A 14

S P R E N G E R   I N S T I T U U T
Haagsteeg 6, 6708 PM Wageningen
Tel.: 08370-19013

(Publikatie uitsluitend met toestemming van de directeur)

RAPPORT NO. 2051

Dr. L. Ficek

THE RELATIVE HUMIDITY IN AN EMPTY CONTAINER WITH WATER-VAPOUR PRODUCTION, VENTILATION AND HEATING. THEORY AND EXPERIMENTS DURING CONTINUOUS TEMPERATURE CONTROL

Uitgebracht aan de directeur van het Sprenger Instituut
Project no. 35

CONTENTS

1. SUMMARY

Eleven experiments involving measurement of the relationship between temper& and relative humidity of air were made in a container with a clip-on cooling unit. The resistance to air circulation exposed by a stow was not simulated. Experiments were made with and without ventilation, heating, source of water. The cooling unit worked with continuous temperature control. During all the experiments the following parameters were measured: temperatures outside the container, in the container and in the clip-on unit; relative humidity outside the container, inside the container, after the circulation-fan, after evaporator and the ventilation air. The rates of water production and heating were set at constant values and therefore, did not require measurements. The equations related to temperature and relative humidity were solved by a computer and i experiment these theoretical values were compared with the experimental results.

2. INTRODUCTION

A study of the relationship between temperature and relative humidity is important for a better understanding of the macro climate in a container, which influences the micro climate around the transported perishable foodstuffs. However, the results of this research are also necessary for a bette understanding of the operation of the cooling unit. It is very important for example for building new cooling units for containers as well as for road refrigeration vehicles. The tested container was situated in the hall of the Sprenger Instituut and all measured points were recorded by a recorder and also on paper tape for computer input. Three selected temperatures were recorded continuously on a chart recorder.

3. EQUIPMENT AND INSTRUMENTS

During all the tests the container in the cooling unit (see fig. 1) was used and it was situated in the hall of Sprenger Instituut. The following values were measured:

- temperatures inside container
  outside container
  inside unit
- relative humidity inside container
  outside container
  after fan
  after evaporator
- capacity of the fan for circulation
- ventilation
- capacity of defensor
- amount of water from the evaporator

3.1. THE CONTAINER

For all experiments a 20 feet container was used, made by Duramin, Eng. Com. Ltd., Harbour Road, Lydney, Gloucestershire, United Kingdom.

Descripton of container:

A. Geometrical data

- dimension inside L=5700 mm W=2270 mm H=2190 mm
- dimension outside L=5990 mm W=2410 mm H=2400 mm
- internal volume 28,34 m^3
- floor area 12,94 m^2
- inside surface of walls A_i=68,79 m^2
- outside surface of walls A_c=69,19 m^2
- average surface of walls $A=\sqrt{A_i . A_c}$ = 64,85 m^2

B. Thermophysical data

K_{20} = 0,36 W/(m^2.K) (= 0,31 kcal/m^2 h ^oC)

The air circulation in the container was from bottom to top. From a T-channel floor these air-channels give a good distribution of air to the whole length of the container. The cross-section of these channels is shown in fig. 2.

3.3. MEASUREMENTS AND INSTRUMENTS

All temperatures were measured using thermocouples. All points, which were measured (besides relation humidity outside container), were recorded by a Fluke 2240 B datalogger recorder (by John Fluke MFG. Co. INC., made in USA) and on paper tape too. The interval between measurements was shorted at the beginning of the experiment (at this moment temperature a relative numidity change very quickly) and at the moment when temperatures and relative humidity were constant the interval between measurements was increased to 1 hour. Always 1 temperature inside container, 1 temperature outside container and 1 temperature after evaporator of unit were also recorded continuously bu a chessell 301 chart recorder. All thermocouple for measurement temperatures inside and outside the container were situated about 100 mm from the wall.

3.3.1. MEASUREMENT OF TEMPERATURES

- Temperatures inside container were measured by 14 thermocouples. The location of these temperature points of measurement is shown in fig. 3 8 thermocouples were placed in each corner; 4 in the middle of each long wall, 1 in the centre of the channel for entrance air and 1 in the cen the channel for exit air. In addition, one thermocouple was placed in the middle of the container for continuous recording.
- Temperatures in entrance and exit opening for air in front of the containe were measured by 2 thermocouples.
- Temperatures around the container were measured by 10 thermocouples as is shown in fig. 4. Three points of measurements were on each side of the long wall and also on the roof, and one was under the container. The location of one point for continuous recording was on the left side of container.
- Temperatures of air in cooling unit were measured before the evaporator at two points and after the evaporator also at two points. Besides temperature of surface of pipes of evaporator was measured at 10 places too. See fig. 5. There was measured temperature at entrance, in the middle of evaporator, and in the end. By 4 thermocouples with copper block temperature of fins was measured too. But these values were not required for calculations (see part no. 4.1.1.)

3.3.2. MEASUREMENT OF RELATIVE HUMIDITY

The relative humidity was measured at four places inside the container, outside the container, after the circulation fan and after evaporator of the unit.
For this work hygrographs and wet and dry bulb thermocouples (around unit) were used. The difference between both (200 mV/1 K) was recorded.
The location of the points is shown in fig. 6.

3.3.3. MEASUREMENT OF THE AIR CAPACITY OF THE FAN

The velocity of air was measured in each channel of the T-profile of the floor. The velocity of the air in these channels is shown in fig. 7. The amount of circulating air is 0,4 m^3/s.

3.3.4. MEASUREMENT OF VENTILATION

Air-renewal by ventilation was measured during experiments by two remote reading vane anemometers. The output of each anemometer, in mV, was recorded by the datalogger together with the other variables.

3.3.5. MEASUREMENT OF RATE OF WATER INTRODUCTION (BY "DEFENSOR")

The capacity of the "defensor" (which is equal to the rate of introduction of water to the container) was measured before the beginning of the experiments. Because it was supposed that this capacity is constant with time, it was not measured during tests.

3.3.6. MEASUREMENT OF HEATER

Also capacity of the heater was not measured during tests. For calculating, a value known from other reports was taken.

3.3.7. MEASUREMENT OF MELT WATER FROM EVAPORATOR

During the experiments the water from the air was condensing on the surface of the evaporator. During the period of defrosting this water was collected in a plastic bag and measured after each test. However, as this measurement is not exact, it was taken only as information value.

4. CHANGES TO MEASUREMENT SYSTEMS DURING THE EXPERIMENTS

4.1. MEASUREMENT OF TEMPERATURE

4.1.1. SURFACE TEMPERATURE OF EVAPORATOR

At the beginning of the tests the surface temperatures of the fins were measured by thermocouples fitted in copper blocks. But as perhaps the contact between block and fins was not good, measured temperatures did not correspond to reality. Therefore six thermocouples were placed on the surface of pipe of evaporator directly (see fig. 4). And than the measurement was more correct.

4.1.2. TEMPERATURE AFTER FAN

The temperature of the circulating air after the fan was measured by two thermocouples. But in tests no. 1 to 6 this temperature was not correct. It is very difficult to say how this can happen. It is possible that there was some thermal radiation from pipes of evaporator at the place where the thermocouples were placed. Therefore these two thermocouples were insulated and in tests no 7 to 11 were right. Temperature t10,17 for tests no. 1 to 6 were corrected by graph (see fig.8), which was made to allow for the insulation.

4.2. MEASUREMENT OF RELATIVE HUMIDITY

During cooling down and also during on-off control of the refrigeration unit, the relative humidity changes quickly with time. A hair cannot respond rapidly enough to record these changes accurately. Therefore hygrographs were replaced by wet and dry bulb thermocouples for measurement inside the container and the refrigeration unit.

5. SCHEDULE OF EXPERIMENTS

All the tests which are made, are shown in table 1. Note: in experiments 2 and 3 errors occurred in the use of the hygrograph for the measurement of relative humidity at point $\Phi 1$. Therefore these tests were repeated (see experiments 4 and 5).

TABLE 1.

control of unit	ventilation	leaking	water prod	number of experiment
on - off	–	–	–	1
	+	–	–	7
		+	–	8
Constant temperature	–	–	–	2 *
				4
		+	–	3 *
				5
		–	+	6
	+	–	–	9
		+	–	10
		+	+	11

6. THEORY

The system, which was tested, can be represented schematically as following.
The theory of the relationship between temperature and relative humidity is derived from the Mollier diagram.
For the initial calculation we suppose $t_1 =$ constant and some X_1. We calculate t_2, X_2, t_3, X_3, t_0 and X_5 (this is the new value of X_1 after one cycle) from the first point (t_1, X_1) to the moment when the difference between X_5 and X_1 is sufficiently small. We can calculate temperatures from heat balance and absolute humidity from mass balance.

For temperature t_2 and humidity X_2 is:

$$t_2 = \frac{\Phi c \cdot \rho \cdot c \cdot t_1 + (kA)\ \text{cont.}\ t_4 + Q\varepsilon D - rVwD}{\Phi c \cdot \rho \cdot c + (kA)\ \text{cont.}} \qquad (1)$$

$$X_2 = X_1 + \frac{VwD}{\Phi c \cdot \rho} \qquad (2)$$

for temperature t_3 and humidity X_3 is:

$$t_3 = \frac{(t2.\Phi c.e.\rho 2) + (\phi v2.\rho 4).(ct4+X4.Cwv.t4+rX4) + Qf+Qh}{\phi c \cdot \rho_2 \cdot c} \qquad (3)$$

$$X_3 = X_2 + \frac{\phi v2 \cdot \rho 4 \cdot X4}{\phi c \cdot \rho 2} \qquad (4)$$

for point 0 is:

$$t_0 = \frac{1}{\alpha . F_e} \Big[\alpha . F_e \left(\frac{t3+t1}{2} \right) - (kA)_{cont.} (t_4 - t_2) - Q_{eD} -$$

$$- \Phi_{v2} . \rho 4 . (ct4+X_4 . Cwv.t4+rX_4) - Q_f - Q_h + \Phi v1 . \rho 1 . (ct1+X1 . C_{wv} . t1+r.X1) \Big] \qquad (5$$

for X_5 (from the same triangles in mollier diagram) is:

$$X_5 = X_2 - (X_2 - y_0) \frac{t3 - t1}{t3 - t_o} \qquad (6)$$

where $X_o = \frac{0{,}622 - P_o}{101300 - Po}$

$$P_O = 133 \cdot 10\, y$$

$$y = 0{,}6609 + \frac{7{,}5.to}{237{,}3 + to}$$

Although these equations are not complicated, their repetitive solution is tedious, and therefore they were solved using the computer of the Spreng Instituut .

The list of all calculated cases is shown in the tables no. 2 and 3.

In the first set (table 2) constant values of the parameters are combined in various ways.

Table 2

calculation no.	circulation (m^3/m)	ventilation (m^3/m)	heating (w)	water (kg/s)	t_4 (^oC)	t_1 (^oC)	x_1 (kg/kg)
1 (21)	0,4	-	-	-	20	13	0,001
2 (22)	0,4	-	750	-	20	13	0,001
3 (23)	0,4	-	-	$3,17.10^{-4}$	20	13	0,001
4 (24)	0,4	0,01	-	-	20	13	0,001
5 (25)	0,4	0,01	750	-	20	13	0,001
6 (26)	0,4	0,01	750	$3,17.10^{-4}$	20	13	0,001
7 (27)	0,4	-	750	$3,17.10^{-4}$	20	13	0,001
8 (28)	0,4	0,01	-	$3,17.10^{-4}$	20	13	0,001

Calculations no. 21 to 28 are the same as table no. 2 but with temperature $t_1 = 5,5^oC$

Table 3

9 (29)	0,3 0,35 0,4 0,45 0,5	0,01	750	$3,17.10^{-4}$	20	13	0,001
10 (30)		0,01	750	-	20	13	0,001
11 (31)		-	750	$3,17.10^{-4}$	20	13	0,001
12 (32)		-	750	-	20	13	0,001
13 (33)	0,4	0,005 0,0075 0,01 0,0125 0,0150	750	$3,17.10^{-4}$	20	13	0,001
14 (34)	0,4		750	-	20	13	0,001
15 (35)	0,4	0,01	500 625 750 875 1000	$3,17.10^{-4}$	20	13	0,001
16 (36)	0,4	0,01			20	13	0,001
17 (37)	0,4	-		$3,17.10^{-4}$	20	13	0,001
18 (38)	0,4	-			20	13	0,001
19 (39)	0,4	0,01	750	$2,27.10^{-4}$ $2,72.10^{-4}$ $3,17.10^{-4}$ $3,62.10^{-4}$ $4,07.10^{-4}$	20	13	0,001
20 (40)	0,4	-	750		20	13	0,001

Calculations no. 29 to 40 are the same as calculations no. 9 to 20, but with temperature $t_1 = 5,5^oC$.

In the second set (table 3) one parameter is changed at a time. For the start of calculation of both sets we had temperature t_1 = 13^oC or 5,5^oC and X_1 = 0,001 kg/kg.

Other constant values for all calculations were:

(kA) for container	K_1 = 23 w/K
ambient temperature	t_4 = 20^oC
engine defensor	Q_1 = 60 W
latent heat of evaporation	r = 2500000 J/kg
specific heat of air	c = 1005 J/kg K
ambient absolute humidity	X_4 = 0,009 kg/kg
fan dissipation	Q_2 = 600 W
(kA) for evaporator	K_2 = 350 W/K

7. RESULTS AND DISCUSSION

During the first experiment we had problems with measurement of relative humidity, especially when the cooling unit worked on-off. When we changed the hygrographs for thermocouples wet and dry, the measurement was good. From test no. 4 all points for relative humidity were measured by thermocouples (in the container, after fan and after evaporator). Only outside relative humidity was still measured by hygrograph.
The surface temperature of the pipes of the evaporator was measured only at the entrance and in the middle during experiment no. 1. During all other tests the surface temperature of the pipes at the end was measured too.
Temperature t10,17 (after fan) at experiments no. 1 to 6 had to be corrected. For tests no. 7 to 11 measurement was good, without mistake.
Results of all tests are given in Mollier-diagram and they are in the appendix of this report. At experiments with on-off control of the unit, we can see in the Mollier-diagram how the temperature and the relative humidity change from the moment the unit starts (when all temperatures are much the same) to the time when the unit stops, (when temperature in the container approached demanded value). We can see also max. fluctuatic of each temperatures and the humidities. Fluctuation of temperature in the

container during test without ventilation was about ± 0,75°C. During tests with ventilation it was about 1°C. Both these values are good and show very good operation of the cooling unit. The cycling period under on-off control was very uniform as we can see very well from the continuous record. When the unit worked under continuous temperature control, all measured values were constant after several hours as can be seen from the continuous record and only they were the measurements taken for calculation and for recording on the Mollier diagram. Small differences between measured values and correct values are normal for such measurement. The initial period at the beginning of the tests, when all values are changing quickly in time is also interesting. This period is shown for example for test no. 4.
The results of the theory and experiments, represented on Mollier diagrams are given in the appendix. These appendixes have three parts. In the first are given the results of the experiments. In the second the results of the calculations. In the third part the comparison between experiment and calculation. The difference, see table 4, between experiment and calculation is not large at 13°C air temperature in the container, thus experiments 4, 5 and 6. At 6,5°C the differences are large because of the low surface temperature of the evaporator in the calculation.

8. CONCLUSION

The results of the experiments and also the relation between tests and theory are very interesting not only for the understanding of simulated situations, but also for the further study of the relationship between macro climate and micro climate in the container as well as in the cooling unit.
Results of the theoretical calculations are also interesting now for the better knowledge of rates in the container, so for other works and experiments in the container.

Table 4.

Comparison between experiment and calculation.

nr.	t_2 ^oC	Φ_2 %	t_0 ^oC
Exp 4	13,1	86	9,7
Cal 1	13,4	88	11,5
Exp 5	13,3	87	9,7
Cal 2	13,3	80	10,2
Exp 6	13,0	100	10,5
Cal 3	13,0	>100	-
Exp 9	6,5	97	4,4
Cal 24	6,2	83	3,3
Exp 10	6,4	98	4,5
Cal 25	6,4	73	1,8
Exp 11	6,0	100	4,2
Cal 26	5,0	>100	1,0

LIST OF SYMBOLS AND UNITS

t_θ	(^oC)	temperature of surface of evaporator
t_1	(^oC)	temperature of air after evaporator
t_2	(^oC)	temperature of air after container
t_3	(^oC)	temperature of air after fan and heater
t_4	(^oC)	temperature of outside air
x_0	(kg/kg)	absolute humidity of the surface of evaporator
x_1	(kg/kg)	absolute humidity after evaporator
x_2	(kg/kg)	absolute humidity after container
x_3	(kg/kg)	absolute humidity after fan and heater
x_4	(kg/kg)	absolute humidity of air outside container
Φe	(m^3/s)	calculation air
Φv_1	(m^3/s)	air of ventilation out
Φv_2	(m^3/s)	air of ventilation in
V_{wD}	(kg/s)	water from defensor
V_{wt}	(kg/s)	water from evaporator
Q_f	(W)	fan dissipation
Q_h	(W)	capacity of heater
Q_{10}	(W)	heat through the walls
Q_{ED}	(W)	engine of defensor
Q_{EW}	(W)	heat for evaporator water from defensor
Q_e	(W)	capacity of evaporator
ρ	(kg/m^3)	density of air
c	(J/kg^oC)	specific heat of air
r	(J/kg)	latent heat of evaporation
x	(W/m^2K)	heat transfer coefficient
Fe	(m^2)	surface of evaporator.

APPENDIX

Wageningen, 14 februari 1979

KF/MJ

The cooling unit is of system clip-on, type Emil EC 5/3 SG, fixed to the front of container.
Description of unit:

- Cooling capacity 8000 W by extrapolation of graph no. 19 report CTI-TNO ref. no. 73-03147 ($20^{o}C$ ambient temp. $15^{o}C$ inside)

- air capacity $0{,}42\ m^3/s = 1512\ m^3/u$ ($\Delta p = 250\ N/m^2$)
- fan energy requirement 680 W (for $0{,}42\ m^3/s$) (= 585 Kcal/h)
- an additional heater of 750 W was situated after calculation fan.

During experiments without ventilation the unit was fixed direct to the front of the container. When ventilation was simulated, special T-pipes were inserted between the unit and container; the open side branches permitted air exchange.
The cooling unit could be operated with either on-off or continuous temperature control.

Fig. 1

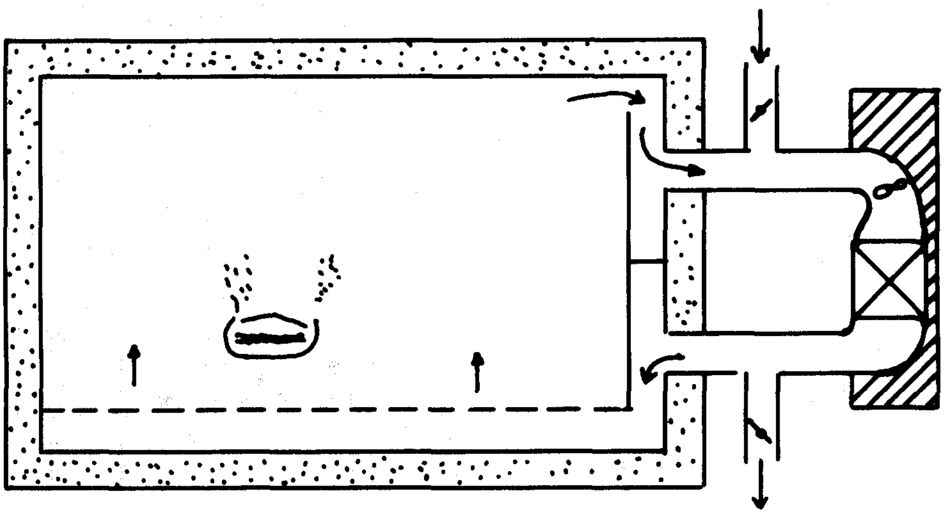


Fig. 1 The container

Fig. 2

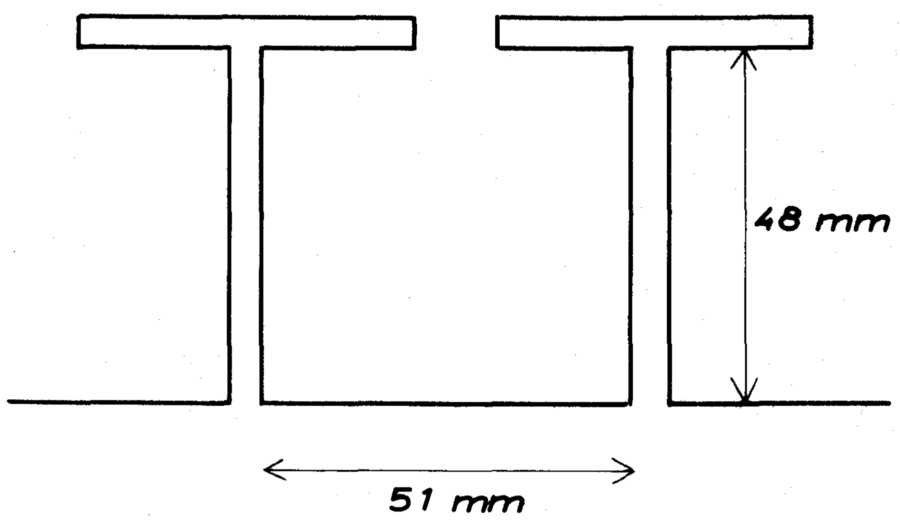


Fig. 2 Profile of the container floor

fig. 3

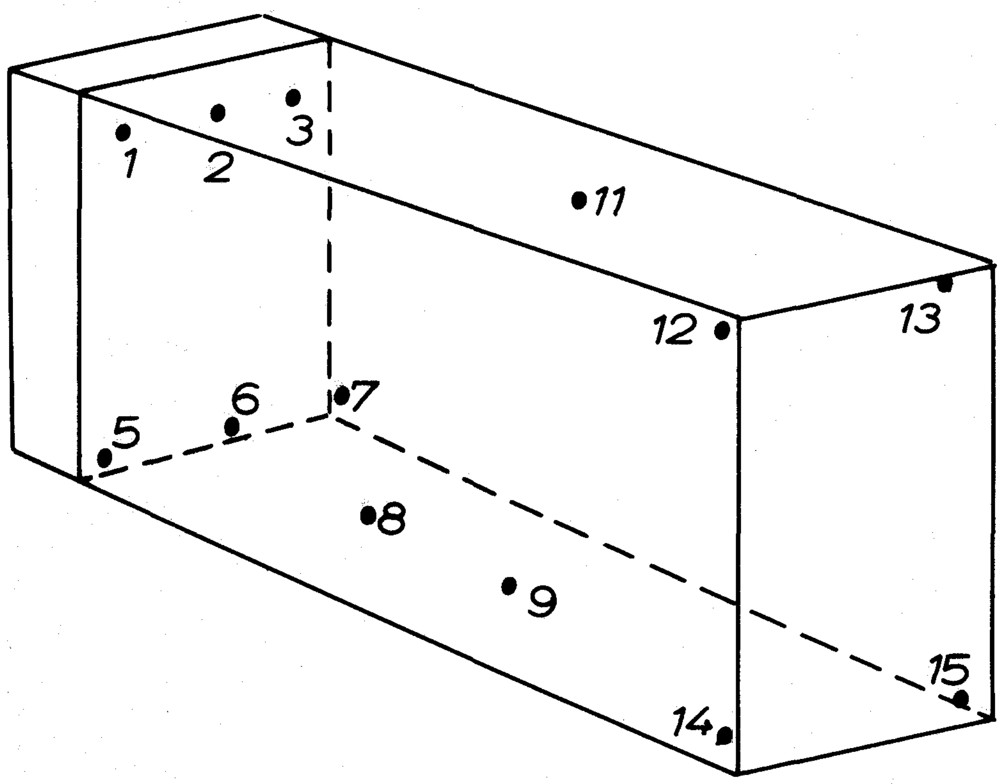


Fig. 3 Points of temperature measurement in the container

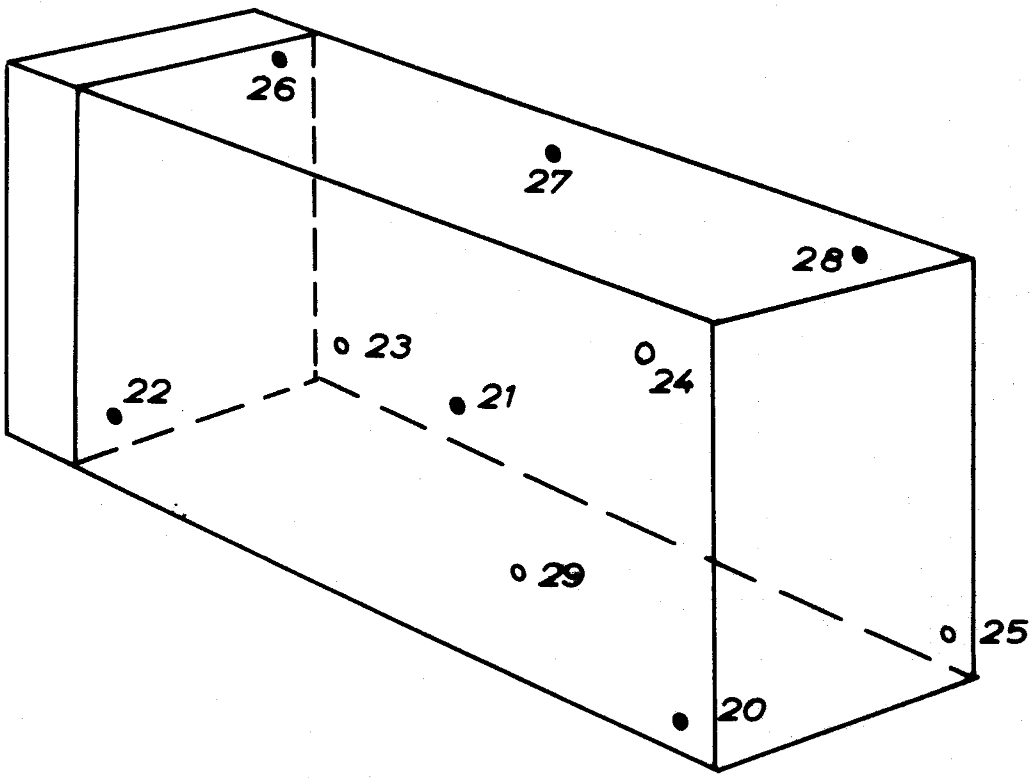


Fig. 4 Points of temperature measurement outside container

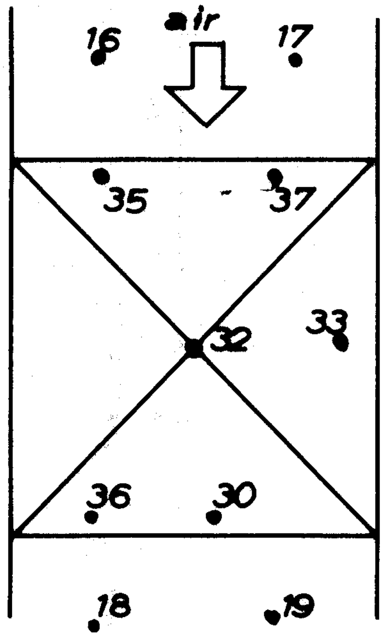


Fig. 5 Points of temperature measurement around the evaporator

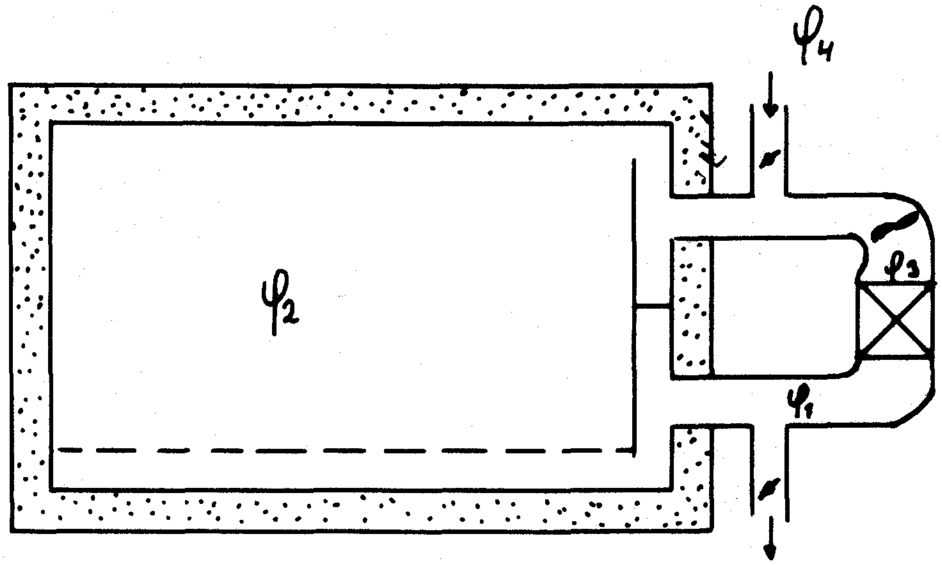


Fig. 6 Points of relative humidity measurement

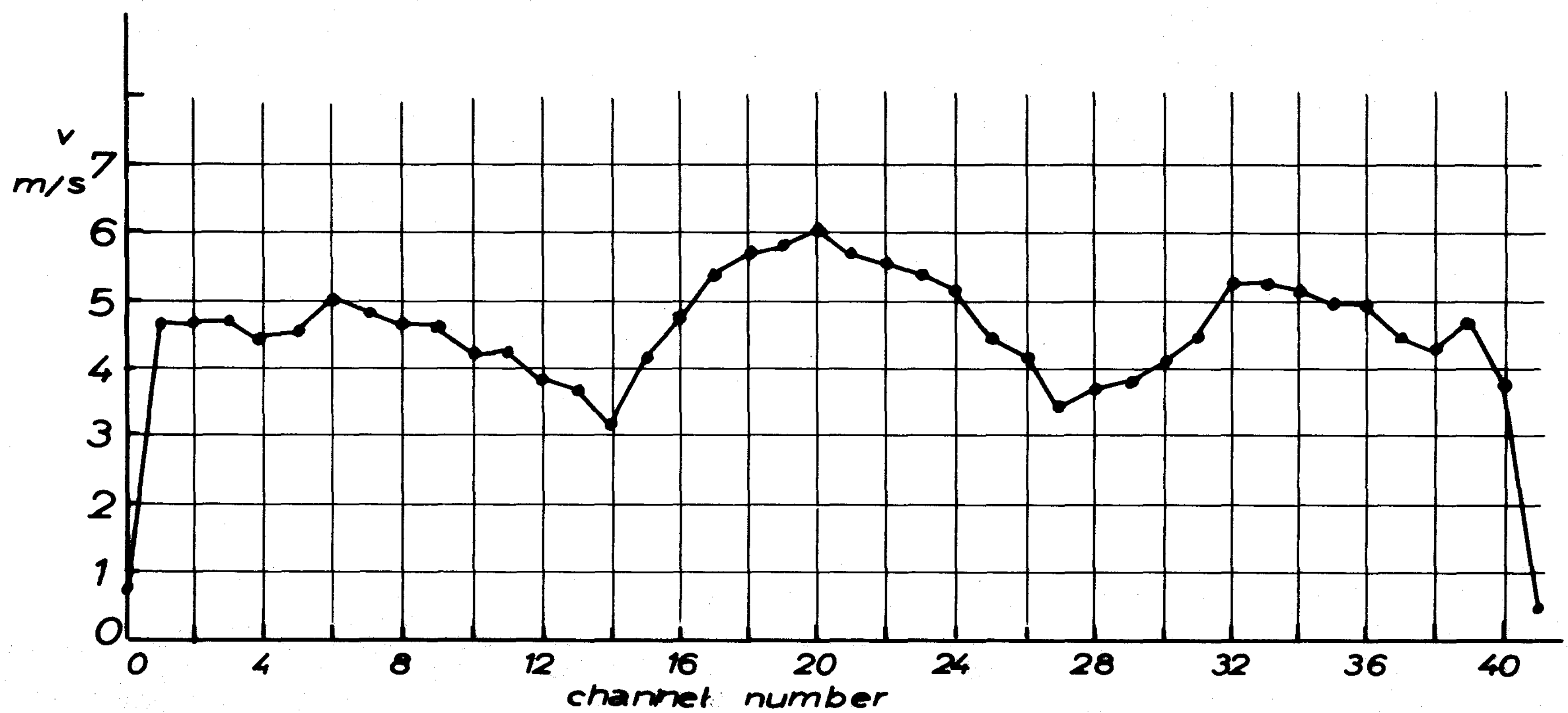
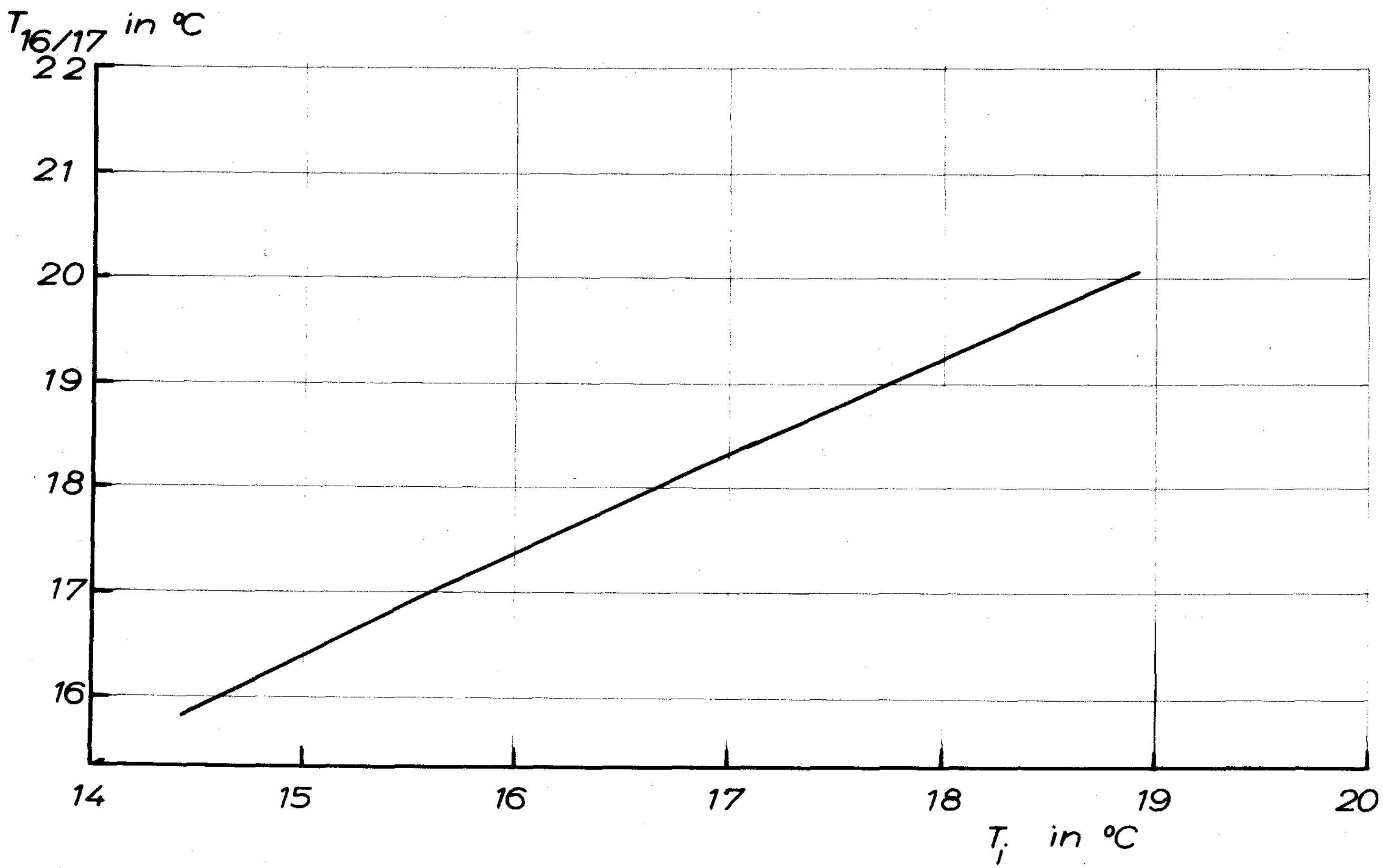


Fig. 7 Air distribution in the T-floor-channels (Empty container).

