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EFFECTS OF VENTILATION-HEATING CONTROL STRATEGIES FOR EARLY WEANING PIG BARNS ON ENERGY CONSUMPTION AND 3-D TEMPERATURE DISTRIBUTIONS

by/par

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ABSTRACT:

A ventilation control chamber has been built at Alfred College, OMAFRA, in order to study the performance of control systems, ventilation and heating equipment, and recirculation ducts with regard to temperature distribution and energy consumption.

The use of the recirculation duct reduced the floor to ceiling temperature gradients and the energy consumption of the heating system. There was only negligible effect by the "heating offset" control strategy on energy consumption.

INTRODUCTION

In modern livestock barns, the success of the ambient environment control depends on many parameters, such as air circulation (speed, distribution, stability), the reliability of the mechanical hardware and the control system.

The use of a recirculation duct in conjunction with air inlets has been extremely successful for a cold climate, in order to distribute the heat uniformly, prevent cold air dropping onto the livestock and reduce temperature gradients in the airspace. As well, the new electronic thermostat controls also contribute to the precision of ambient temperature control. However, the control strategy for the heating phase requires investigation.

A ventilation control chamber has been built to measure temperature distribution, humidity, propane and electricity consumption. The aim of this work is to test and develop control systems with respect to temperature control and energy consumption.

OBJECTIVES

Tests were performed in a ventilation control chamber in order to study: the effects of the control strategy in combination with the use of an air recirculation duct on the temperature distribution and energy consumption for heating and fans.

METHODS AND PROCEDURES

A ventilation control chamber has been built at Alfred College of Agriculture and Food Technology, Ontario, in order to study the performances of control systems on ambient temperature distribution and energy consumption.

This chamber is composed of a pre-conditioning area equipped with a heater to stabilize the temperature of the air before entering the testing chamber. The pre-conditioning chamber is equipped with 10 x 750 watt electric heaters controlled with a Thevco TC3-IN4F1 thermostat. The incoming air is mixed with circulation fans. Three sensors (thermocouple type "T") measure the air temperature entering the ventilation testing chamber. The relative humidity is measured with a Vaisala sensor, model HMP12. Figures 1 to 3 show the locations of the "T thermocouples", relative humidity and the dimensions of the chamber. There are three vertical and horizontal temperature profiles identified as south, central, and north (27 thermocouples).

The propane consumption is measured with a load cell (Intertechnology, 0-100 lbs, model 363-P3-100-20P3). The ventilation rate is measured with an "Airdata Multimeter" (Shortridge Instrument, model ADM-870). The electrical power (kw) is measured with a Hioki power tester (model 3161). The datalogger is a Digistrip II (Kaye Instrument) connected to a computer.

The ventilation control chamber is controlled with a Thevco TC2-2V2S electronic thermostat. There is a 3.3 m baffle air inlet controlled by a static pressure controller Thevco SP-2. A 3.3 m recirculation duct is installed under the air inlet. A variable speed 20 cm fan (GlassPac, Canada) is used in the recirculation duct. The chamber has 3 variable speed exhaust fans (200, 300 and 450 mm, GlassPac, Canada). Supplemental heat is provided by a typical "brooder-hover" propane heater (Shenandoah Mfg. Co., 30,000 Btu/h, open flame). All fans and the heater are controlled by the Thevco TC2-2V2S electronic thermostat.

Piglet simulation

For this study, the ventilation chamber was used to simulate a hot nursery. The inlet simulated the heat and moisture produced by 55 piglets at 7 kg. From heat and moisture production data, 55 piglets housed at 27.7°C (82°F) would generate 1050 watts of sensible heat and 1600 watts of latent heat equivalent to 2.3 kg/h of moisture production. A total of 2.66 kw of heat was generated with 13 electrical heaters (750 w each) controlled by a Thevco rheostat (3000 w, model LD3000). Figure 4 shows the piglet electrical control curve. The moisture was produced by 4 house-type drum humidifiers in order to transform sensible to latent energy. The quantity of water evaporation was measured by a load cell.

Testing procedure

In order to compare the results among the tests, the incoming air temperature was maintained at 0°C. Each test was 4 hours long in order to use 3 hours of comparable data. Data were sampled every 10 s.

The control strategy is presented in Table 1. The effects of the heater offset and differential were studied in order to prevent the "over-shoot" phenomenon commonly encountered in units with excessive heater, minimum fan sizes and unbalanced reactivity of the control system. The set point was 27.7°C (82°F) as recommended by most swine practionners for 7 kg piglets. The heaters were turned on at 26.9°C (80.5°F) (Tests 1 and 4) or 26.7°C (80°F) (Tests 2 and 3) with a steady .2°C (.5°F) differential. The intent was to reduce the "over-shoot". The recirculation duct was "on" or "off".

RESULTS AND DISCUSSION

Table 2 presents the average temperature and associated standard deviation for 6 locations, 2 for each profile, near the floor. Figure 5 shows the temperature data over time for 5 locations in the central profile. Finally Figures 6 and 7 present the isotherms and standard deviation distribution over the central profile.

