The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2132-37

Winter College on Optics and Energy

8 - 19 February 2010

Intermittent technology for solar drying of crops

I. Farkas

Szent Istvan University
Hungary

Strada Costiera 11, 34151 Trieste, Italy - Tel.+39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it

INTERMITTENT TECHNOLOGY FOR SOLAR DRYING OF CROPS

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

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

C O N T E N T S

CONCEPT OF INTERMITTENT DRYING

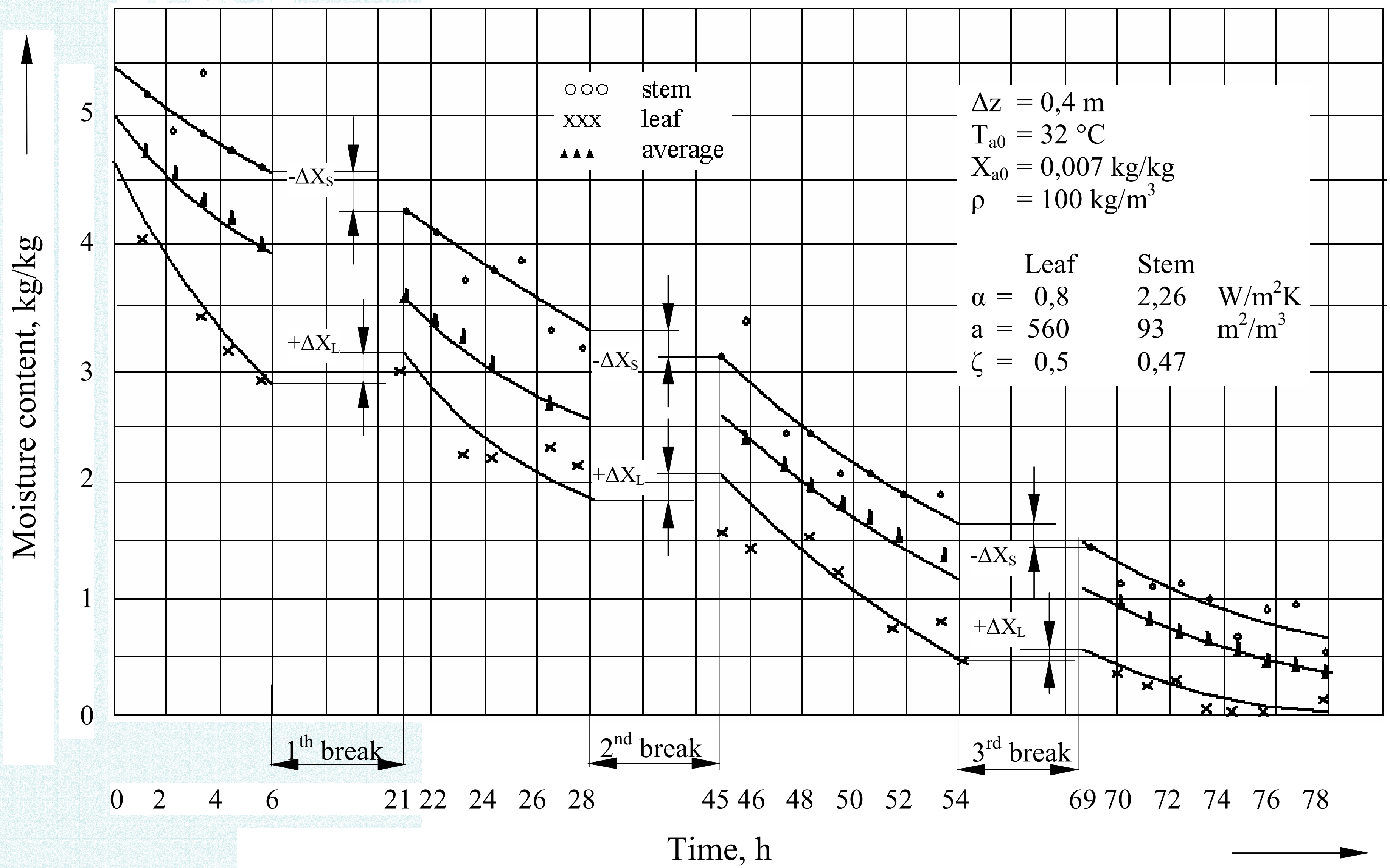
- APPLICATION POSSIBILITIES
  - IN CASE OF MULTICOMPONENT MATERIALS
  - USING THE INTERNAL ENERGY OF MATERIAL BED
- BENEFITS OF INTERMITTENT DRYING
  - ENERGY SAVING
  - HOMOGENEOUS MATERIAL BED
  - AVOIDING QUALITY DEGRADATION
- COMBINATION WITH THE USE OF SOLAR ENERGY

ALFALFA DRYING

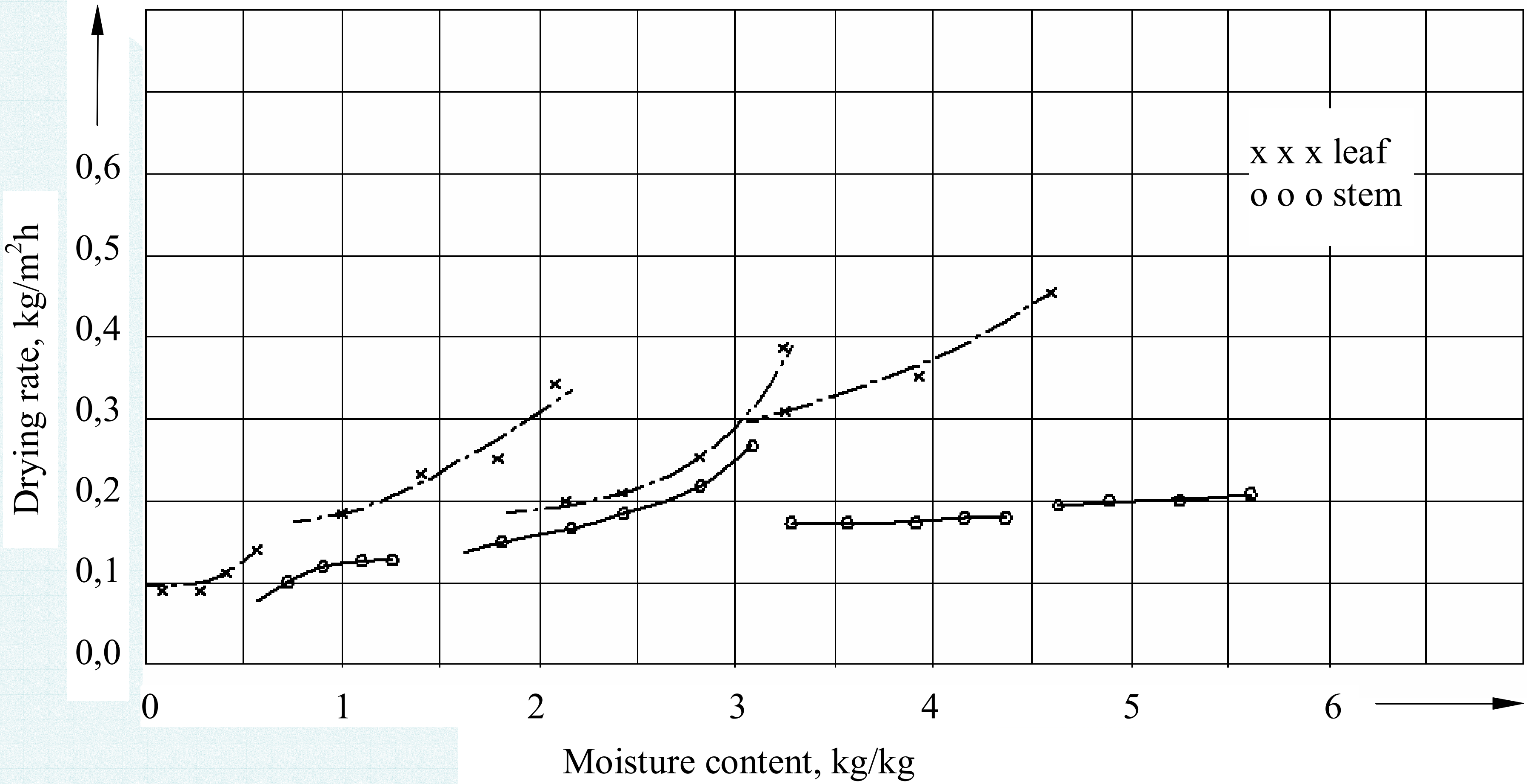
- ALFALAFA IS USED INITIALLY FOR ANIMAL FEEDING
- IT HAS TWO MAIN COMPONENTS:
  - LEAF
  - STEM
- PREREQUISITS DURING THE ALFALFA DRYING:
  - AVOID DETOUCHING OF LEAF AND STEM
  - AVOID OVERDRYING
  - REDUCE THE CONSUMED ENERGY
- INTERMITTENT DRYING CAN BE SUCCESSFULLY APPLIED