Fig. 8 Correction of couples 16 and 17



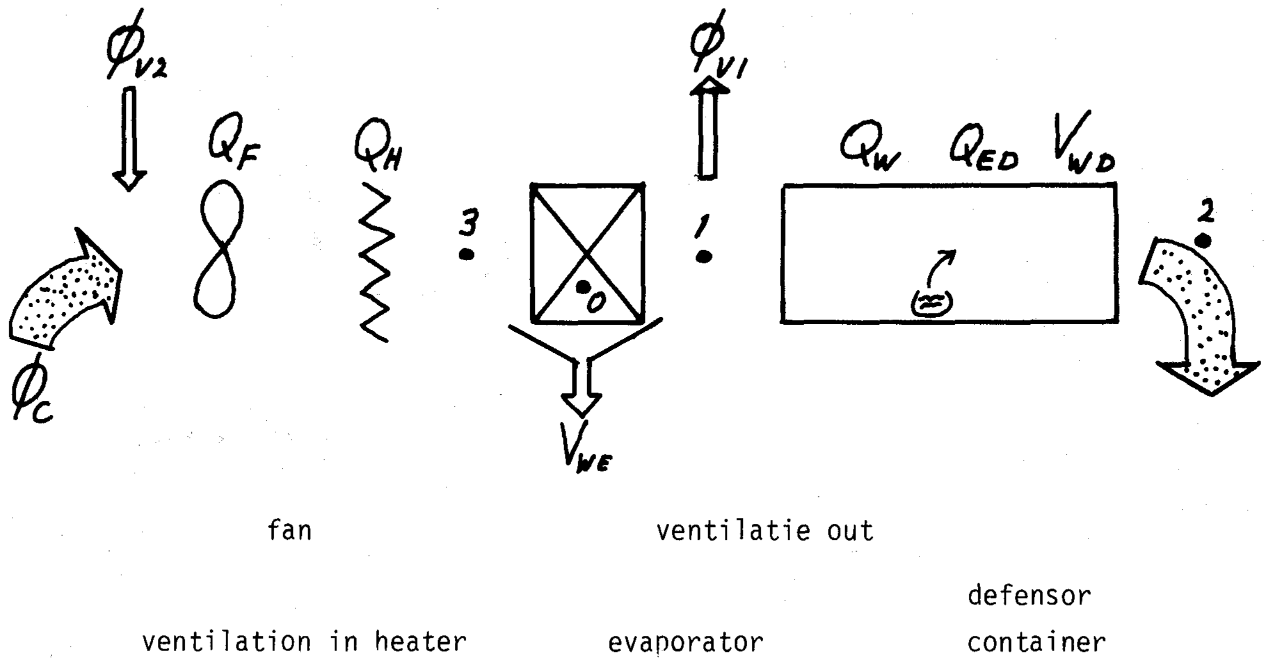
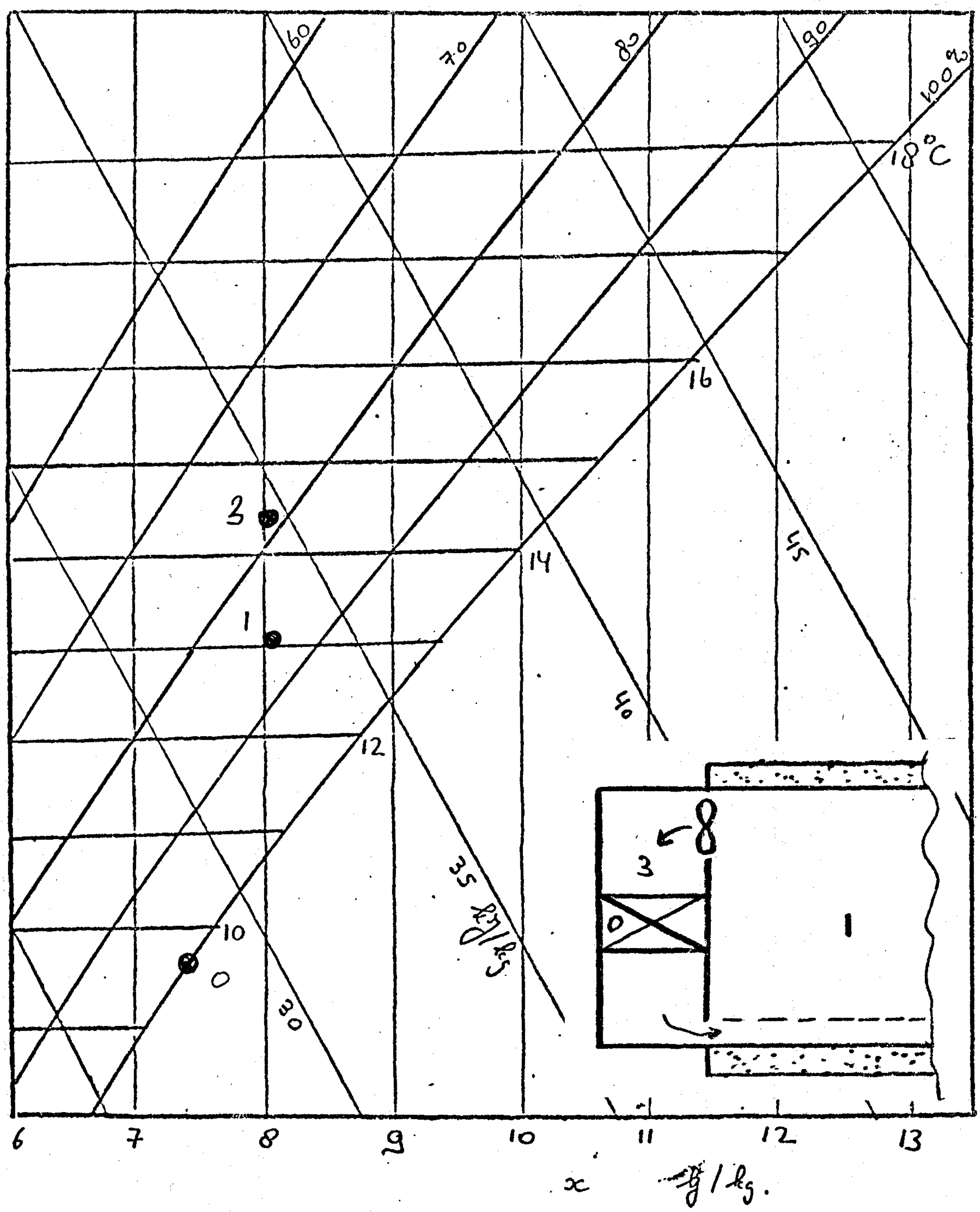


Fig. 9 Outline of the container for the calculations



eriment Nº	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
4	0,4	0	0	0	20	13

fig 10 Condition of air in the stationairy phase

Fig. 11 Experiment 4
Temperature and relative humidi
around the evaporator

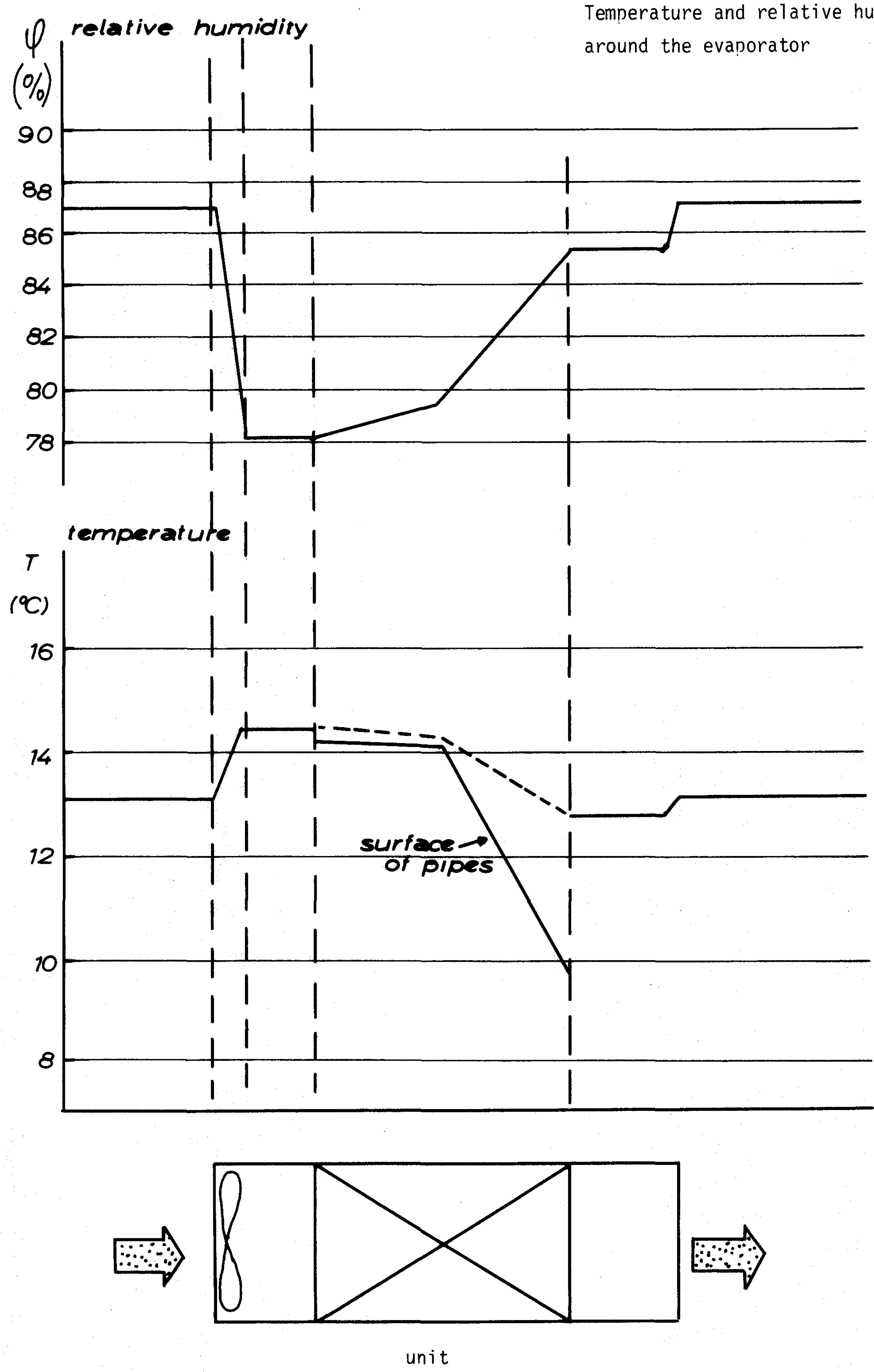
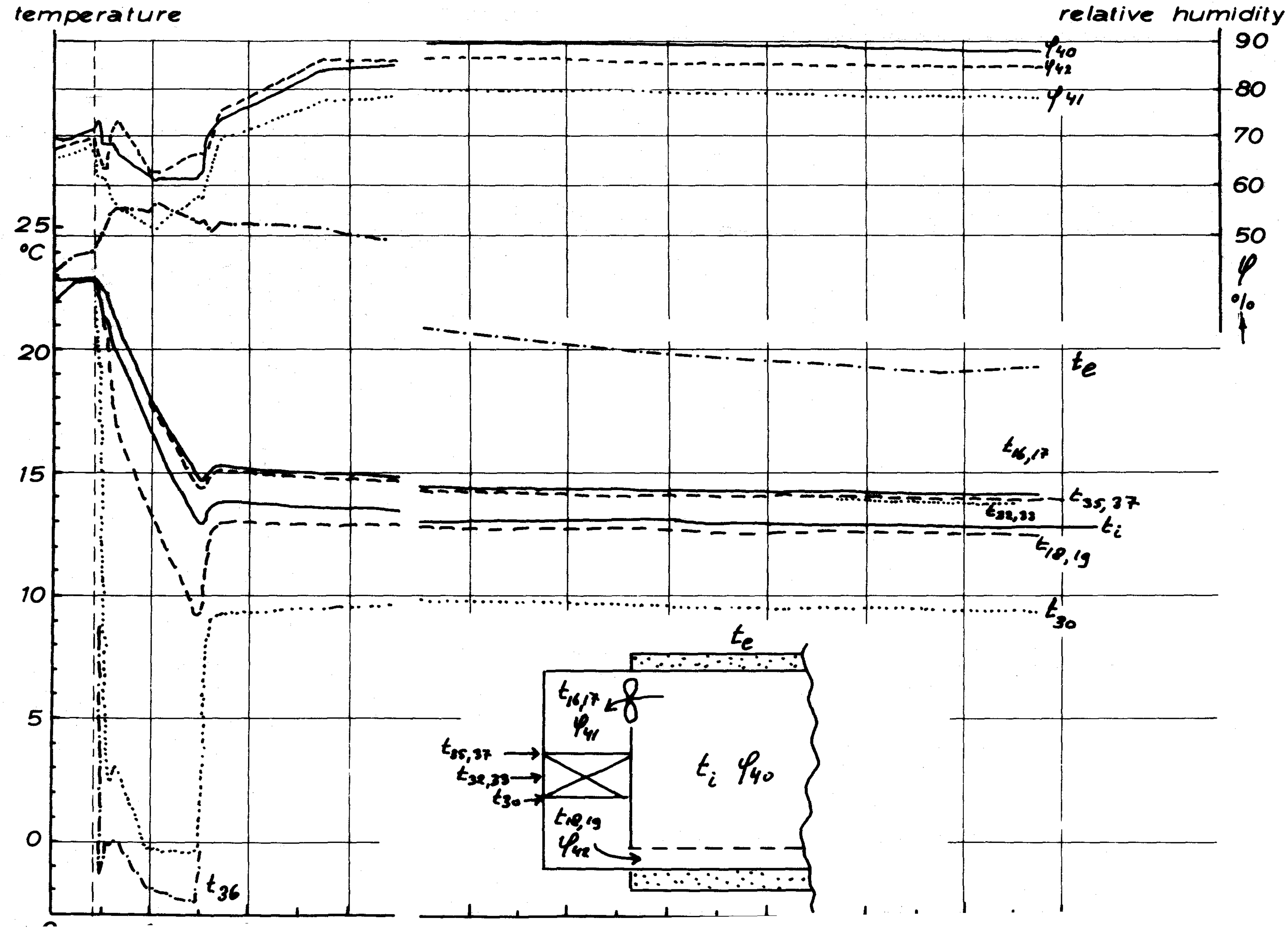
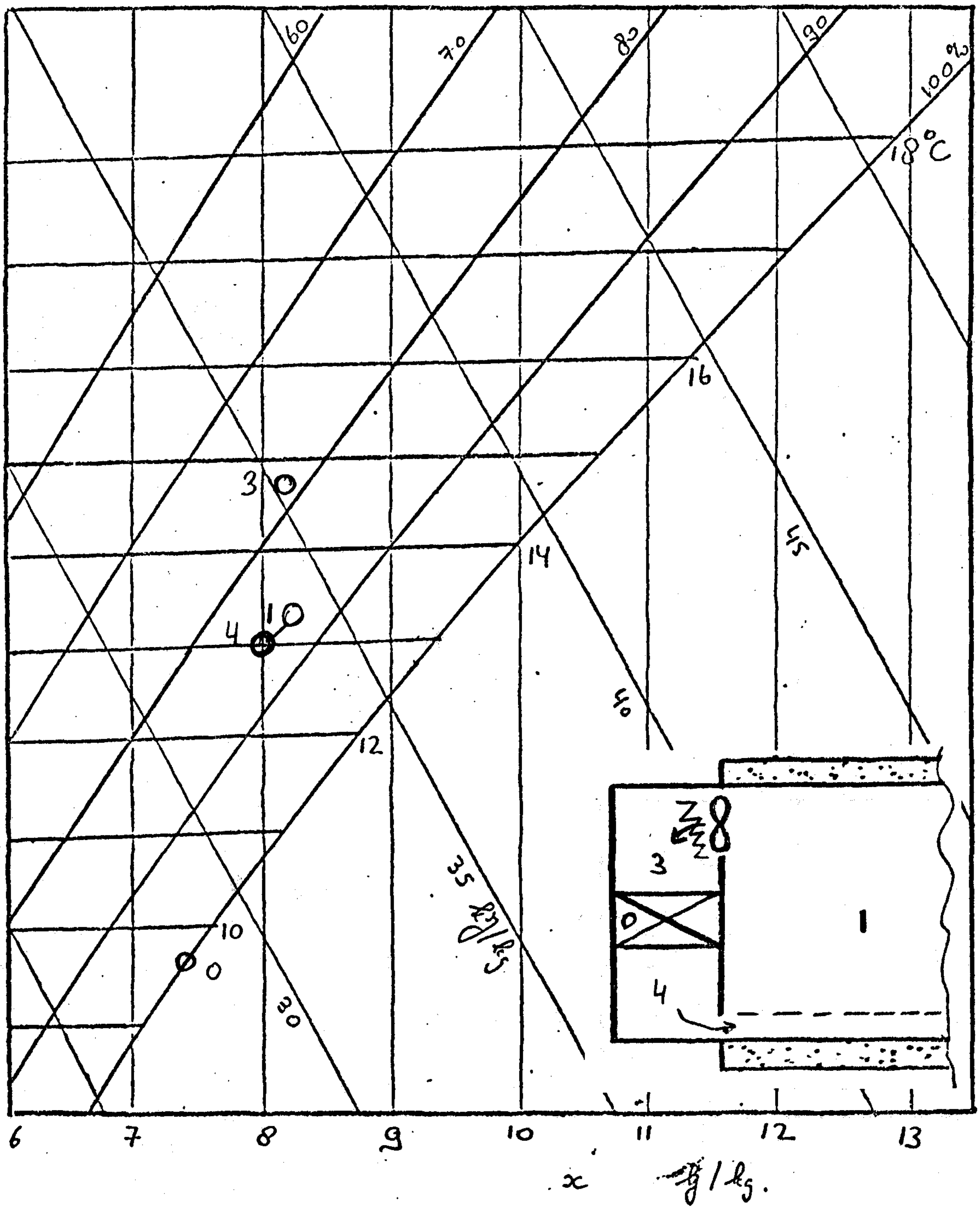


Fig. 12 Experiment 4

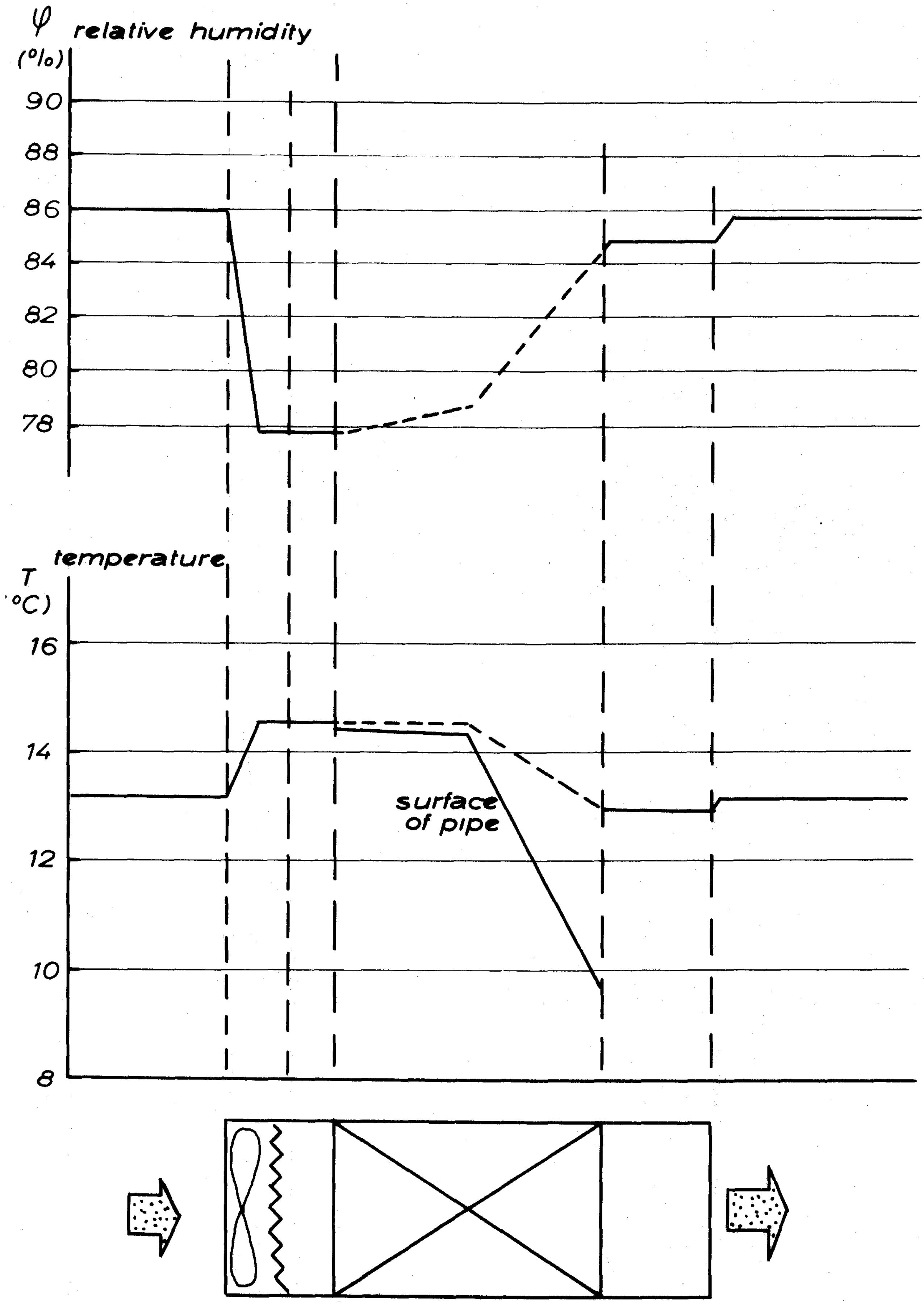


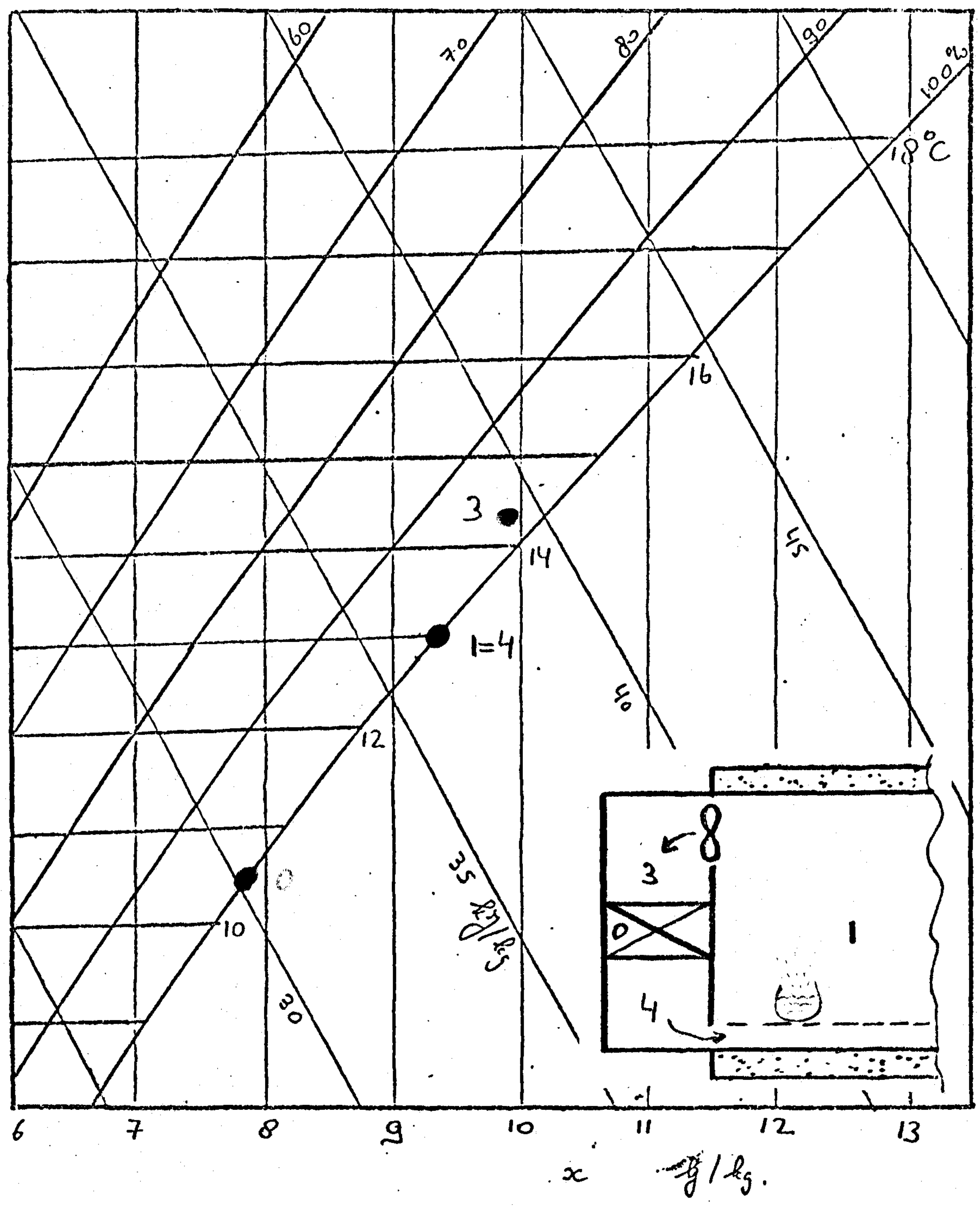


experiment Nº	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
5	0,4	0	750	0	26	13,3

