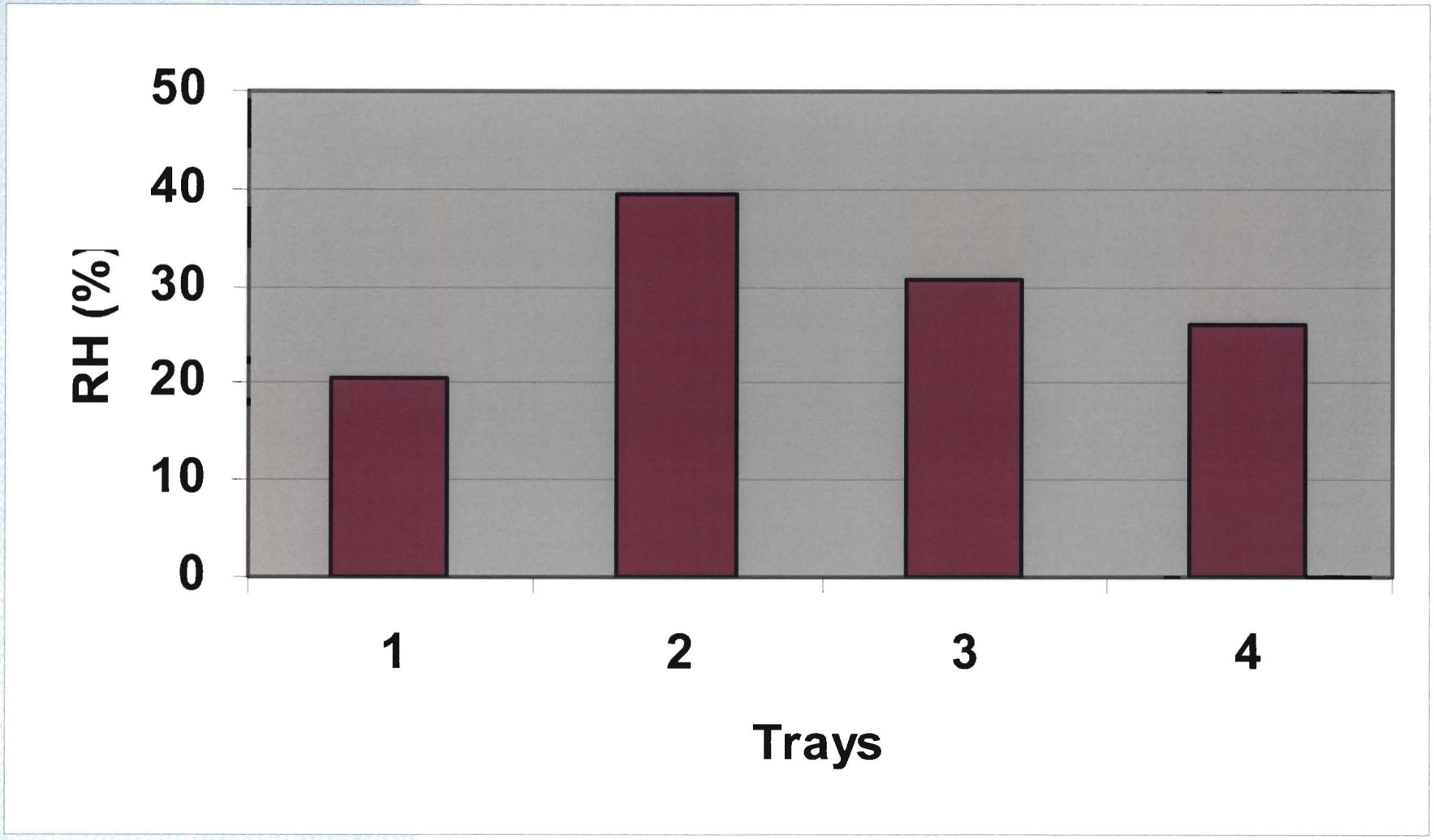
WET BASE MOISTURE CONTENT IN THE DIFFERENT TRAYS FOR THE APPLES



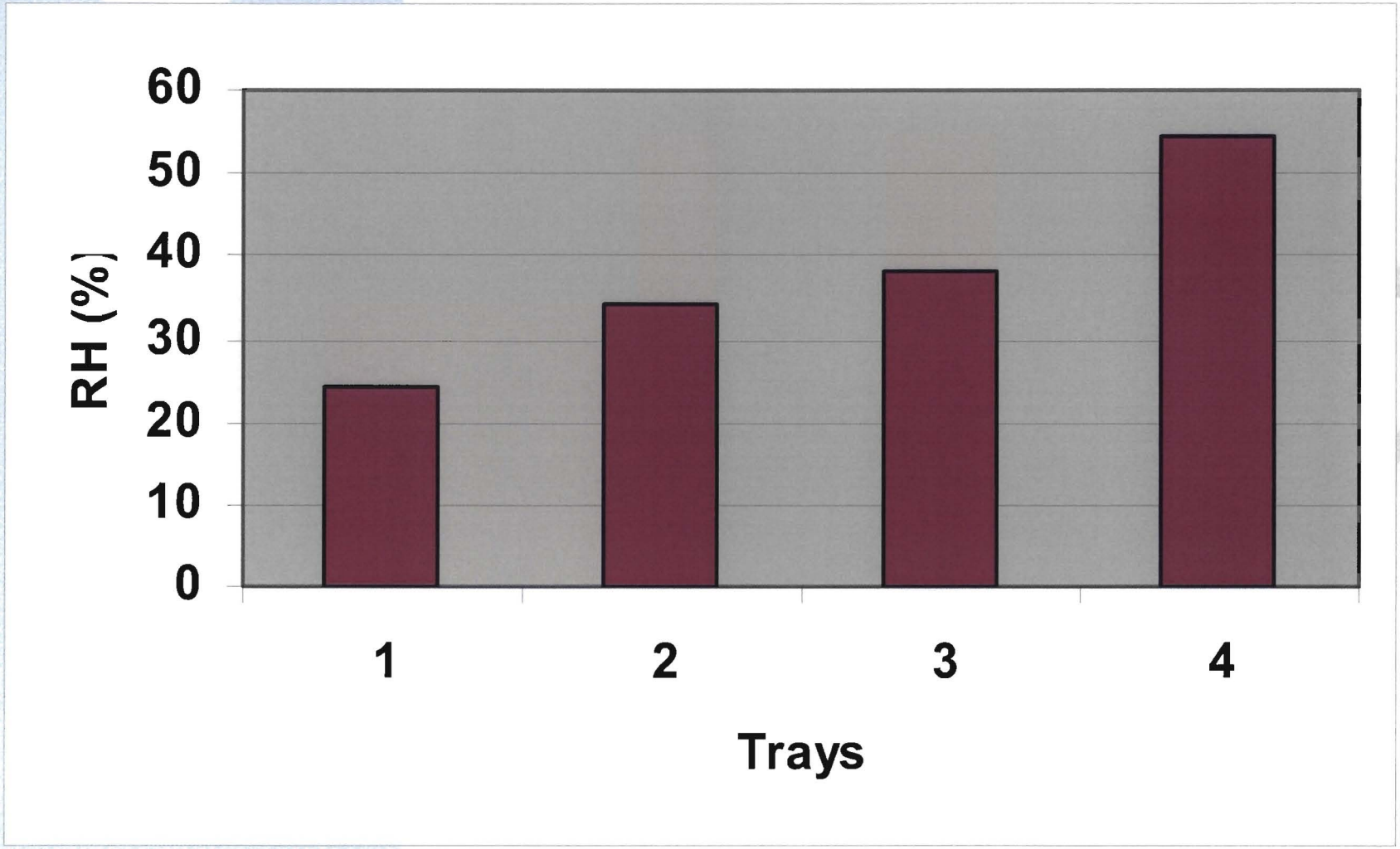
DRY BASE MOISTURE CONTENT IN THE DIFFERENT TRAYS FOR THE POTATOES



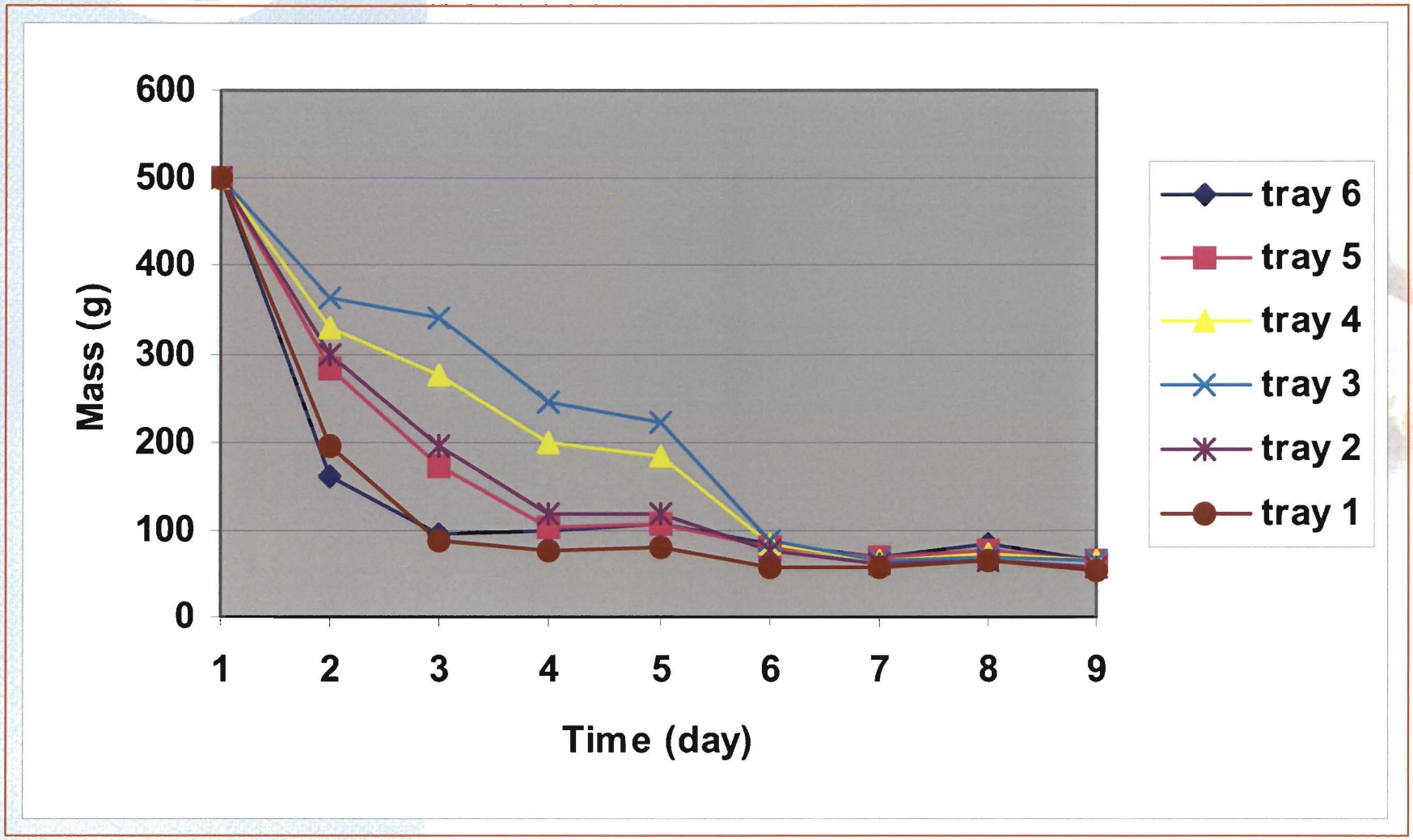
DRY BASE MOISTURE CONTENT IN THE DIFFERENT TRAYS FOR THE STRAWBERRIES AND PINEAPPLES