PICTURE OF ALFALFA FIELD, STEM AND LEAF

RESULTS OF INTERMITTENT DRYING EXPERIMENT



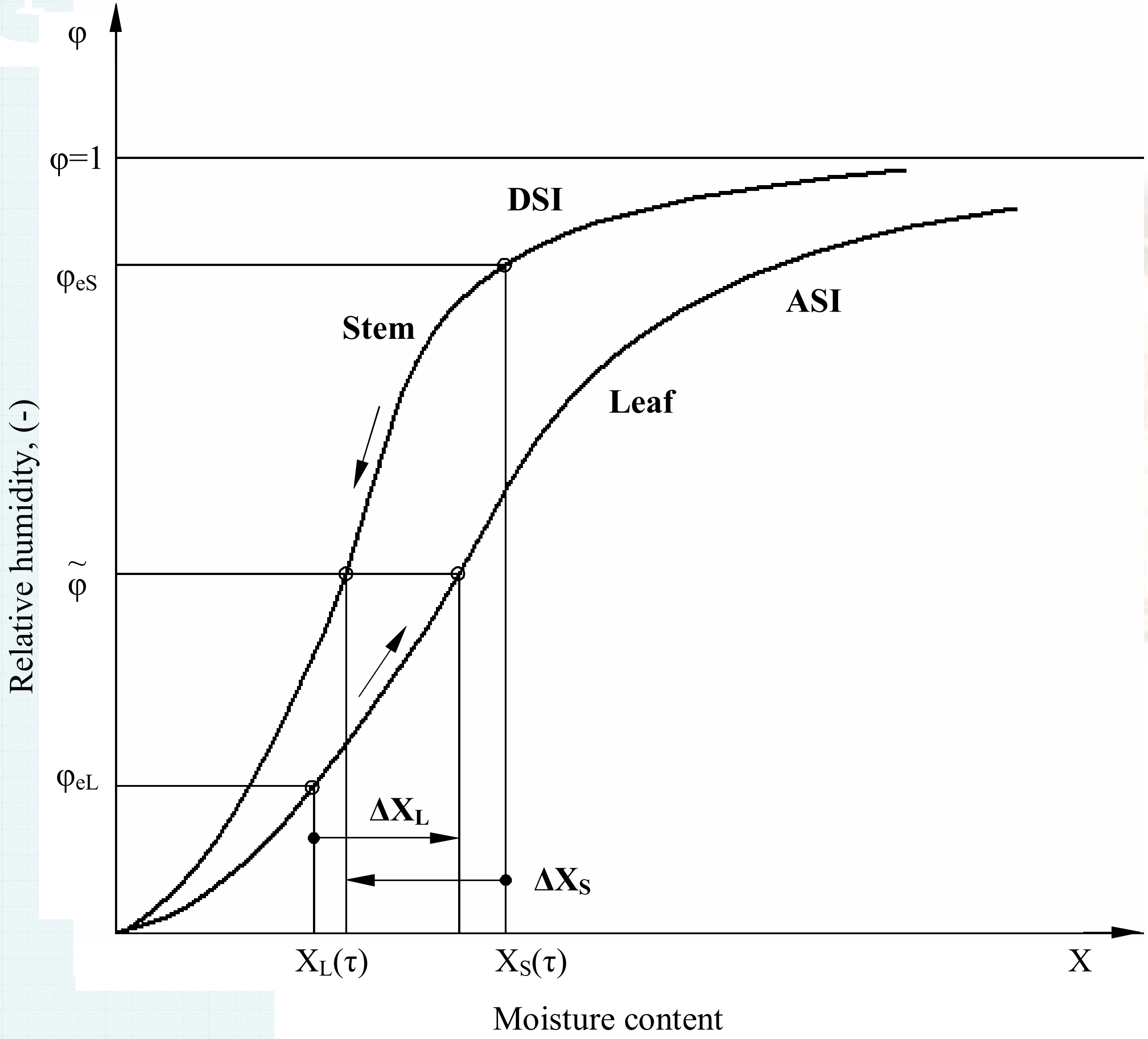
THE DRYING RATE CURVES OF THE COMPONENTS



MODELLING OF ALFALFA DRYING PROCESS

- **DRYING AND REWETTING PROCESSES**
- **PHYSICALLY BASED MODEL (PBM) IS ADVISED**
- **PHYSICAL PROPERTIES OF COMPONENTS ARE NEEDED**
  - **SORPTION AND DESORPTION ISOTHERMS**
- **WAY OF MODELLING**
  - **THICK LAYER**
  - **THIN LAYER**

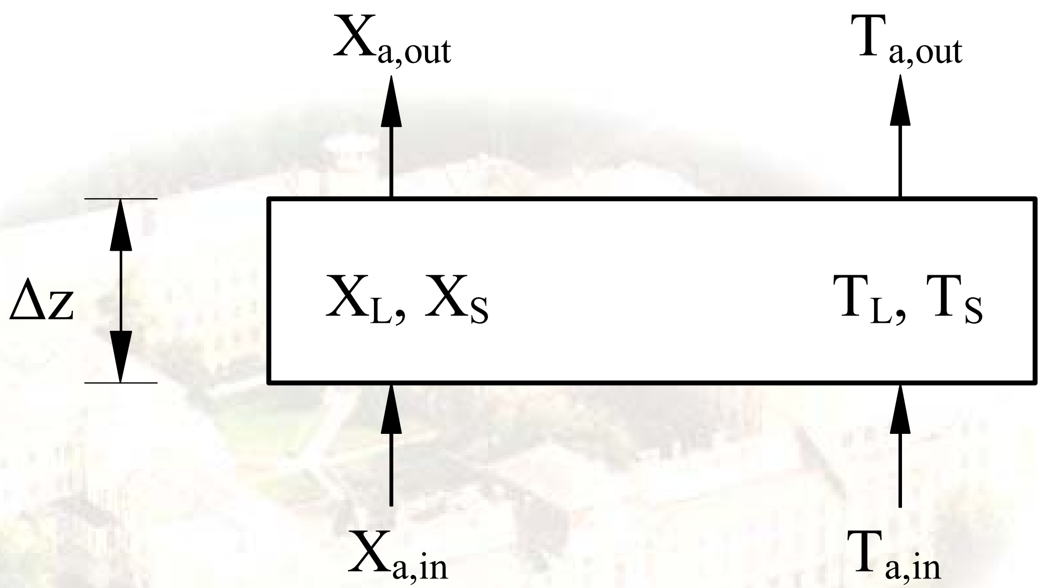
APPROXIMATION OF EQUILIBRIUM STATE DURING THE BREAK



THIN LAYER MODEL OF ALFALFA DRYING

Nomenclature:

X - moisture content, kg/kg
T - temperature, C
z - height, m
a - specific surface area, m2/m3
t - time, s
c - specific heat, J/kgK
r - latent heat, J/K
α - heat transfer coefficient, W/m2K
β - mass transfer coefficient, m/s
ε - porosity, m3/m3
ρ - density, kg/m3
φ - relative humidity, -
ϕ - air flow rate, kg/s



Subscripts:

L - leaf
S - steam
a - air
e - equilibrium

Solution of the model:

X_L, X_S, X_a, T_L, T_S, T_a (6 equations) + sorption isotherms : X_{eL}, X_{eS}

Heat balance of air:

$$c_{pa}\rho_a\varepsilon\frac{\partial T_a}{\partial t} = -a_L(N_L c_{pw} + \alpha_L)(T_a - T_L) -$$

$$-a_S(N_S c_{pw} + \alpha_S)(T_a - T_S) -$$

$$-c_{pa}\phi_a\frac{\partial T_a}{\partial z}$$

$$\frac{\partial T_a}{\partial z} \cong \frac{T_{a,out} - T_{a,in}}{\Delta z}$$

Mass balance of air:

$$\rho_a\varepsilon\frac{\partial X_a}{\partial t} = (a_L N_L + a_S N_S) - \phi_a\frac{\partial X_a}{\partial z}$$

$$\frac{\partial X_a}{\partial t} \cong \frac{X_{a,out} - X_{a,in}}{\Delta t}$$

Heat balance of stem:

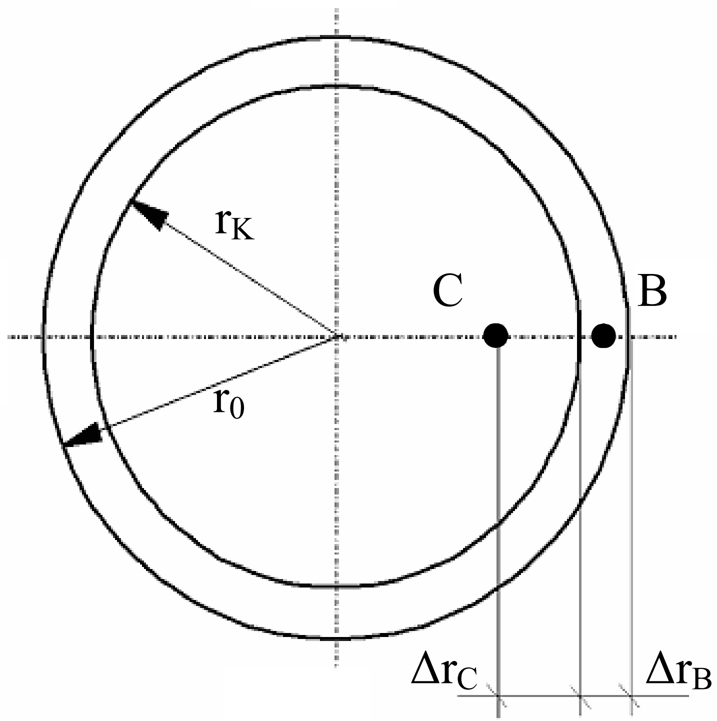
$$\frac{\partial T_S}{\partial t} = \frac{\alpha_S a_S}{c_S \rho_S}(T_a - T_S) - \frac{a_S r}{c_S \rho_S} N_S$$

$$c_S \rho_S \frac{\partial T_S}{\partial t} = a_S \left[\alpha_S (T_a - T_S) - r N_S\right]$$ **(revised form)**

Mass balance of steam:

$$\frac{\partial X_S}{\partial t} = -\beta_S a_S (X_S - X_{eS})$$

Modelling of the internal moisture conduction of the stem



C – cambium

B – bark layer

$$\mathbf{r_B = r_0 - r_K}$$

$$\mathbf{r_C = r_K \left(1 - \frac{1}{\sqrt{2}}\right)}$$

$$\mathbf{K_{CB} = K_C\,2\,K_B = \frac{D_C}{(\Delta r_C)^2}\;\frac{D_B}{(\Delta r_B)^2}}$$

Modelling of internal moisture conduction of stem

$$\frac{\partial X_S}{\partial t} = \frac{\partial X_{SC}}{\partial t} + \frac{\partial X_{SB}}{\partial t} = -\beta_S a_S (X_S - X_{eS})$$

Mass balance of cambium:

$$\frac{\partial X_{SC}}{\partial t} = K_{CB}(X_{SC} - X_{SB})$$

Drying rate of stem:

$$N_S = \beta_S \rho_S (X_S - X_{eS})$$

Desorption isotherms of stem:

$$X_{es} = \begin{cases} \exp\left(\dfrac{\ln\varphi - 3.16}{0.766}\right), & \text{if } \varphi < 0.7 \\ \exp\left(\dfrac{\ln\varphi - \ln 0.96}{0.16}\right), & \text{if } 0.7 < \varphi < 1 \\ 1.29, & \text{if } \varphi = 1 \end{cases}$$

Heat balance of leaf:

$$\frac{\partial T_L}{\partial t} = \frac{\alpha_L a_L}{c_L \rho_L}(T_a - T_L) - \frac{a_L r}{c_L \rho_L} N_L$$

$$c_L \rho_L \frac{\partial T_L}{\partial t} = a_L \left[\alpha_L (T_a - T_L) - r N_L \right] \quad \text{(revised form)}$$