In Table 5, the data show non-significant differences in temperature among tests. However, the 0.2°C reduction of the heater offset point resulted in a 0.2° to 0.5°C temperature reduction at the floor level. The average temperature at the sensor location (#114) was equal to the heater "on" temperature, not the set point temperature. The control strategy has to take this fact into consideration for the "heating period" of the year. As shown in Figure 5, temperature fluctuated between 25 and 27.5°C at the floor level. The heating cycles were very steady along the test period. Even with the use of a recirculation duct, there were some slight temperature gradients among locations.

Figure 6 shows that the temperatures were very uniform across the central profile. The cooler zone is located at the air inlet area and over the left side of Figure 6 where the humidifiers were located. The highest standard deviation was measured at the ceiling near the air inlet, with only 0.4 to 0.5 °C of standard deviation at the floor level.

As shown in Figure 8, the power of the minimum ventilation fan (200 mm) peaked cyclically indicating some "overshoot". These peaks coincide with the high temperature peaks. The response of the TC2-2V2S temperature probes was always slower than the "T" thermocouples. As well, a reading of 0.1 to 0.3°C above the thermocouple was commonly observed.

Effects of the ventilation duct

The comparison between Figures 5 and 9 (recirculation "on" versus "off") shows lower temperature gradients between thermocouples when the recirculation duct was used. As well, during the 3 h period, there were 21 heating cycles versus 18 cycles with the recirculation "on". This suggests a more rapid reaction of the system to heat addition.

The average temperature ranged between 25.75°C to 26.75°C with the recirculation "on" (Figure 6) versus 25.2°C to 28.8°C without recirculation (Figure 10). On Figure 10, the coolest point was observed near the air inlet and the warmest area was at the opposite end of then chamber where the fans are. The highest standard deviations were recorded at the ceiling with the recirculation "off" (Figure 10). However, the standard deviations at the floor level were similar to the tests with the recirculation "on".

Energy consumption

Table 3 presents the results related to the energy consumption. There was relatively no difference between Tests 1 and 2 (recirculation "on") and Tests 3 and 4 (recirculation "off"). However, there was a difference of 0.08 to 0.11 kg of extra propane consumption among the Tests 1 and 4 (with recirculation) versus Tests 2 and 3 (no recirculation). There was no difference on the fan energy consumption.

Since the ventilation rates were between 90 and 100 L/s, which was far above the necessary 38 L/s needed to maintain 70% relative humidity, the moisture level inside the chamber reduced during the test. However, since the moisture production remained fairly constant, the latent energy would be similar.

Since the room was relatively small, the electricity consumption of the recirculation fan would not have been proportional to a full scale barn.

SUMMARY AND CONCLUSION

A ventilation control chamber has been built at Alfred College in order to study the performances of control systems, ventilation and heating equipment and recirculation duct with regard to temperature distribution and energy consumption.

The effects of 2 control strategies, with or without recirculation, have been tested. The main results are:

1 - The floor to ceiling temperature gradients and standard deviations were reduced with the use of the recirculation duct.

2 - An average reduction of 20% of propane consumption has been measured with the use of the recirculation duct. The extra electrical energy has not been measured.

3 - For the establishment of a winter control strategy, the desired temperatures are related to the set temperature for the heater.

4 - There was no difference on temperature cycles, energy consumption and temperature stratification between the 2 tested control strategies.

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Table 1 Test description.

Variables	Test Number			
	1	2	3	4
Heating "on" (T°C)	26.9	26.7	26.7	26.9
Heating "off" (T°C)	27.2	26.9	26.9	27.2
Set Point	27.7	27.7	27.7	27.7
Recirculation System	on	on	off	off

Notes: sampling rate at 10 second intervals, duration of test = 4 hours

Table 2 Temperatures and standard deviations over the floor area.

		Location						
Test #		South		Center		North		Sensor
		107	116	104	113	101	110	114
1	T°	27.5	28.5	26.2	26.8	25.6	26.3	26.9
	σ	.6	.6	.5	.5	.5	.6	.5
2	T°	27.0	28.0	25.9	26.6	25.3	25.9	26.6
	σ	.7	.6	.6	.6	.6	.6	.6
3	T°	25.8	27.3	25.9	26.7	26.2	26.1	26.7
	σ	.5	.6	.6	.6	.6	.7	.6
4	T°	26.1	27.0	26.6	27.0	26.8	26.6	27.0
	σ	.6	.7	.7	.7	.9	.7	.6

T° = Temperature, °C, σ = standard deviation

Table 3 Propane and electricity consumption, test duration 3 h.

Variables	Test Number 1	2	3	4
Propane (kg)	.41	.41	.52	.49
Electricity for the exhaust fan (kwh)	.36	.35	.35	.34
Moisture production rate (kg/h)	2.41	2.39	2.33	2.30
Standard deviation	.09	.08	.13	.31
Ventilation rate (L/s)	93.7	98.2	98.6	96.7
Standard deviation	5.3	3.4	3.7	5.2
Inside relative humidity (%)	56.7	51.1	45.6	43.1
Standard deviation	1.7	1.5	1.8	.5
Exterior temperature (°C)	.2	-.2	-.3	-.1
Standard deviation	.2	.3	.5	.7
Exterior relative humidity (%)	21.5	20.8	20.5	20.1
Standard deviation	.4	.2	.2	.1