DRY BASE MOISTURE CONTENT IN THE DIFFERENT TRAYS FOR THE PEARS AND KIWI



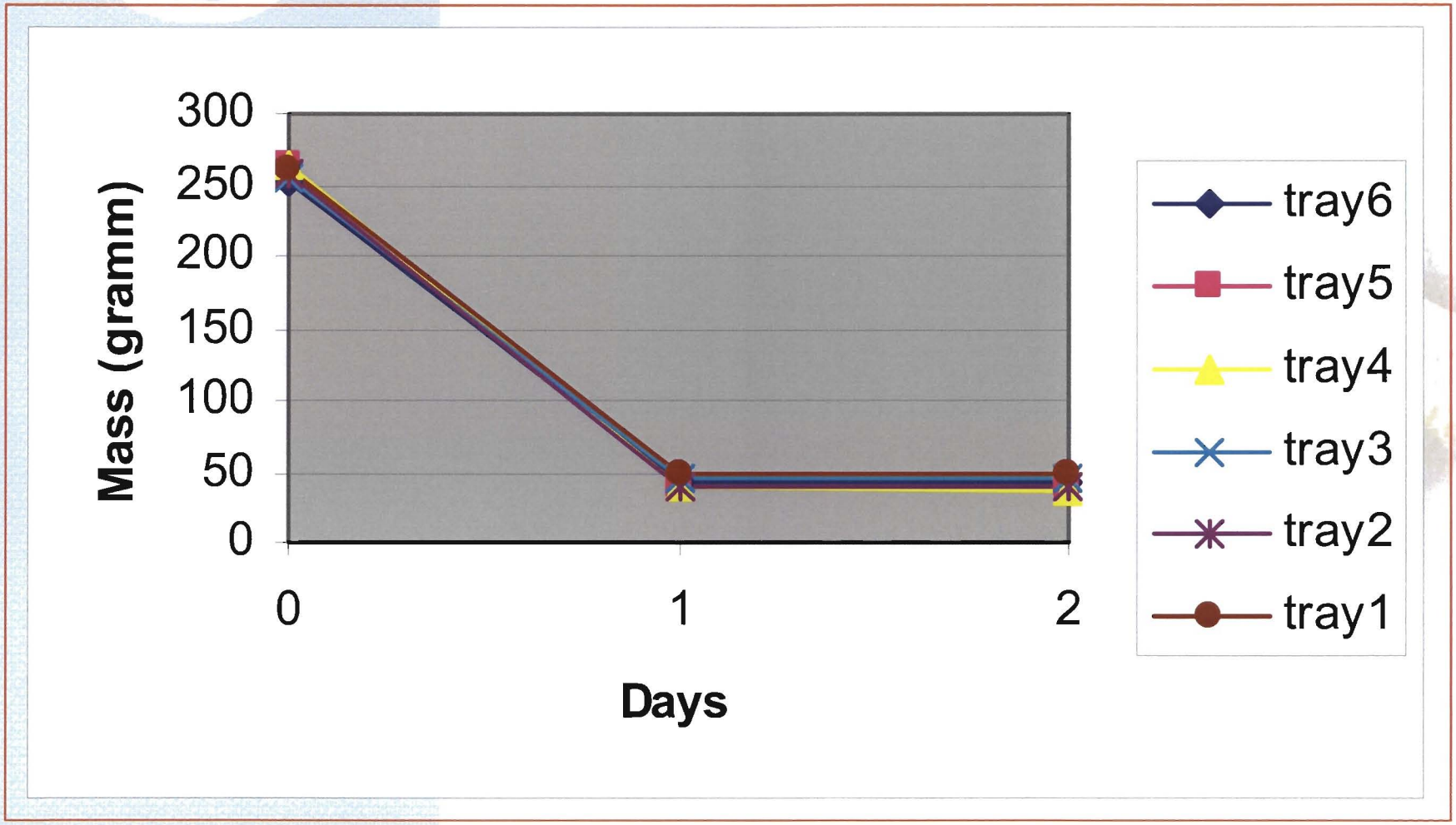
MASS LOSS OF CARROTS DURING THE DRYING PERIOD



RH, AVERAGE TEMPERATURE AND DAILY WEIGHT LOSS FOR CARROTS

Day	RH ext, %	Temp, ºC ext	RH int, %	Temp, ºC, int	Weight loss, g
1					499,5
2	16,89	22,71	15,13	23,07	270
3	11,49	20,5	11,04	21,65	147,55
4	7,59	22,64	7,15	22,59	107,25
5	8,84	21,14	12,74	21,74	103,8
6	13,88	14,7	14,56	21,39	60,83
7	29,92	19,78	28,52	23,22	60,6
8	74,87	13,22	77,37	16,43	68,05
9	61,16	11,33	57,11	16,8	58,4

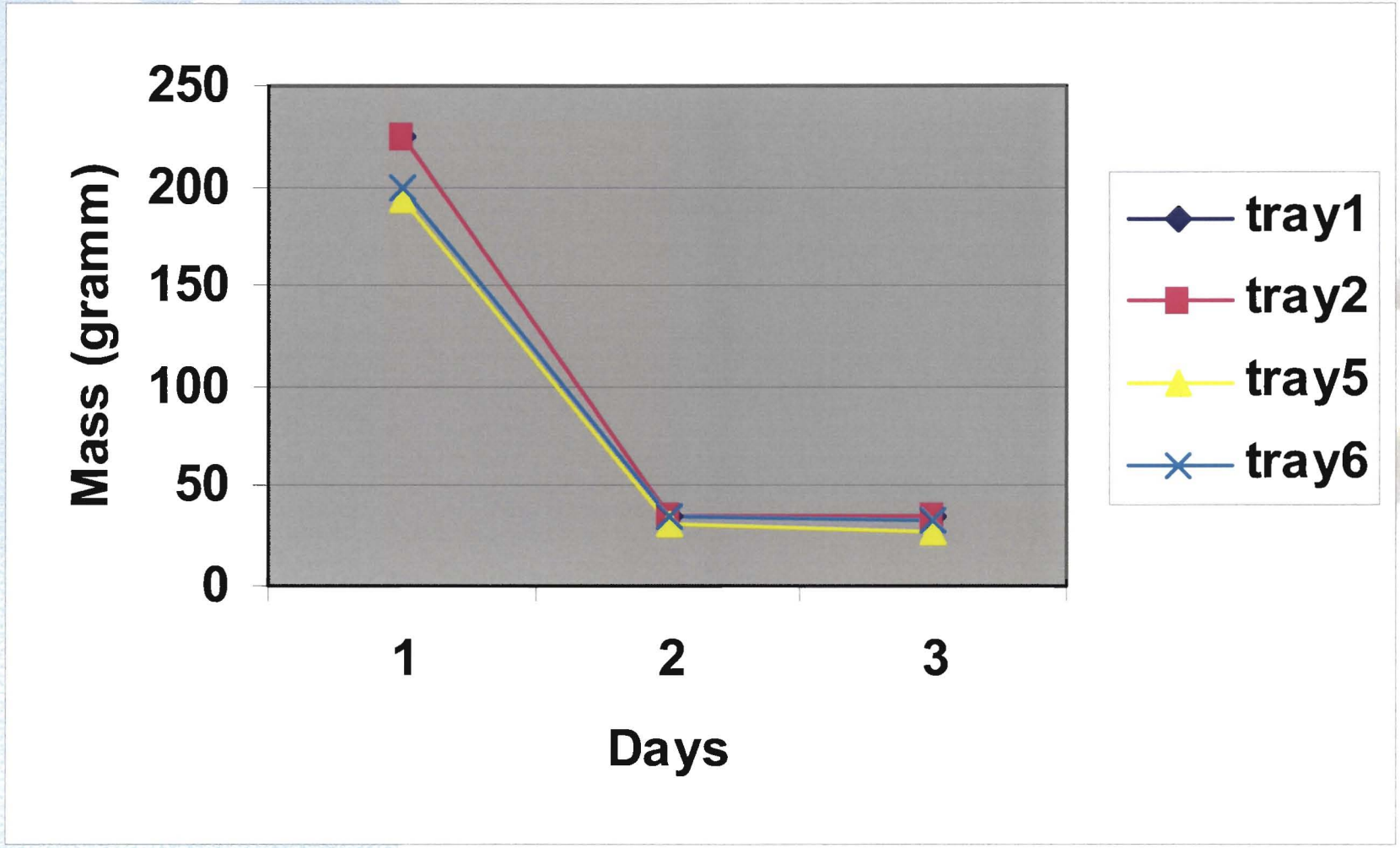
MASS LOSS OF APPLES DURING THE DRYING PERIOD