fig 13 Condition of air in the stationairy phase

Fig. 14 Experiment 5
Temperatures and relative humidity
around the evaporator

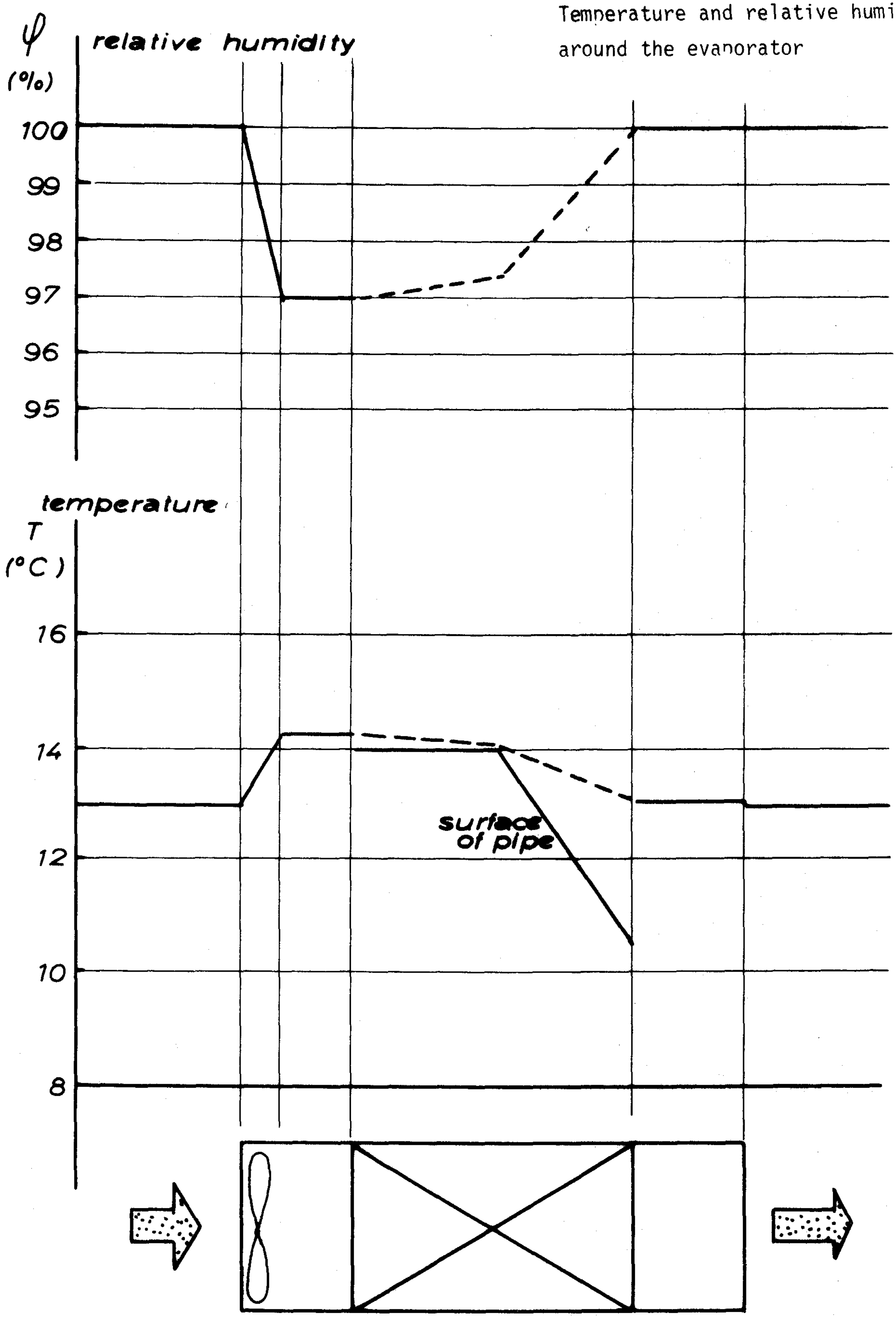


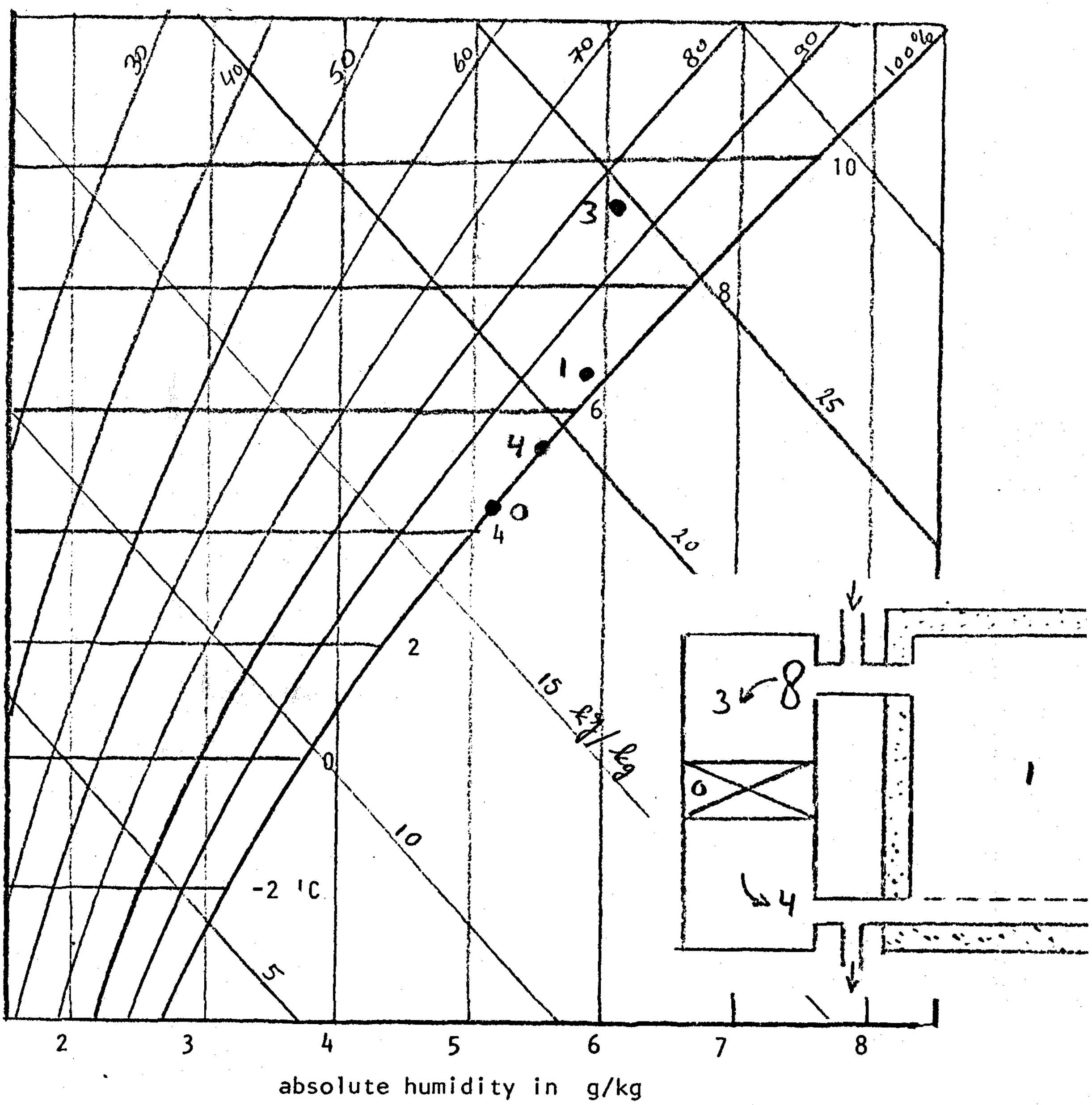


experiment nr	circulation [m³/s]	ventilation [m³/s]	heating [kW]	water [kg/s]	t_4 [°C]	t_1 [°C]
6	0,4	0	0	$3{,}17 \cdot 10^{-4}$	19	13,0

fig 15 Condition of air in the stationairy phase

Fig. 16 Exneriment 6
Temnerature and relative humidity
around the evanorator





experiment nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
9	0,4	0.01	0	0	20	5,5

Fig. 17 Condition of air in the stationairy phase

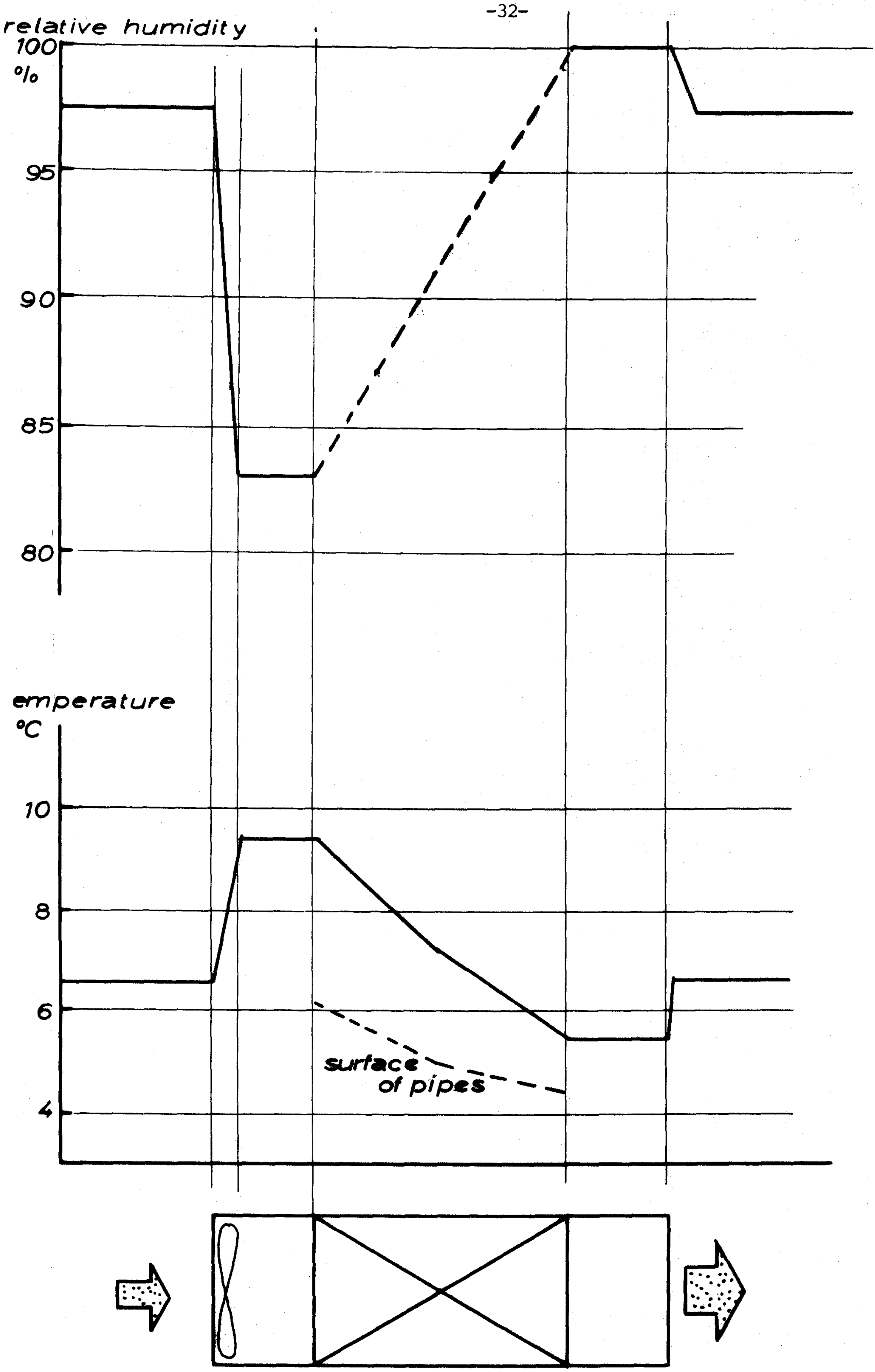


Fig. 18 Experiment 9 Temperature and relative humidity around the time

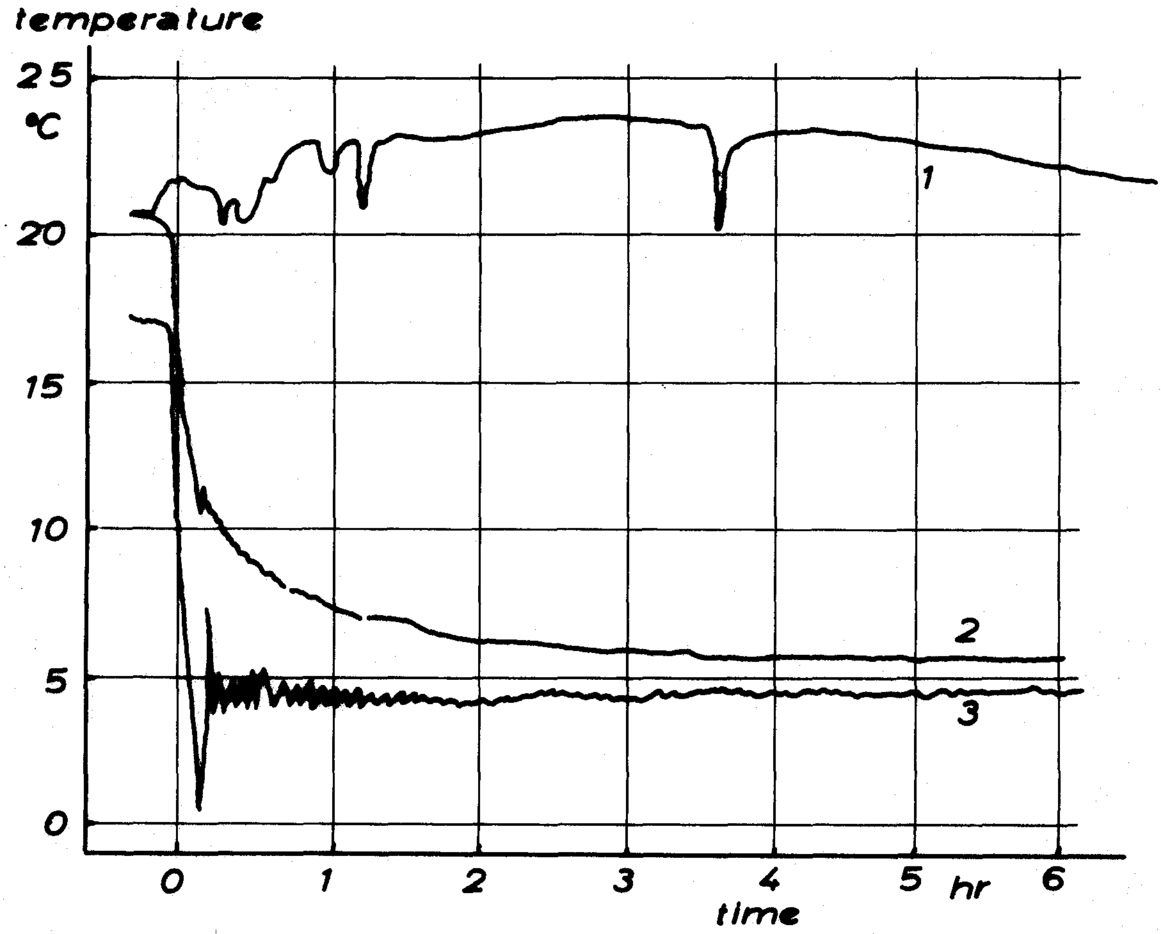


Figure 19 Exneriment 9
Cooling downtemneratures

1. ambient
2. inside the container
3. after the evanorator

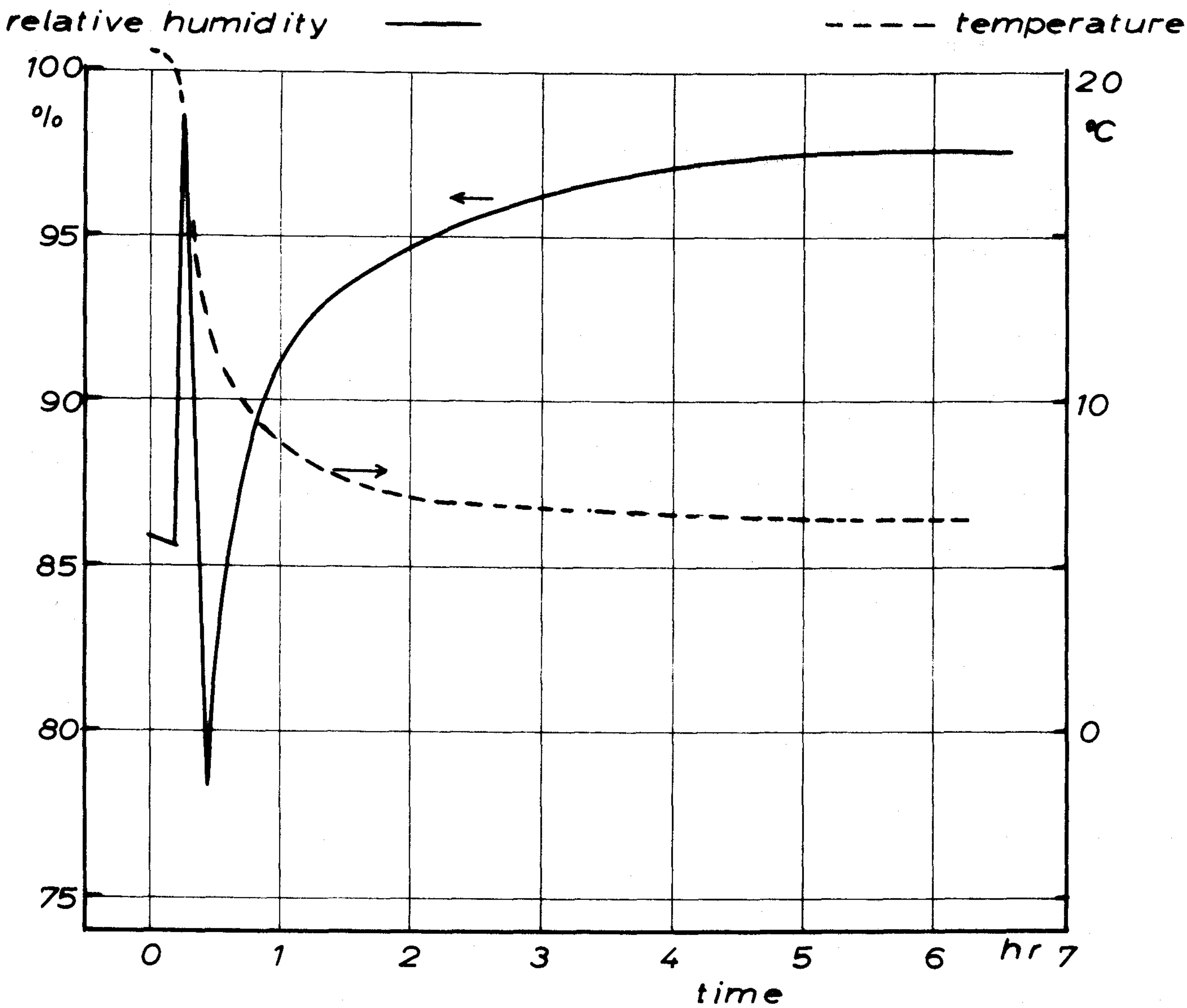
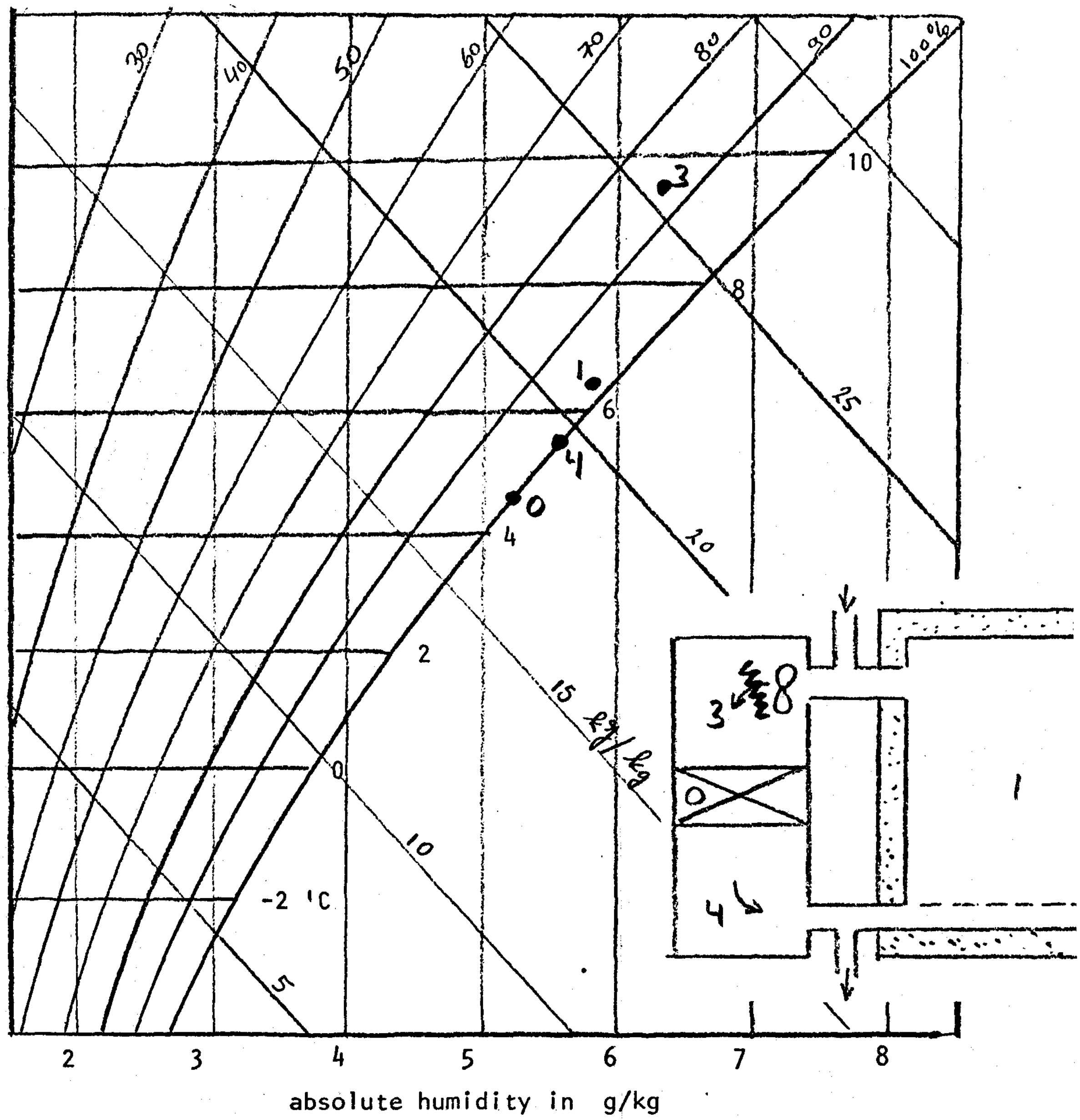


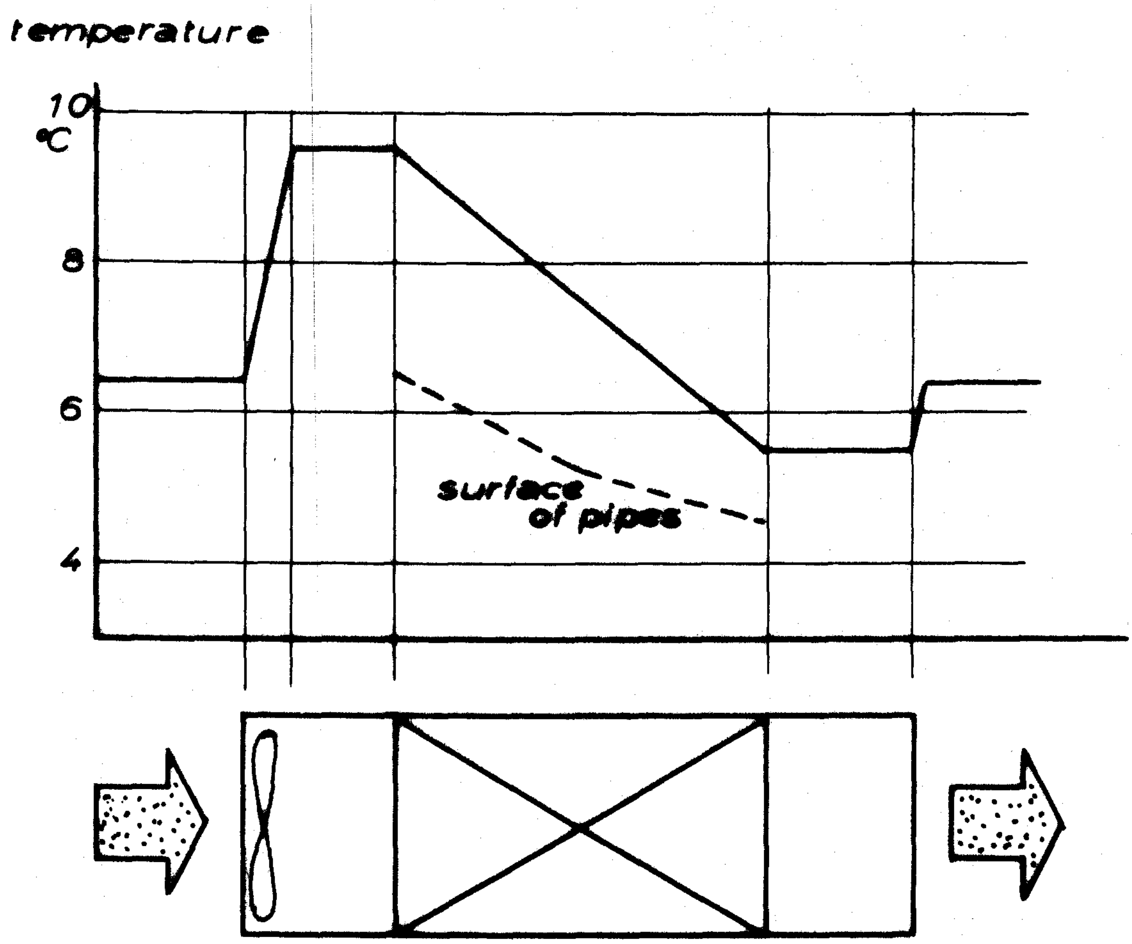
Fig. 20 Experiment 9
Relative humidity inside the container during cooling down

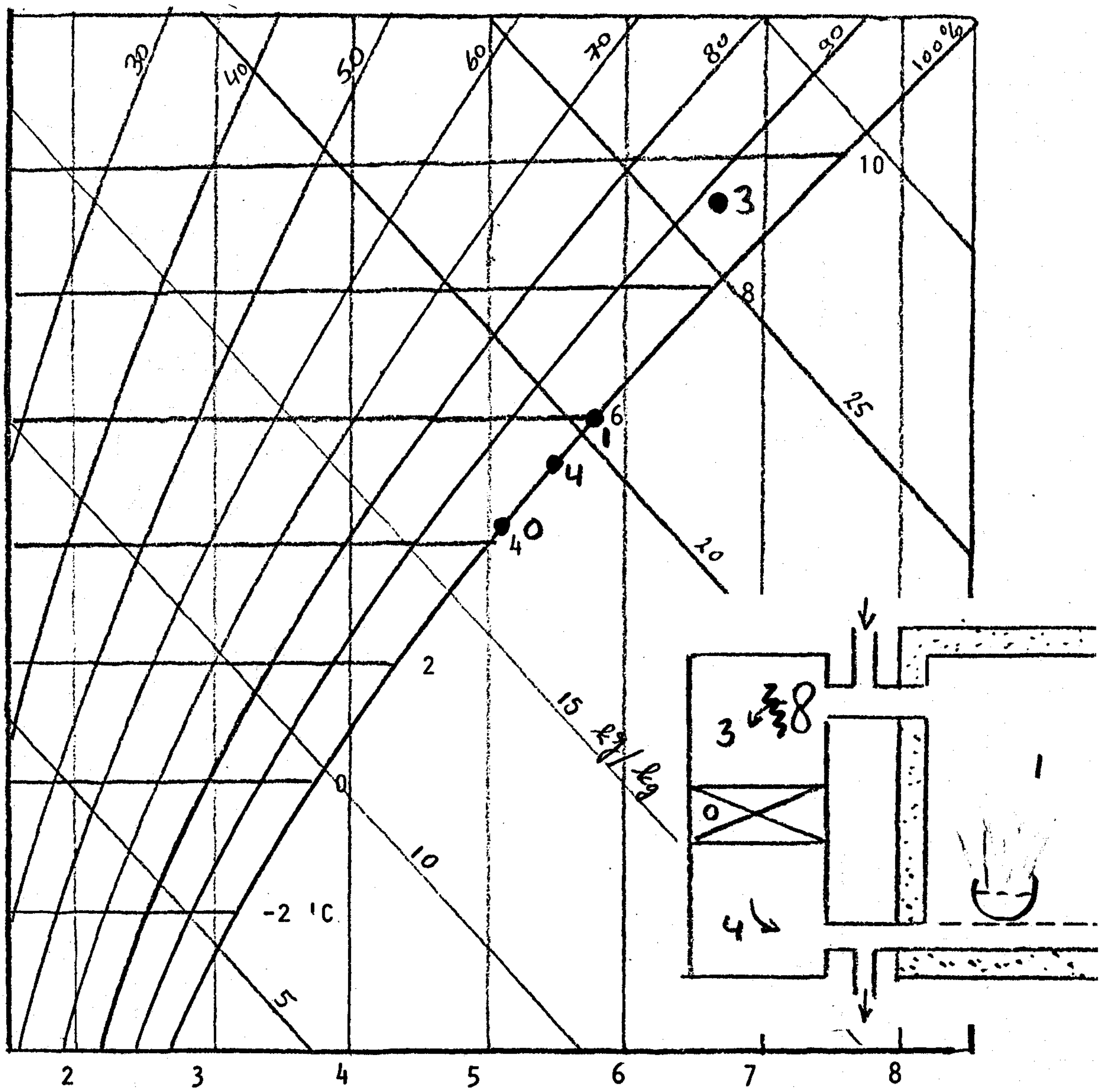


experiment nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
10	0,4	0,01	750	0	24,2	5,5

Fig. 21 Condition of air in the stationairy phase

Fig. 22 Experiment 10
Temperature around time in the unit

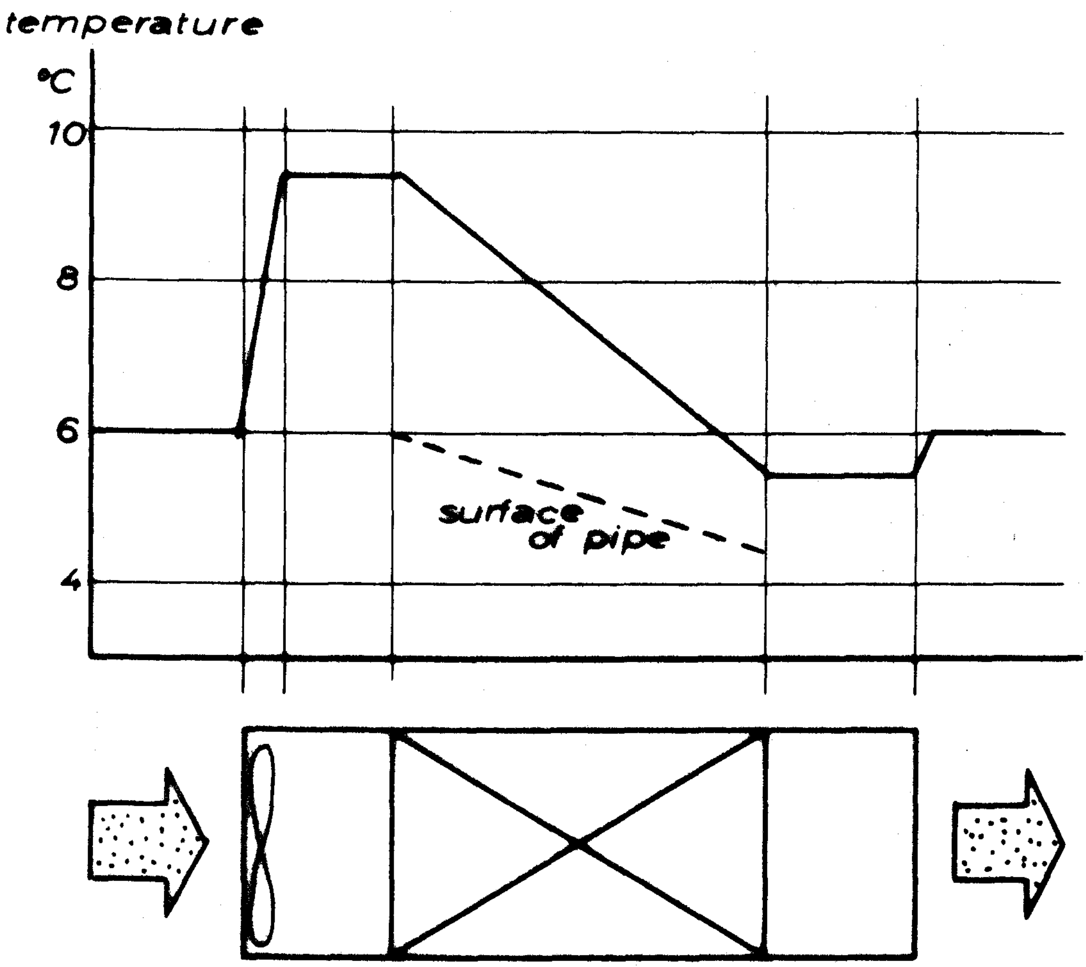


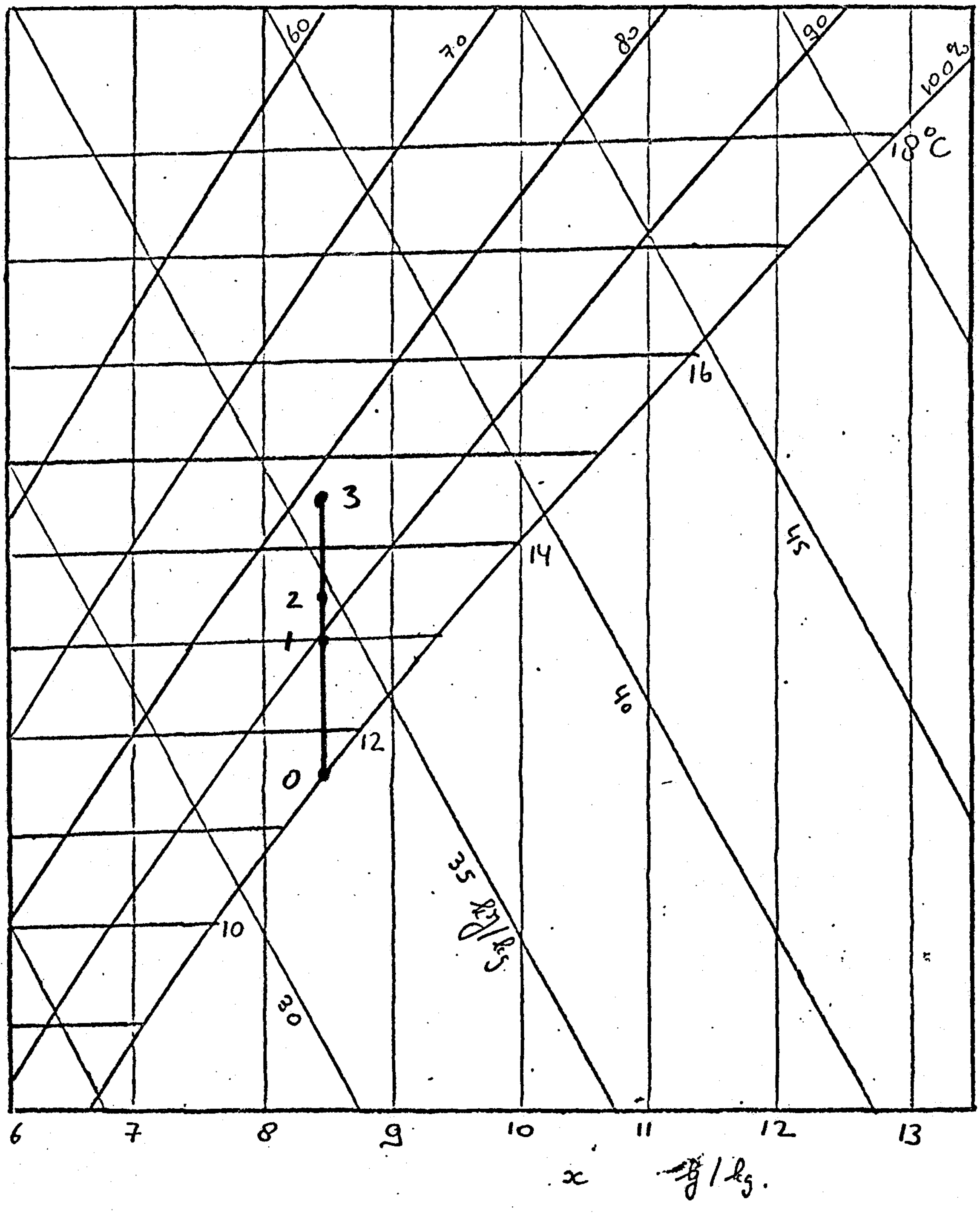


experiment nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
11	0,4	0,01	750	$3,17.10^{-4}$	26,3	5,5