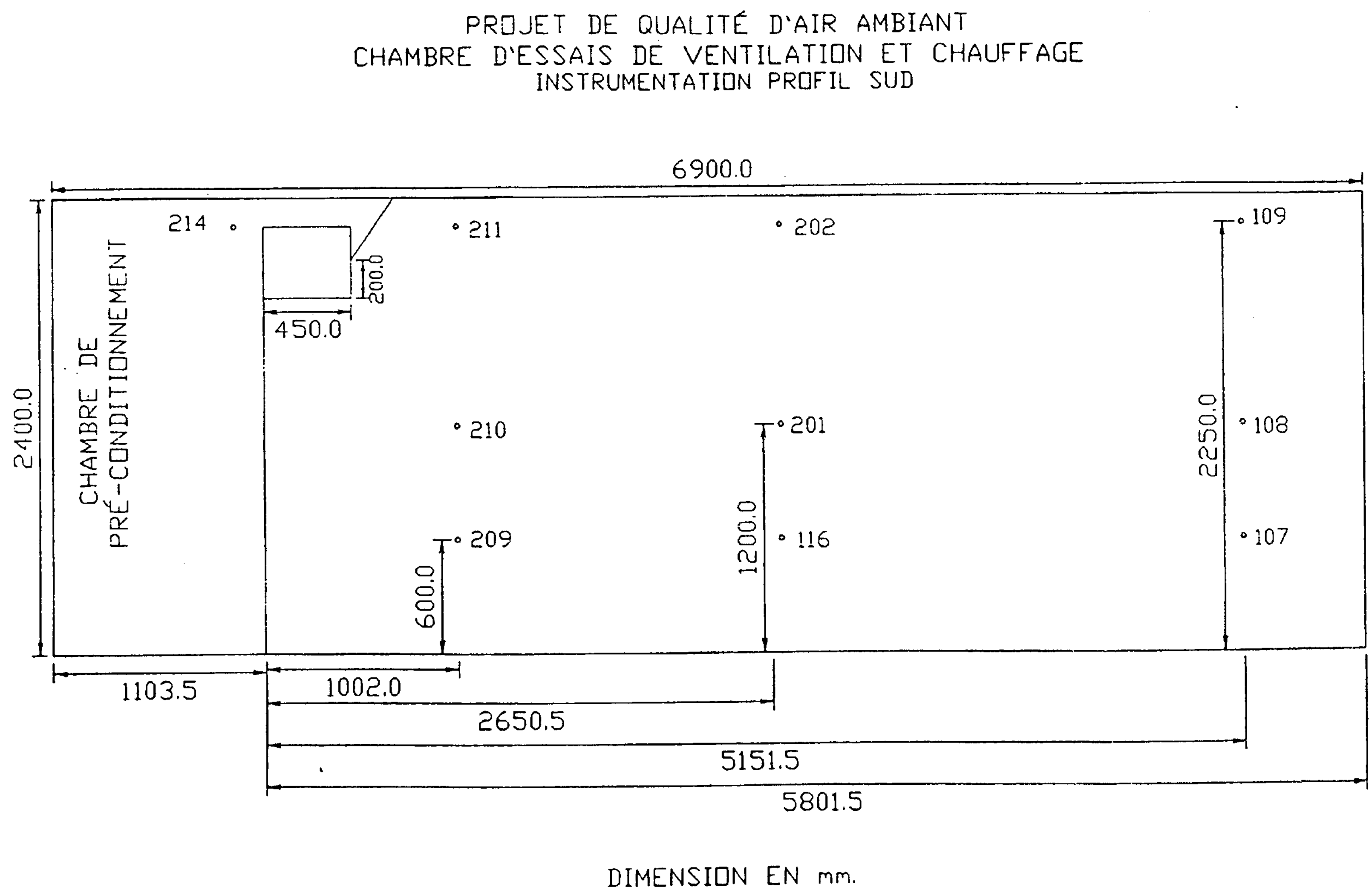


Figure 1. Dimensions and sensor locations in the ventilation control chamber; profile view, south section.