RH, AVERAGE TEMPERATURE AND DAILY WEIGHT LOSS FOR APPLES

Days	RH ext, %	Temp, °C ext	RH int, %	Temp int, °C	Weight loss, g
1					259
2	59,6	17,98	66,44	21,23	42,4
3	33,22	24,27	31,04	34,05	41,2

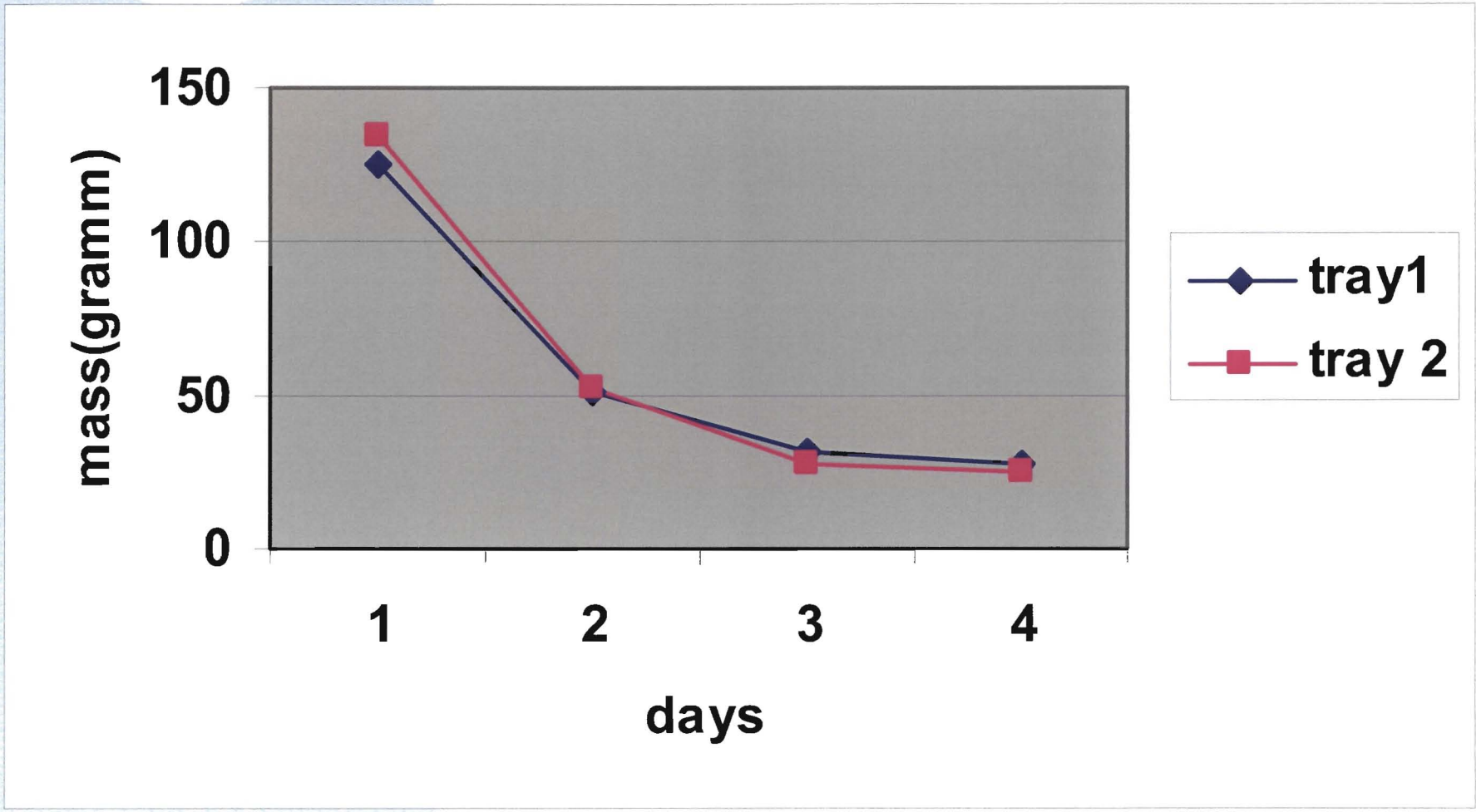
LOSS OF WATER DURING THE DRYING PERIOD FOR THE POTATOES



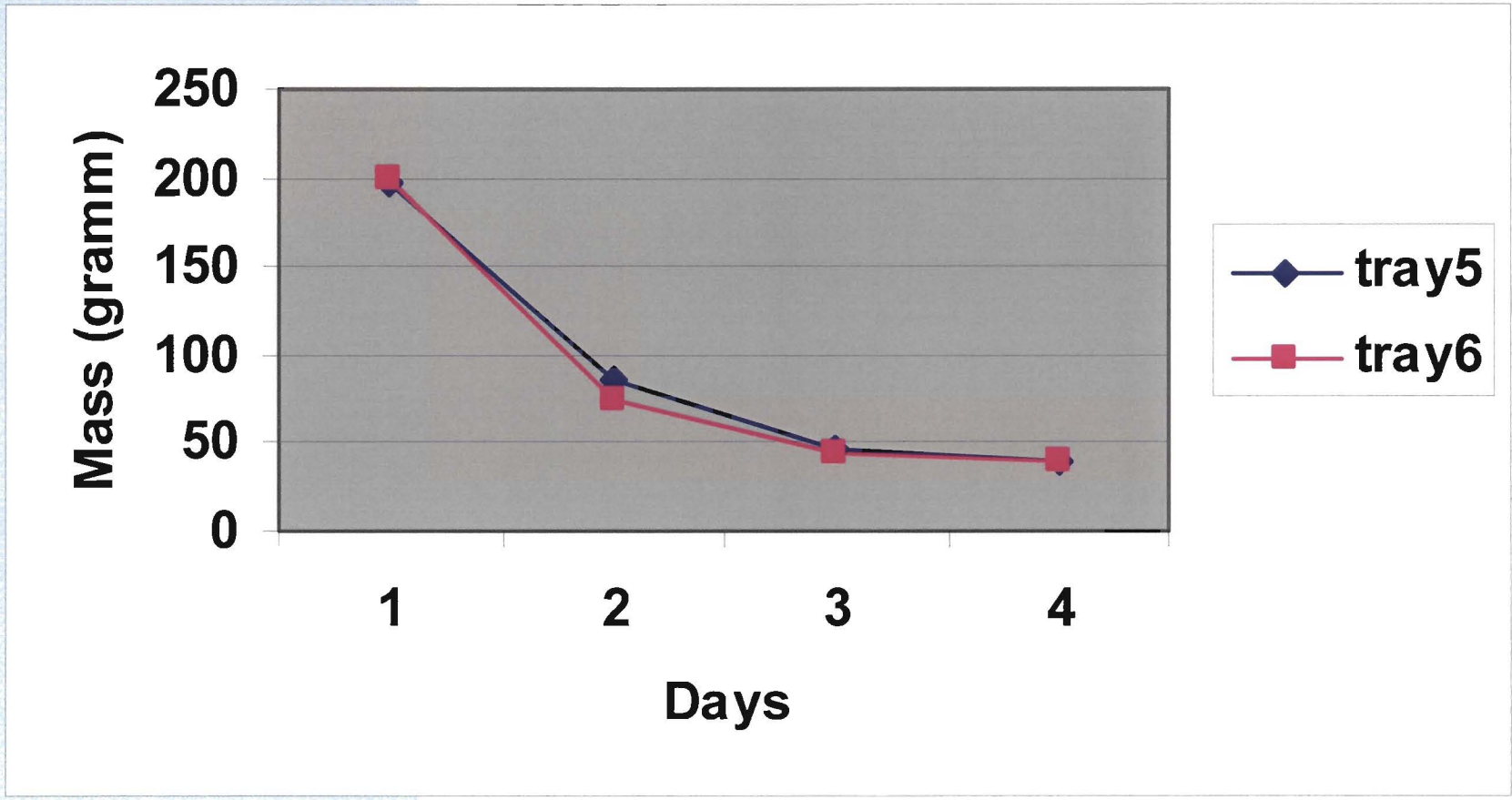
RH, AVERAGE TEMPERATURE AND DAILY WEIGHT LOSS FOR POTATOES

Days	RH ext, %	Temp, °C ext	RH int, %	Temp int, °C	Weight loss, g
1					210
2	32	26	28,6	38,5	34,5
3	32,5	28,5	26,2	43,4	32,5