Fig. 23 Condition of air in the [illegible]ry phase

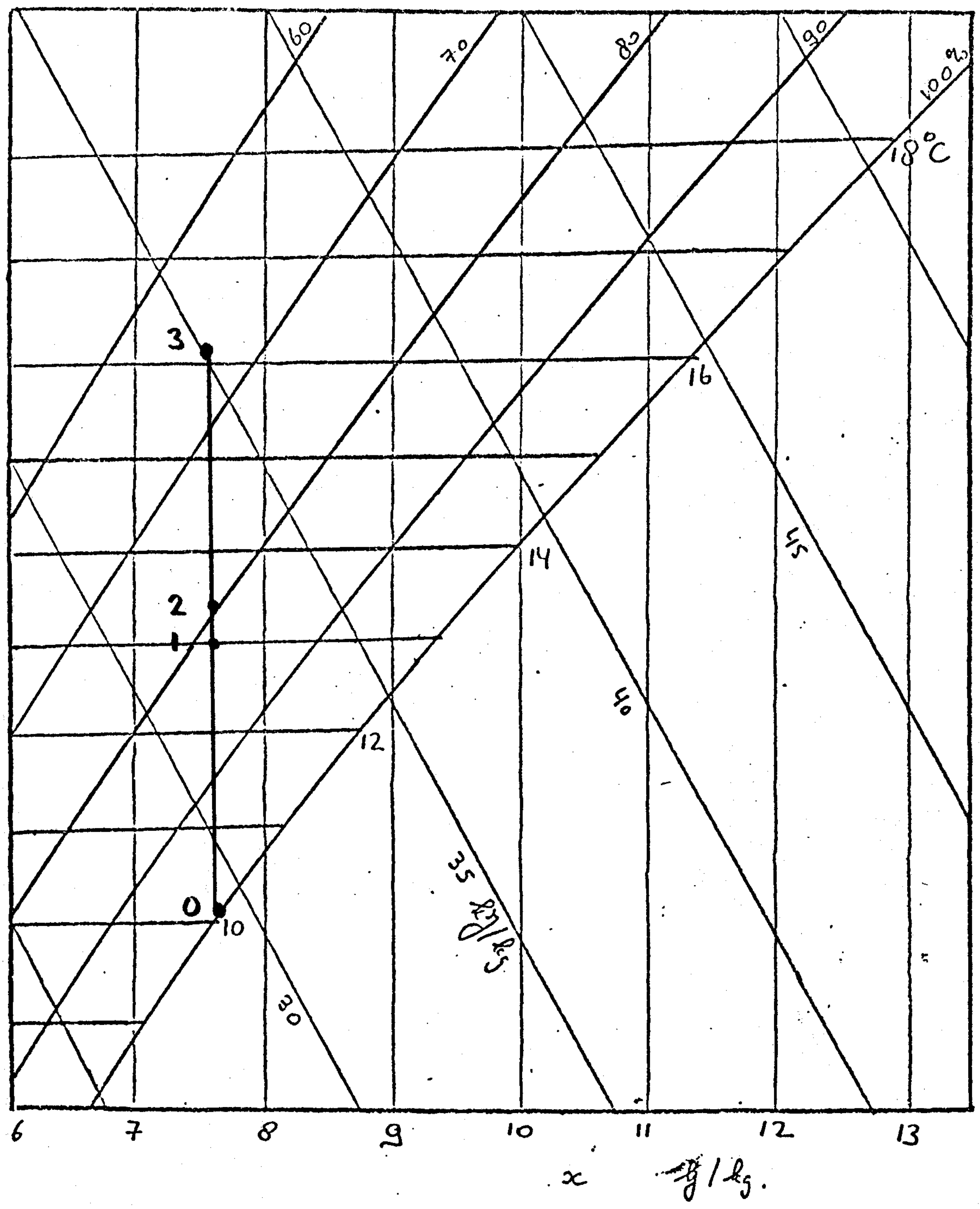
Fig. 24 Experiment 11
Temperature in the unit





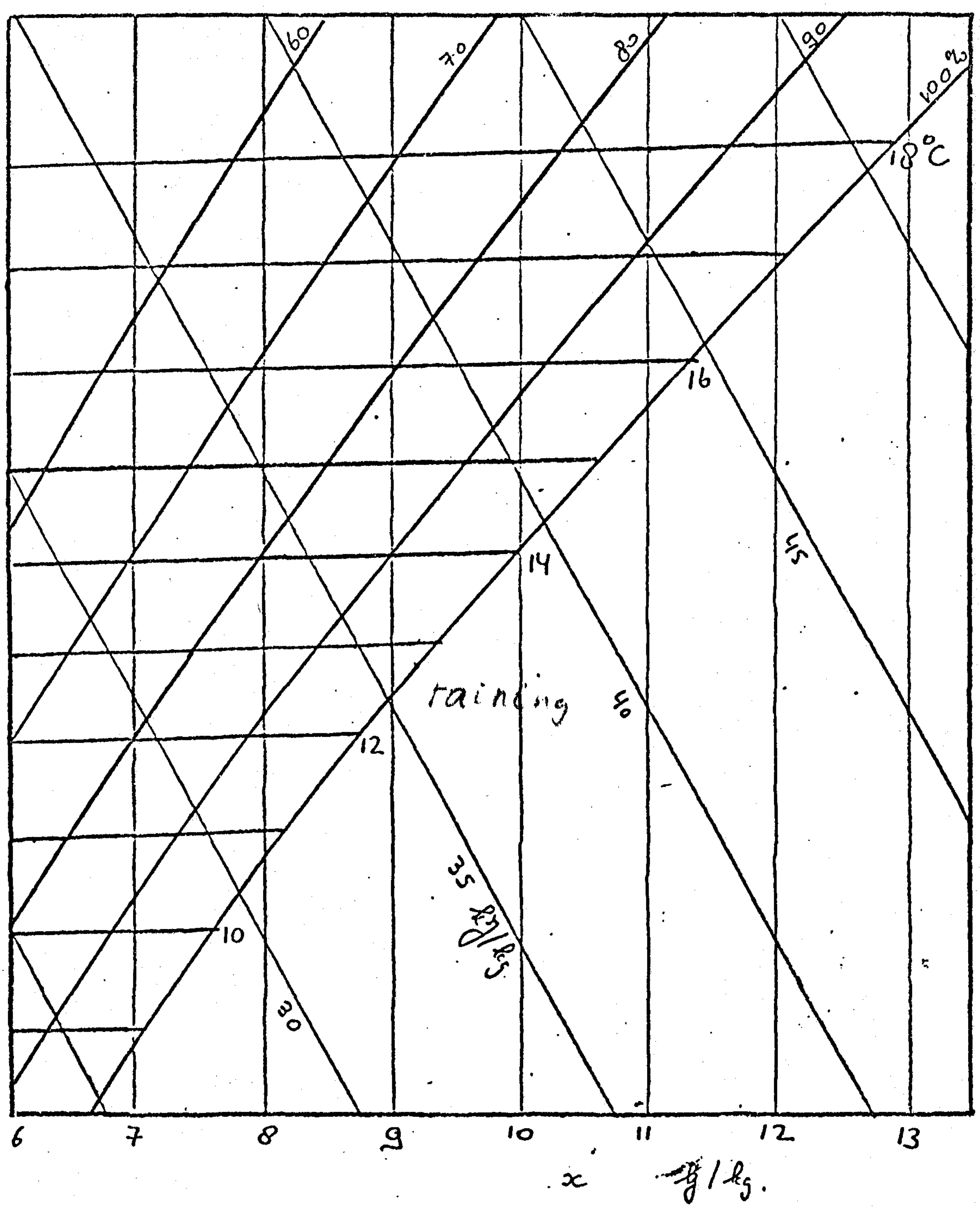
Calculation Nº	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
1	0,4	0	0	0	20	13

Fig. 25



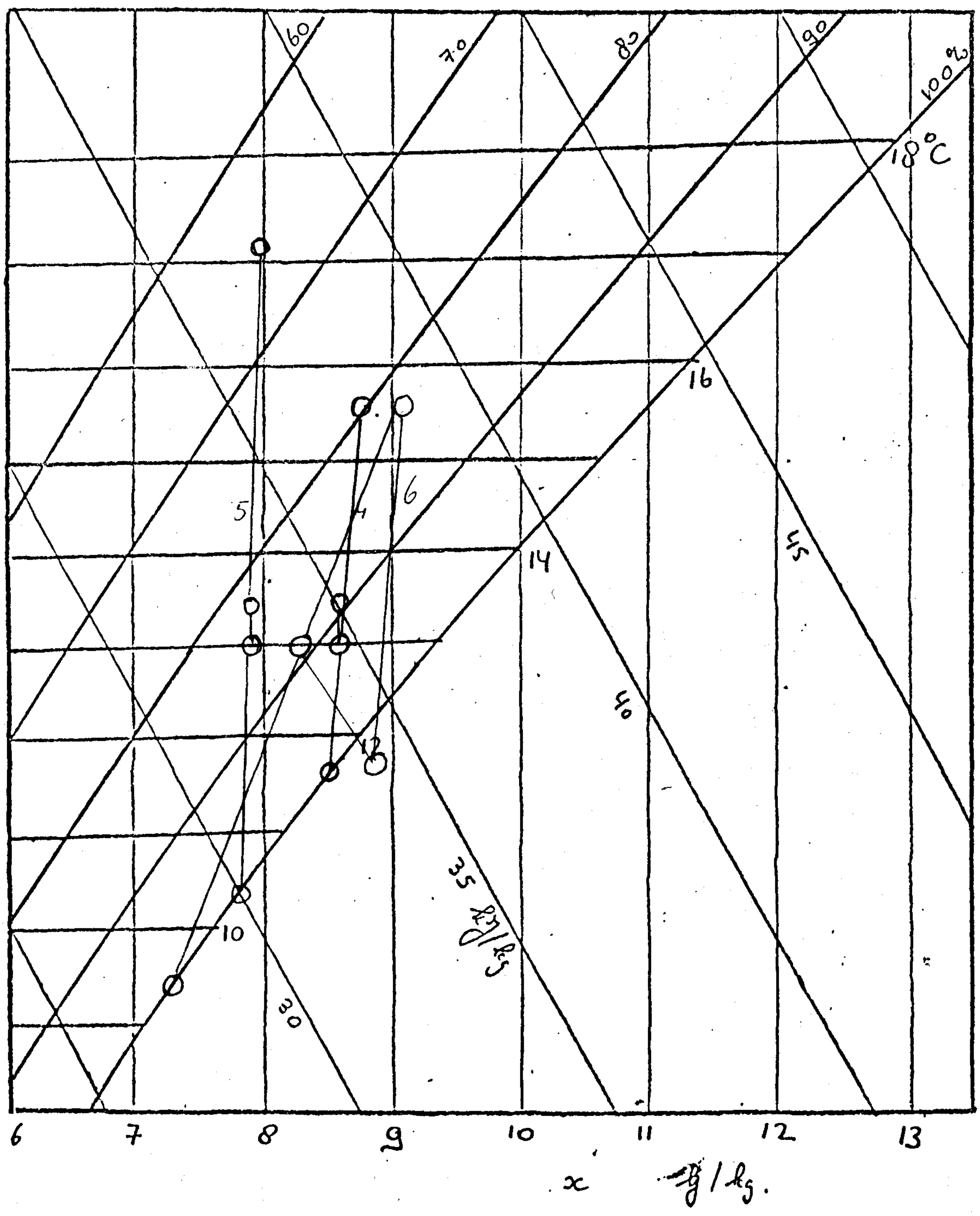
station nr	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
2	0,4	0	750	0	20	13

Fig. 26



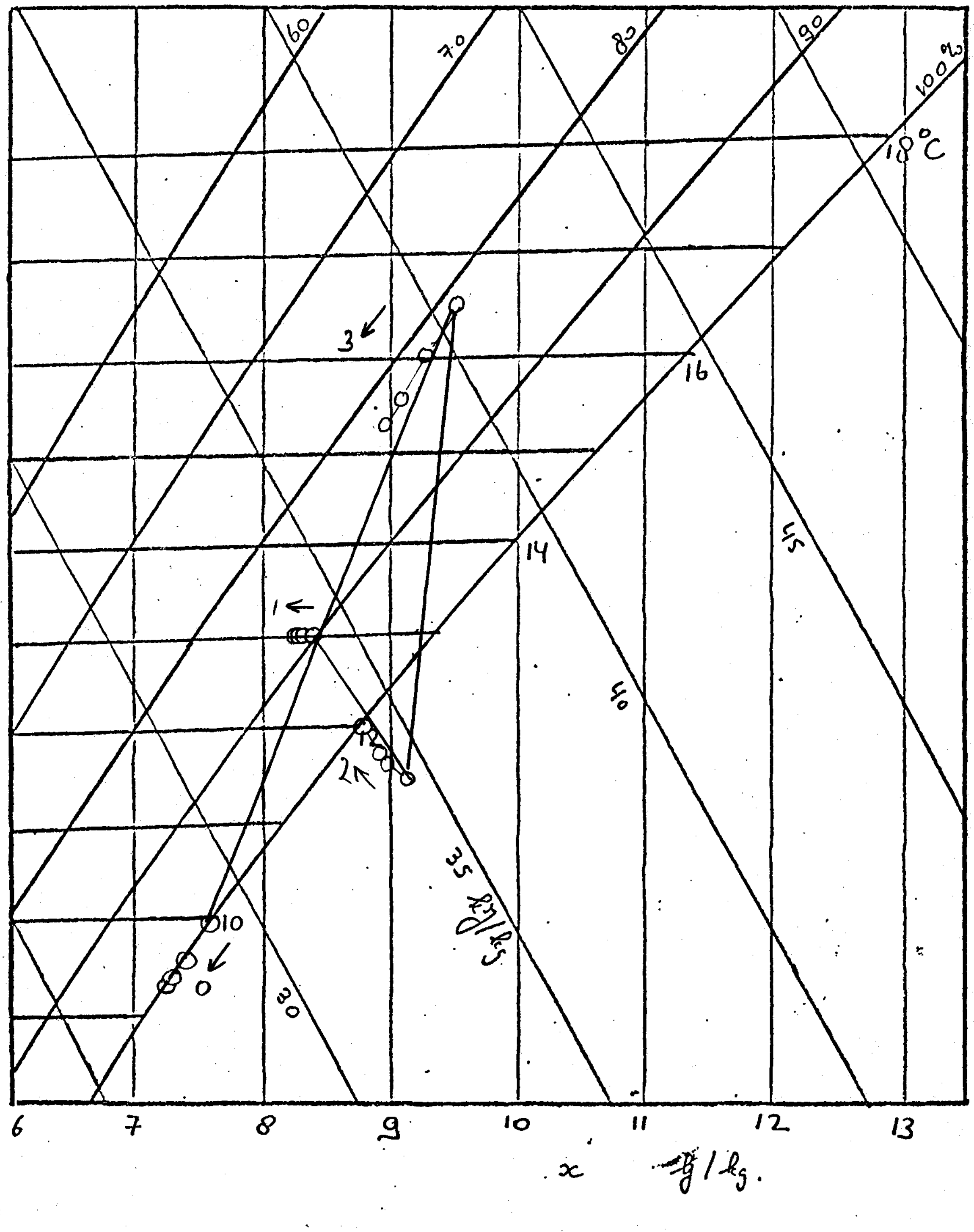
Calculation Nº	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
3	0,4	0	0	$3,17 \cdot 10^{-4}$	20	13

Fig. 27



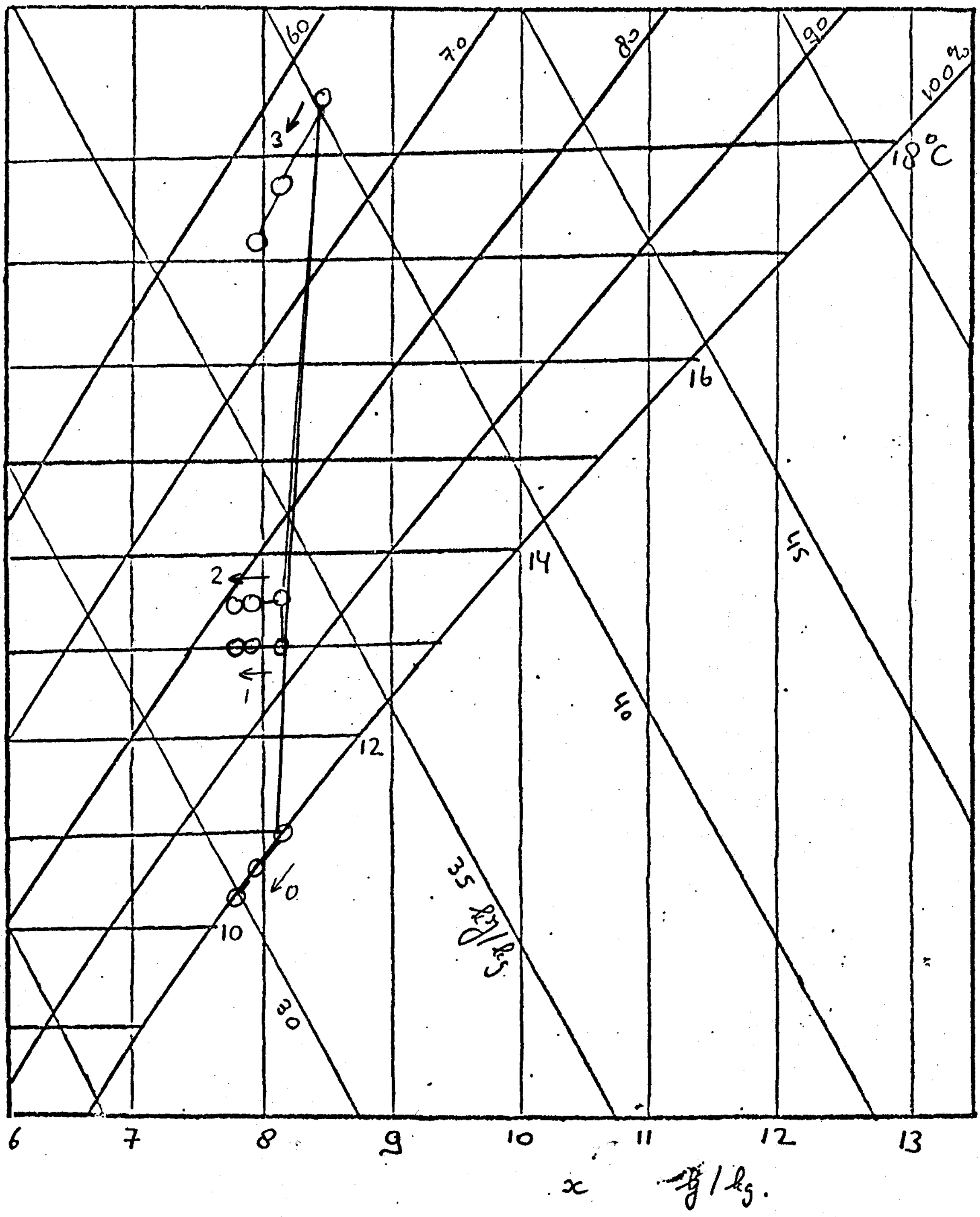
station Nr	circulation flow [m³/s]	ventilation flow [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
4	0,4	0,01	0	0	20	13
5	0,4	0,01	750	0	20	13
6	0,4	0,01	750	$3,17 \cdot 10^{-4}$	20	13
8 >100%	0,4	0,01	0	$3,17 \cdot 10^{-4}$	20	13

Fig. 28



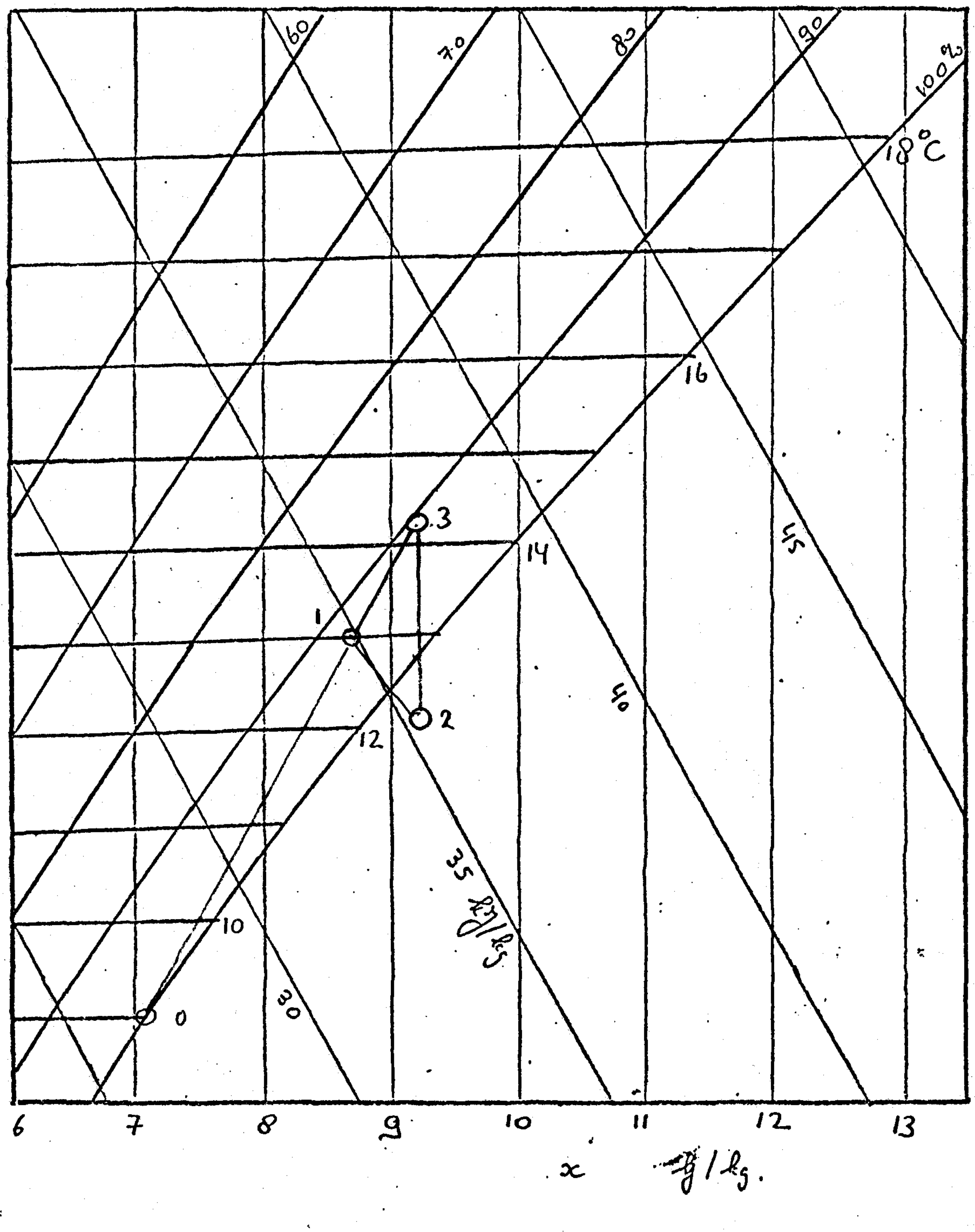
Calculation No	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
9	0,3	0,01	750	$3{,}17.10^{-4}$	20	13
	0,35					
	0,4					
	0,45					
	0,5					

Fig. 29



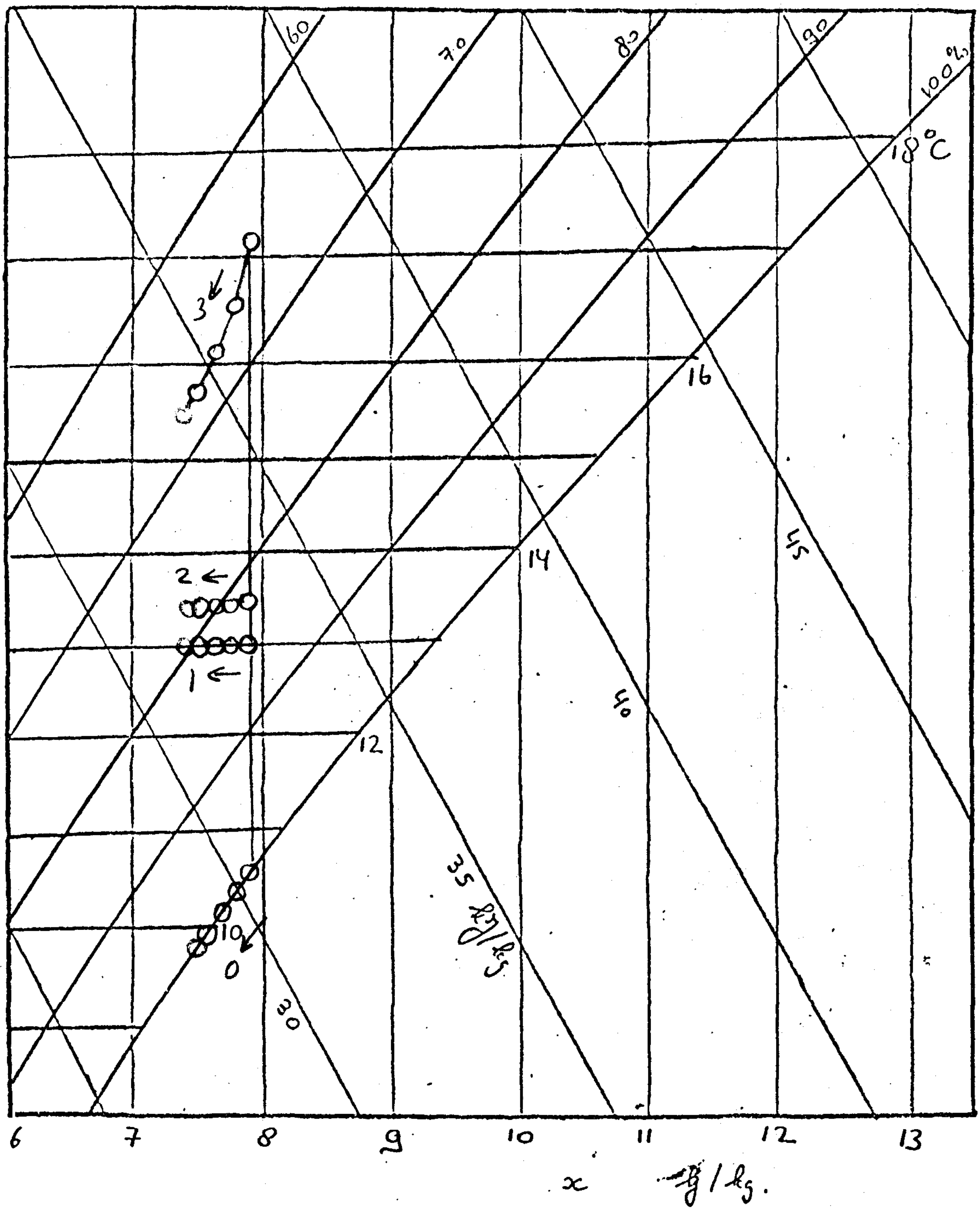
...ulation No	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t4 [°C]	t1 [°C]
	0,3					
	0,35					
10	0,4	0,01	750	–	20	13
	0,45					
	0,5					