Mass balance of leaf:

$$\frac{\partial X_L}{\partial t} = -\beta_L a_L (X_L - X_{eL})$$

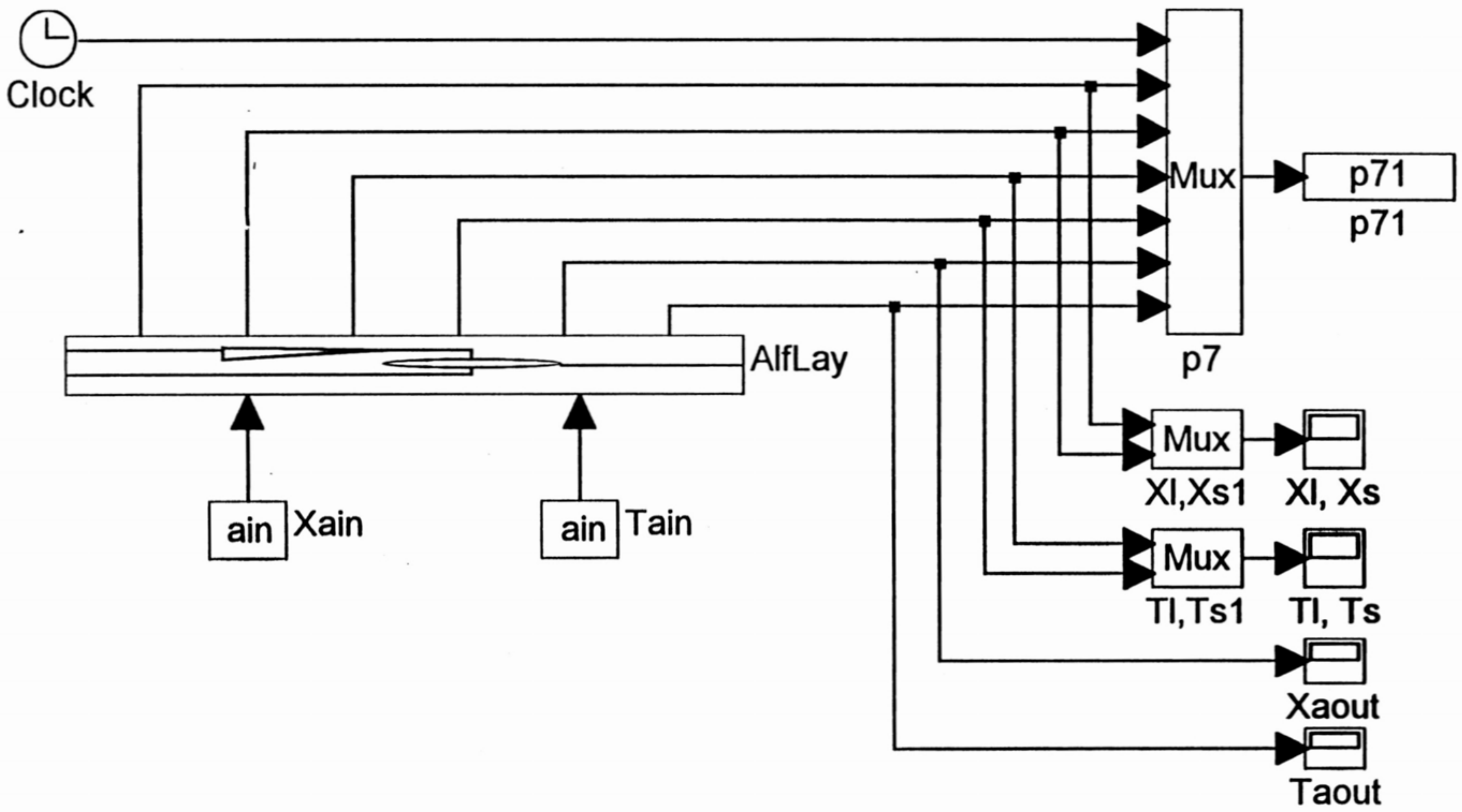
Drying rate of leaf:

$$N_L = \beta_L \rho_L (X_L - X_{eL})$$

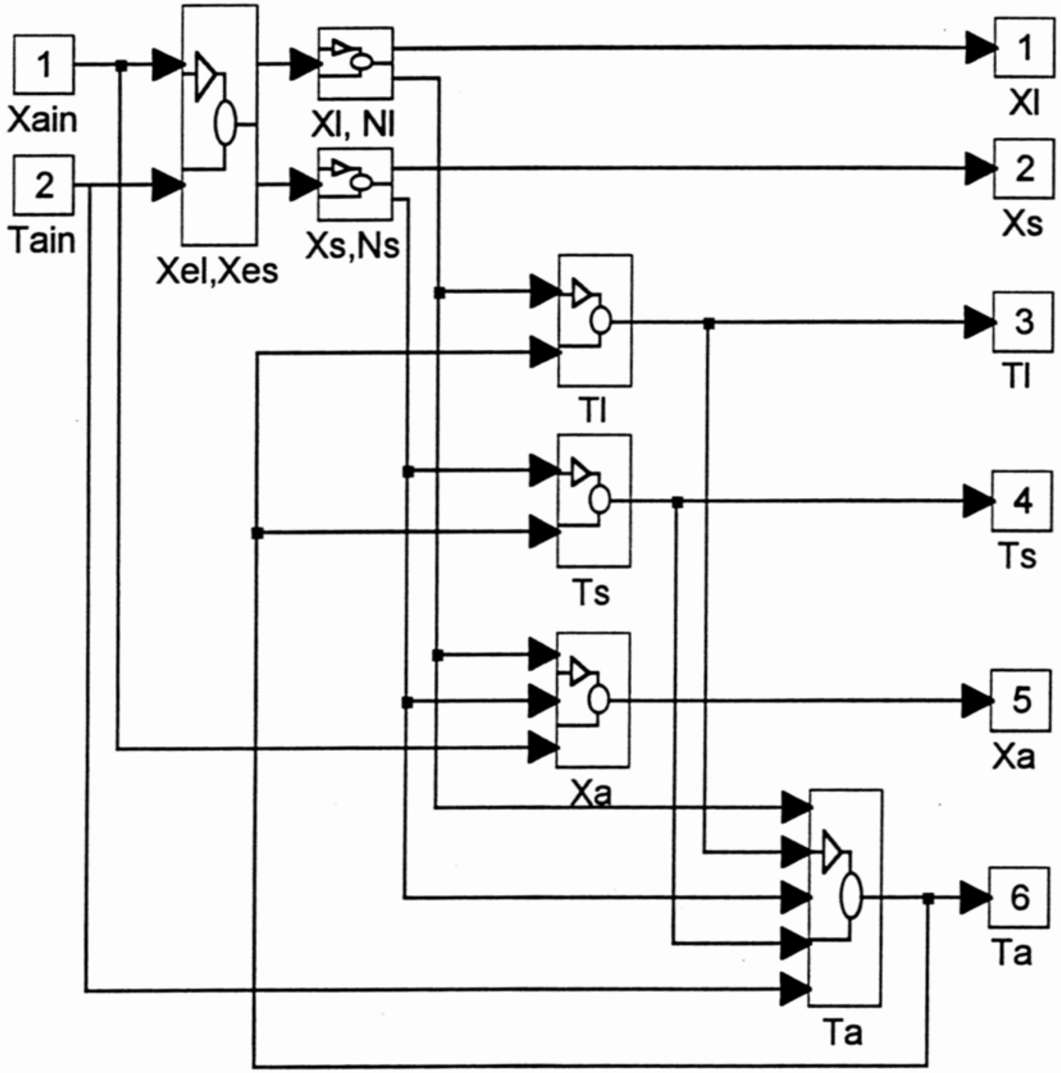
Desorption isotherm of leaf:

$$X_{eL} = \begin{cases} \exp\left(\dfrac{\ln\varphi - \ln 59}{2.3}\right), & \text{if } \varphi < 0.64 \\ \exp\left(\dfrac{\ln\varphi - \ln 0.89}{0.17}\right), & \text{if } 0.64 < \varphi < 1 \\ 1.985, & \text{if } \varphi = 1 \end{cases}$$

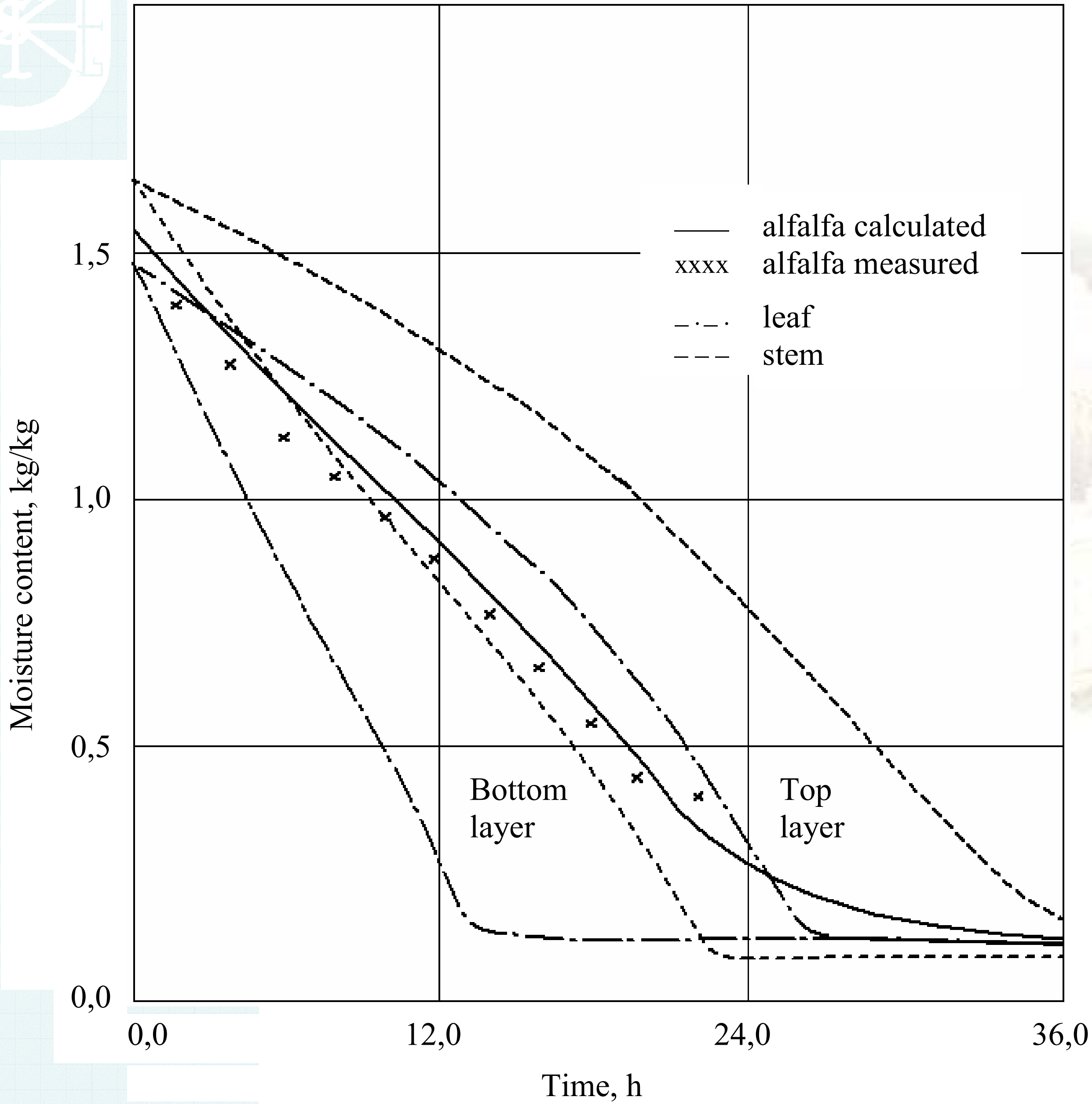
BLOCK-ORIENTED REALIZATION OF THIN-LAYER ALFALFA MODEL