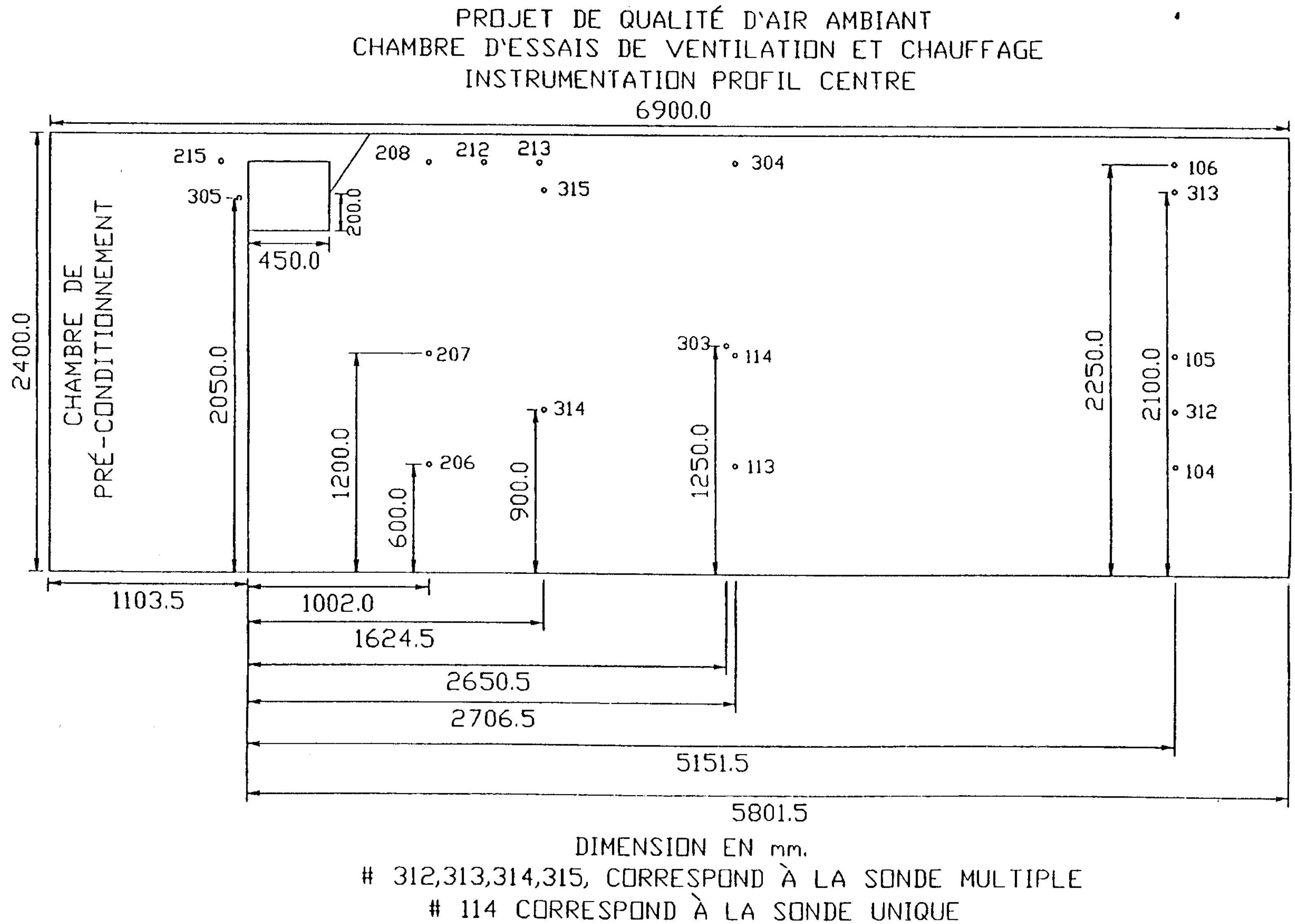


Figure 2. Dimensions and sensor locations in the ventilation control chamber; profile view, central section.