Fig. 30



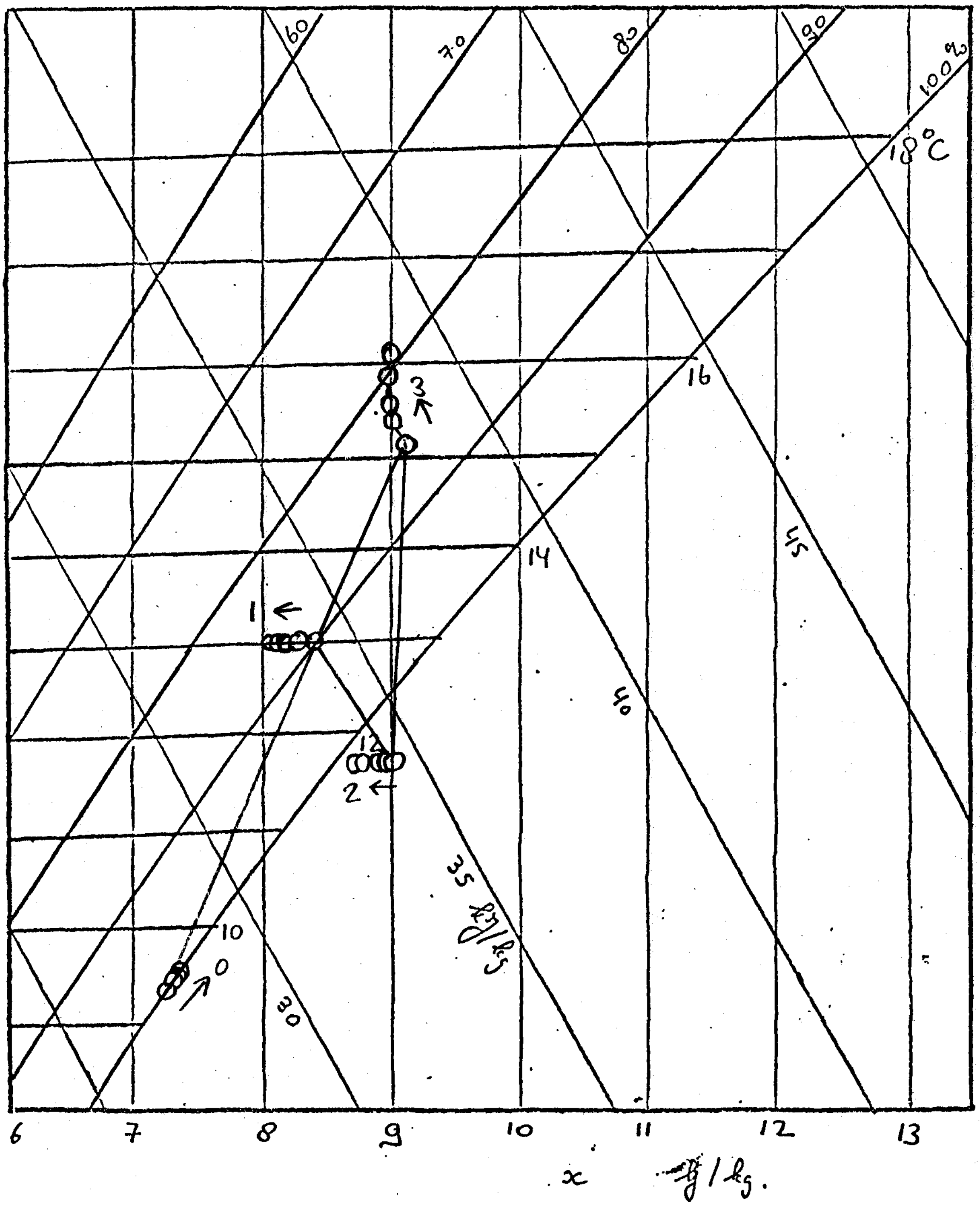
Calculation N°		circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
	*	0,3					
	*	0,35					
11	*	0,4	–	750	$3,17 \cdot 10^{-4}$	20	13
	*	0,45					
		0,5					

Fig. 31 * high humidity >100%



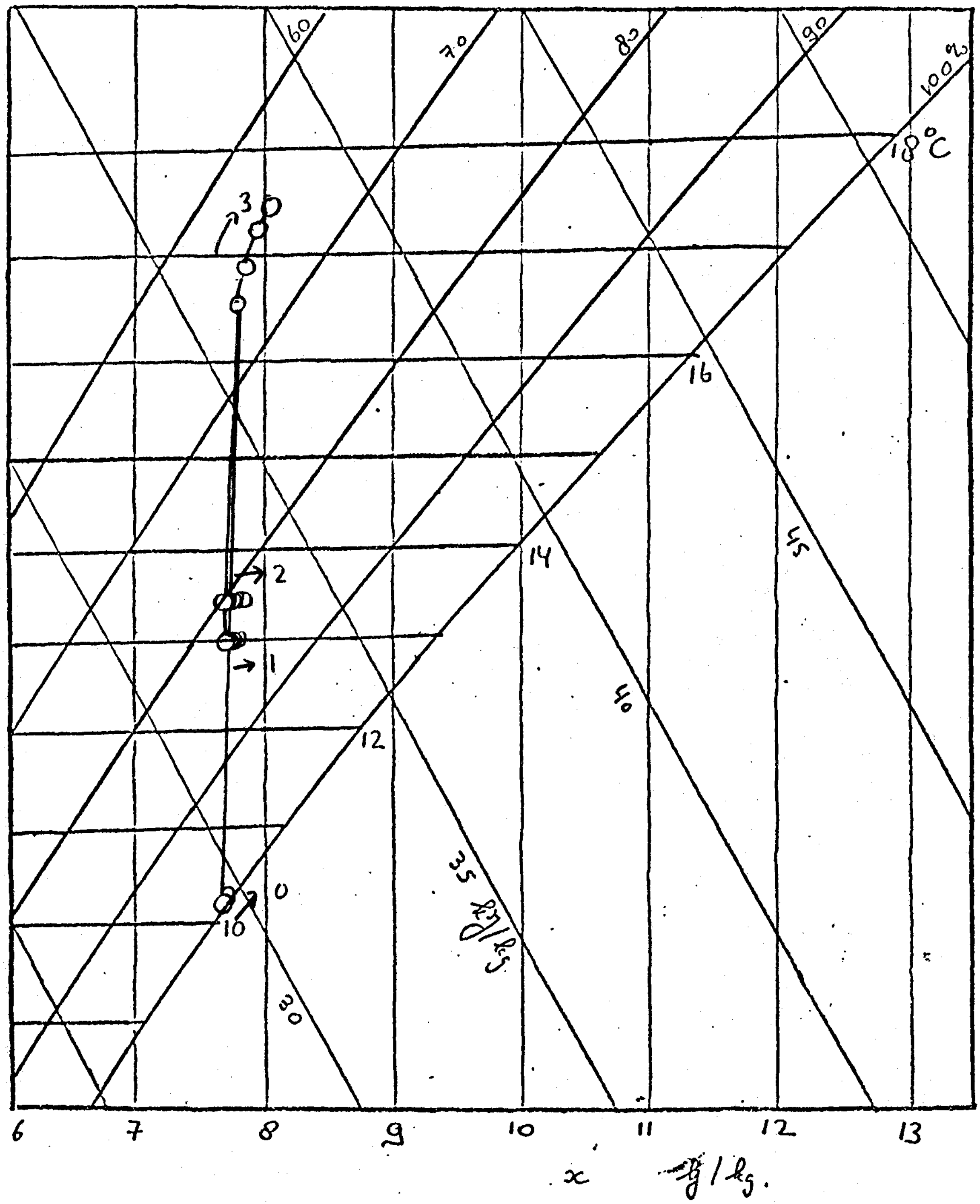
tation Nr	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
12	0,3 0,35 0,4 0,45 0,5	–	750	–	20	13

Fig. 32



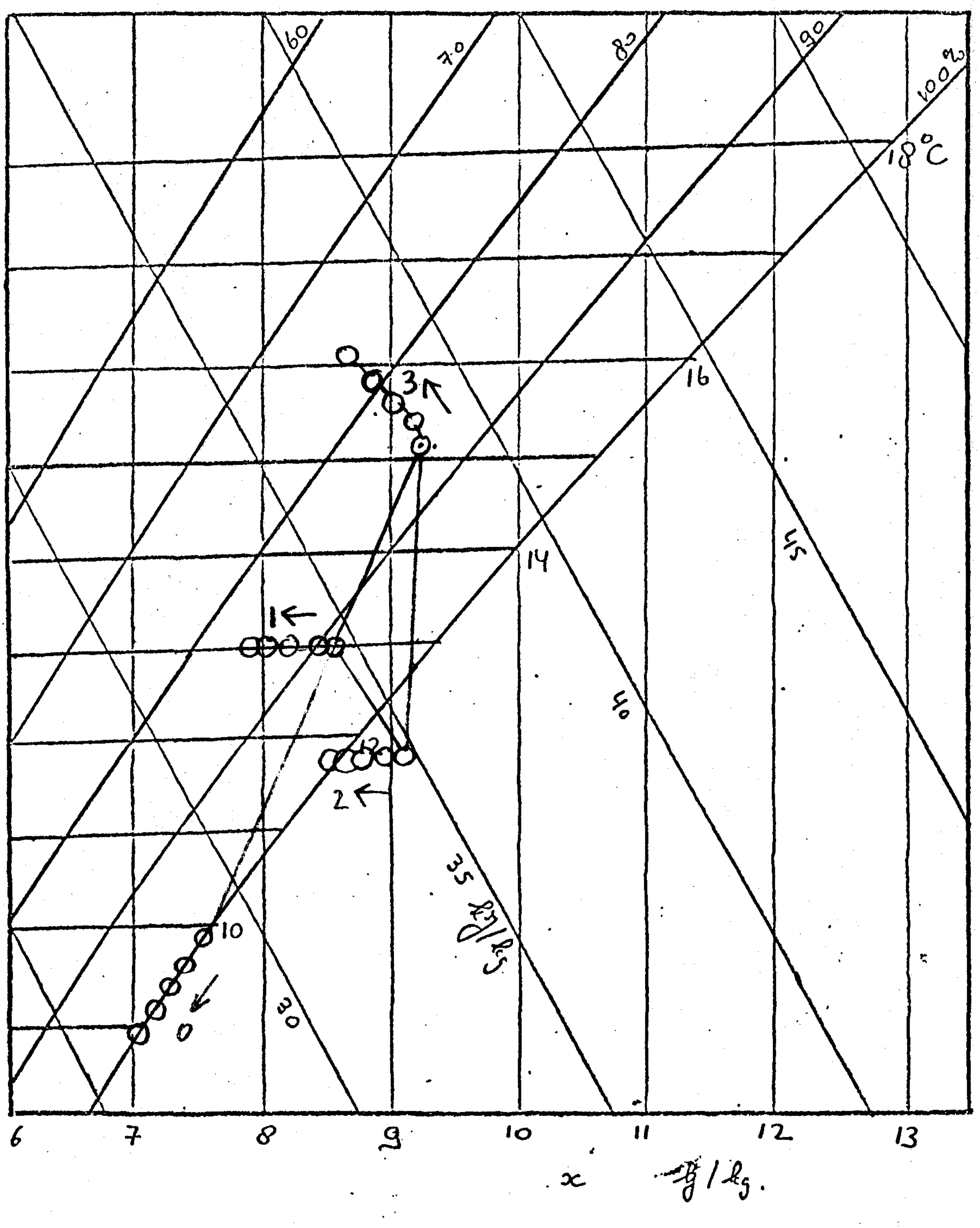
Calculation No	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
13	0,4	0,005 0,0075 0,01 0,0125 0,015	750	$3,17 \cdot 10^{-4}$	20	13

Fig. 33



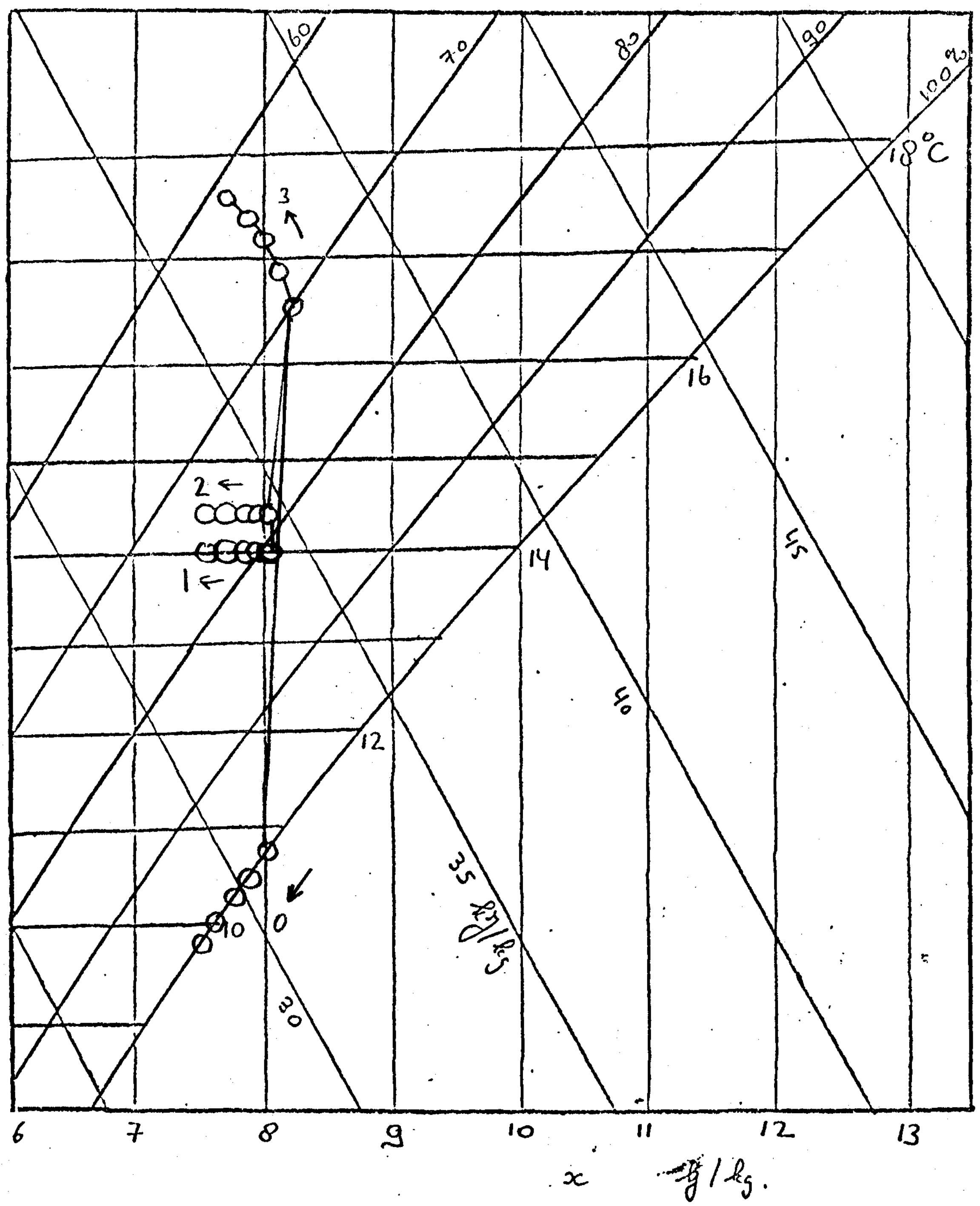
...lation No	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
14	0,4	0,005 0,0075 0,01 0,0125 0,015	750	-	20	13

Fig. 34



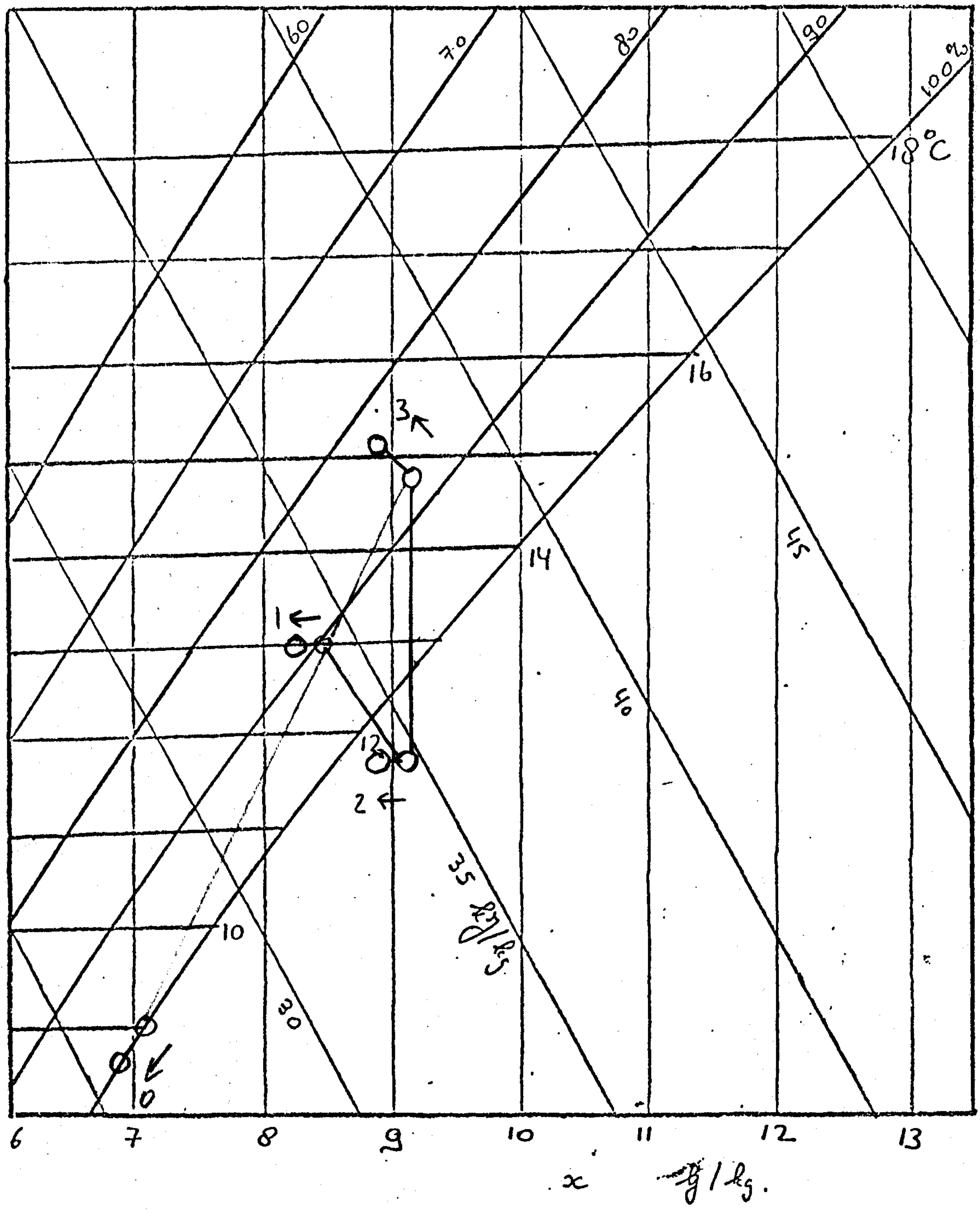
Calculation N°	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
15	0,4	0,01	500 625 750 875 1000	$3,17.10^{-4}$	20	13

Fig. 35



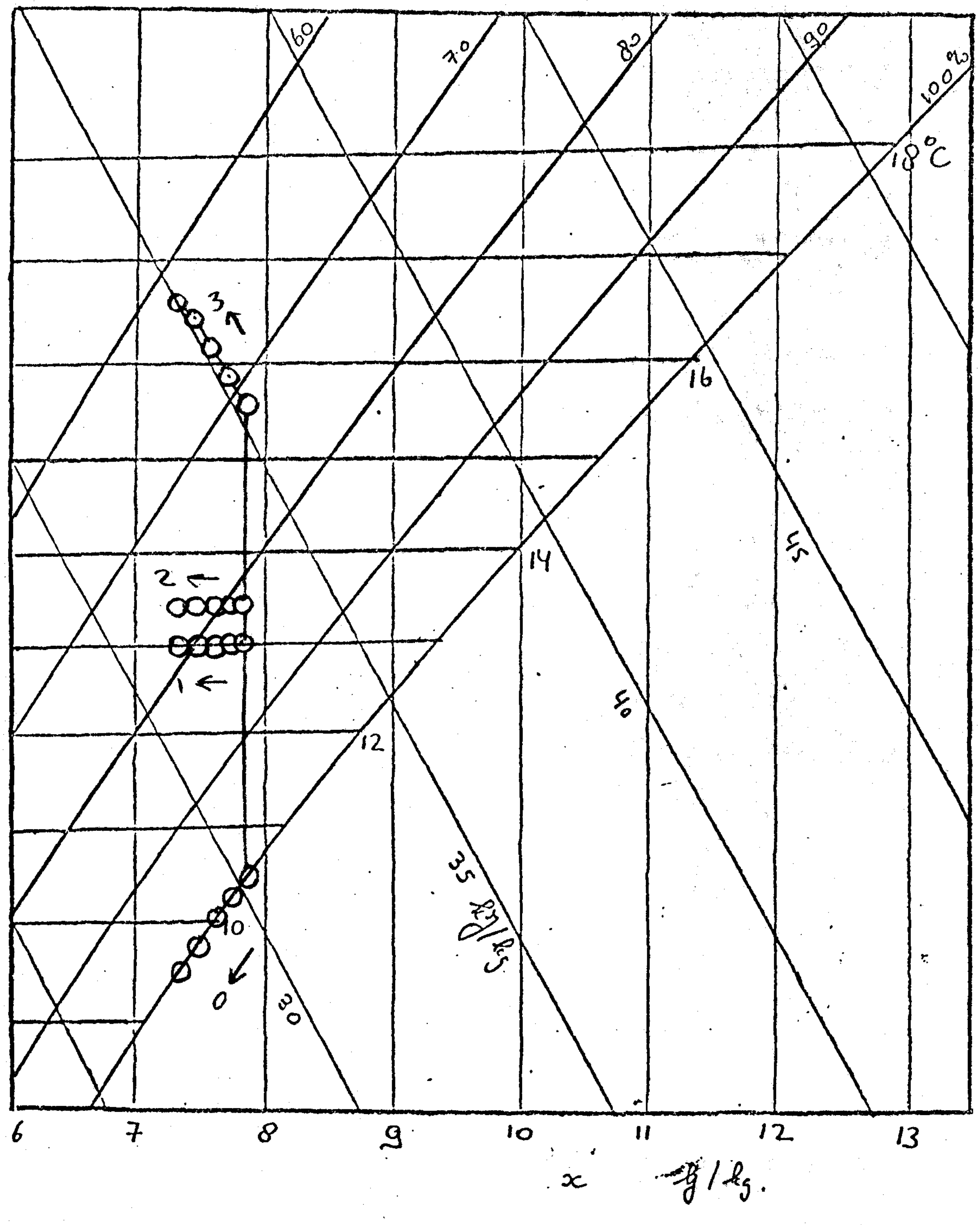
...lation Nr	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
16	0,4	0,01	500 625 750 875 1000	-	20	13

Fig. 36



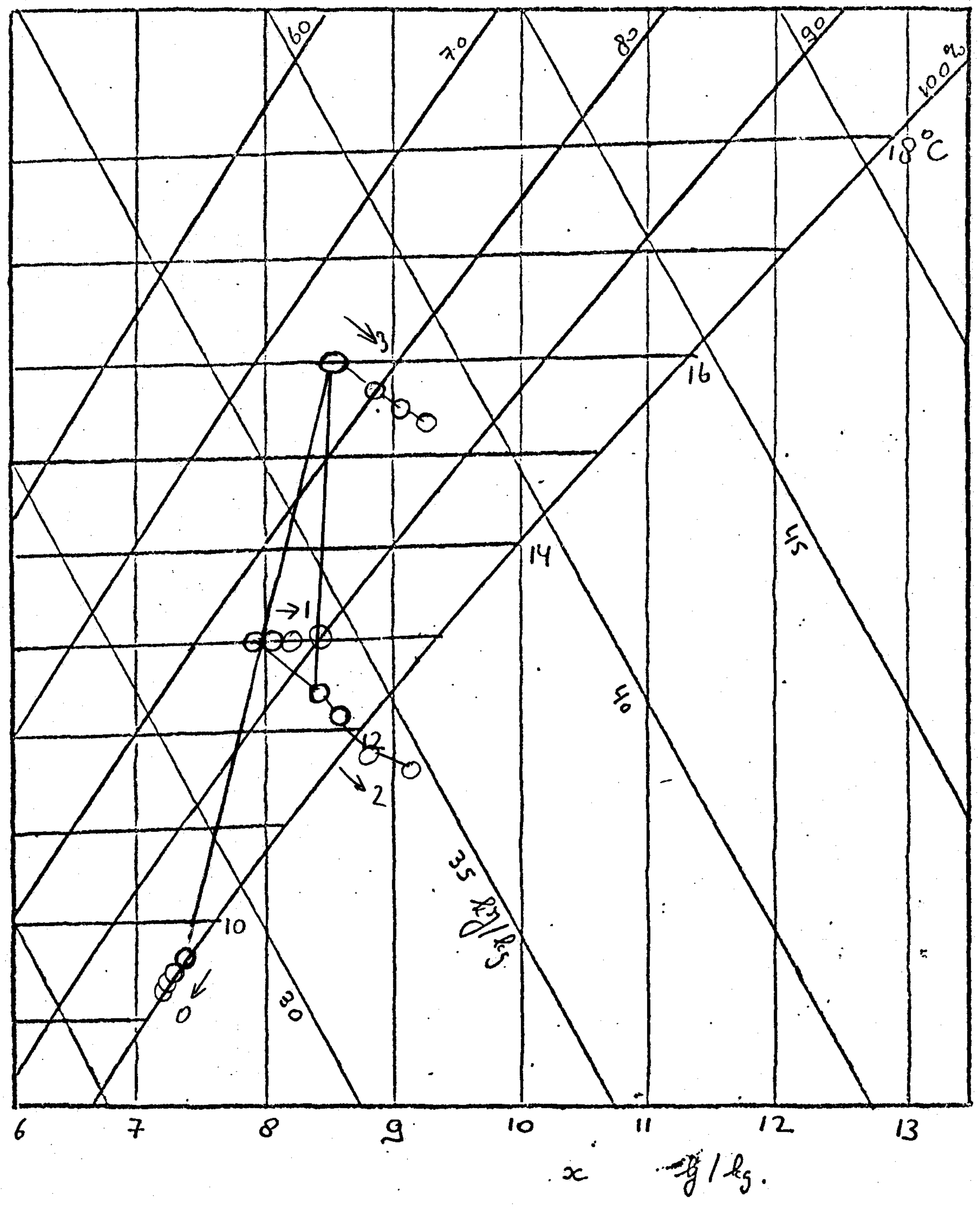
calculation Nº		circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
	*			500			
	*			625			
17	*	0,4	–	750	$3{,}17.10^{-4}$	20	13
				875			
				1000			

Fig. 37



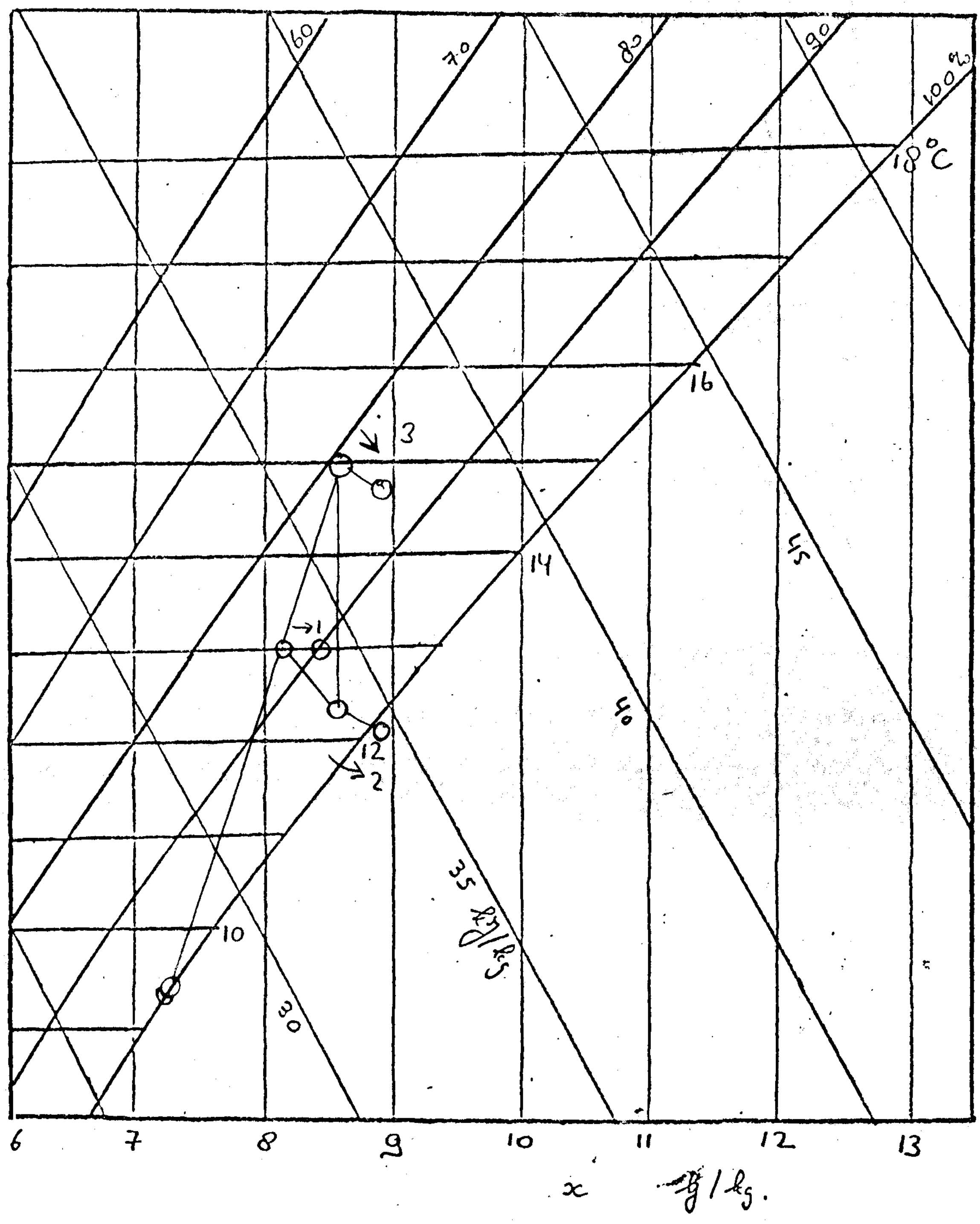
[illegible] nr	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	[illegible] [°C]
18	0,4	–	500 625 750 875 1000	–	20	13

Fig. 38



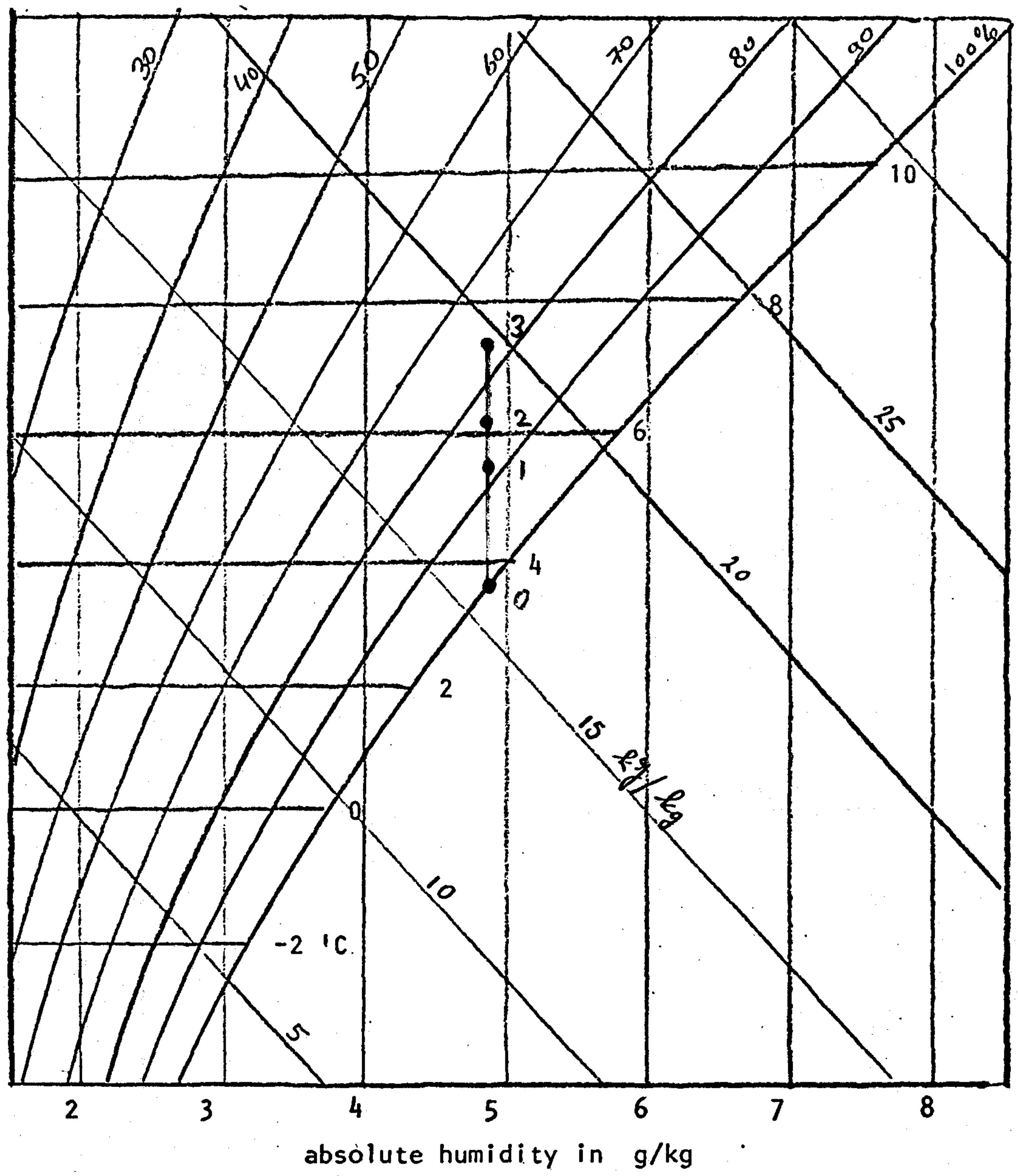
calculation Nº	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
19	0,4	0,01	750	$2,27.10^{-4}$	20	13
				$2,72.10^{-4}$		
				$3,17.10^{-4}$		
				$3,62.10^{-4}$		
*				$4,07.10^{-4}$		