LOSS OF WATER DURING THE DRYING PERIOD FOR THE STRAWBERRIES



LOSS OF WATER DURING THE DRYING PERIOD FOR THE PINEAPLE



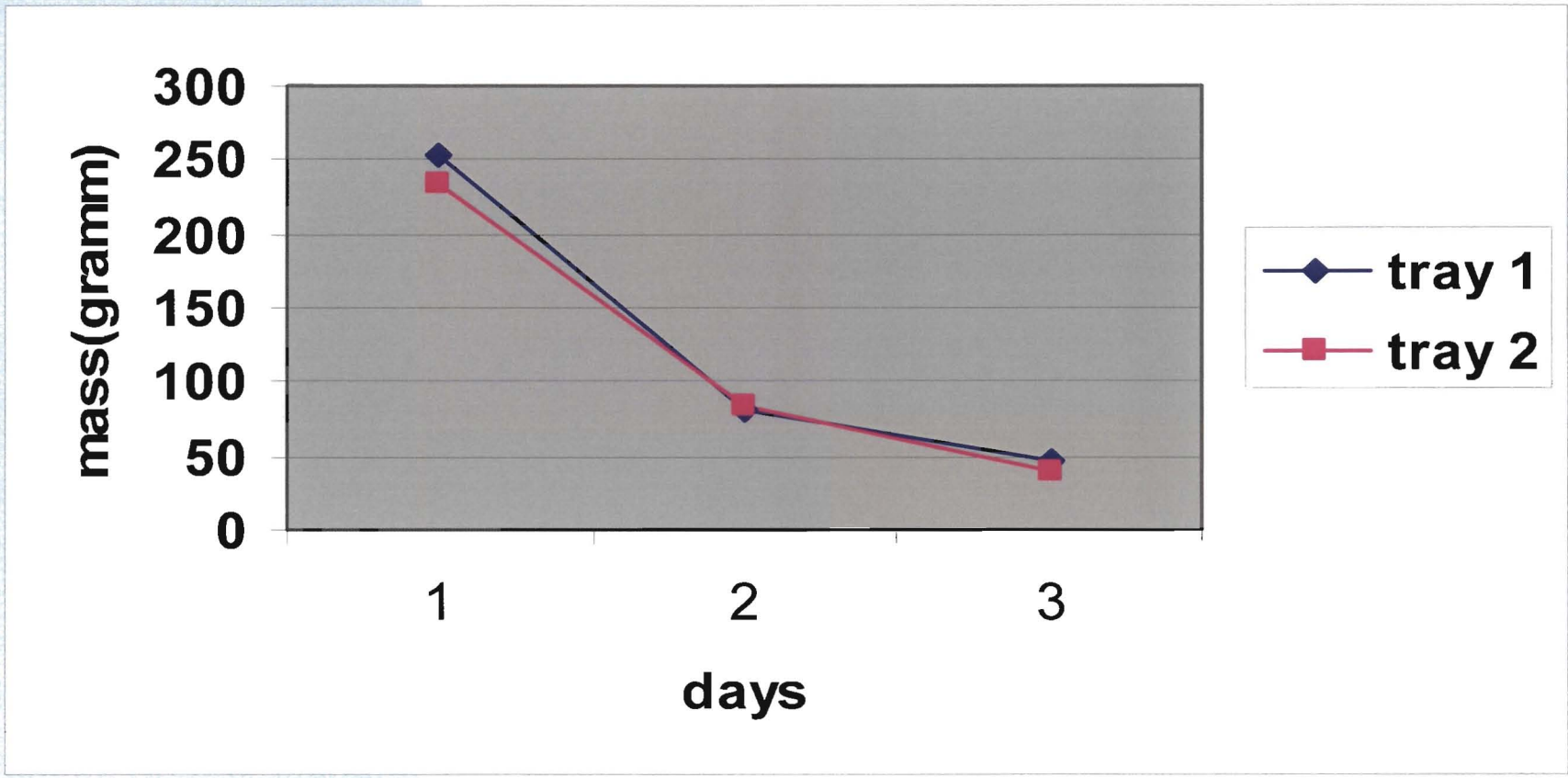
RH, AVERAGE TEMPERATURE AND DAILY WEIGHT LOSS FOR STRAWBERRIES

Days	RH ext, %	Temp, °C ext	RH int, %	Temp int, °C	Weight loss, g
1					129,4
2	33,5	27,2	26,3	39,1	51,6
3	73,9	20,5	65	27	29,3
4	54,5	24,4	36,2	36,6	26,2

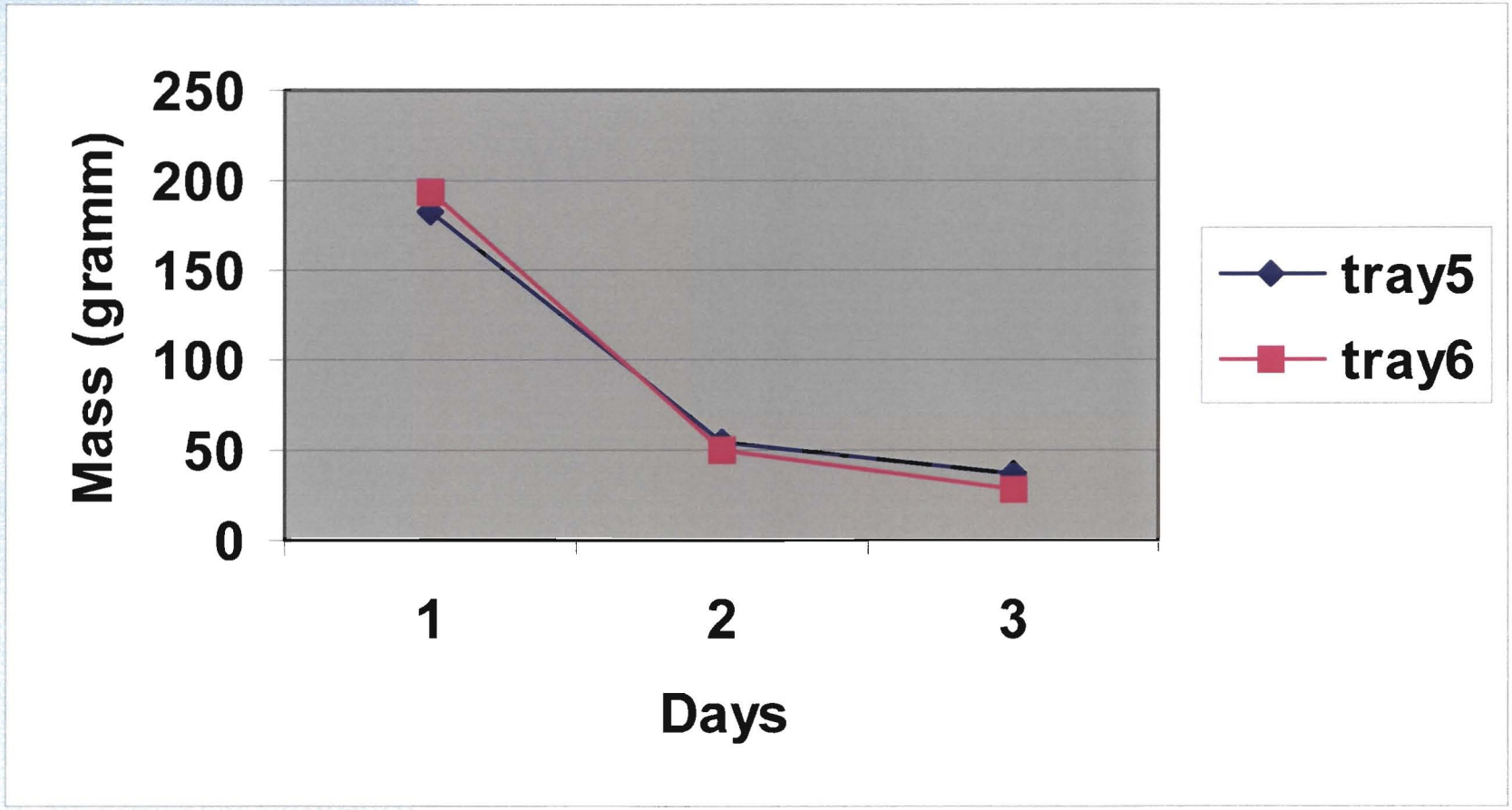
RH, AVERAGE TEMPERATURE AND DAILY WEIGHT LOSS FOR PINEAPPLES

Days	RH ext, %	Temp, ºC ext	RH int, %	Temp int, ºC	Weight loss, g
1					197,7
2	33,5	27,2	28,1	37,4	79,7
3	73,9	20,5	69	26,4	44,8
4	54,5	24,4	38,3	35,9	39,8

LOSS OF WATER DURING THE DRYING PERIOD FOR THE PEARS



LOSS OF WATER DURING THE DRYING PERIOD FOR THE KIWI



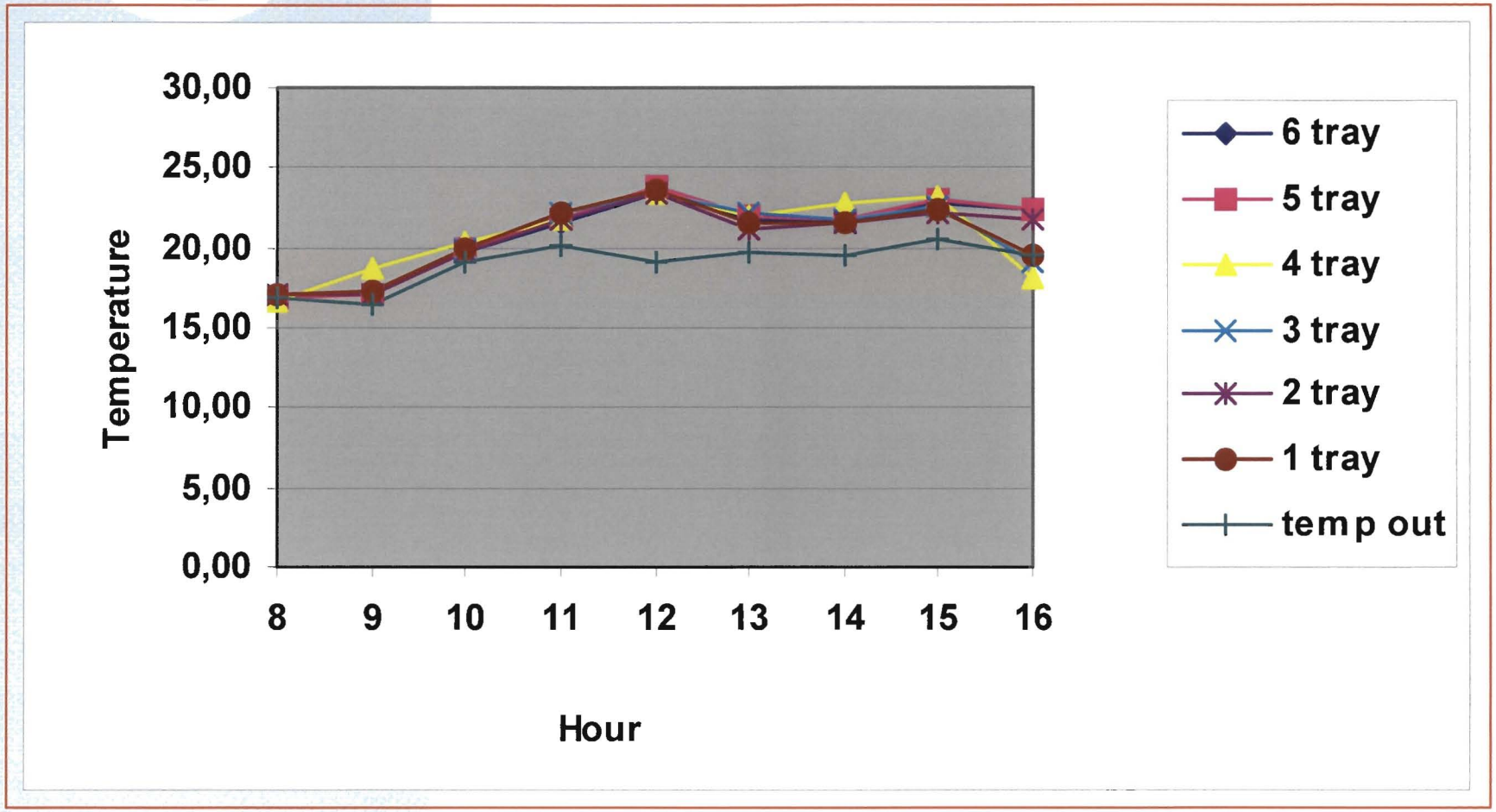
RH, AVERAGE TEMPERATURE AND DAILY WEIGHT LOSS FOR PEARS