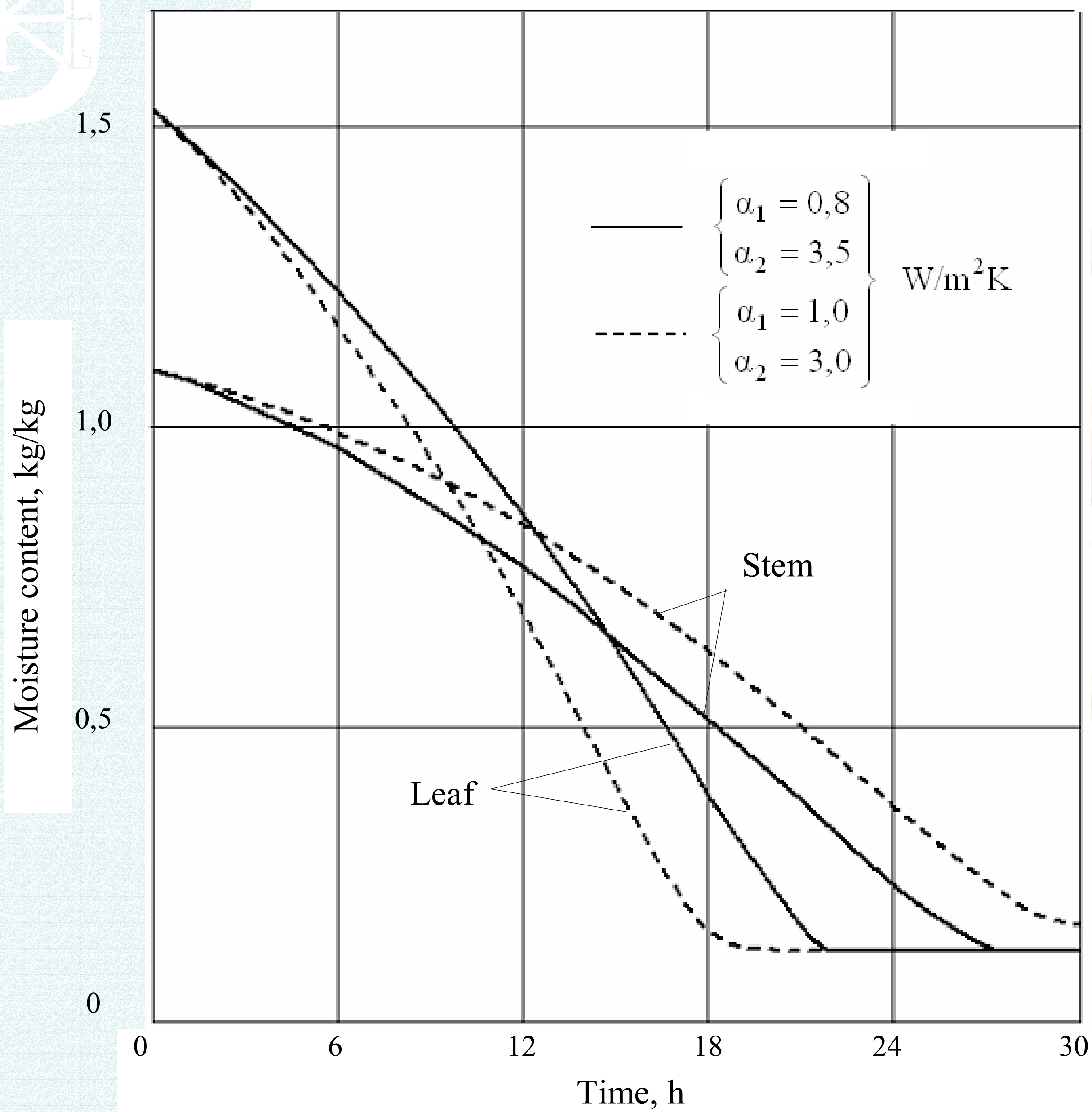
BLOCK-ORIENTED REALIZATION OF THIN-LAYER ALFALFA MODEL



DRYING CURVES OF ALFALFA



INFLUENCE OF HEAT TRASFER COEFFICIENTS



USE OF THE TWO-COMPONENT MODEL

- FULL-SCALE PHYSICALLY-BASED MODEL IS PREFERABLE FOR DESIGN
  - LONG CALCULATION TIME
  - SELECTION OF TIME AND SPACE DISCRETIZATIONS
  - NUMERICAL ERRORS AND STABILITY PROBLEMS

- FOR DRYING OPERATION AND/OR OPTIMIZATION
  - REDUCED ORDER MODEL
  - BLACK-BOX (I/O) MODEL

STEPS OF MODEL REDUCTION

i. Neglecting the dynamics of temperature of material components

$$\frac{\partial T_L}{\partial t} = 0, \qquad \frac{\partial T_S}{\partial t} = 0$$