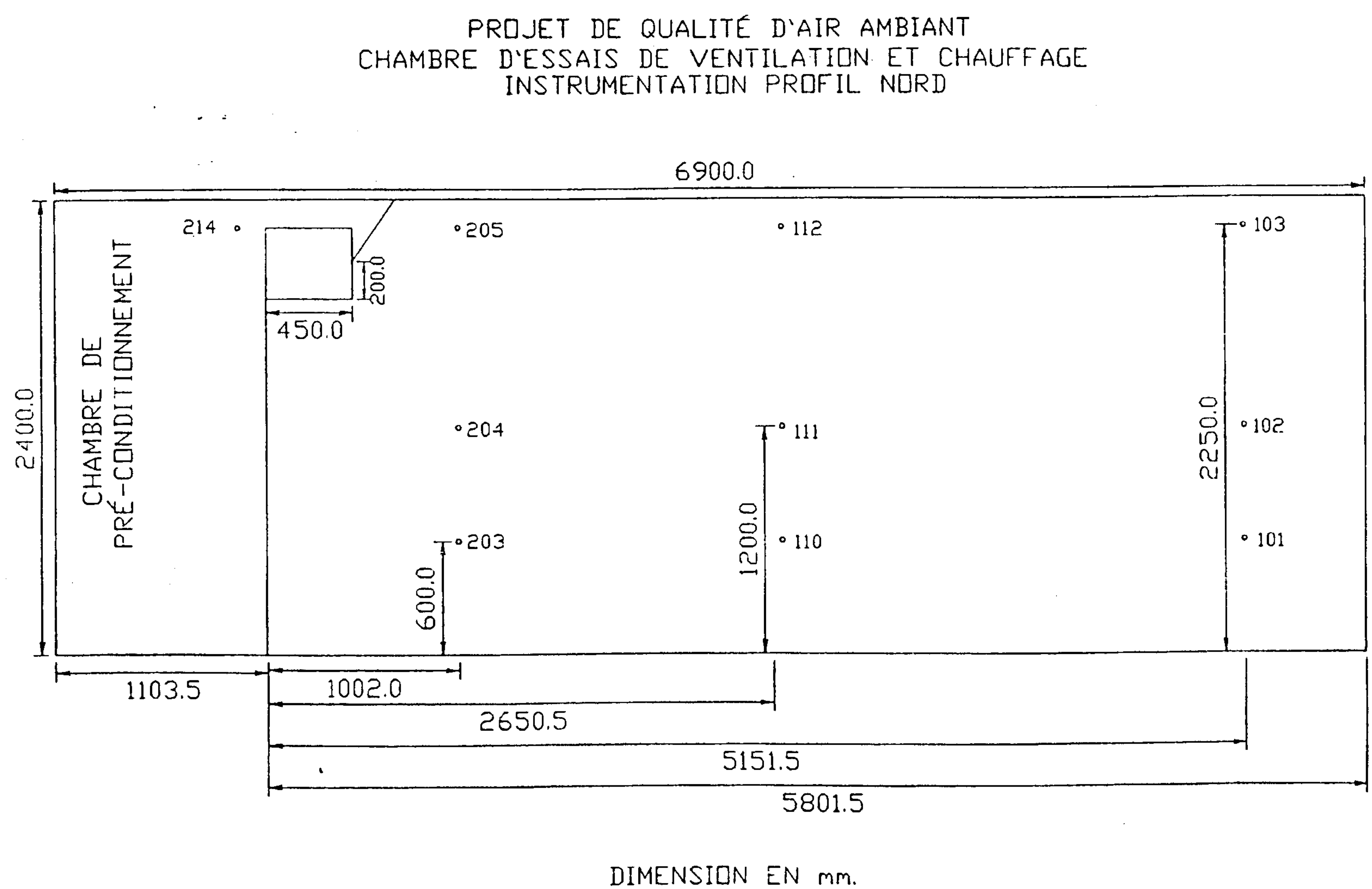


Figure 3. Dimensions and sensor locations in the ventilation control chamber; profile view, north section.

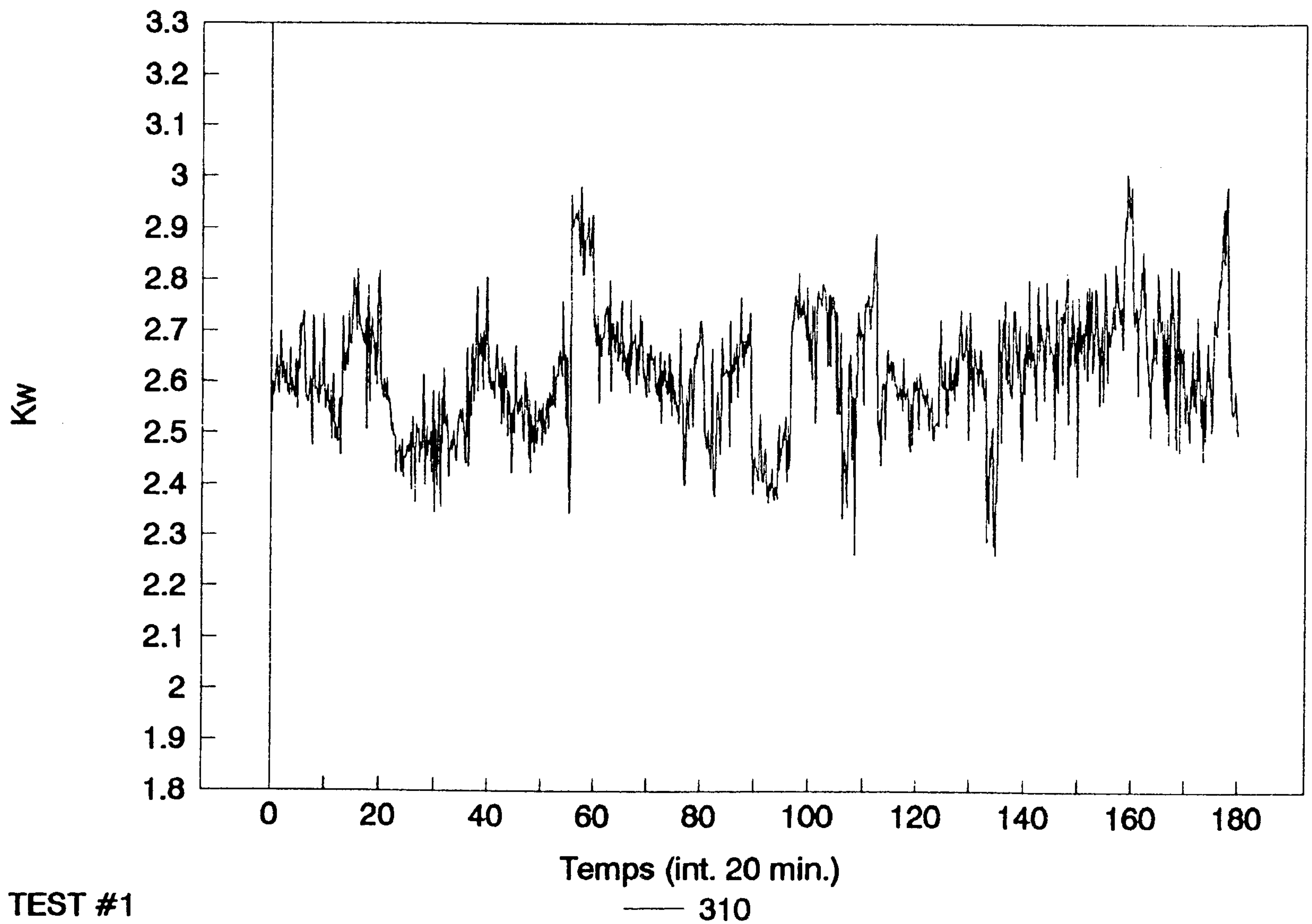


Figure 4. Simulated piglets, target of 22.6 kw of total heat.