Days	RH ext, %	Temp, °C ext	RH int, %	Temp int, °C	Weight loss, g
1					243,9
2	36,7	21,7	33	33	81,8
3	62	19	47.3	26,4	43,2

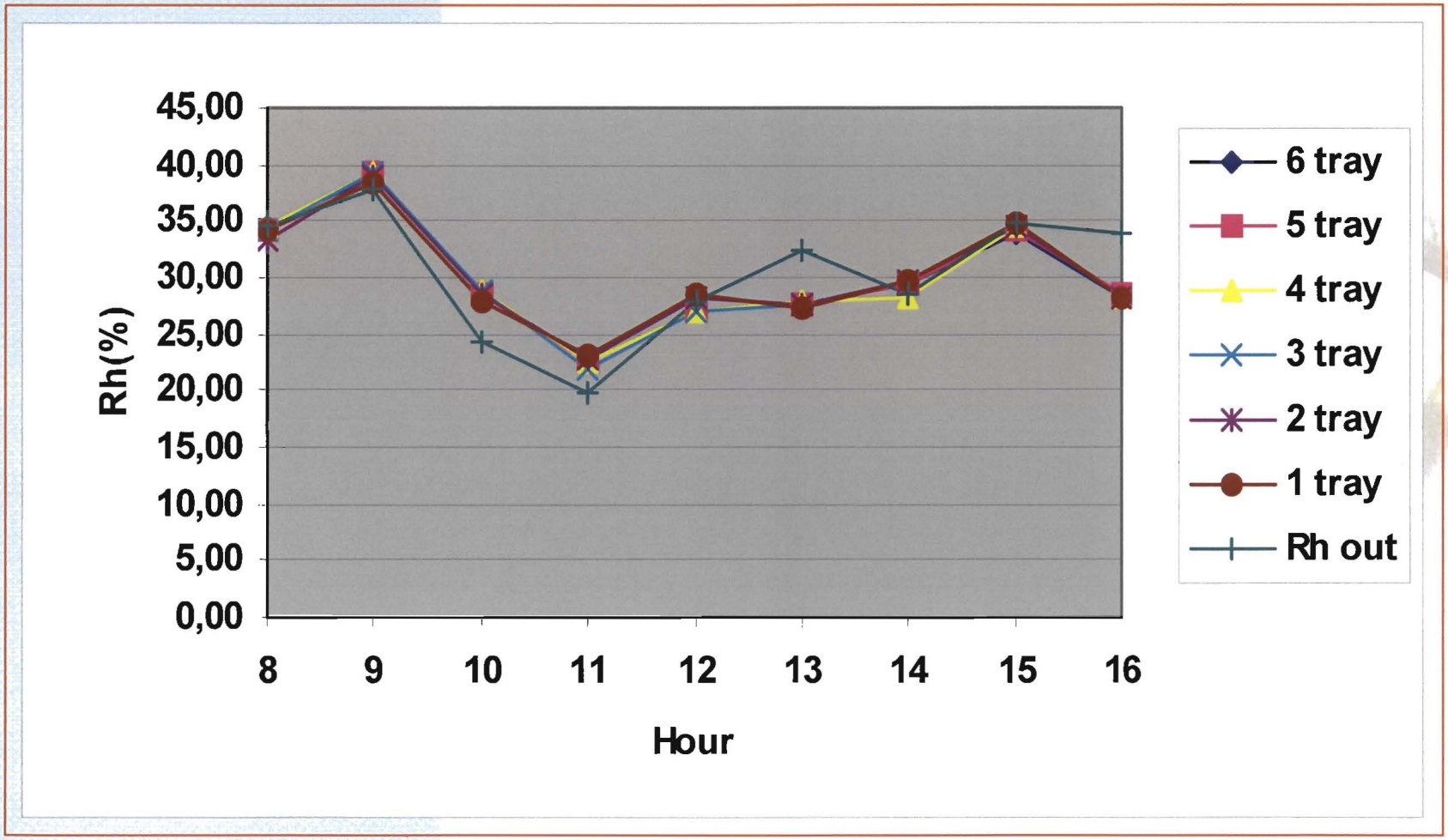
RH, AVERAGE TEMPERATURE AND DAILY WEIGHT LOSS FOR KIWI

Days	RH ext, %	Temp, °C ext	RH int, %	Temp int, °C	Weight loss, g
1					187,6
2	36,7	21,7	33,5	31	52,2
3	62	19	48,2	25,8	31,6