ii. Additional neglecting the dynamics of the air temperature

$$\frac{\partial T_a}{\partial t} = 0$$

iii. Additional neglecting the dynamics of the air moisture

$$\frac{\partial X_a}{\partial t} = 0$$

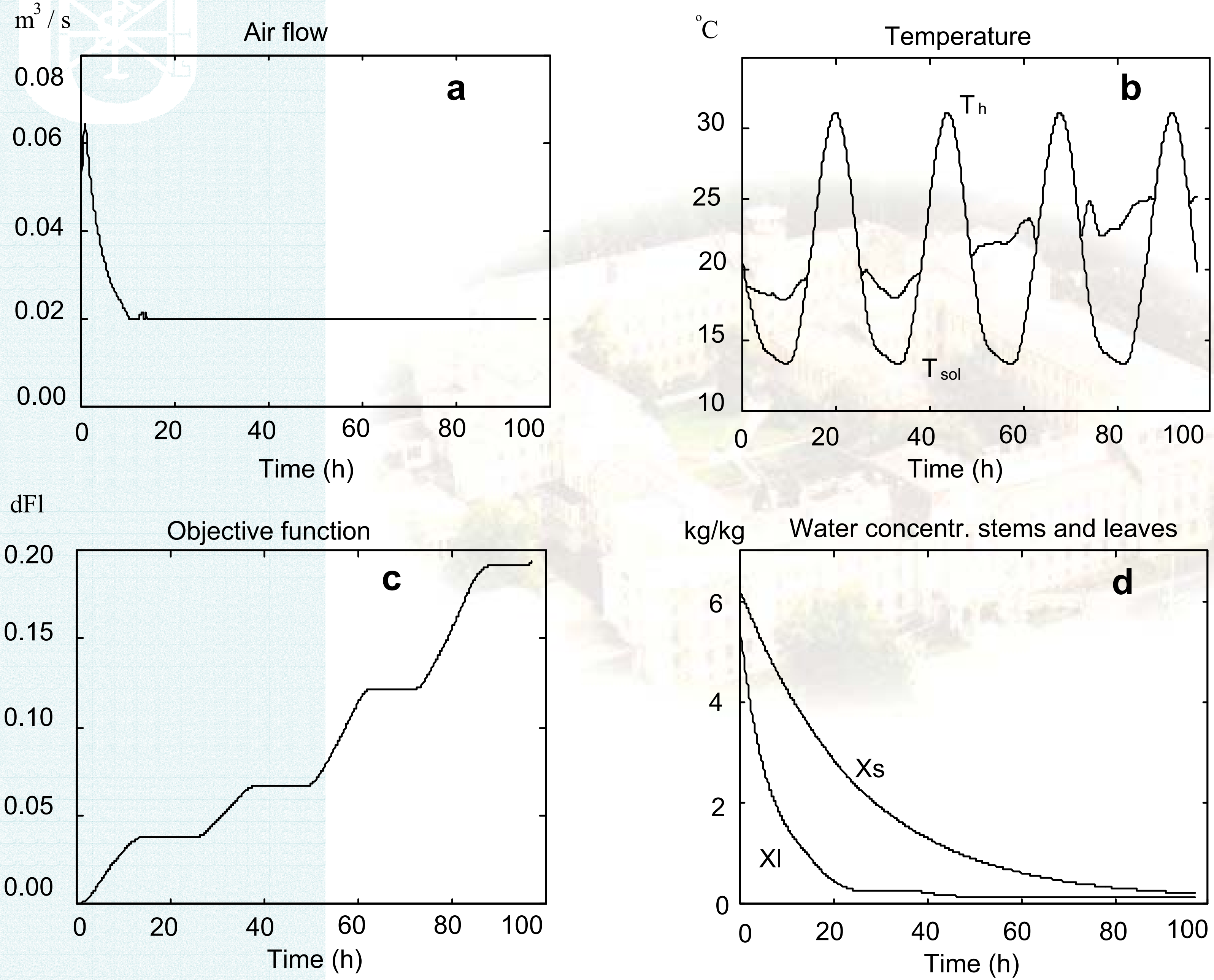
INFLUENCE OF MODEL REDUCTION

- NEGLECTING THE DYNAMICS OF TEMPERATURES CONCERNING TO MATERIAL COMPONENTS

  - THE CALCULATION TIME IS ABOUT TEN TIMES LESS

  - THE ACCURACY STAYS WITHIN 0.5 % COMPARED TO THE ORIGINAL MODEL

RESULTS OF OPTIMAL OPERATION



OBJECTIVE FUNCTION, CONSTRAINTS AND INPUT DATA

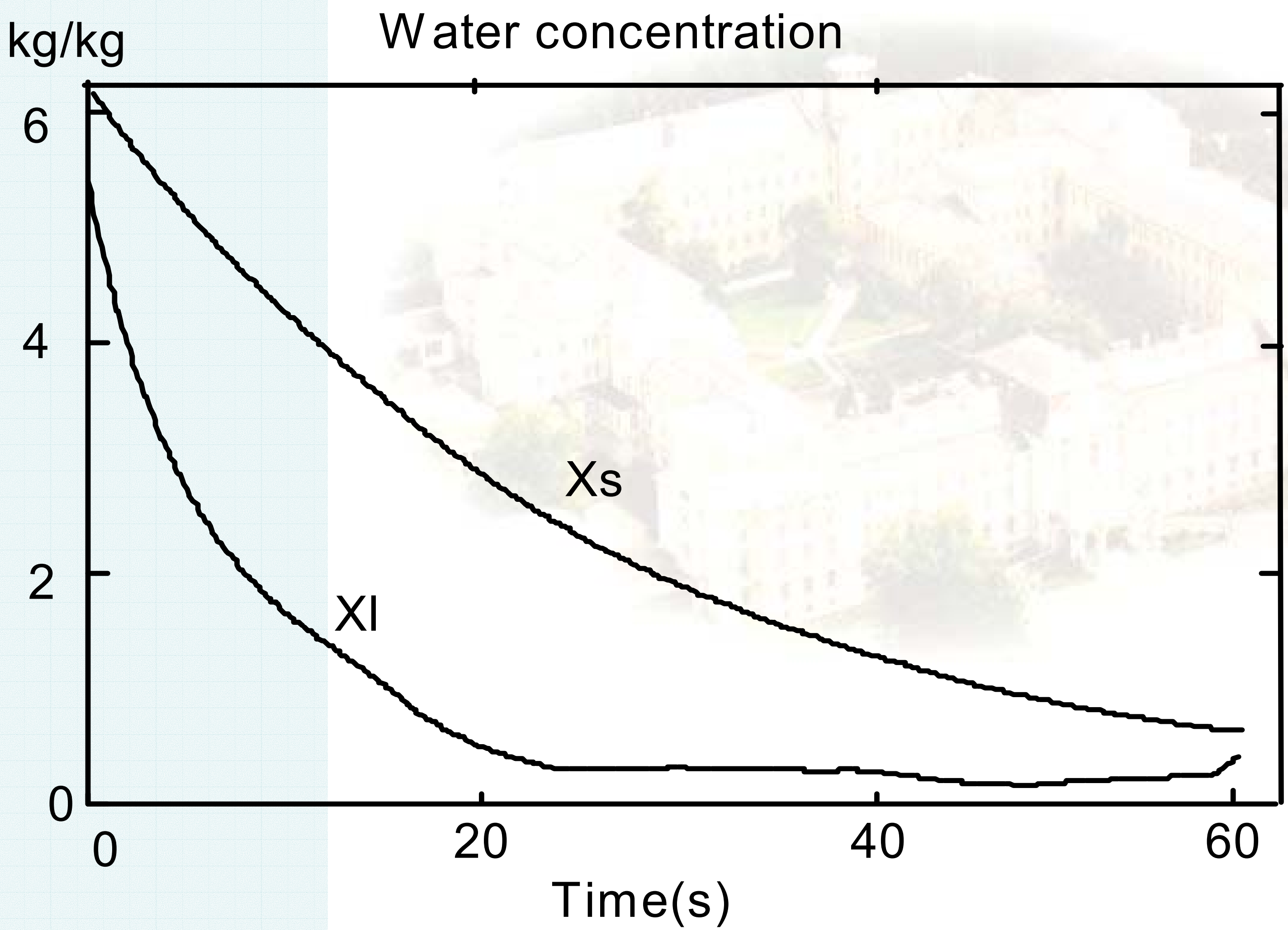
$$J = \int_{t0}^{tf} \left\{ \frac{\Delta P \Phi_a El}{\eta_f} + \frac{\Phi_a \rho_a c_{pa} (T_h - T_{sol}) Fuel}{\eta_h} \right\} dt$$

.