Fig. 39



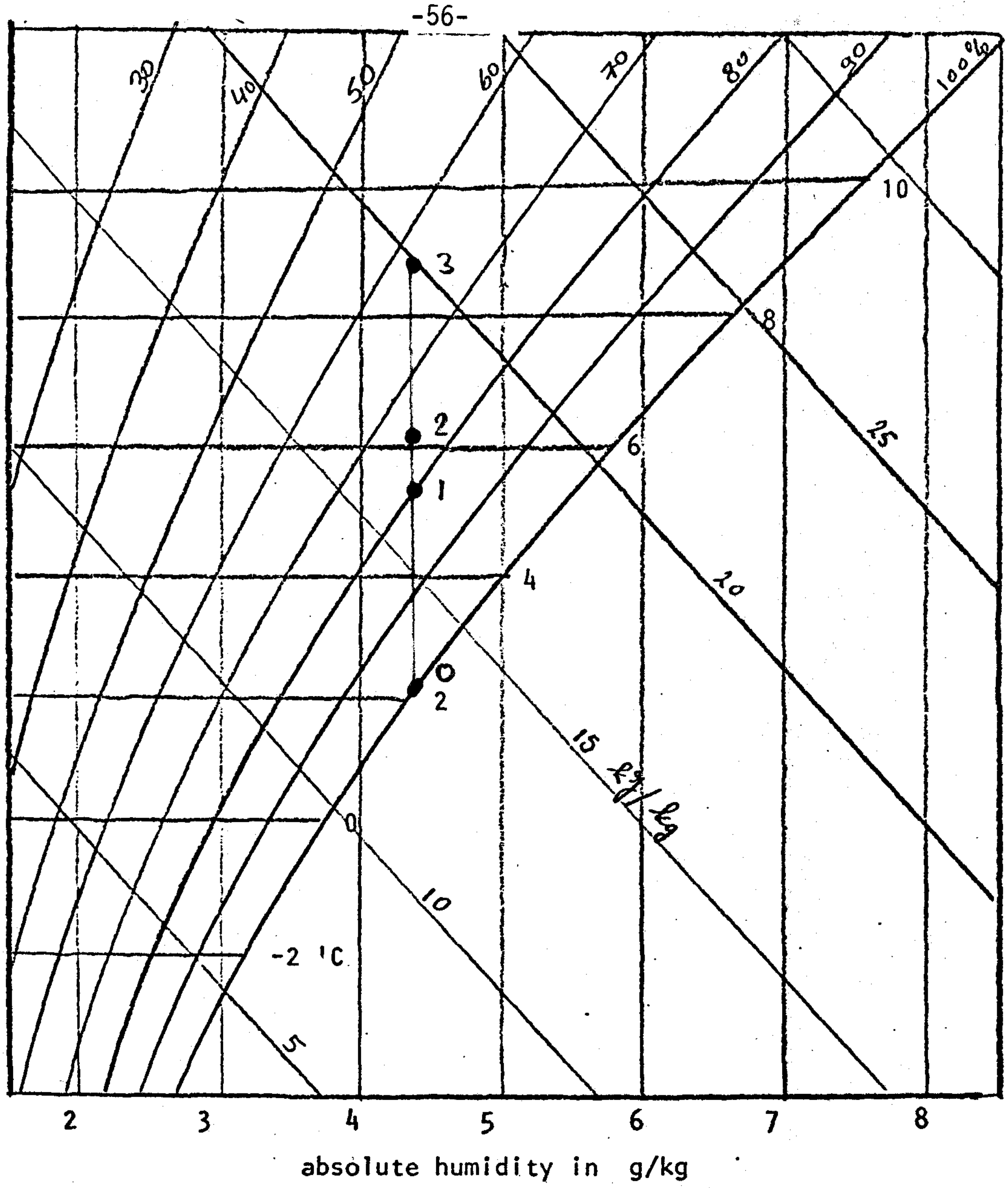
[illegible]	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
				$2{,}27.10^{-4}$		
				$2{,}72.10^{-4}$		
0 *	0,4	–	750	$3{,}17.10^{-4}$	20	13
*				$3{,}62.10^{-4}$		
*				$4{,}07.10^{-4}$		

Fig. 40



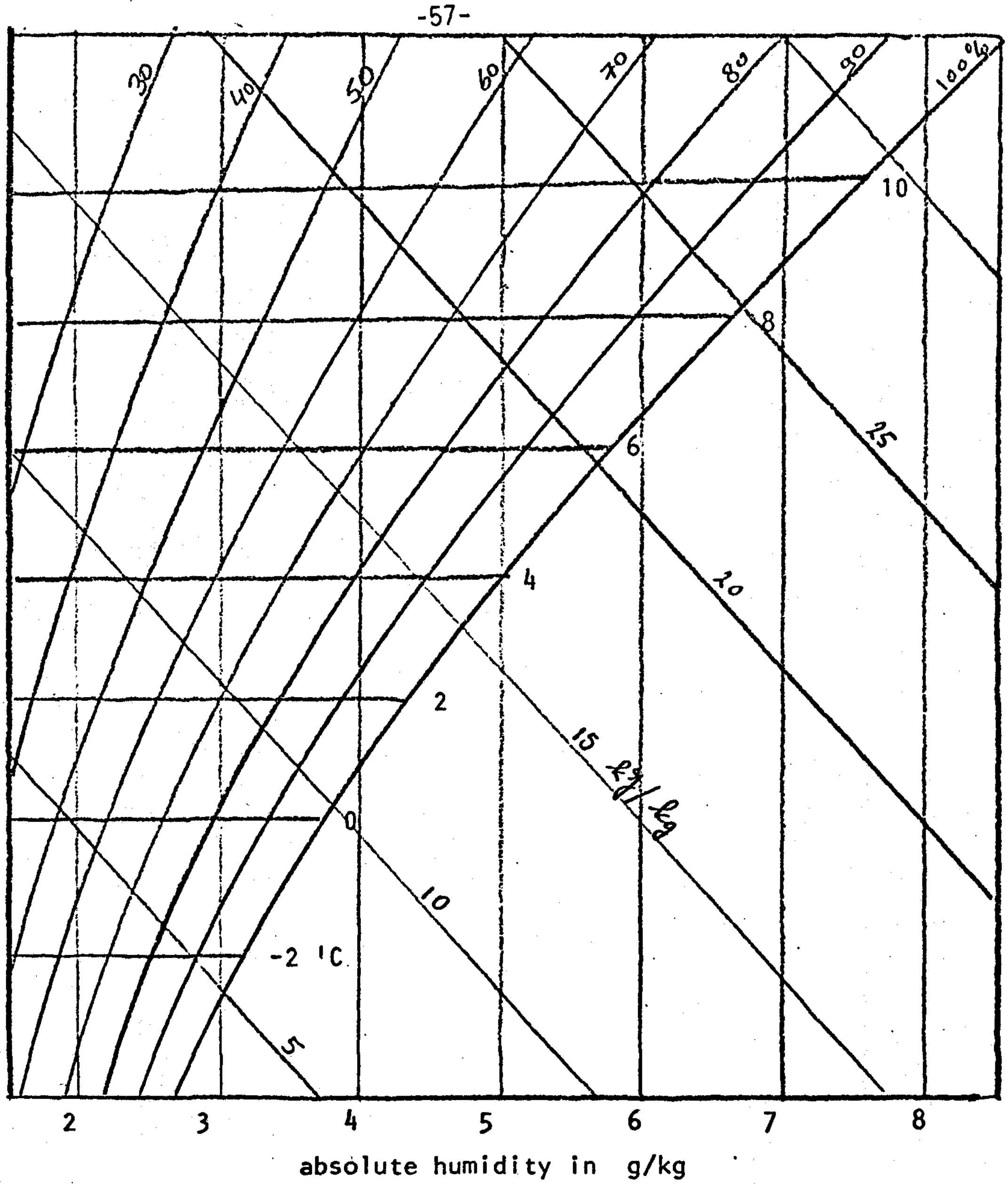
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
21	0,4	0	0	0	20	5,5

Fig. 41



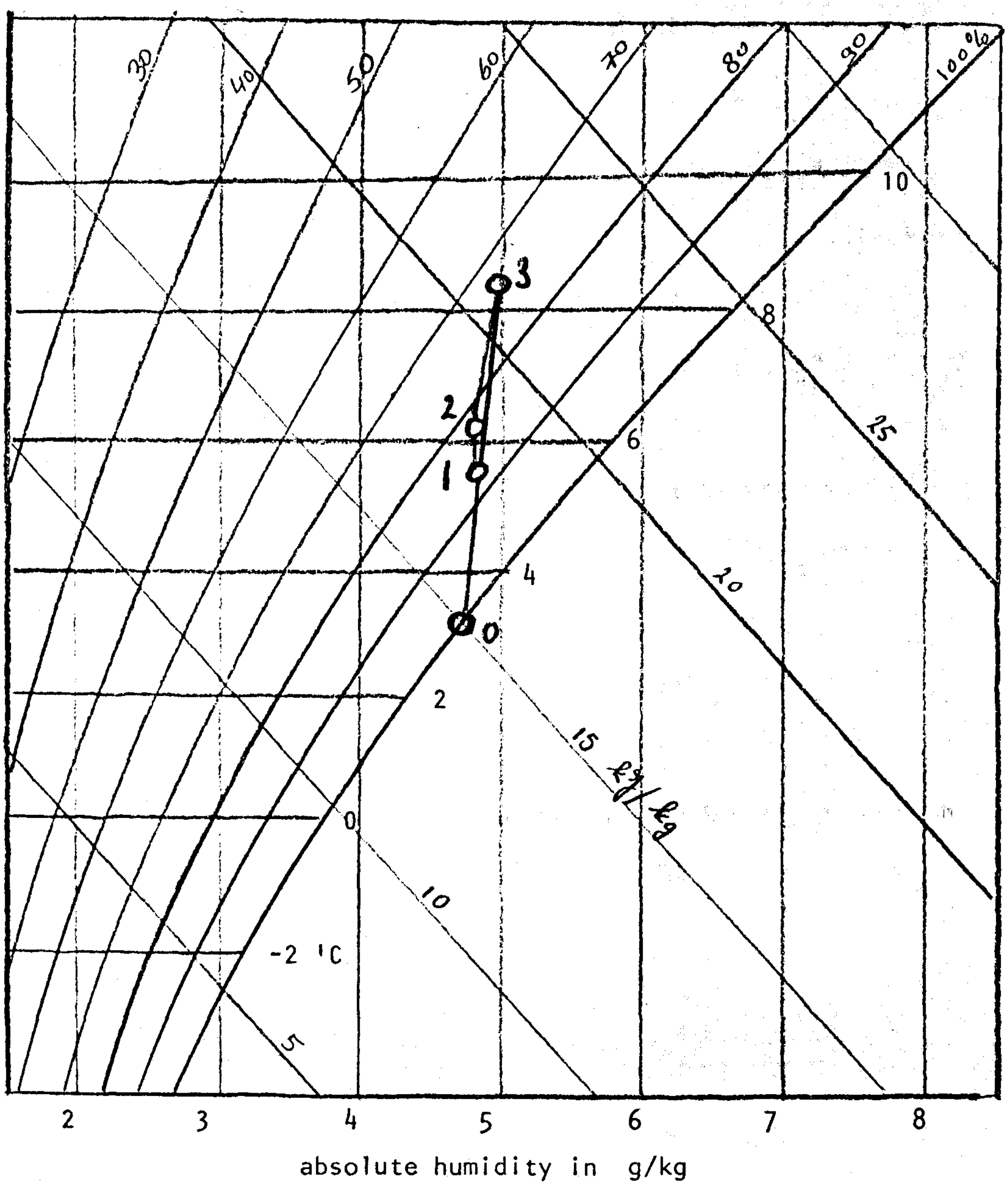
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
22	0,4	0	750	0	20	5,5

Fig. 42



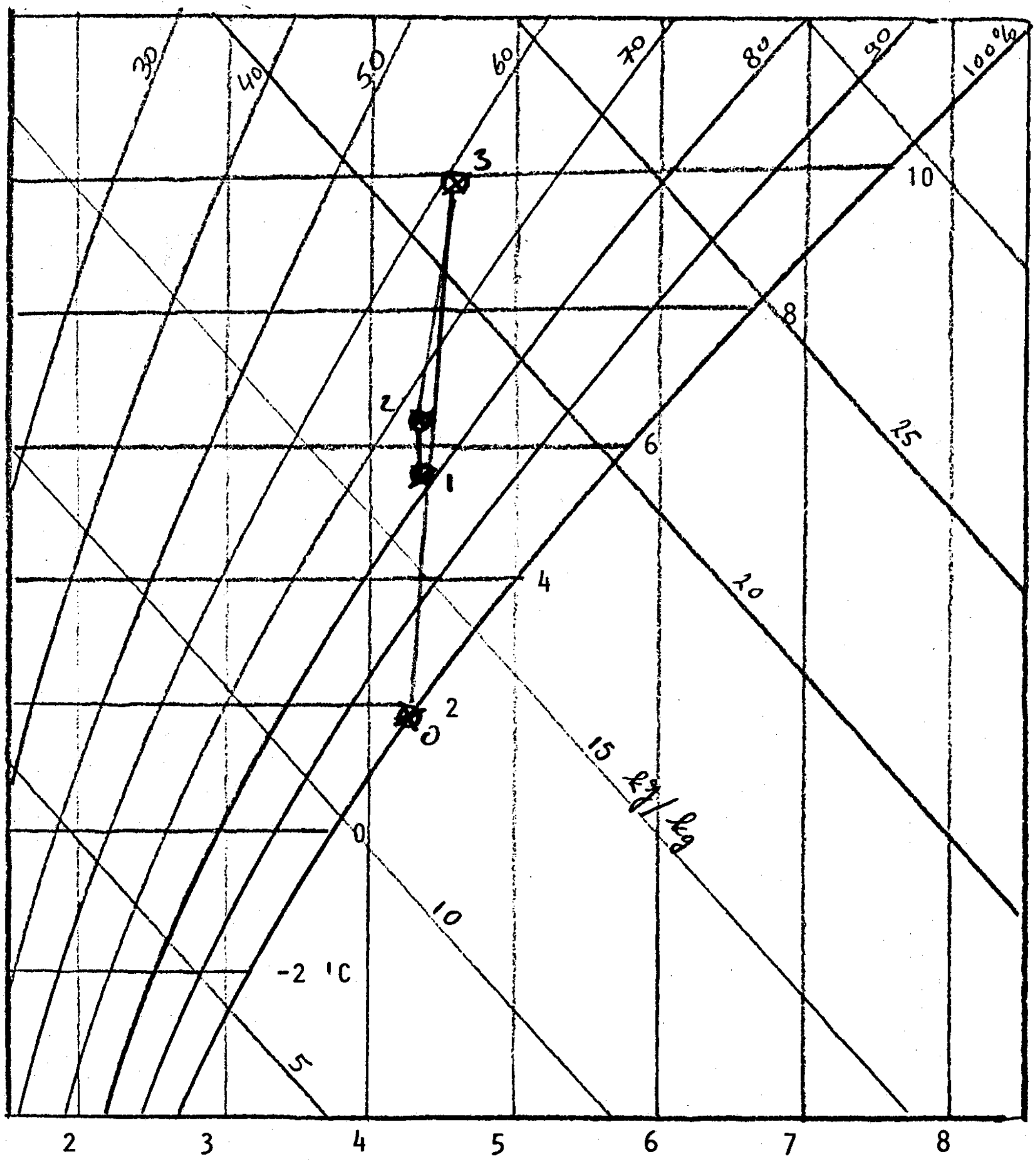
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
23 *	0,4	0	0	$3{,}17 \cdot 10^{-4}$	20	5,5

Fig. 43



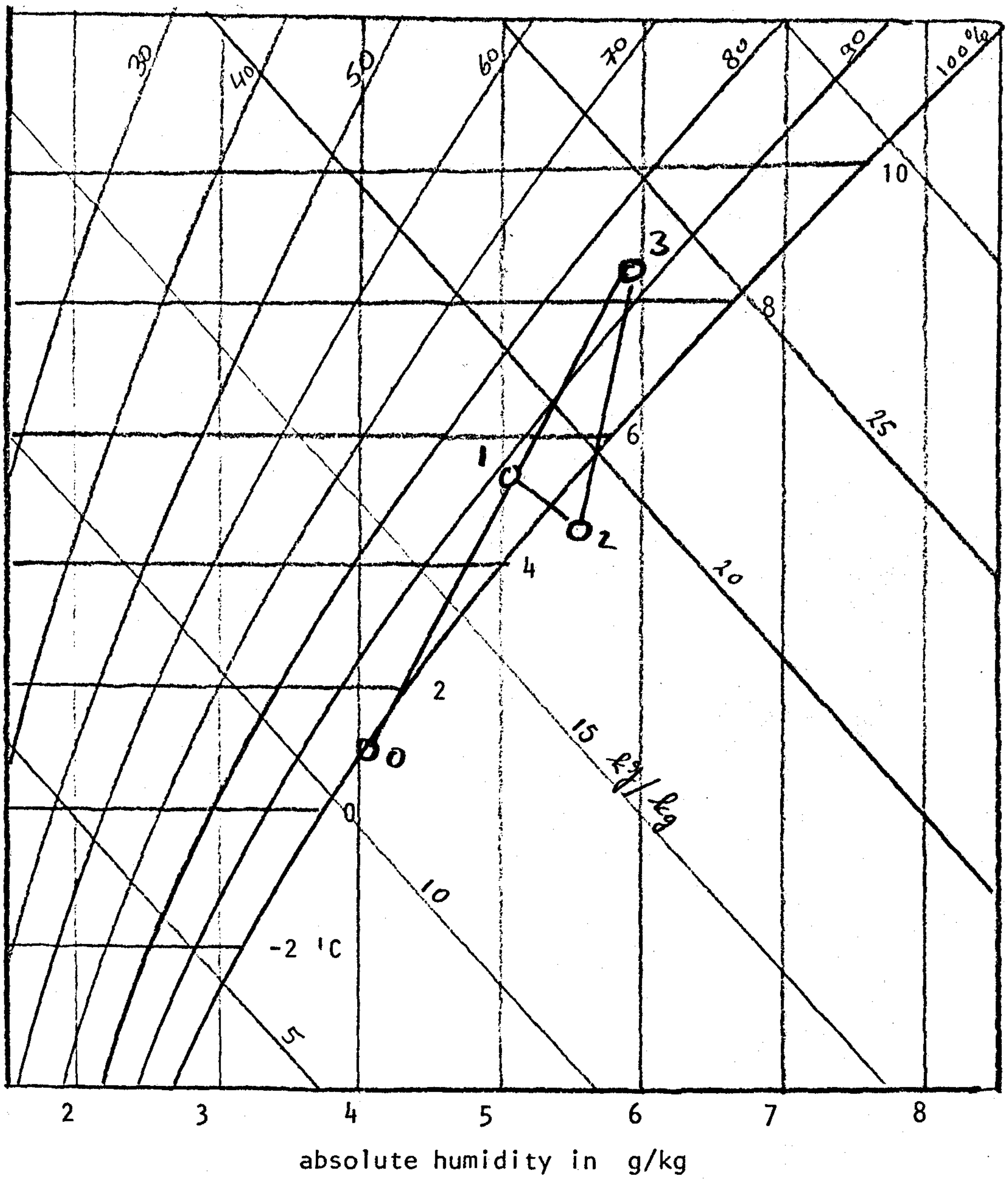
:ulation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
24	0,4	0,01	0	0	20	5,5

Fig. 44



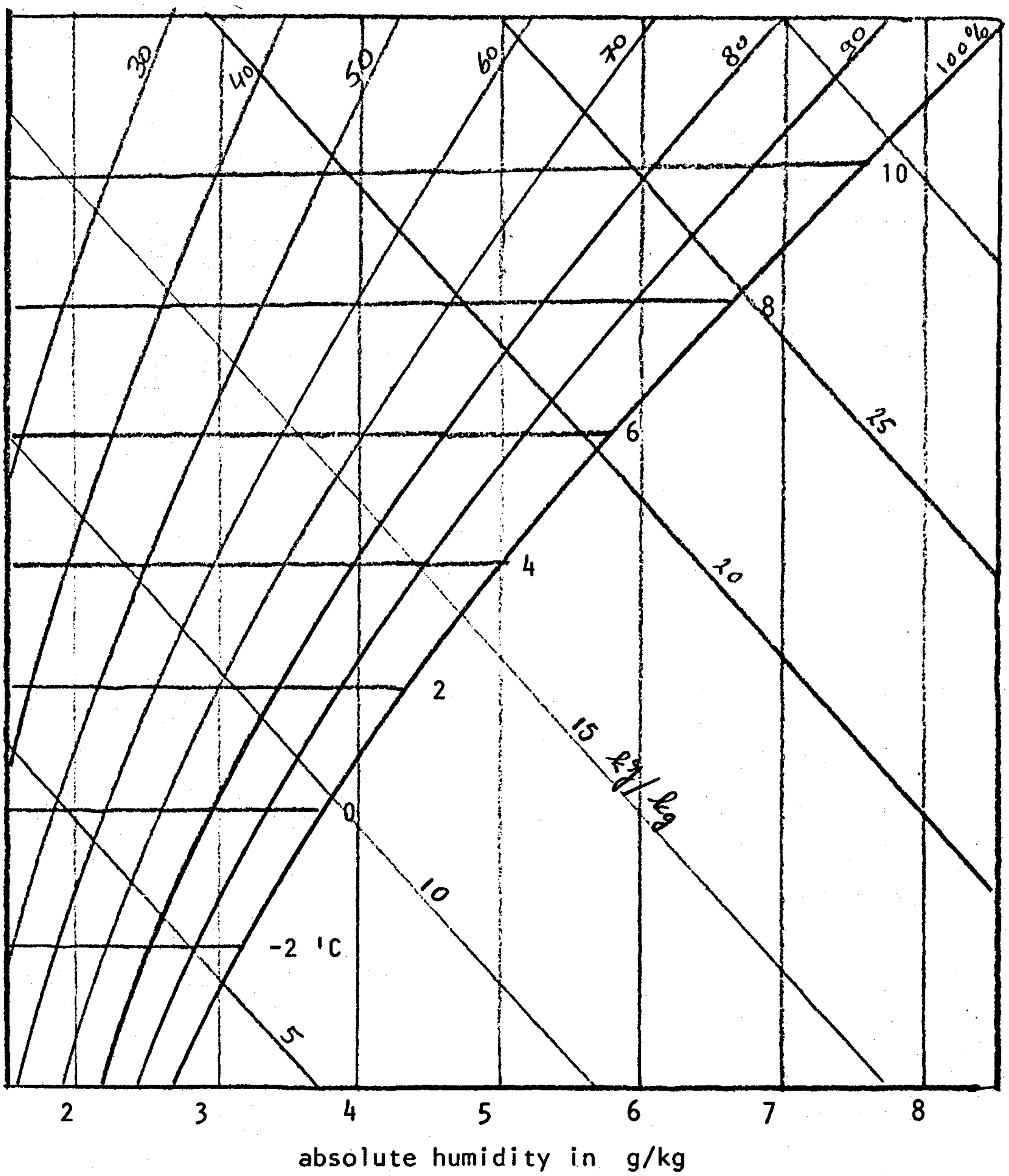
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
25	0,4	0,01	750	0	20	5,5

Fig. 45



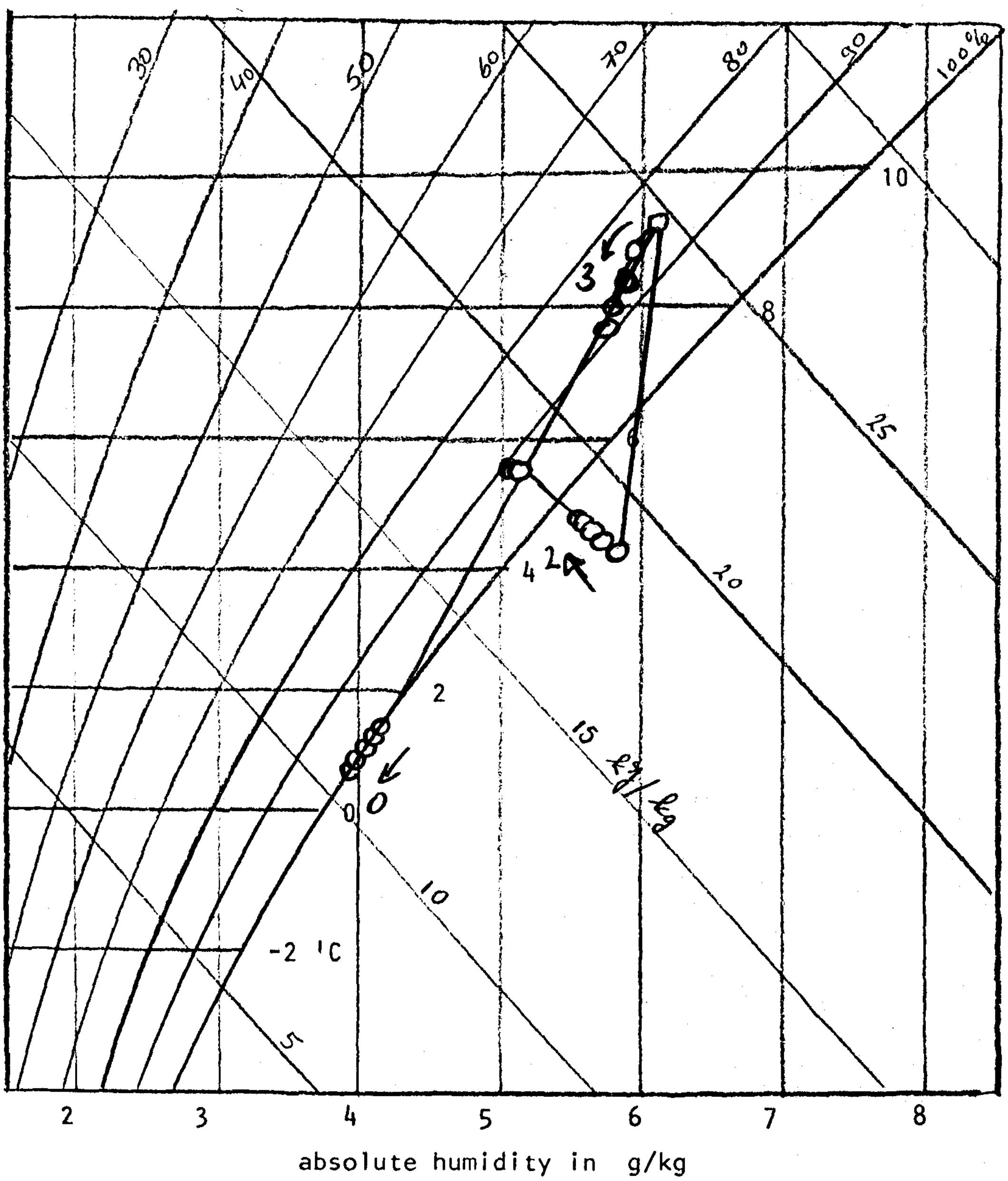
lation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
26	0,4	0,01	750	$3{,}17 \cdot 10^{-4}$	20	5,5

Fig. 46



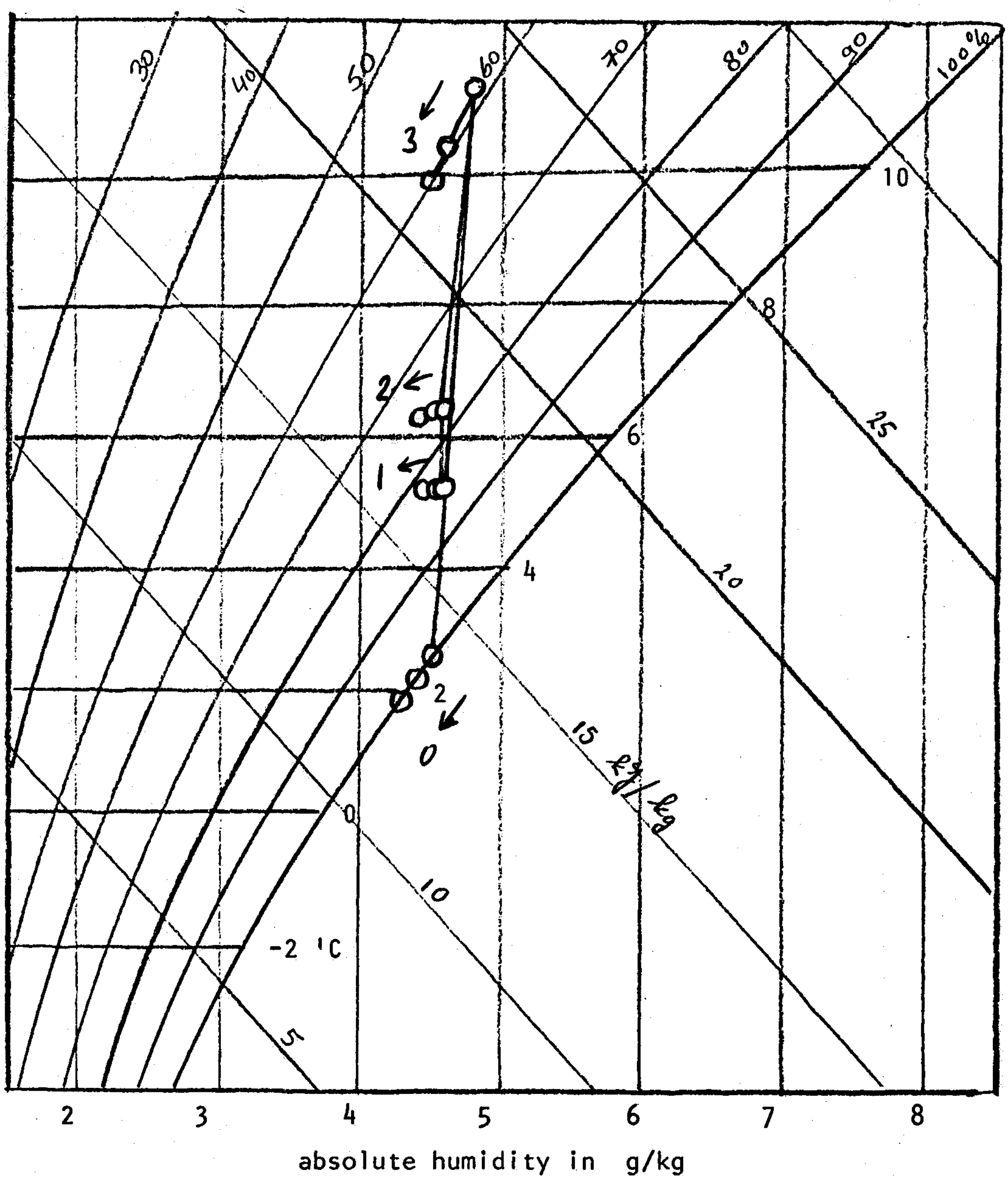
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
28 *	0,4	0,01	0	$3,17.10^{-4}$	20	5,5