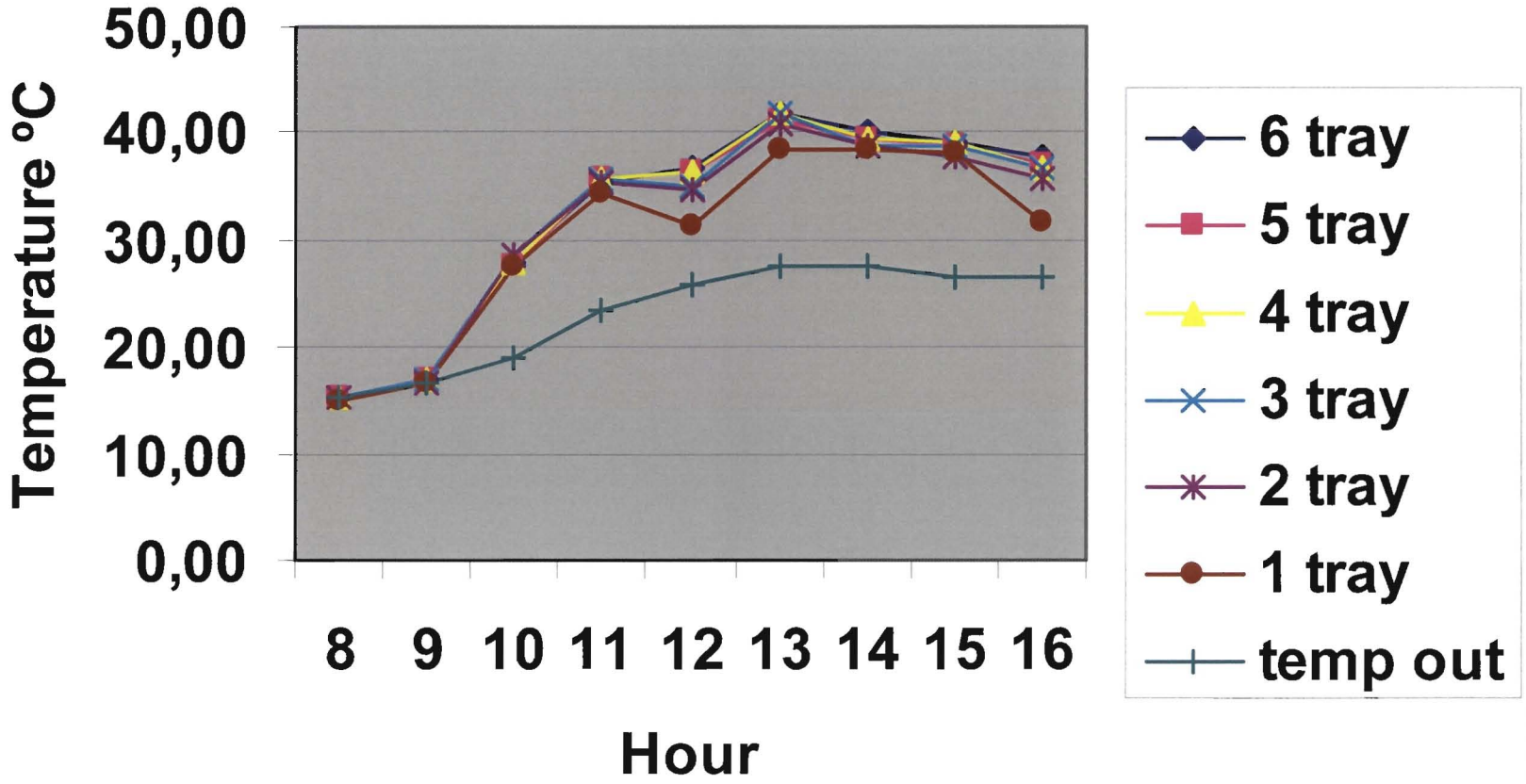
TEMPERATURE DISTRIBUTION INSIDE AND OUTSIDE THE DRYER FOR THE CARROTS



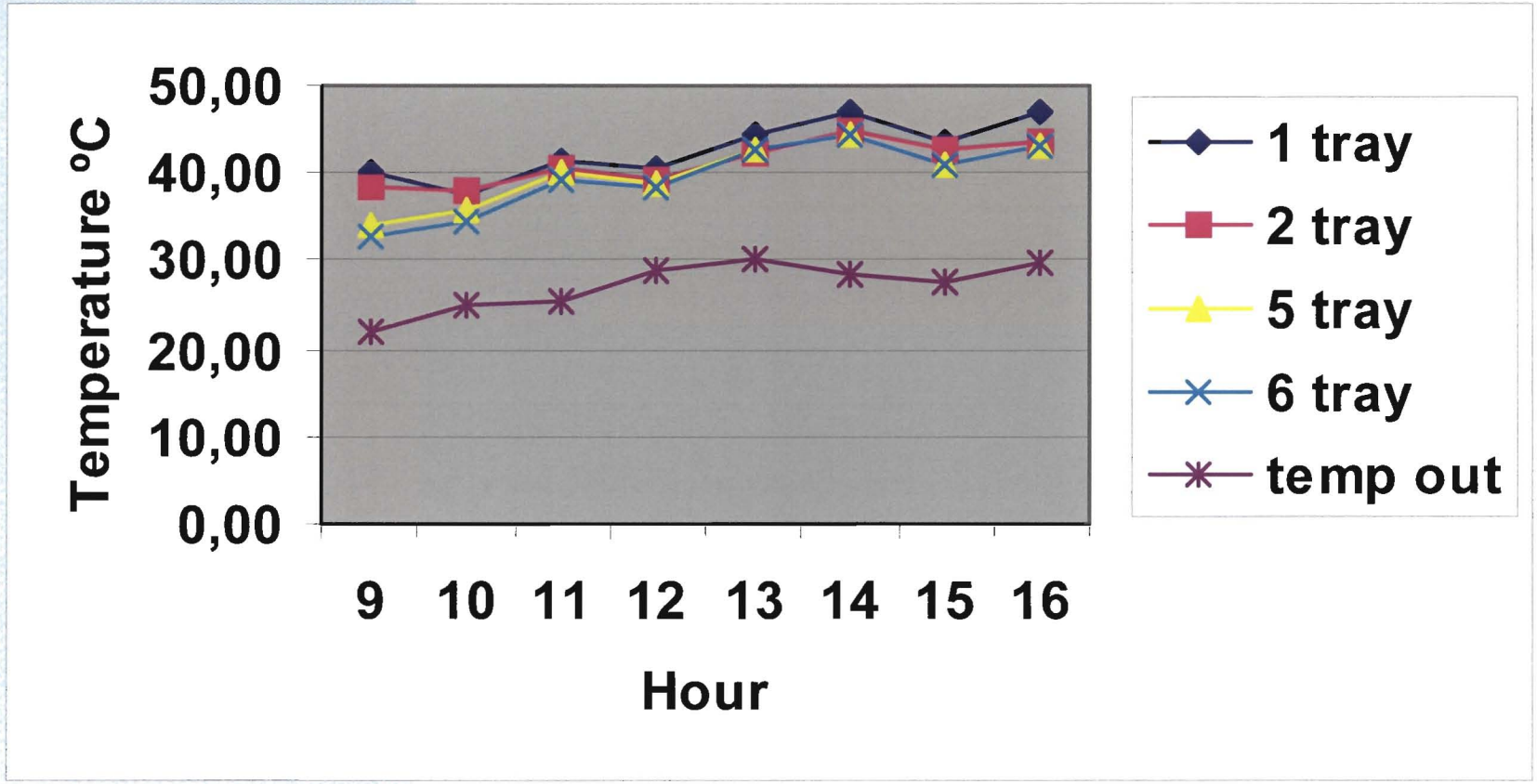
RELATIVE HUMIDITY DISTRIBUTION DURING DRYING PERIOD