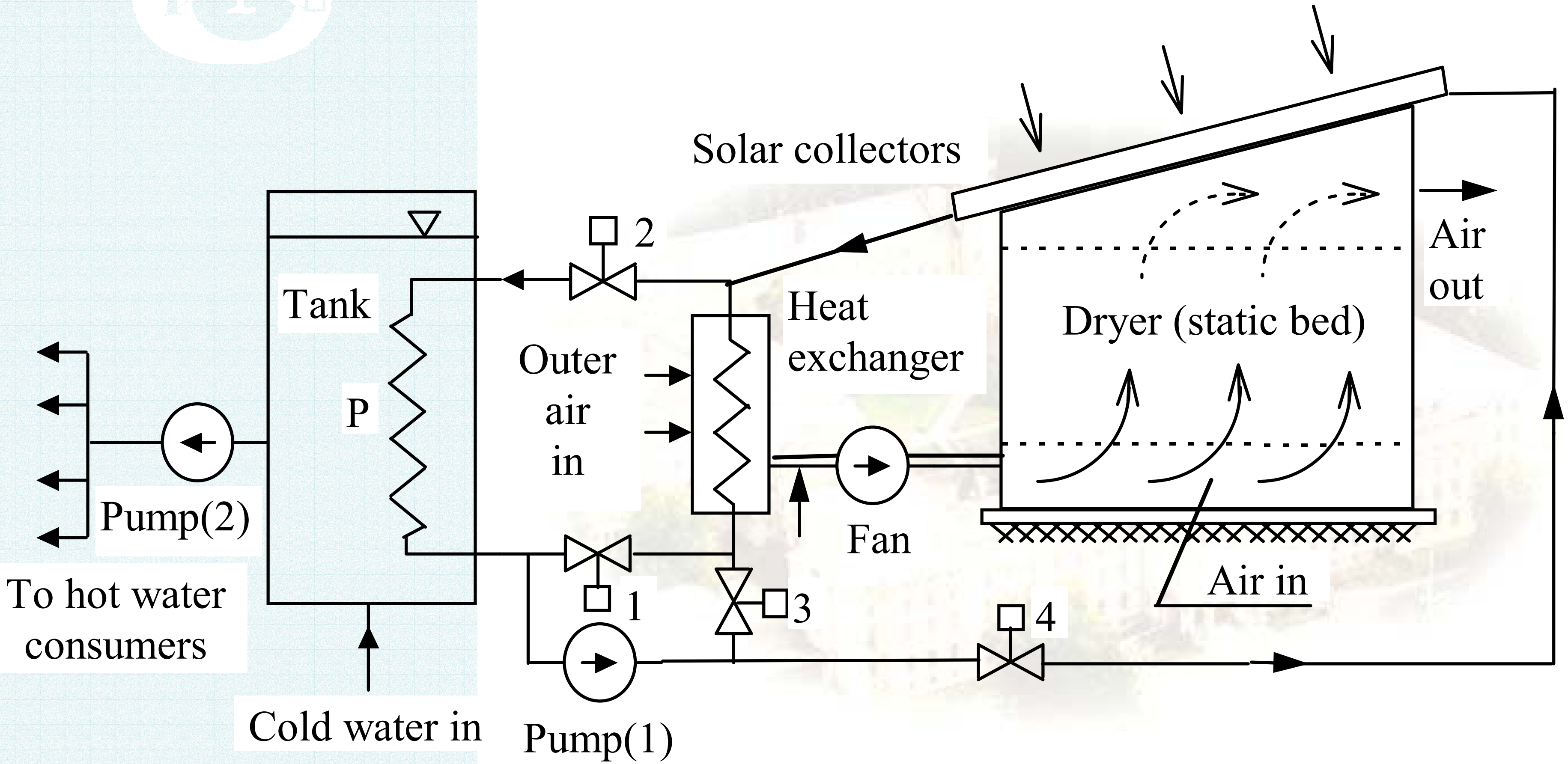
with

$$\Delta P = aH \frac{\Phi_a^{1.6}}{A_d} \exp(X_{mean})$$

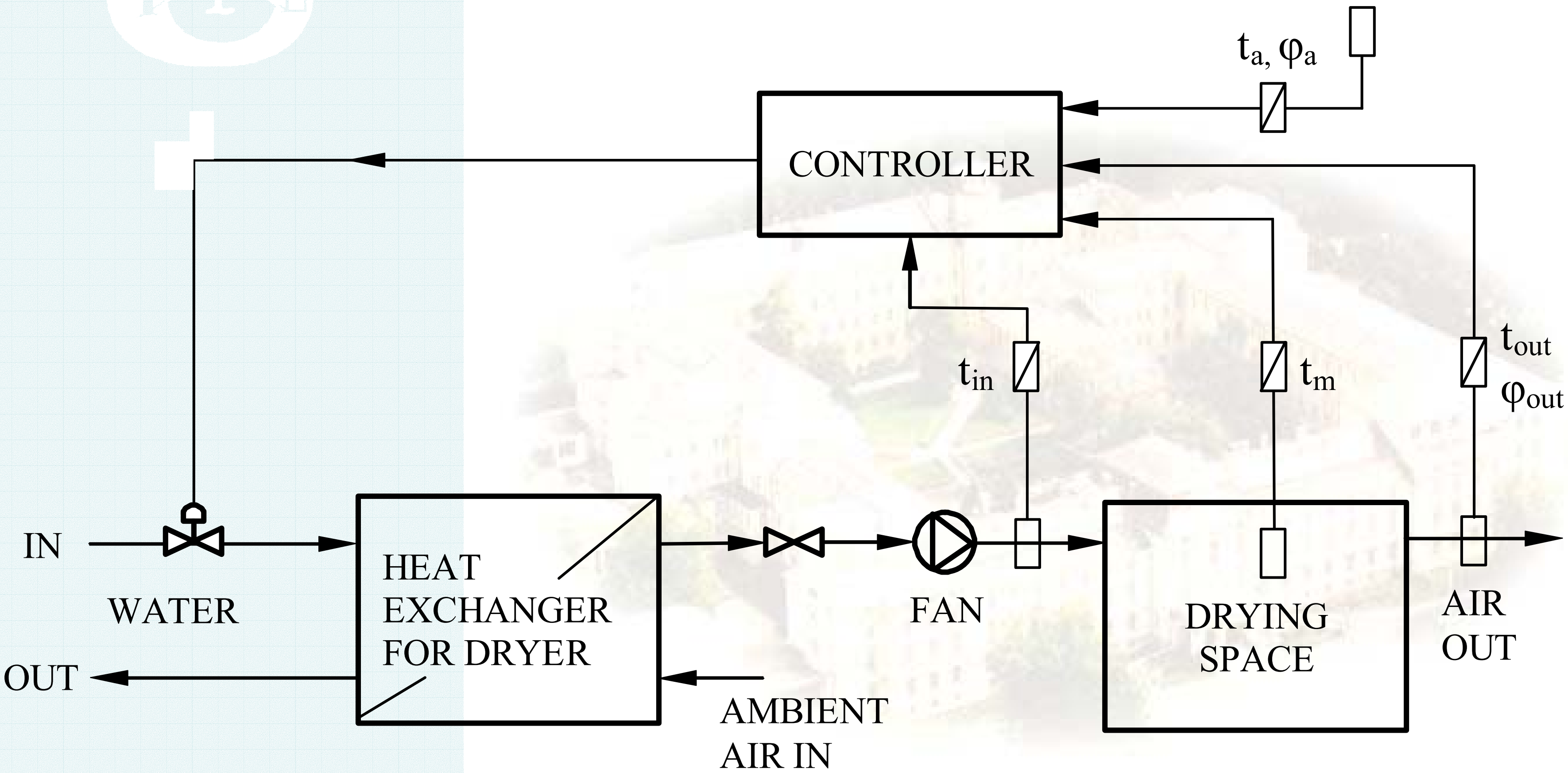
DRYING HISTORY OF STEMS AND LEAVES FOR INCREASED FINAL CONSTRAINS AND FINAL TIME OF 60 HOURS



LAYOUT OF AN INTEGRATED SOLAR DRYING SYSTEM



CONTROL SHEME OF THE ALFALFA DRYER



CONTROL PARAMETERS FOR ALFALFA DRYING (OVERALL VALUES FOR THE DRYING BED)

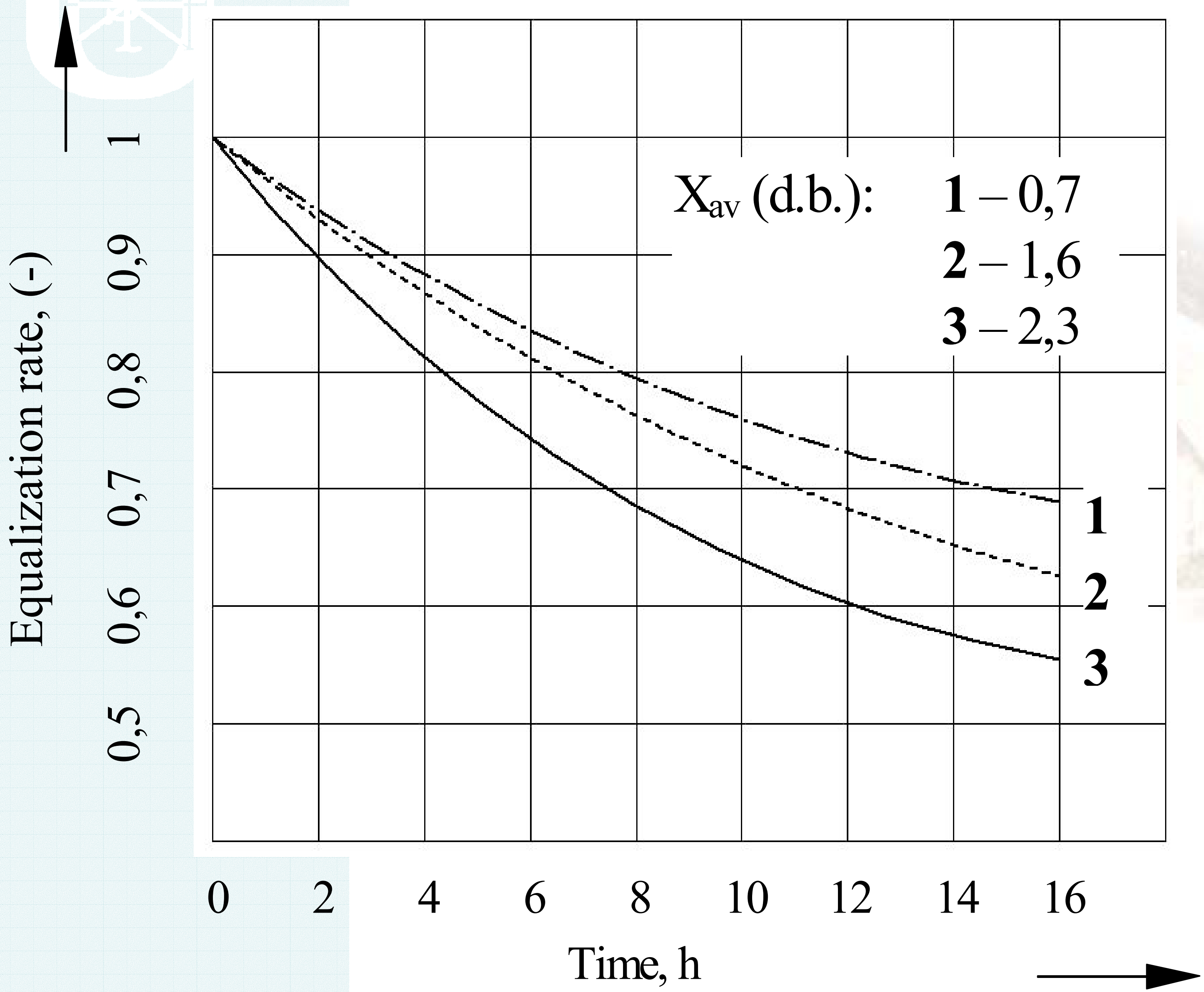
Temperature equalization rate:

$$\vartheta = \frac{T_{a,in} - T_{a,out}}{T_{a,in}}$$

Moisture equalization rate:

$$\chi = \frac{(X_S - X_L)_{end}}{(X_S - X_L)_{beginning}}$$

MOISTURE EQUALIZATION FOR ALFALFA AT 32 ^{0}C



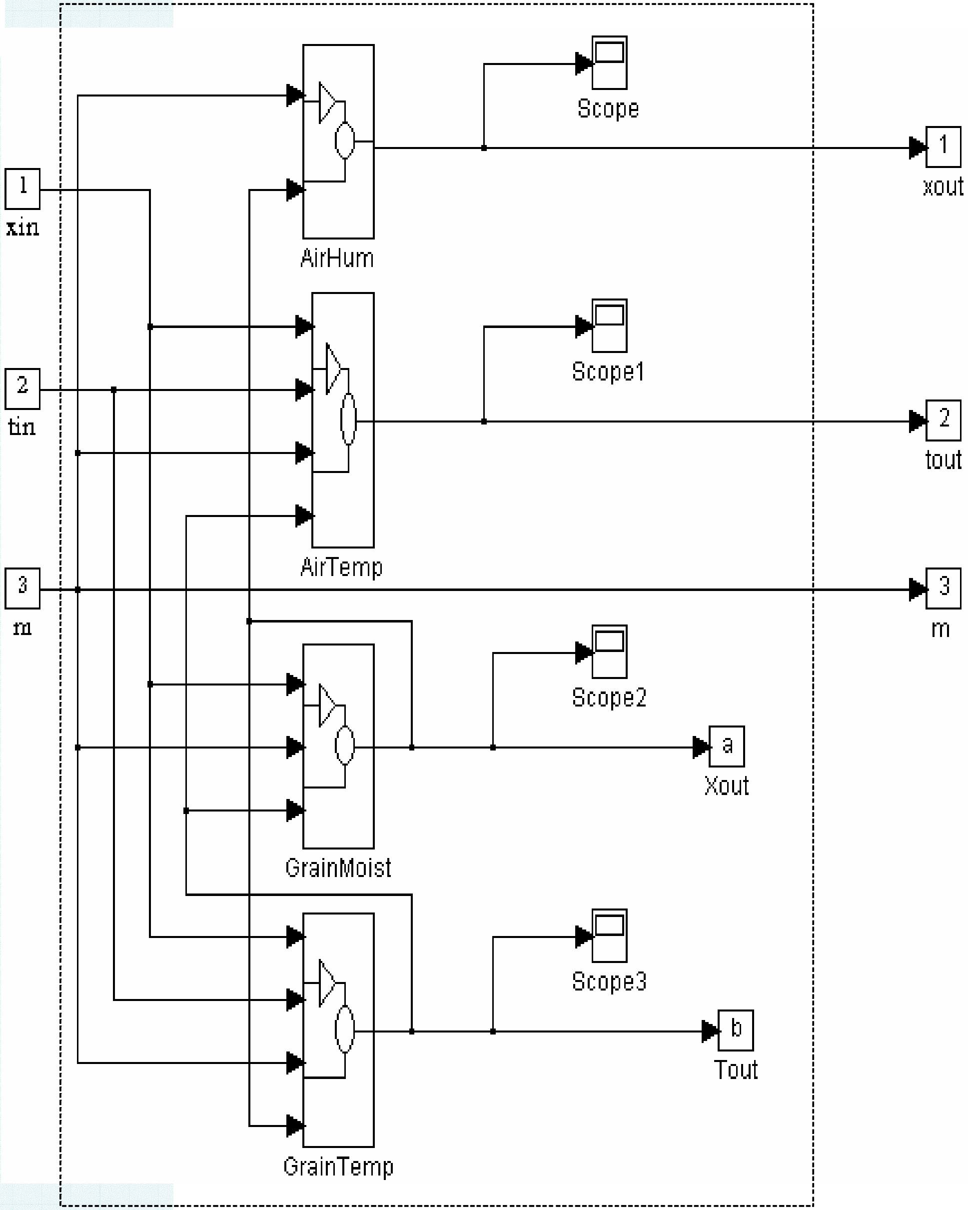
MODELLING OF CORN DRYING PROCESS

- **PHYSICALLY BASED MODEL (PBM) IS ADVISED**

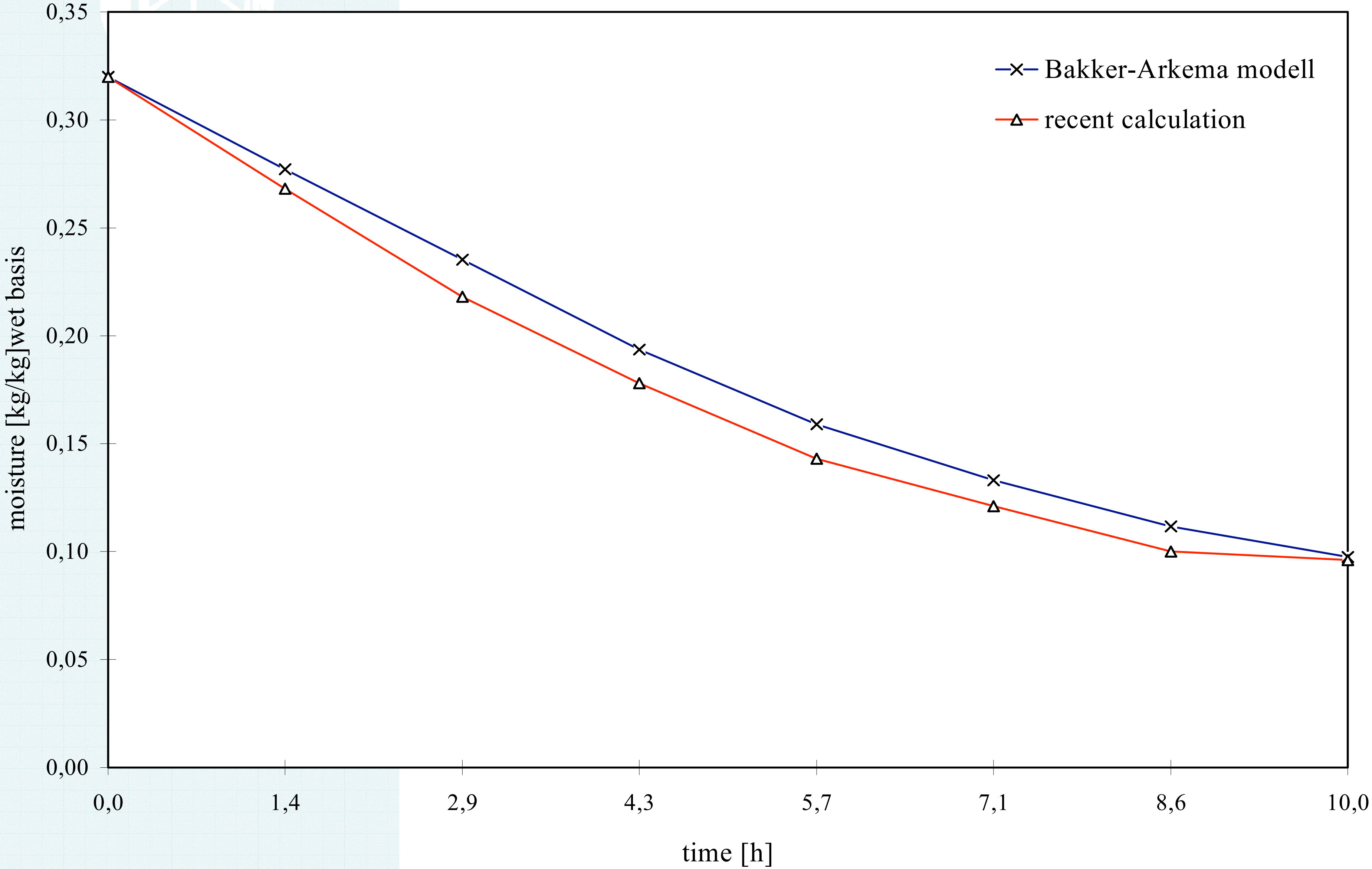
- **THIN LAYER MODELLING IS APPLIED**

- **BLOCK-ORIENTED REALIZATION**

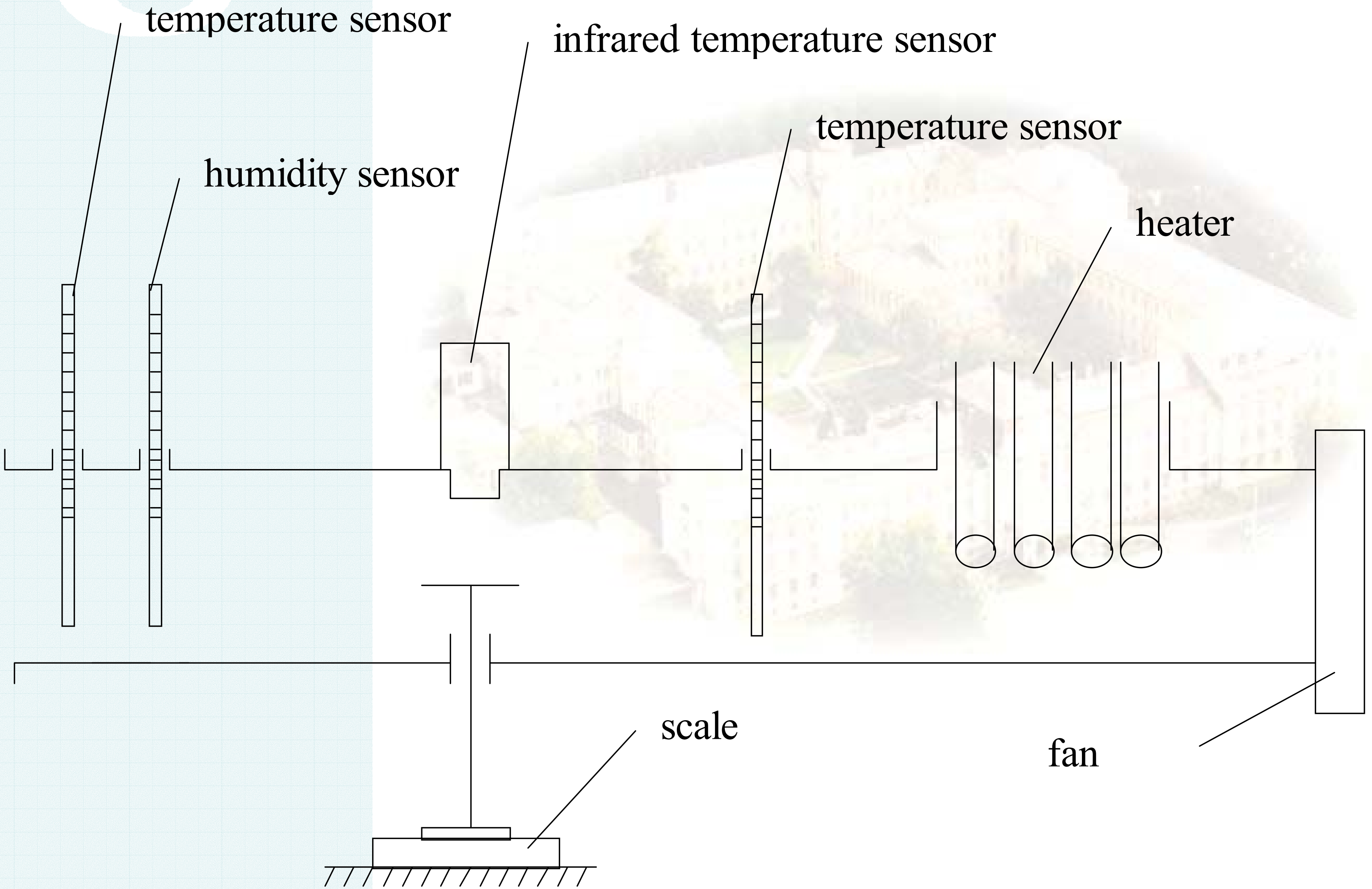
BLOCK ORIENTED MODELLING OF THIN LAYER DRYING