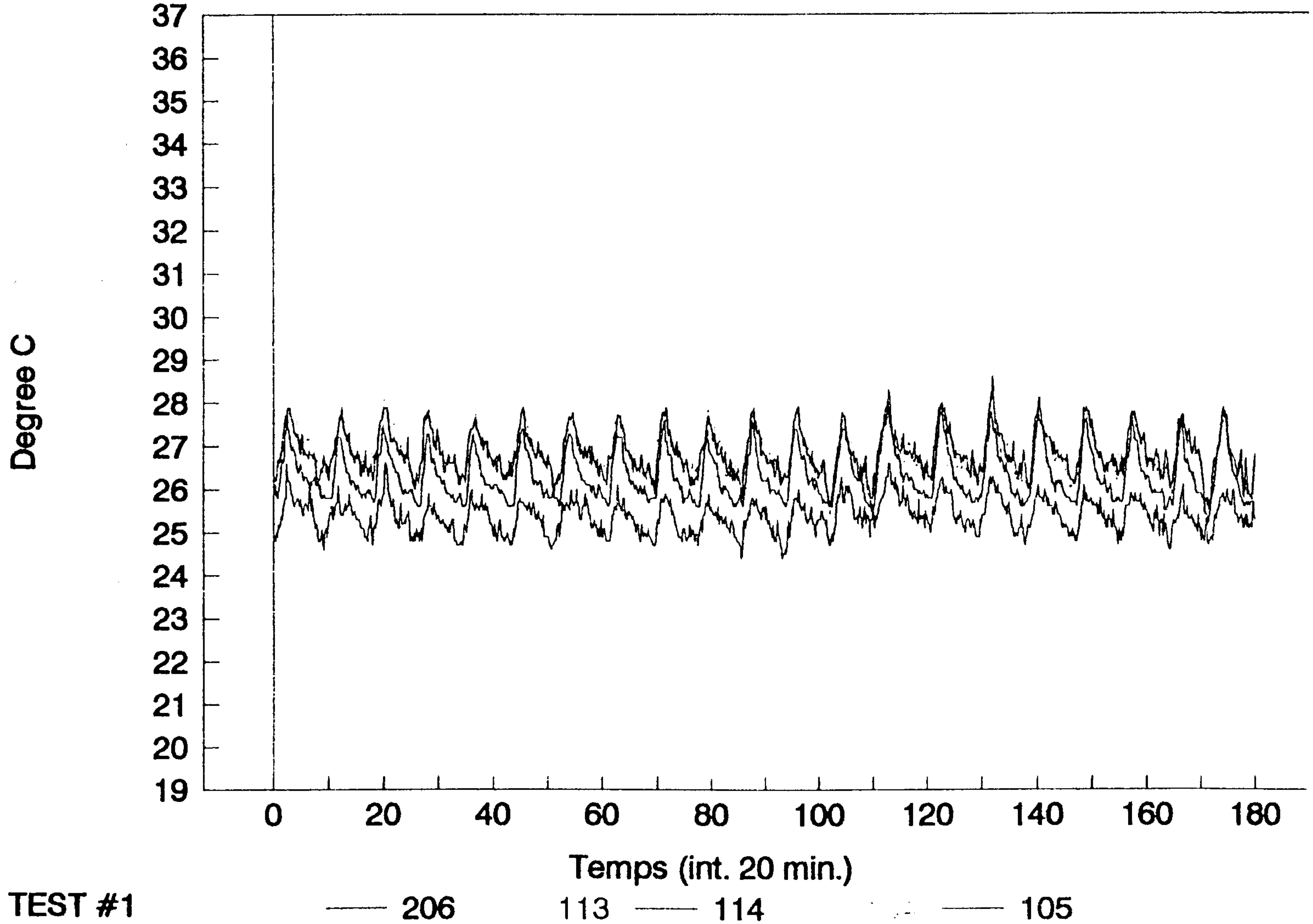


Figure 5. Temperatures, central section, test #1, heater on at 26.9°, off at 27.2°, set point = 27.7°, recirculation "on".