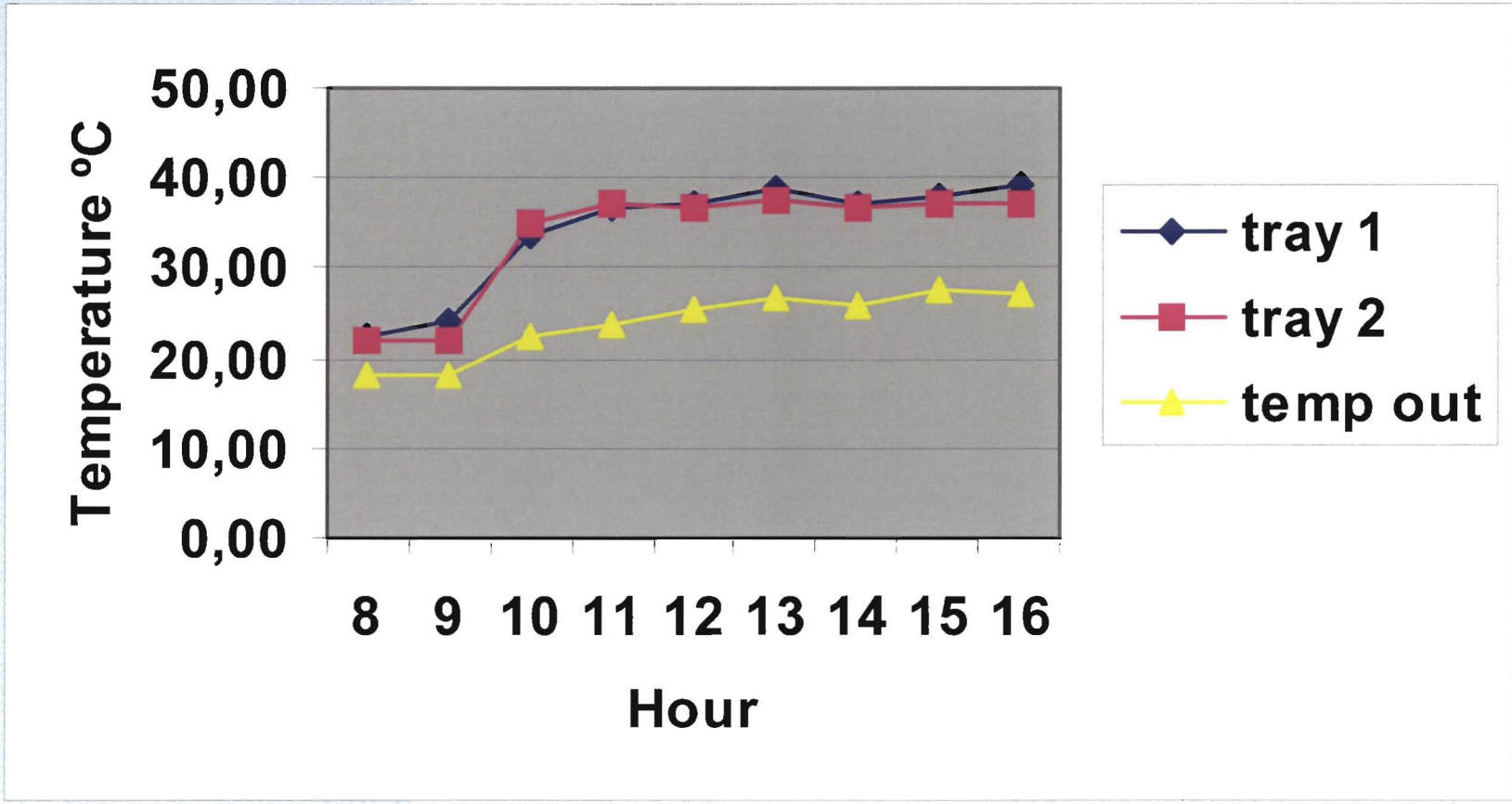
TEMPERATURE DISTRIBUTION INSIDE AND OUTSIDE THE DRYER FOR THE APPLES



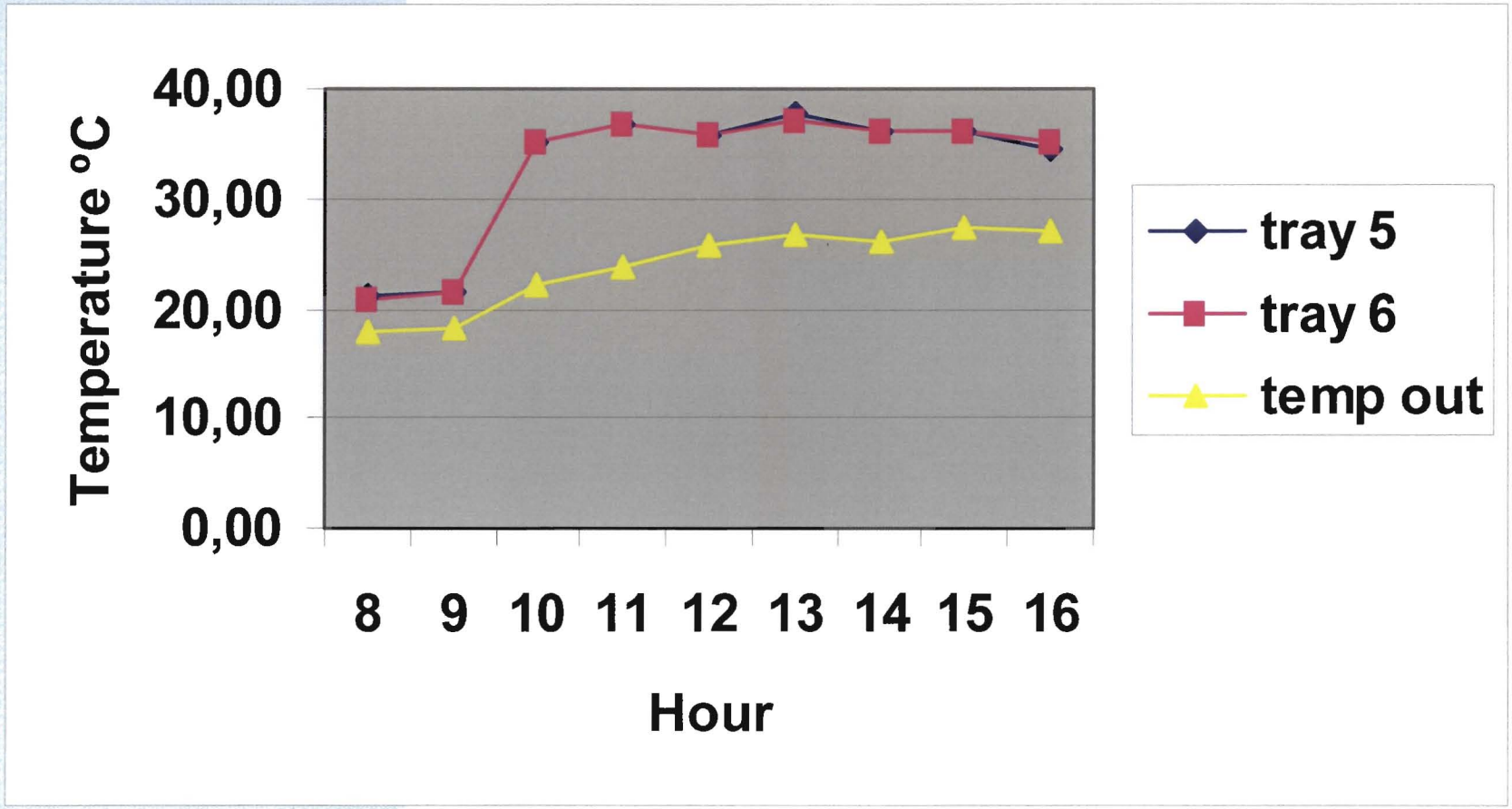
TEMPERATURE DISTRIBUTION OUTSIDE AND INSIDE THE DRYER FOR THE POTATOES



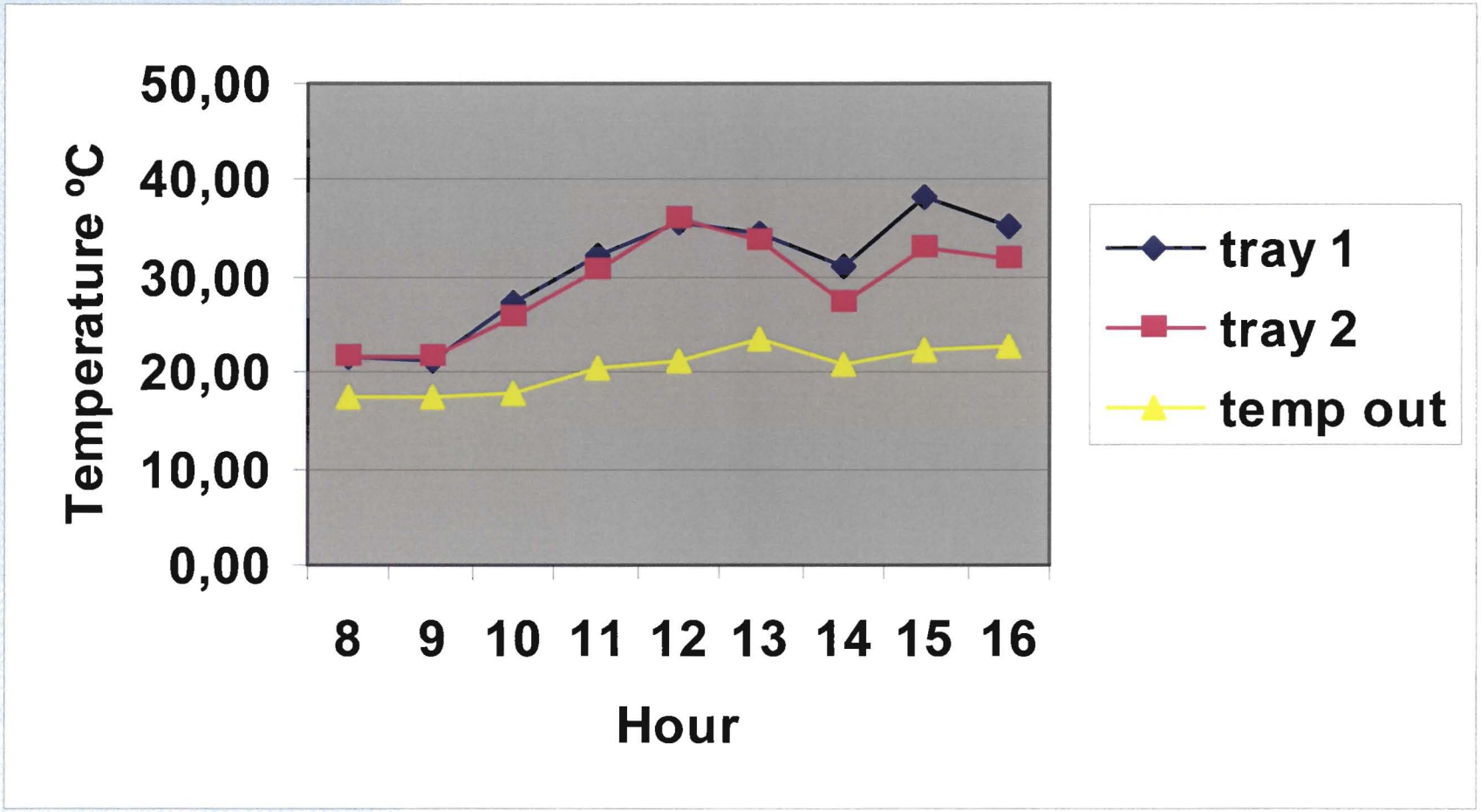
TEMPERATURE DISTRIBUTION OUTSIDE AND INSIDE THE DRYER FOR THE STRAWBERRIES



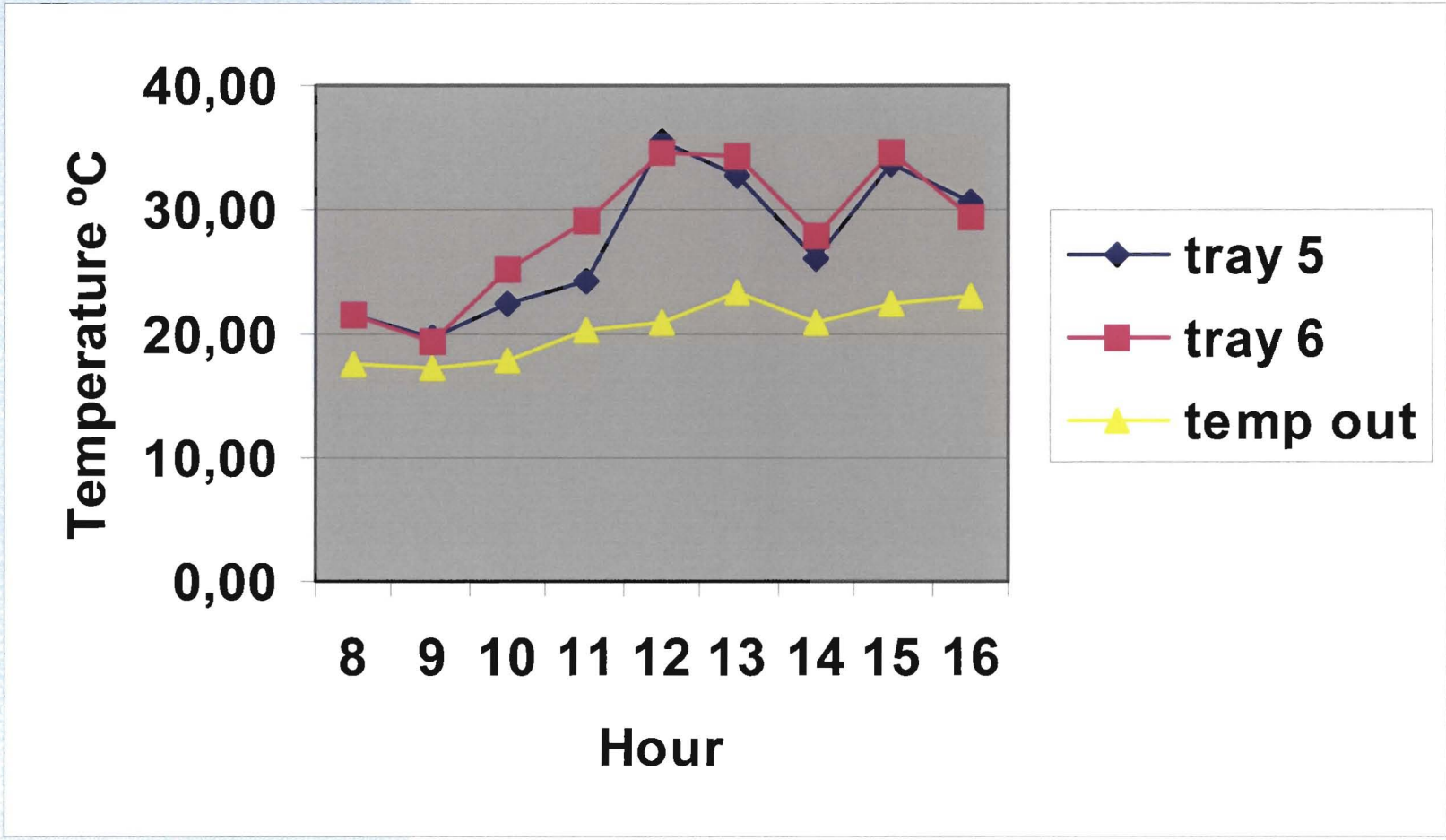
TEMPERATURE DISTRIBUTION OUTSIDE AND INSIDE THE DRYER FOR THE PINEAPPLES



TEMPERATURE DISTRIBUTION OUTSIDE AND INSIDE THE DRYER FOR THE PEARS



TEMPERATURE DISTRIBUTION OUTSIDE AND INSIDE THE DRYER FOR THE KIWI



RESULT OF THE EXPERIMENTS (1/3)

- The carrots lose water during the second part of the day when the temperature inside the chamber is higher.