Fig. 47



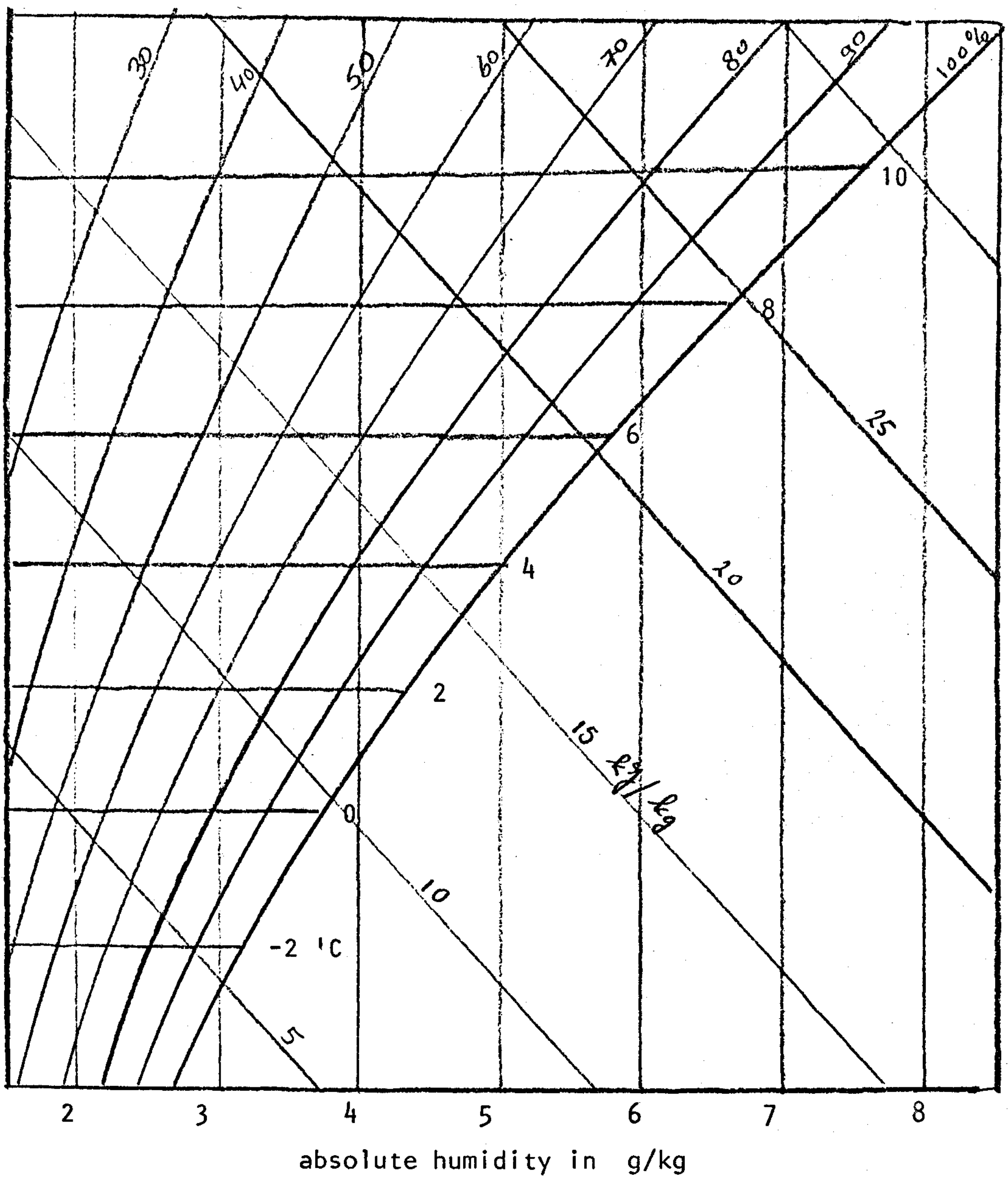
ulation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
	0,3					
	0,35					
)	0,4	0,01	750	$3{,}17.10^{-4}$	20	5,5
	0,45					
	0,5					

Fig. 48



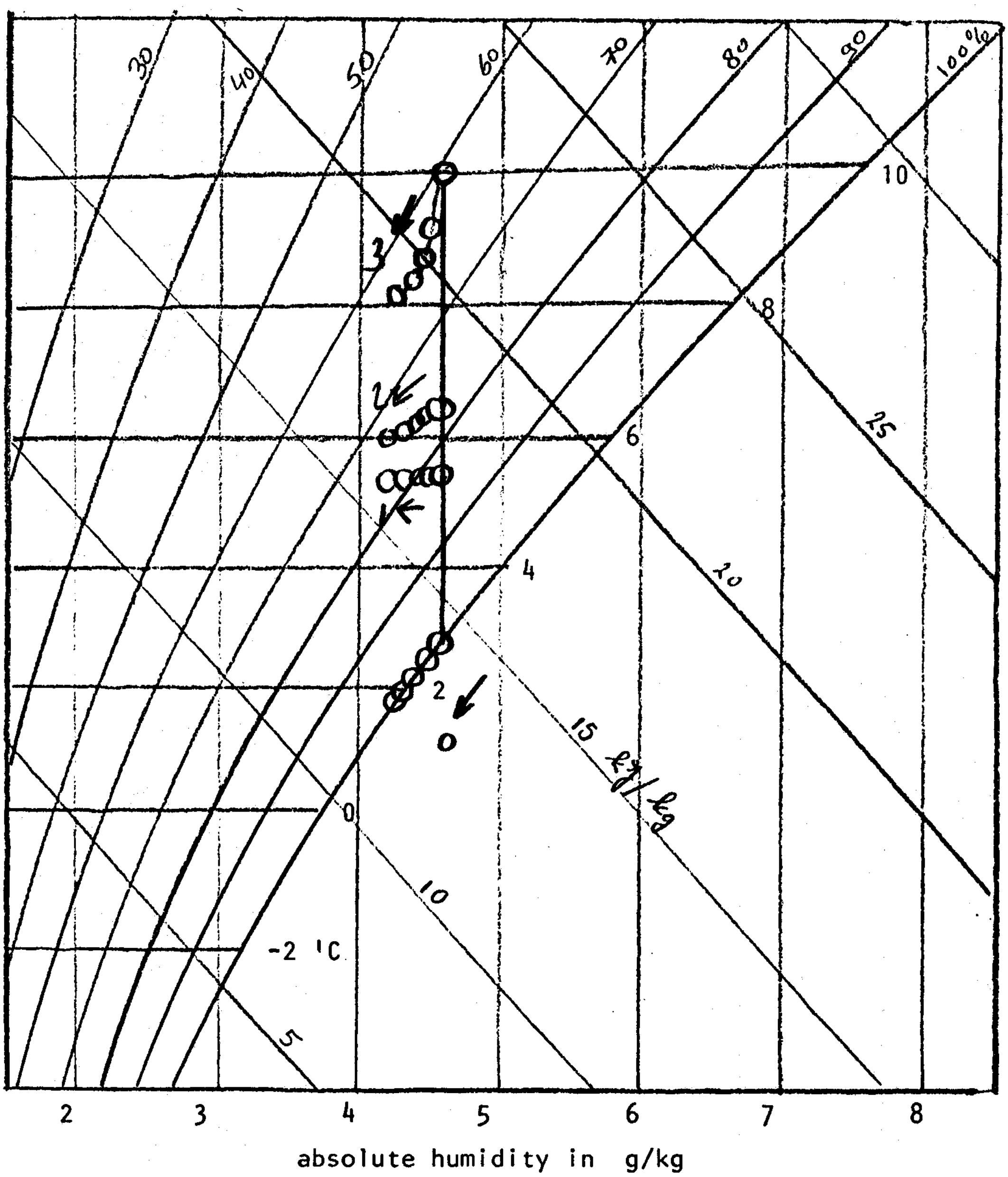
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
	0,3					
	0,35					
30	0,4	0,01	750	-	20	5,5
	0,45					
	0,5					

Fig. 49



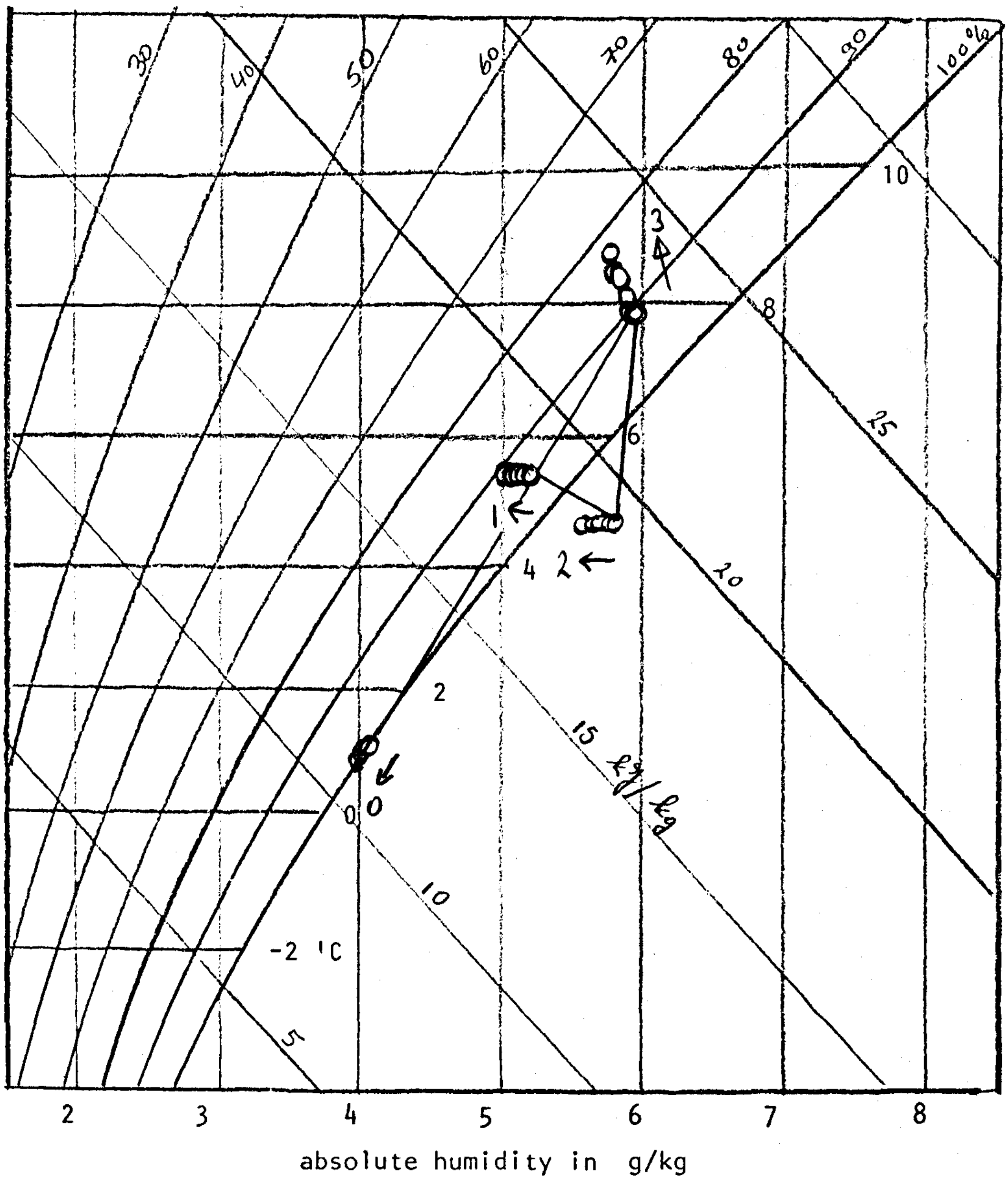
ulation nr		circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
	*	0,3					
	*	0,35					
31	*	0,4	-	750	$3{,}17.10^{-4}$	20	5,5
	*	0,45					
	*	0,5					

Fig. 50



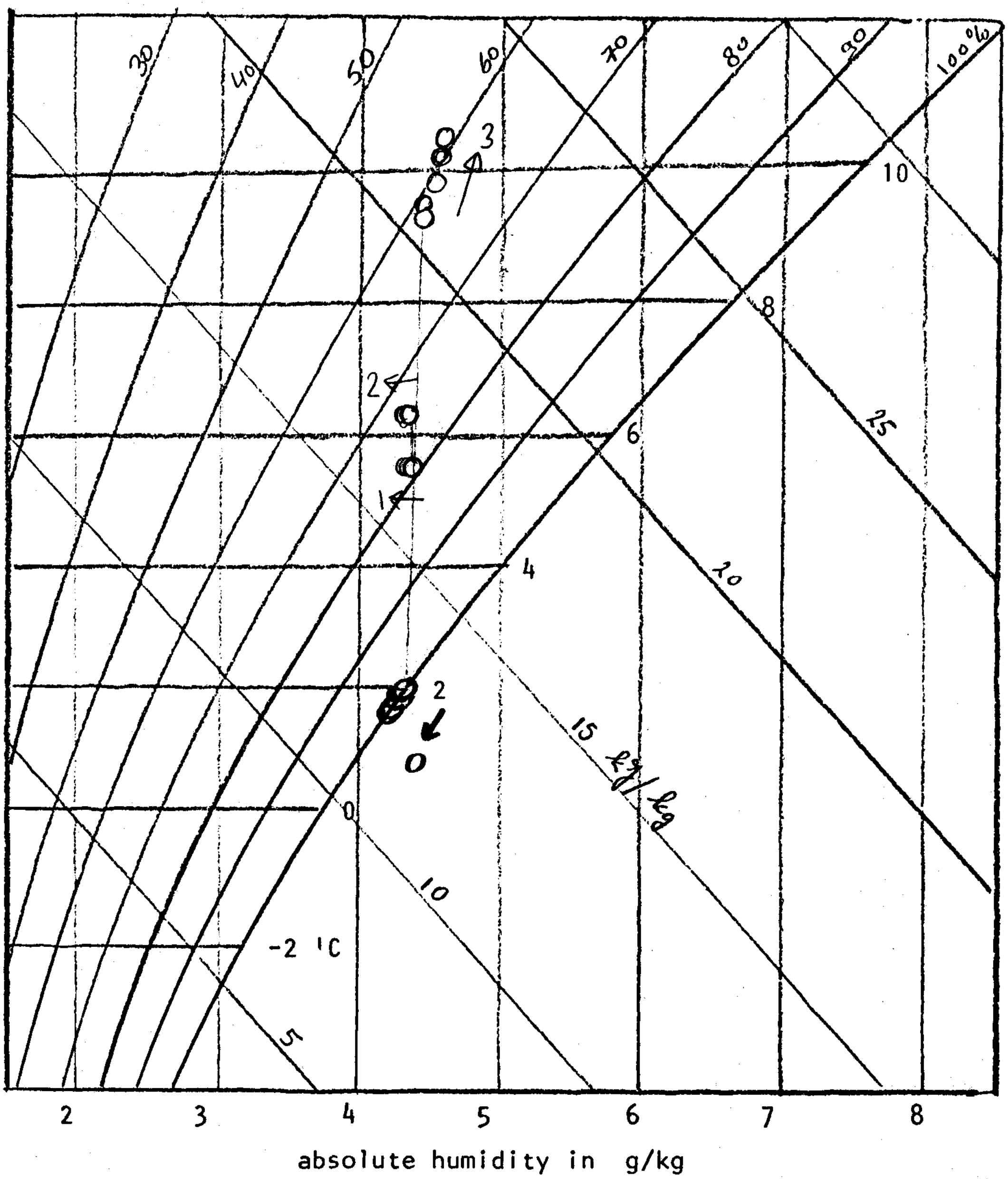
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
32	0,3	-	750	-	20	5,5
	0,35					
	0,4					
	0,45					
	0,5					

Fig. 51



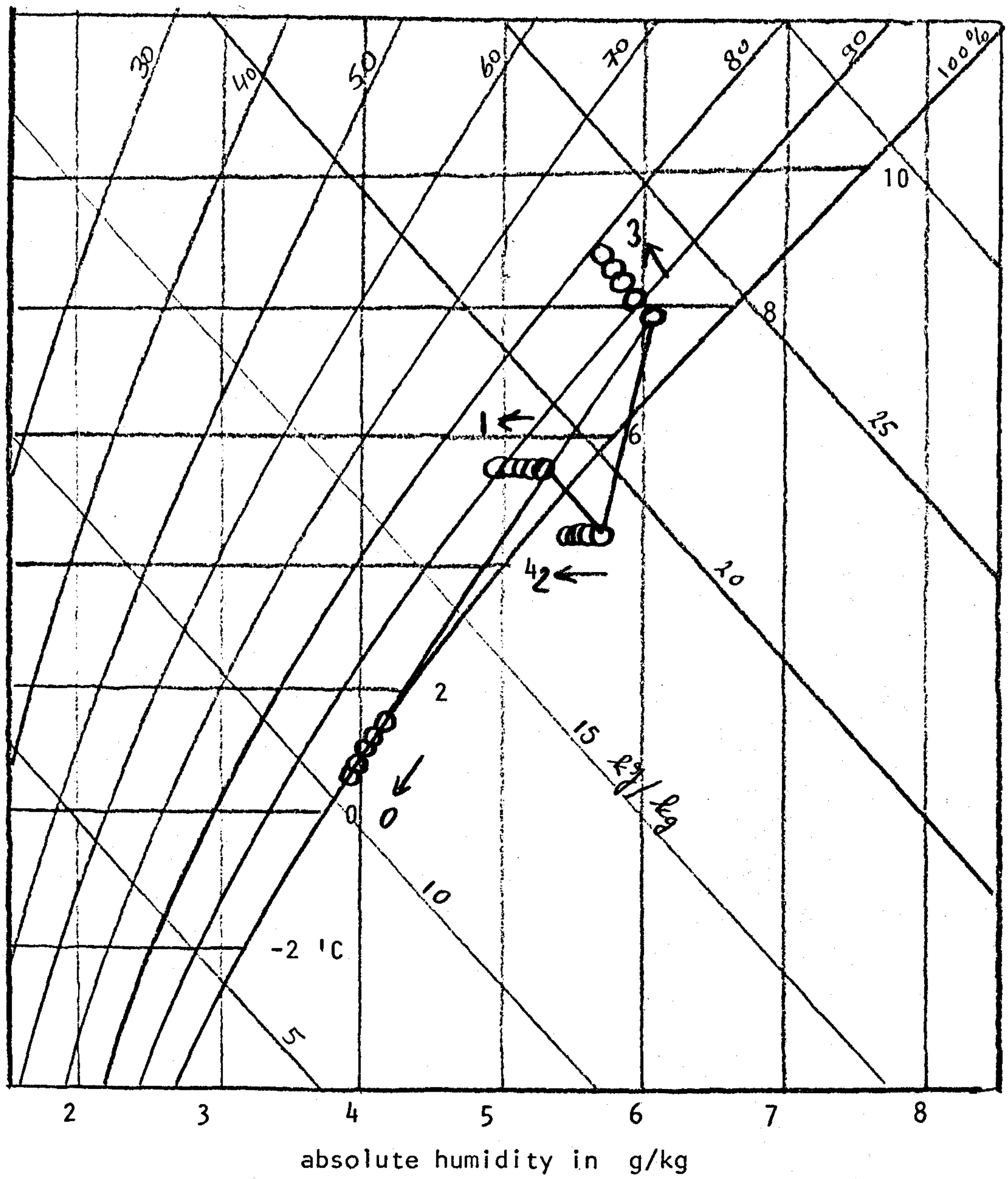
ulation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
		0,005				
		0,0075				
33	0,4	0,01	750	$3{,}17.10^{-4}$	20	5,5
		0,0125				
		0,015				

Fig. 52



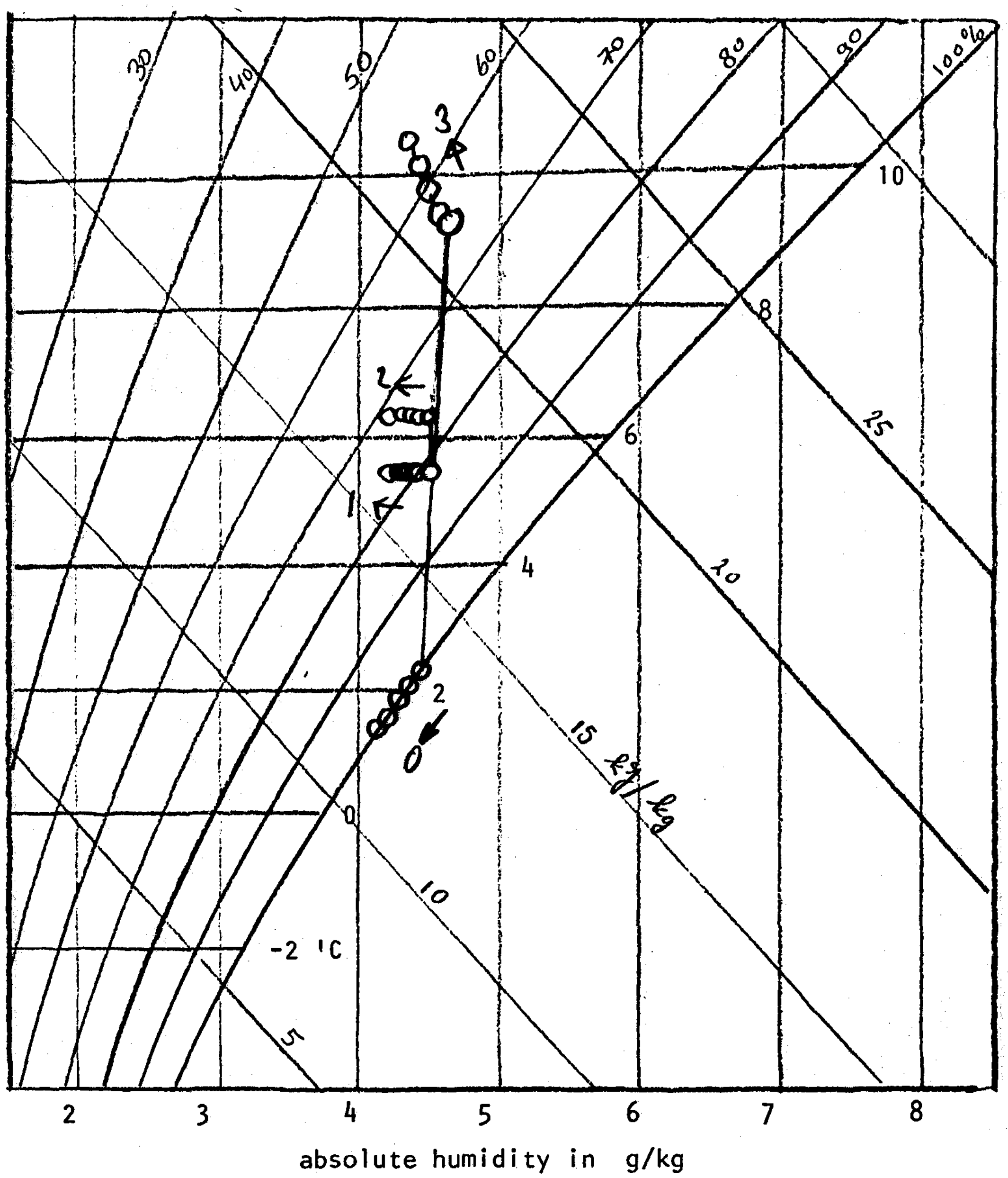
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
		0,005				
		0,0075				
34	0,4	0,01	750	-	20	5,5
		0,0125				
		0,015				

Fig. 53



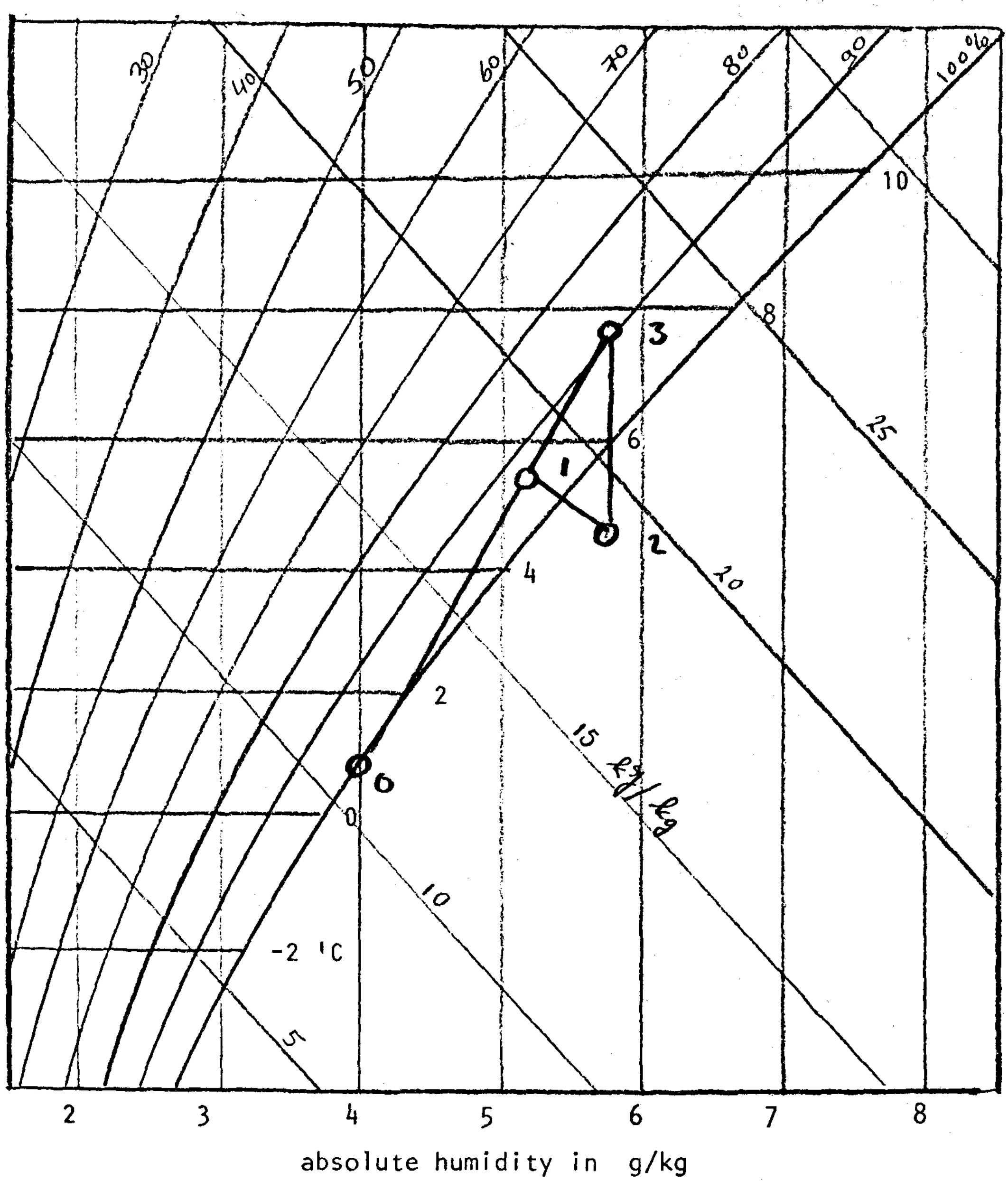
ulation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
			500			
			625			
35	0,4	0,01	750	$3{,}17.10^{-4}$	20	5,5
			875			
			1000			

Fig. 54



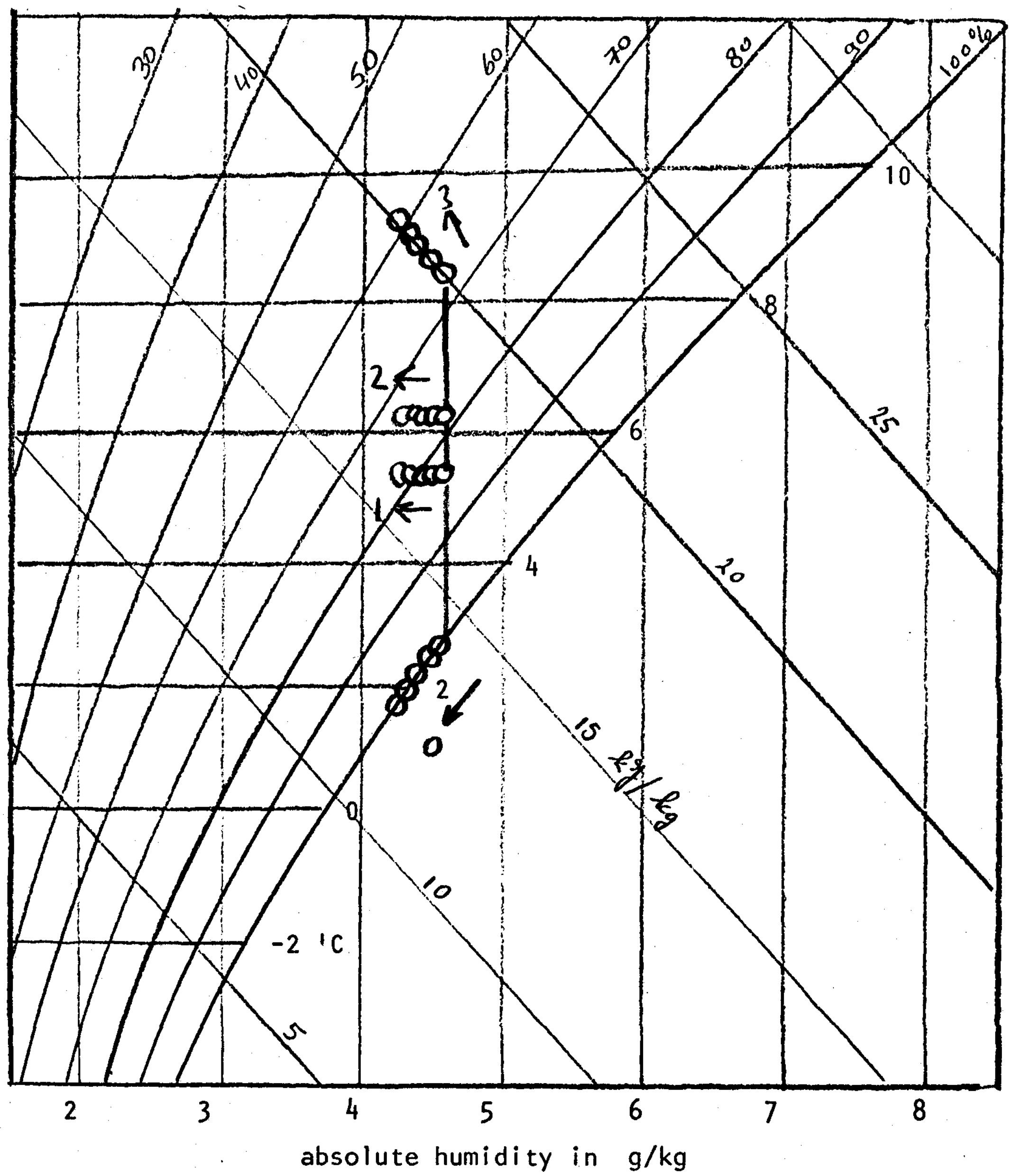
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
36	0,4	0,01	500 625 750 875 1000	-	20	5,5