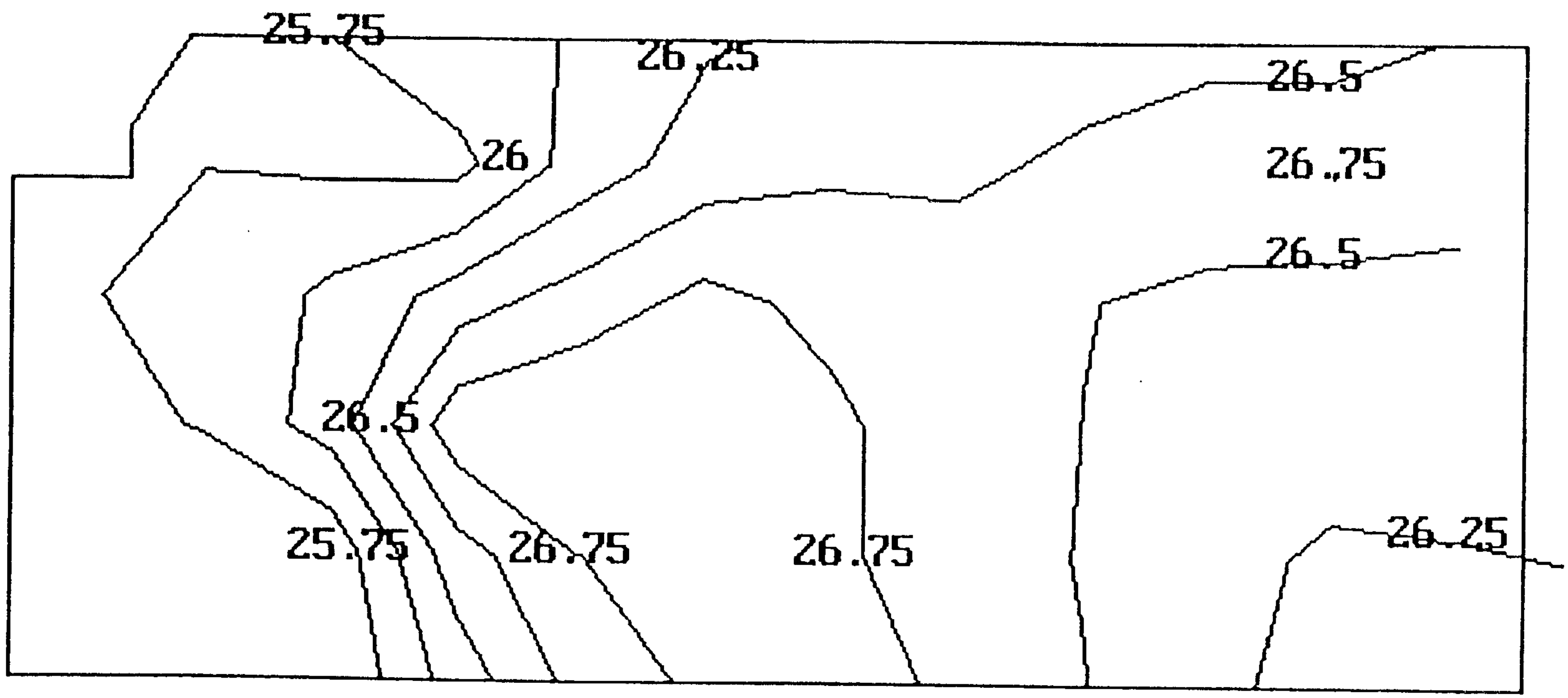


Figure 6. Isotherms, central section, test #1, average over 3 h.