- The moisture content is more lower for the slice carrots (2 mm) than for the cubic.

- For the apples the final moisture content is more or less the same for all the trays and therefore the different shapes of the product have not any influence on the final status of the drying.

- The temperature and air humidity outside can influence the drying period. For carrots there is not a substantial difference from these parameters as because of low solar radiation due to cloudy weather.

RESULT OF THE EXPERIMENTS (2/3)

•The difference of the moisture content could be caused from the different flow air inside the trays.

•The main finding is that the air humidity inside the drying chamber can influence the rate of weight loss.

• For apples the maximum in weight loss was observed after 24 hours, when the percentage of air humidity was of 66%.

• For carrots the air humidity in the chamber was much lower compared to the apples and therefore an appreciable weight loss was observed after 9 days. This confirms the relevance of the air humidity to obtain a rapid and significant weight loss.

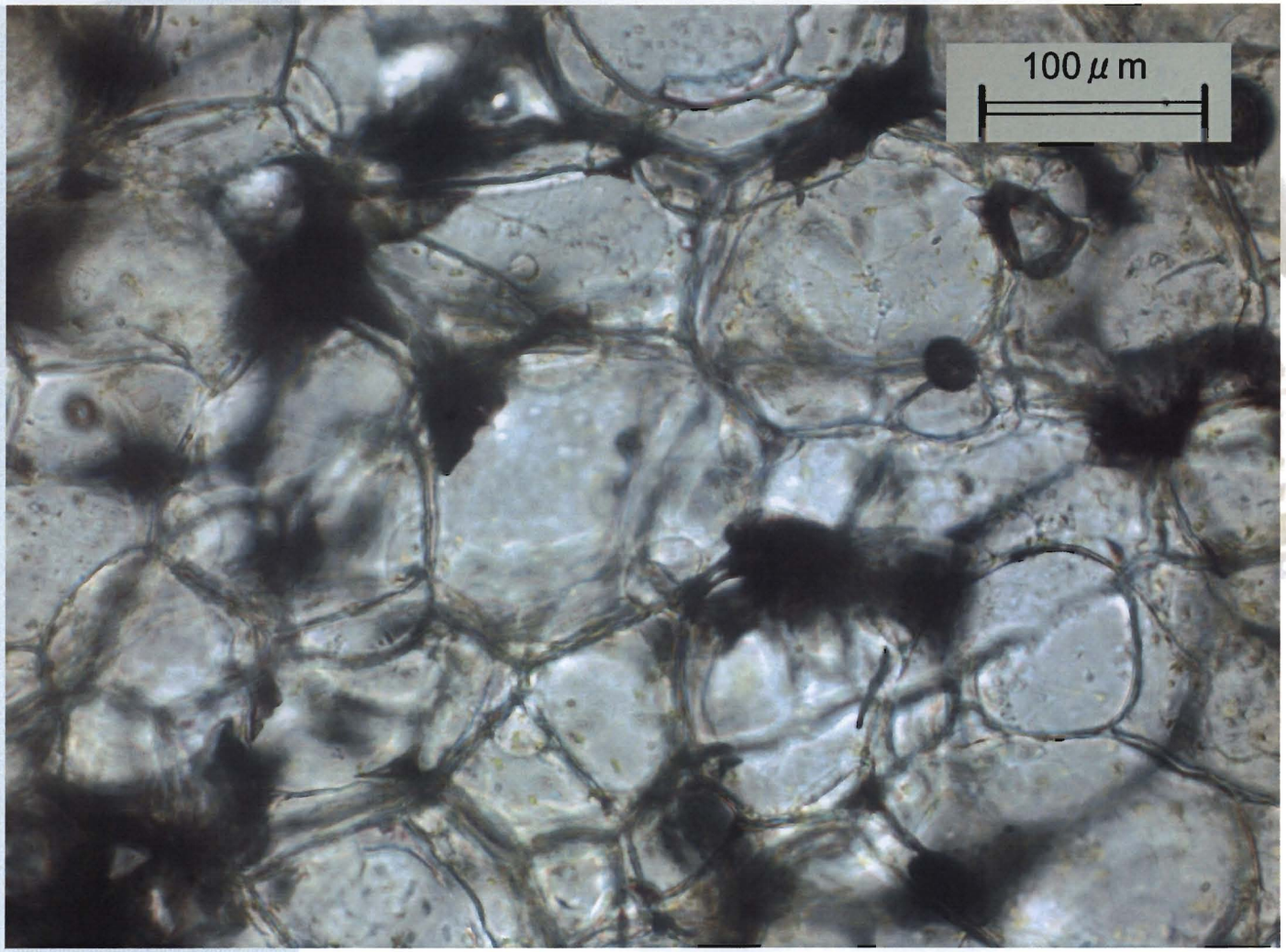
RESULT OF THE EXPERIMENTS (3/3)

• In the case of the other products such as potatoes, strawberries, pine apple, pears, kiwi is possible to obtain faster drying with high temperature and low humidity, then is better to dry these products in the second part of the morning until 4 p.m.

• The drying period influences the characteristics of the fruits in particular colour which is darker in the external layers, and sweetness. They taste sweeter because the loss of water has increased sugar concentration. We did not denote changes in bitterness or acidity, except for kiwi, that is more acidic upon chewing.

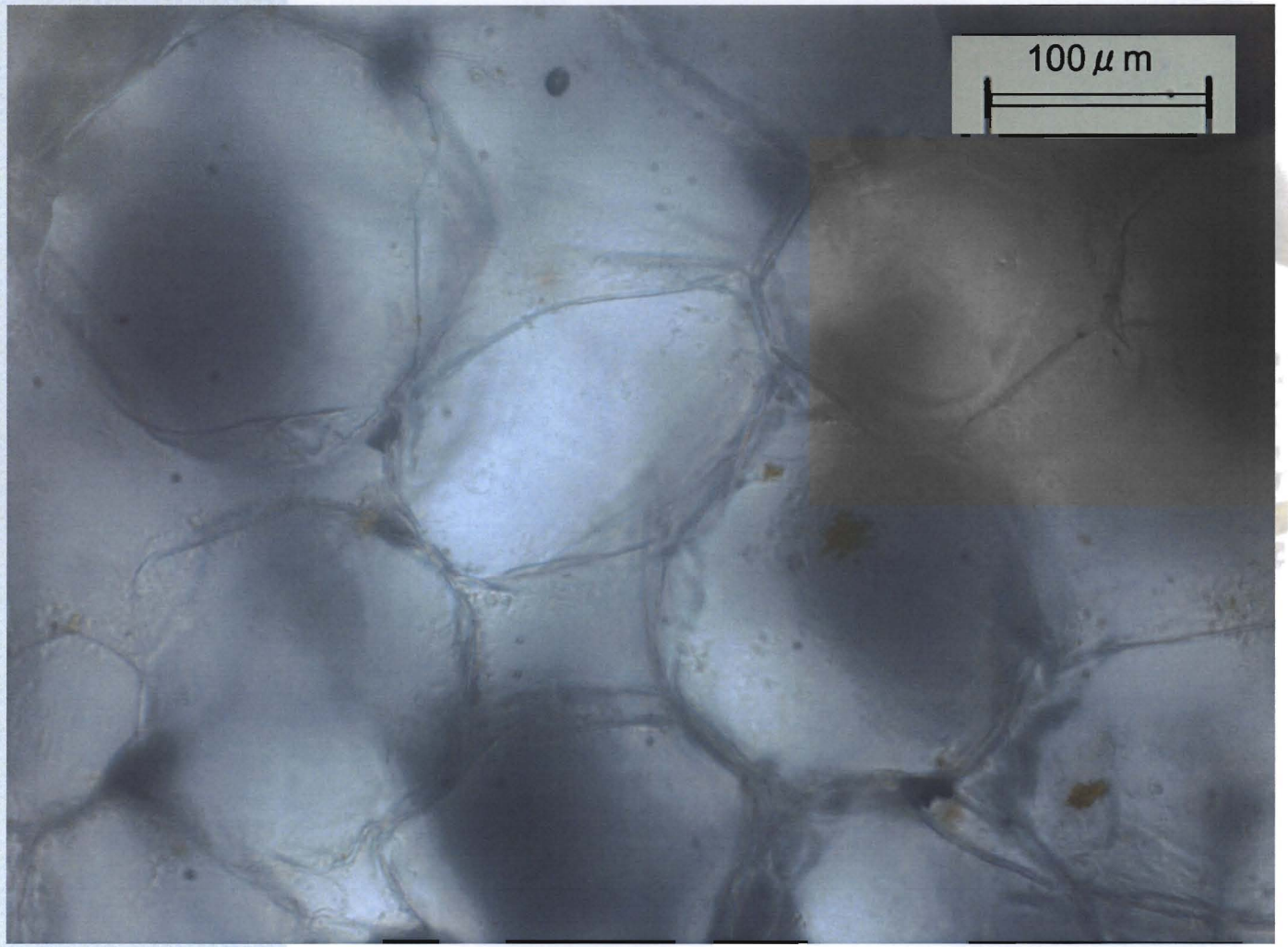
Microstructure of apple during drying

(surface layer)



Microstructure of apple during drying

(center layer)



CONCLUSIONS

• Integrated solar energy/technology system is efficiently used in solar drying of fruit and vegetable.

•Efficiency of solar dryer including the collector part is an important issue.

• Several preliminary measurements are to be carried on for determination of the sorption isotherms, diffusion coefficients, etc.

• During the drying process the measurement of temperature and moisture content of the material to be dried are the most important.

• Optical measurement of moisture content could serve a basis in controlling the on-line drying process.

• Influences of drying parameters have been determined for different fruits and vegetables during solar drying process.

THANK YOU FOR YOUR KIND ATTENTION!