Fig. 55



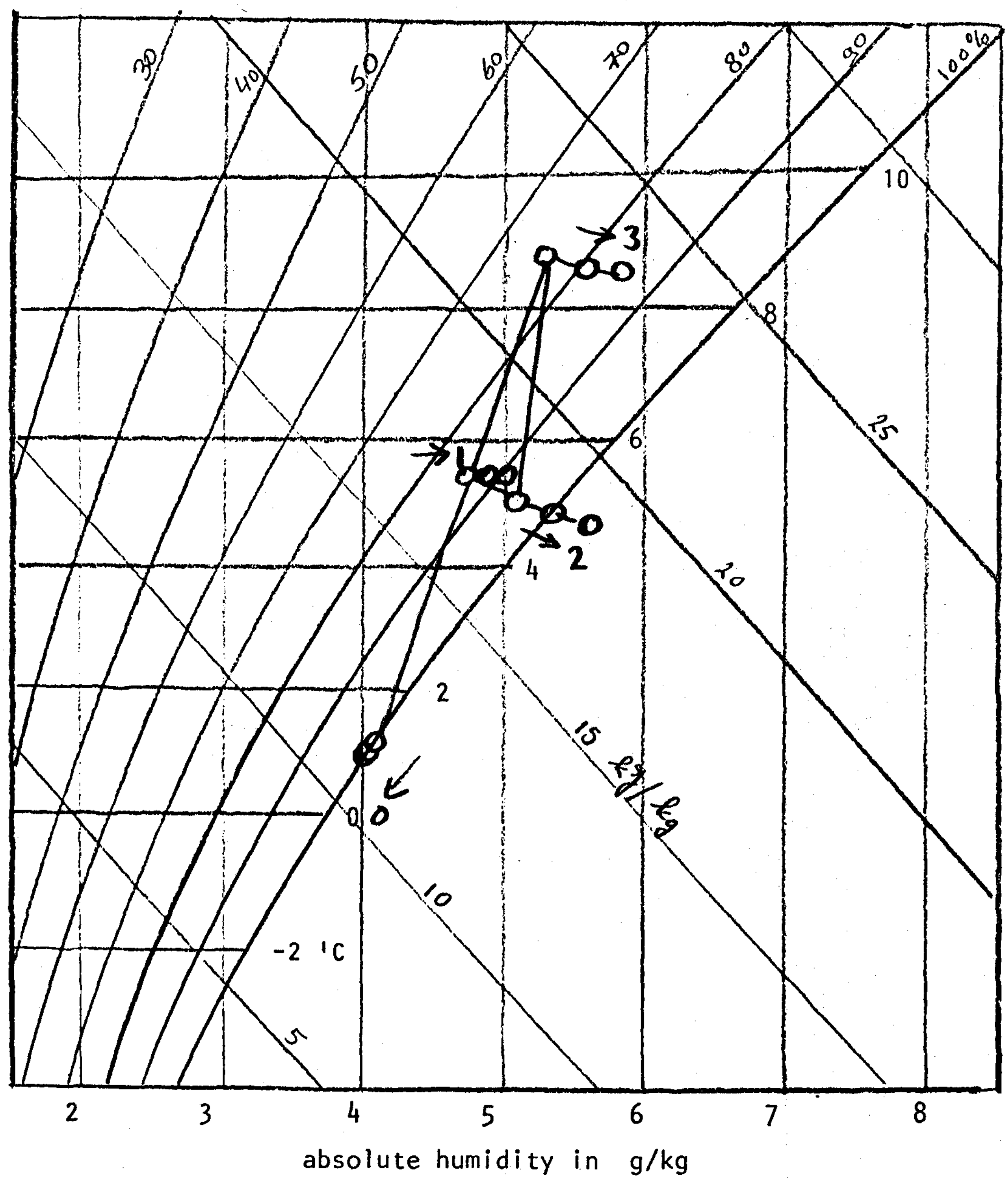
ılation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
*			500			
*			625			
7 *	0,4	-	750	$3,17.10^{-4}$	20	5,5
*			875			
			1000			

Fig. 56



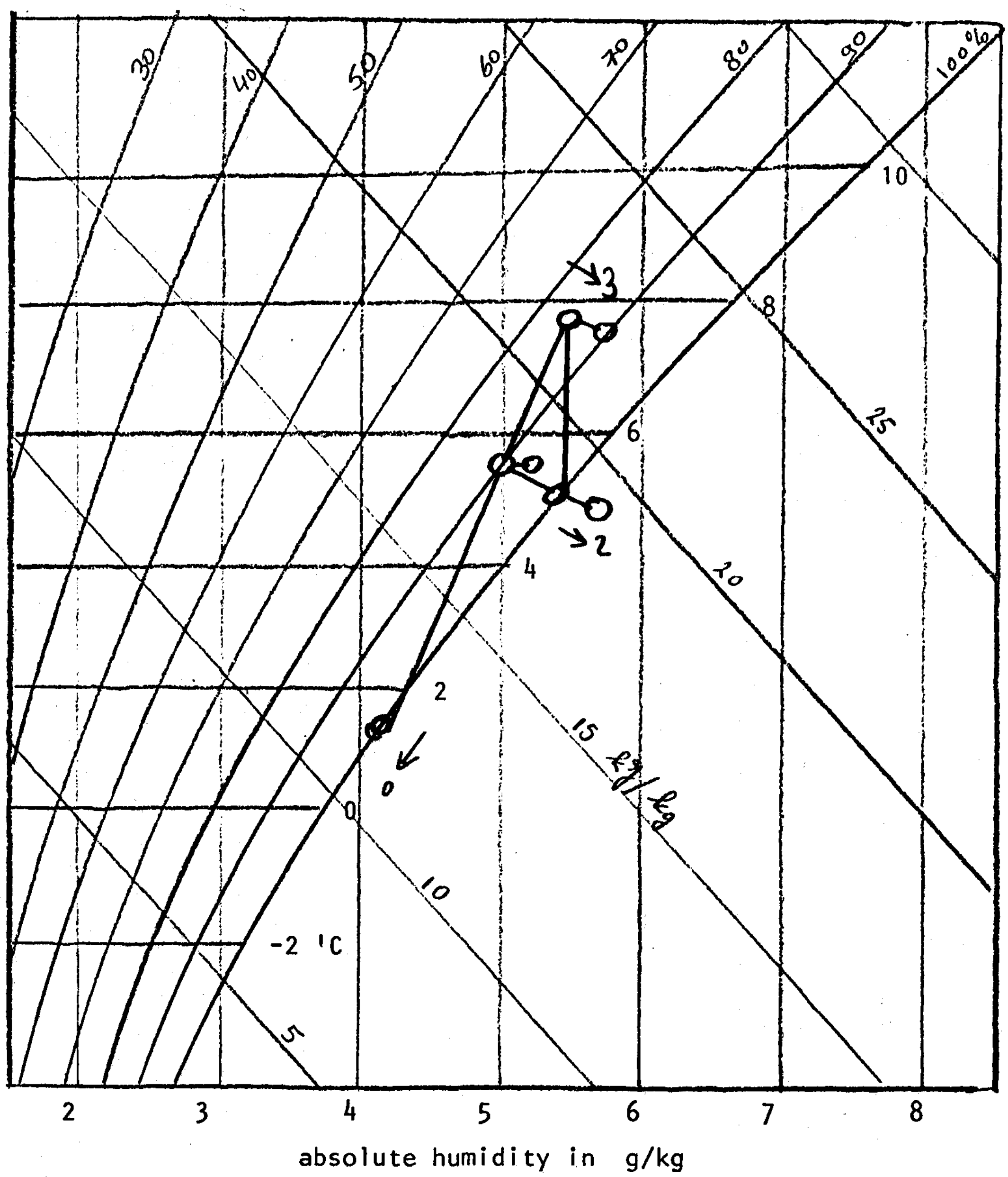
calculation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
38	0,4	-	500 625 750 875 1000	-	20	5,5

fig. 57



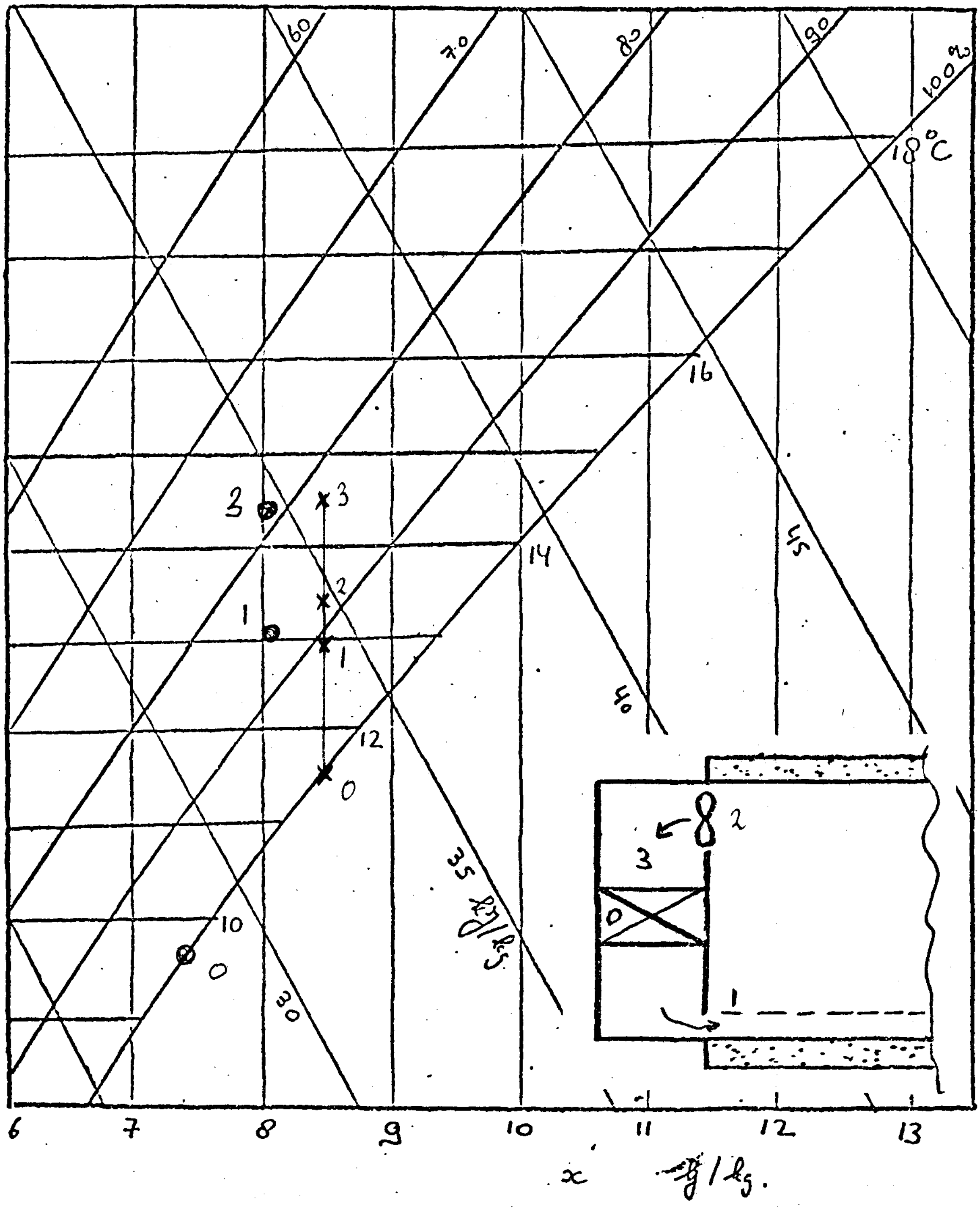
ılation nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
9	0,4	0,01	750	$2{,}27.10^{-4}$	20	5,5
				$2{,}72.10^{-4}$		
				$3{,}17.10^{-4}$		
x				$3{,}62.10^{-4}$		
x				$4{,}07.10^{-4}$		

fig. 58



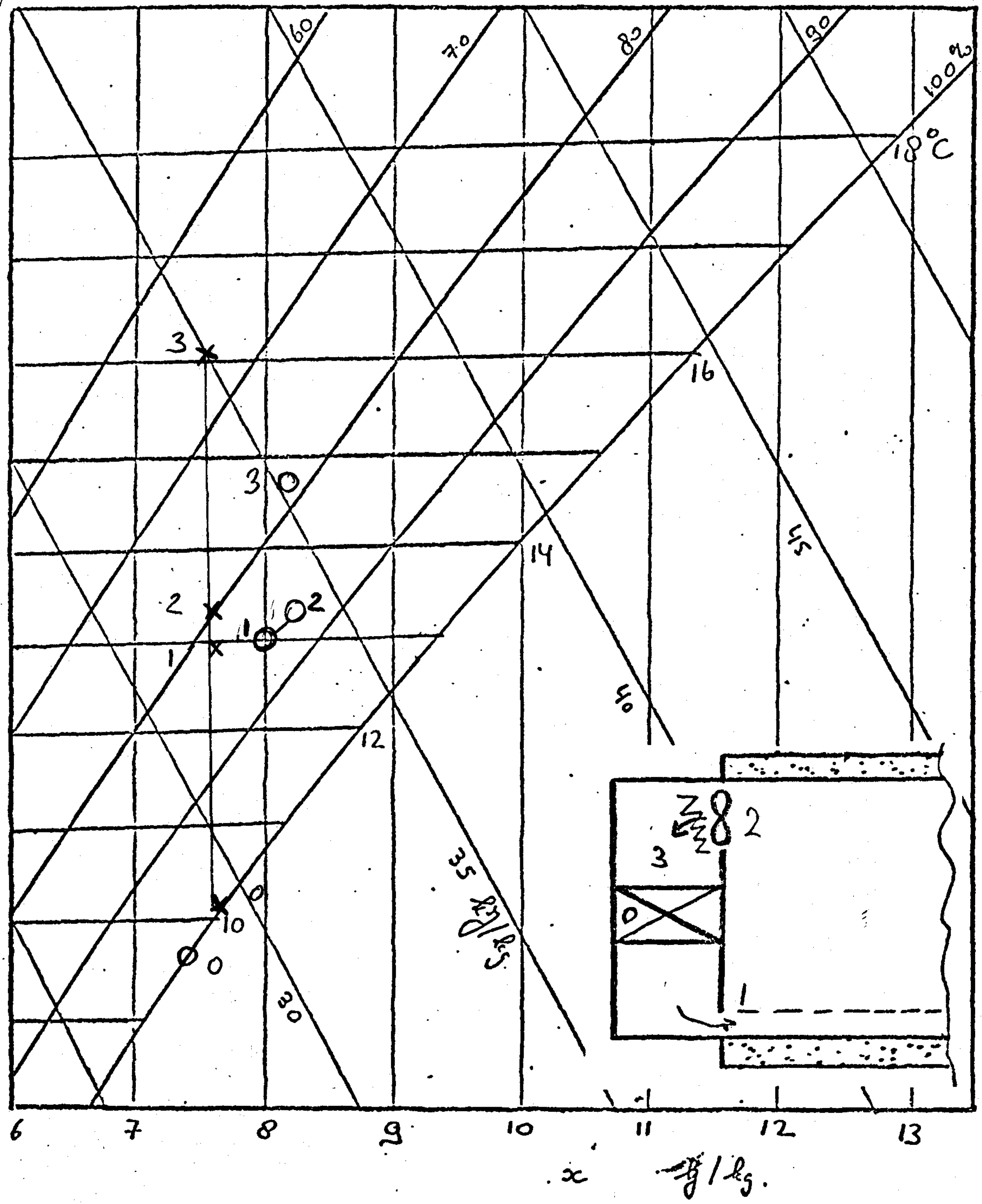
calculation nr		circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
40		0,4	-	750	$2,27.10^{-4}$	20	5,5
					$2,72.10^{-4}$		
	*				$3,17.10^{-4}$		
	*				$3,62.10^{-4}$		
	*				$4,07.10^{-4}$		

fig. 59



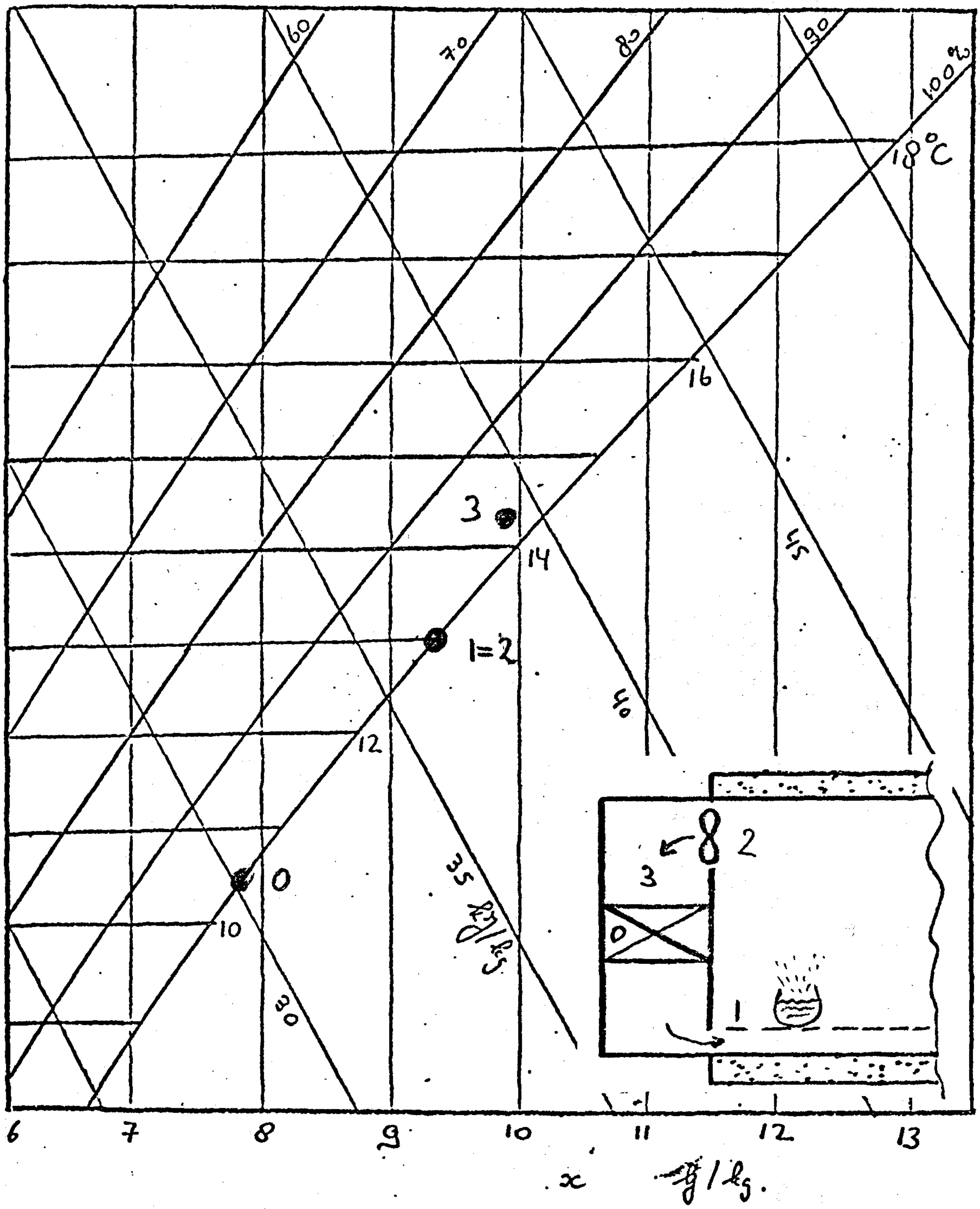
...ment ?	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
/ O	0,4	0	0	0	20	13
...iation 1 X	0,4	0	0	0	20	13

fig 60 Condition of air in the stationairy phase



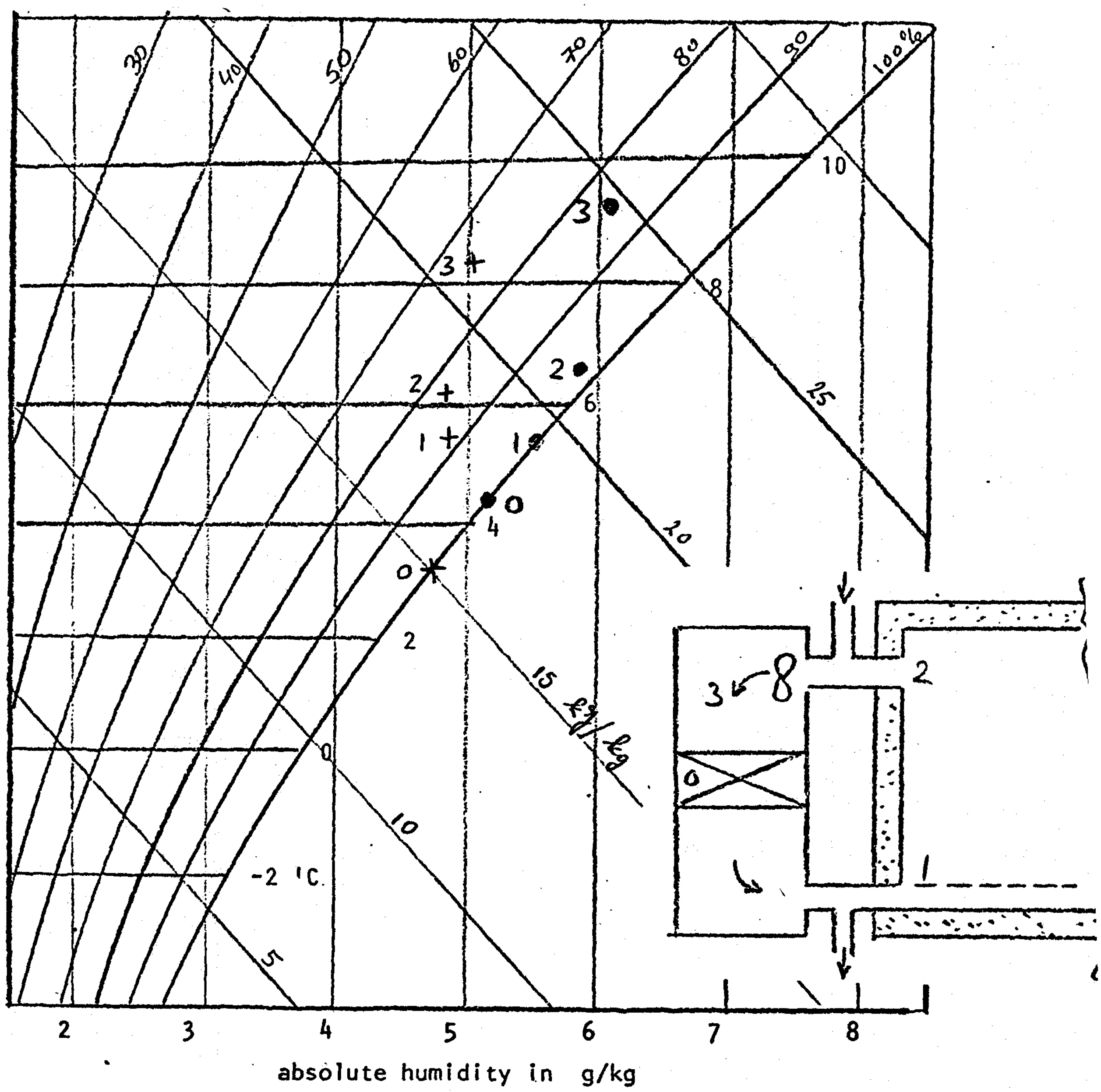
experiment Nº	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
5 0	0,4	0	750	0	26	13,3
calculation 2	0,4	0	750	0	20	13

fig 61 Condition of air in the stationairy phase



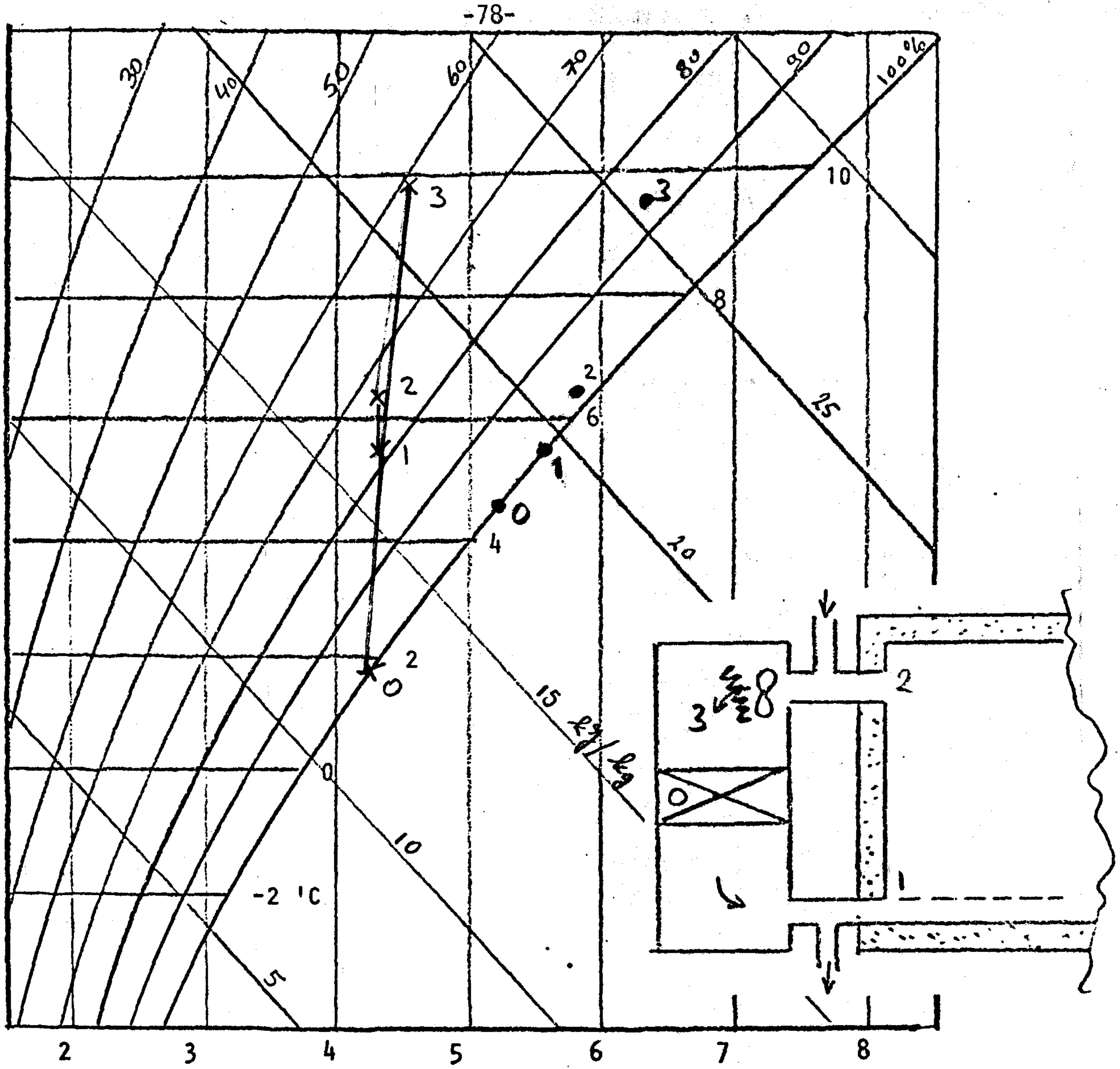
eriment №	circulation [m³/s]	ventilation [m³/s]	heating [W]	water [kg/s]	t_4 [°C]	t_1 [°C]
6	0,4	0	0	$3,17 \cdot 10^{-4}$	19	13,0
ulation 3 *	0,4	0	0	$3,17 \cdot 10^{-4}$	20	13

fig 62 Condition of air in the stationairy phase



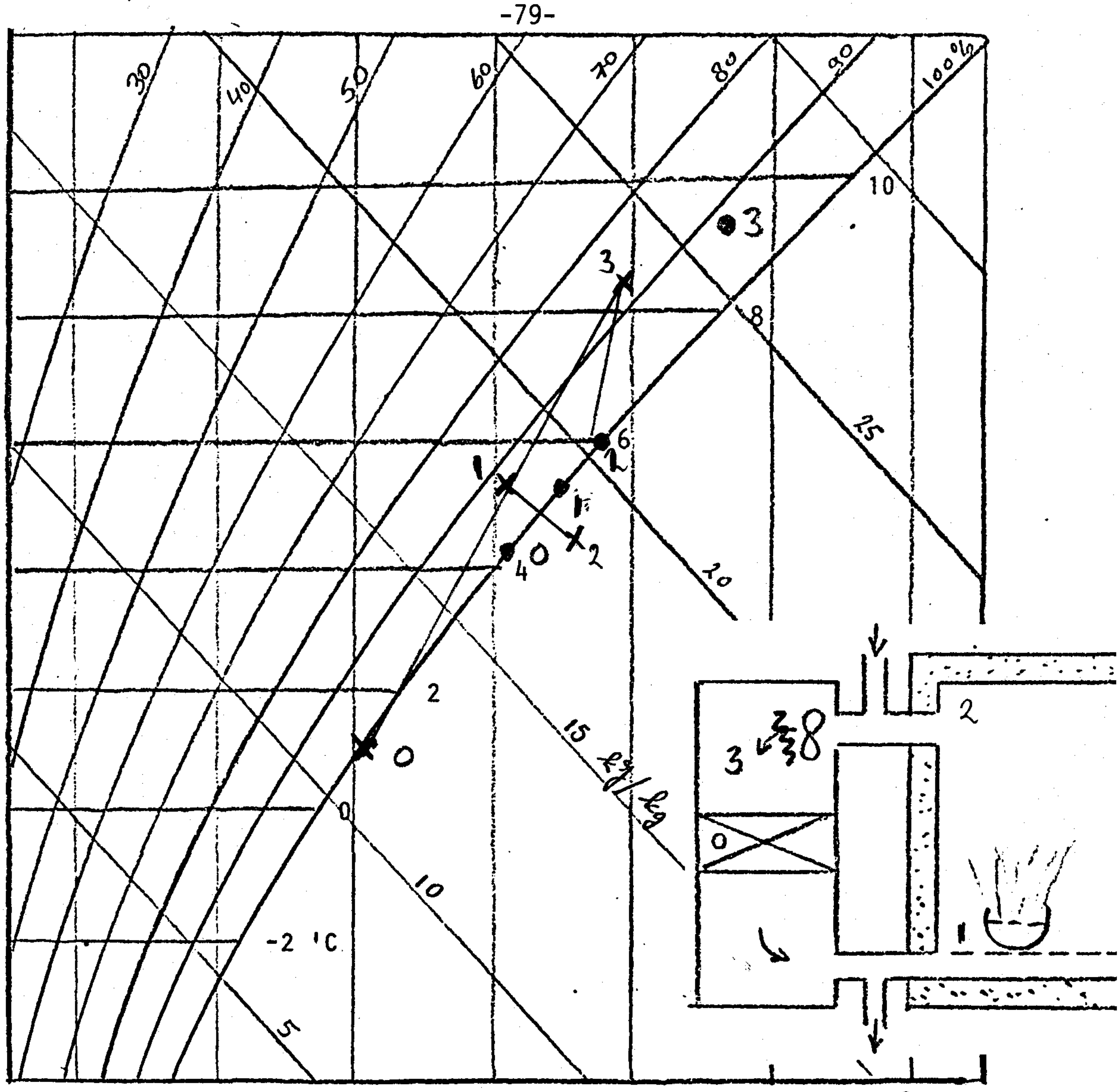
experiment nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
9 ● calculation	0,4	0,01	0	0	20	5,5
24 +	0,4	0,01	0	0	20	5,5

Fig. 36 Condition of air in the stationairy phase



experiment nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
10 ▸	0,4	0,01	750	0	24,2	5,5
calculation 25 ×	0,4	0,01	750	0	20	5,5

Fig 64 Condition of air in the stationairy phase



experiment nr	circulation m^3/s	ventilation m^3/s	heating W	water kg/s	t4 'C	t1 'C
11 •	0,4	0,01	750	$3,17.10^{-4}$	26,3	5,5
calculation 26 X	0,4	0,01	750	$3,17.10^{-4}$	20	5,5

fig. 65