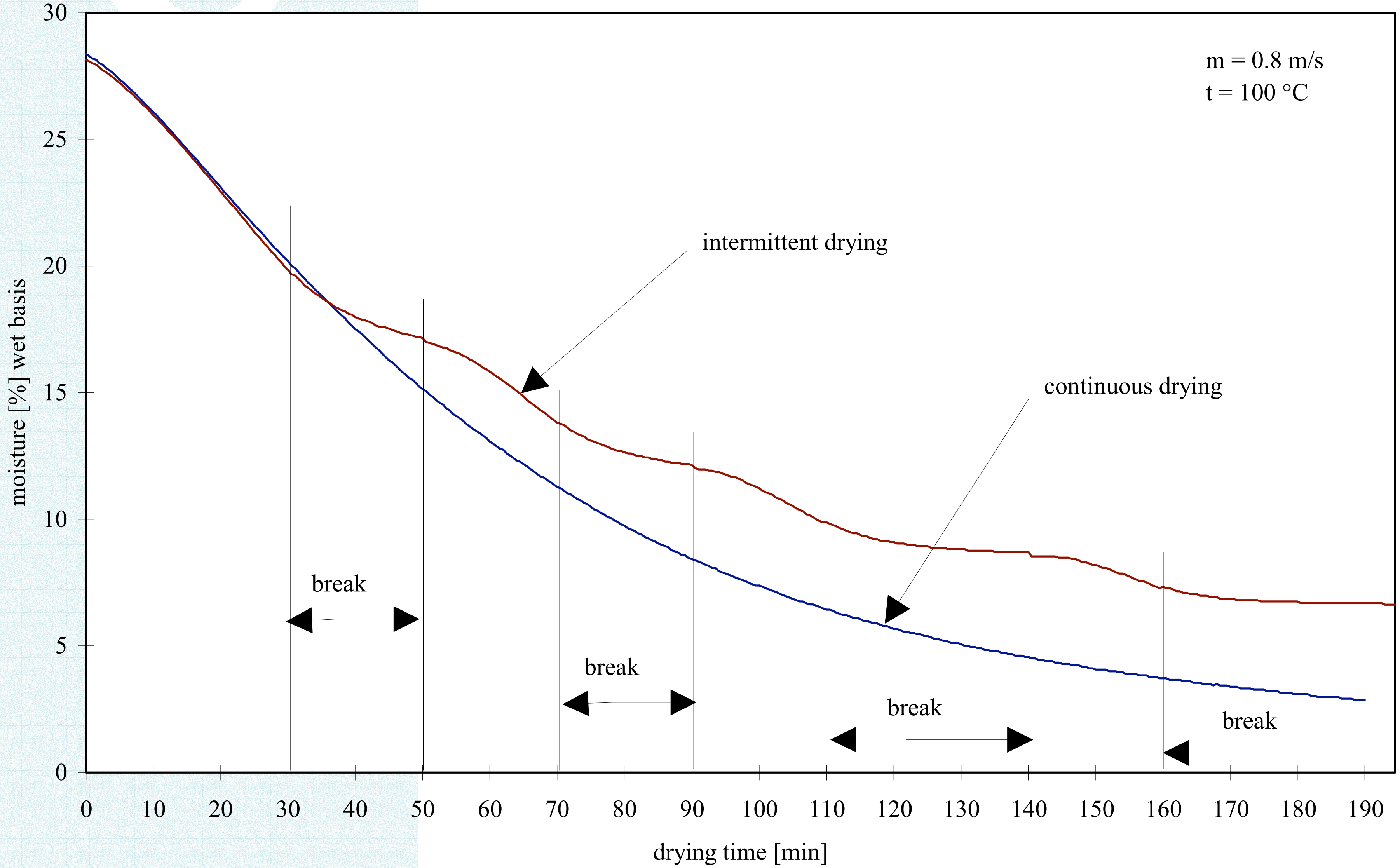
COMPARISION OF DRYING CURVES



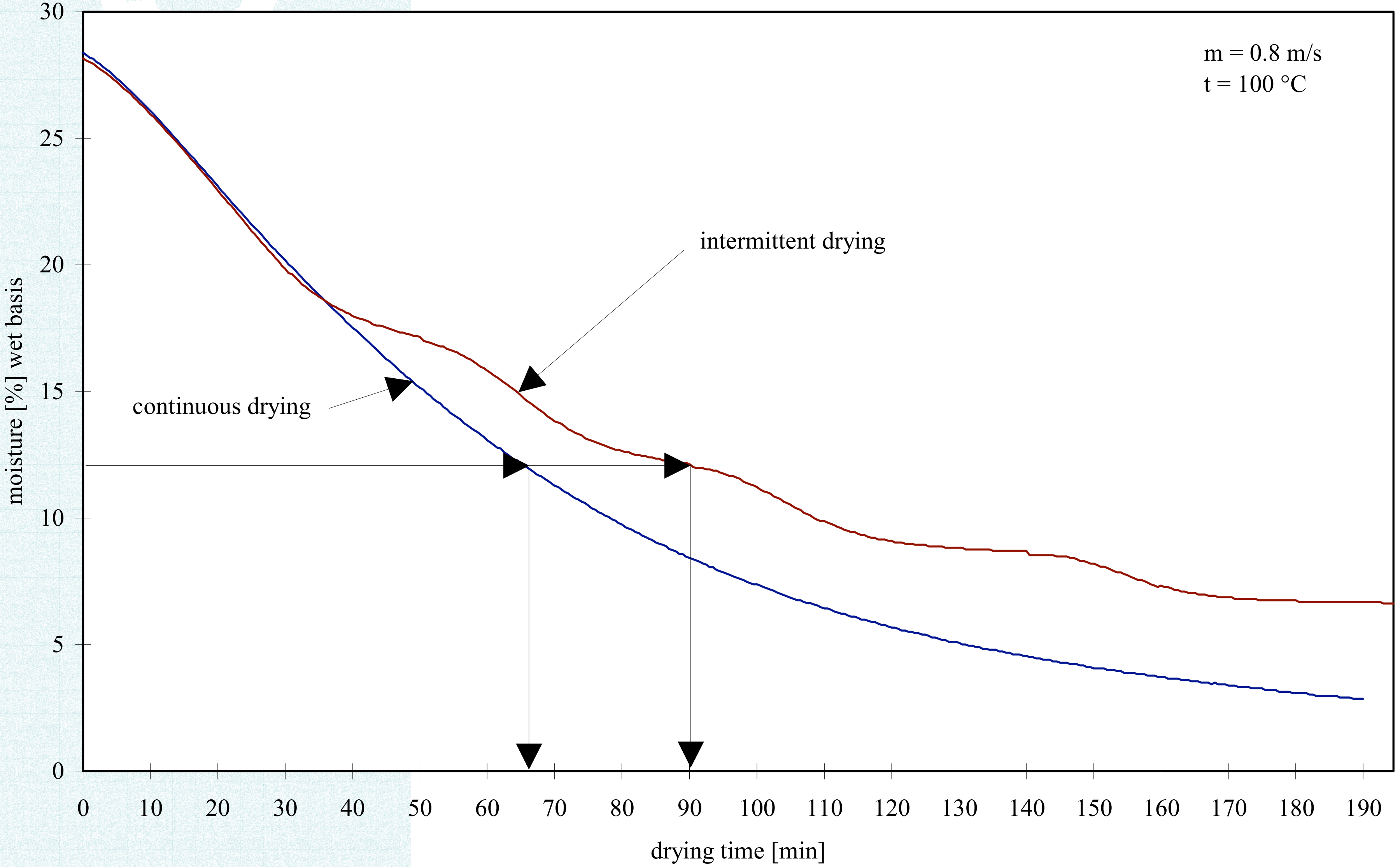
MEASURING SET-UP FOR THIN LAYER DRYING



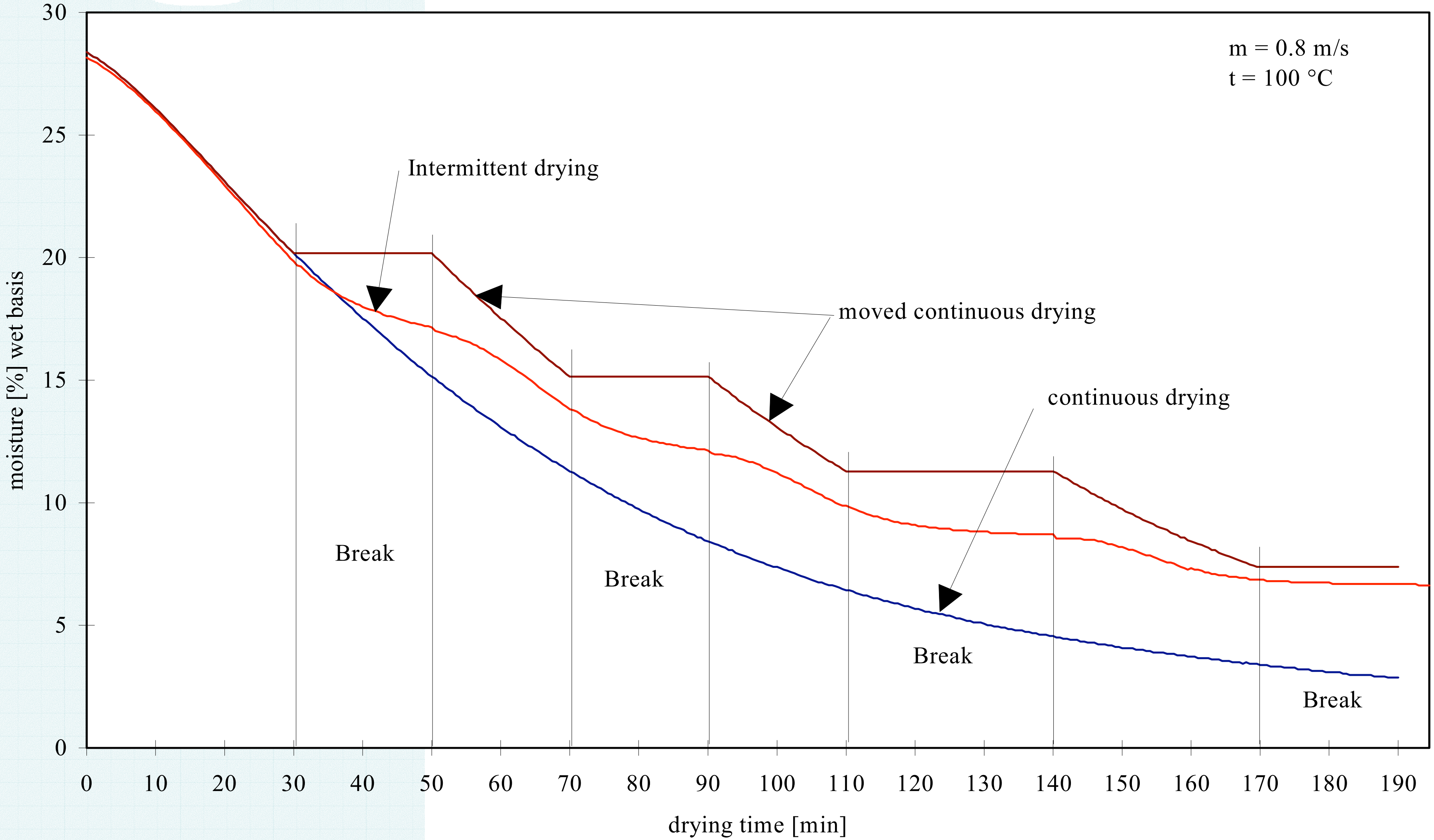
COMPARISION OF CONTINUOUS AND INTERMITTENT DRYING



COMPARISION OF THE TOTAL DRYING TIME



COMPARISION OF CONTINUOUS AND INTERMITTENT DRYING WITH TIME TRANSFORMATION



COMPARISION OF INTERMITTENT VS CONTINUOUS DRYING PROCESSES

- LONGER TOTAL DRYING TIME

- SHORTER EFFECTIVE DRYING TIME (20-25%)
- LOWER SURFACE TEMPERATURE (10-15 °C)
- IT HELPS AVOIDING DEGRADATION IN NUTRIENTS
- SAVING ENERGY

CONCLUSIONS

- INTERMITTENT DRYING COULD BE APPLIED SUCCESSFULLY
  - UNDER DIFFERENT CONDITIONS
  - FOR DIFFERENT MATERIALS
- TWO-COMPONENT MODEL FOR ALFALFA DRYING IS ADVISED
  - THIN LAYER MODEL IS ADVISED
  - BLOCK-ORIENTED SOLUTION IS ADVANTAGEOUS
  - MODEL REDUCTION IS NEEDED FOR CONTROL
- INTERMITTENT DRYING IS MOSTLY BENEFITIAL
  - IN A SENSE OF QUALITY ISSUES
  - IN ENERGY SAVINGS
- USABLE IN CONNECTION WITH SOLAR DRYING
- NEW POSSIBILTIES IN DESIGN OF OPTIMAL OPERATION

THANK YOU FOR YOUR KIND ATTENTION!