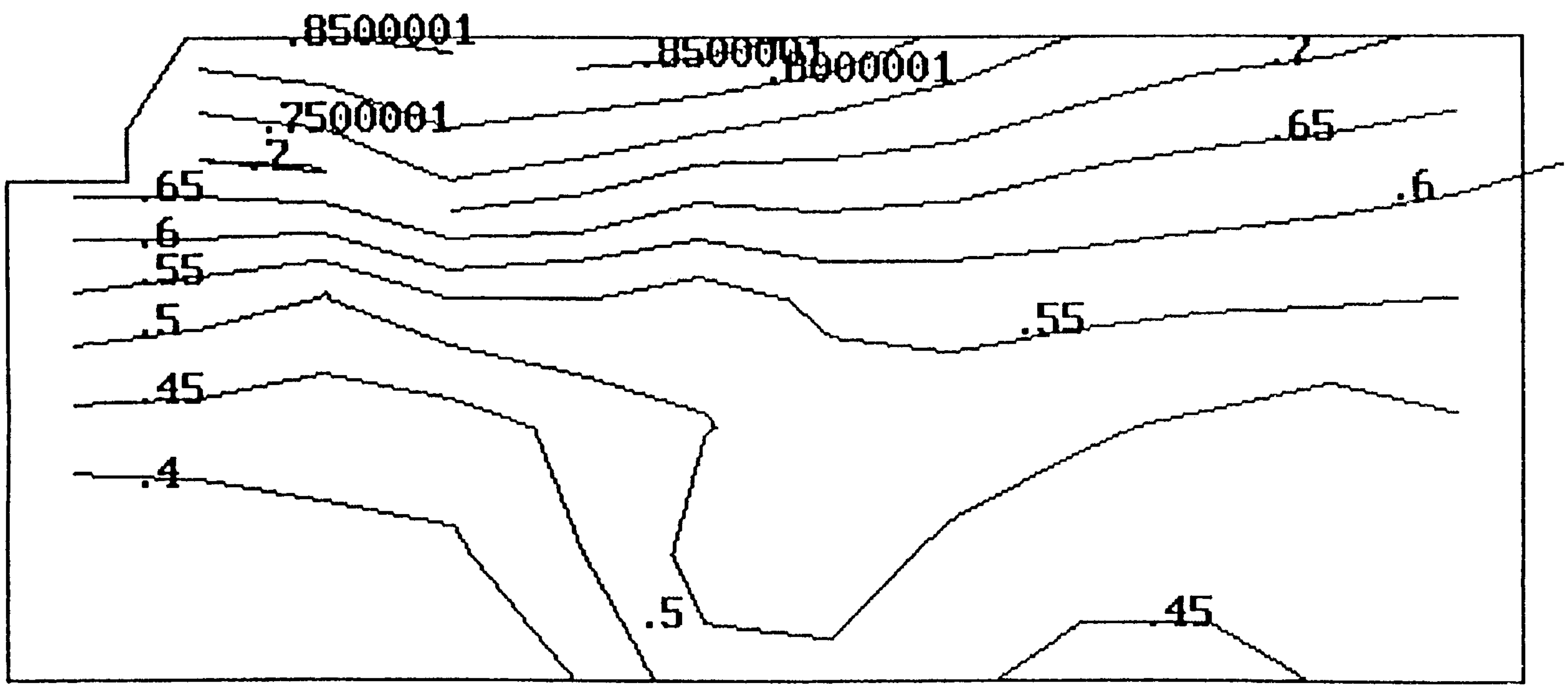
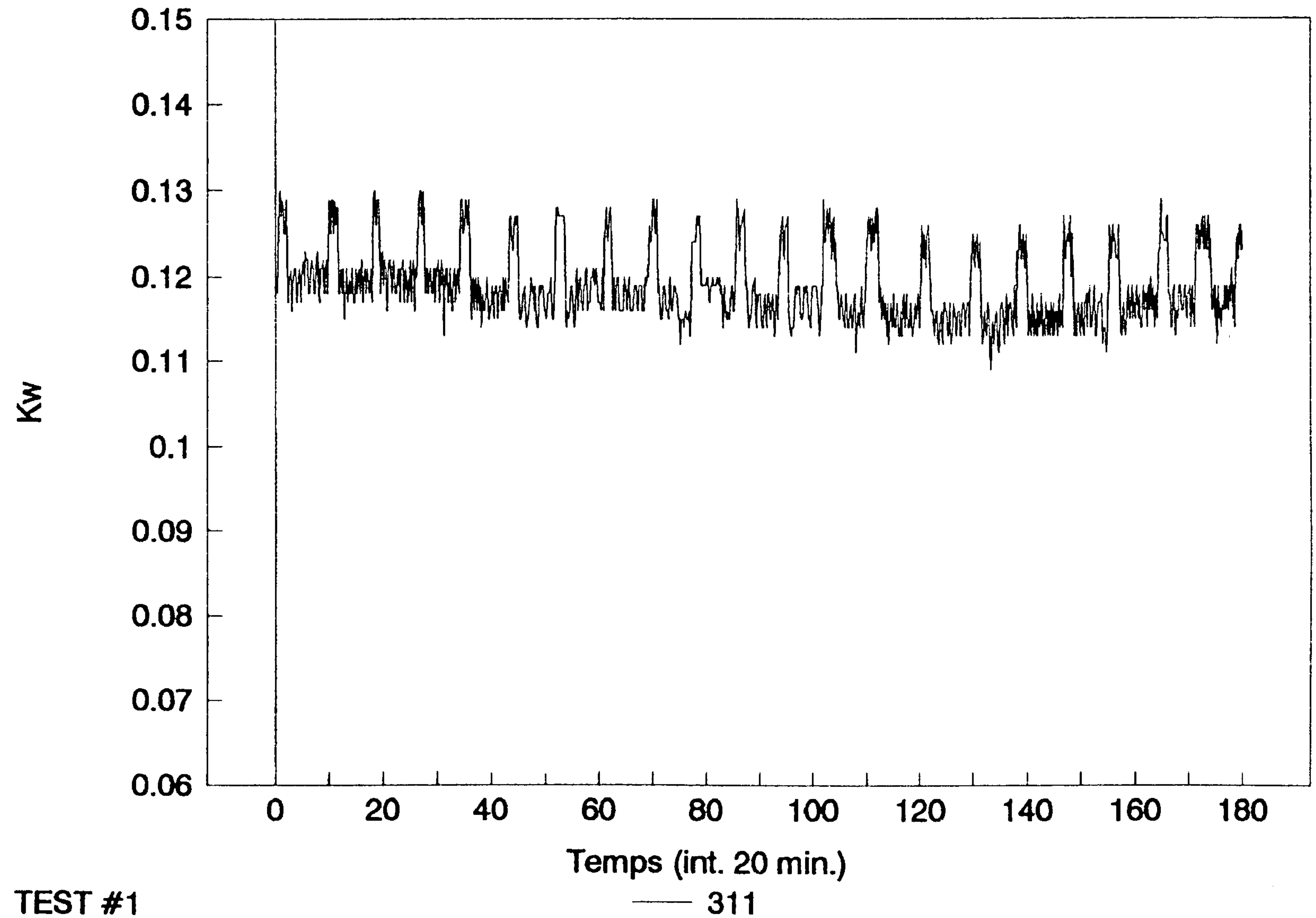


Figure 7. Standard deviation profile, central section, test #1, average over 3 h.



TEST #1

Figure 8. Power consumption by the minimum ventilation fan (200 mm).

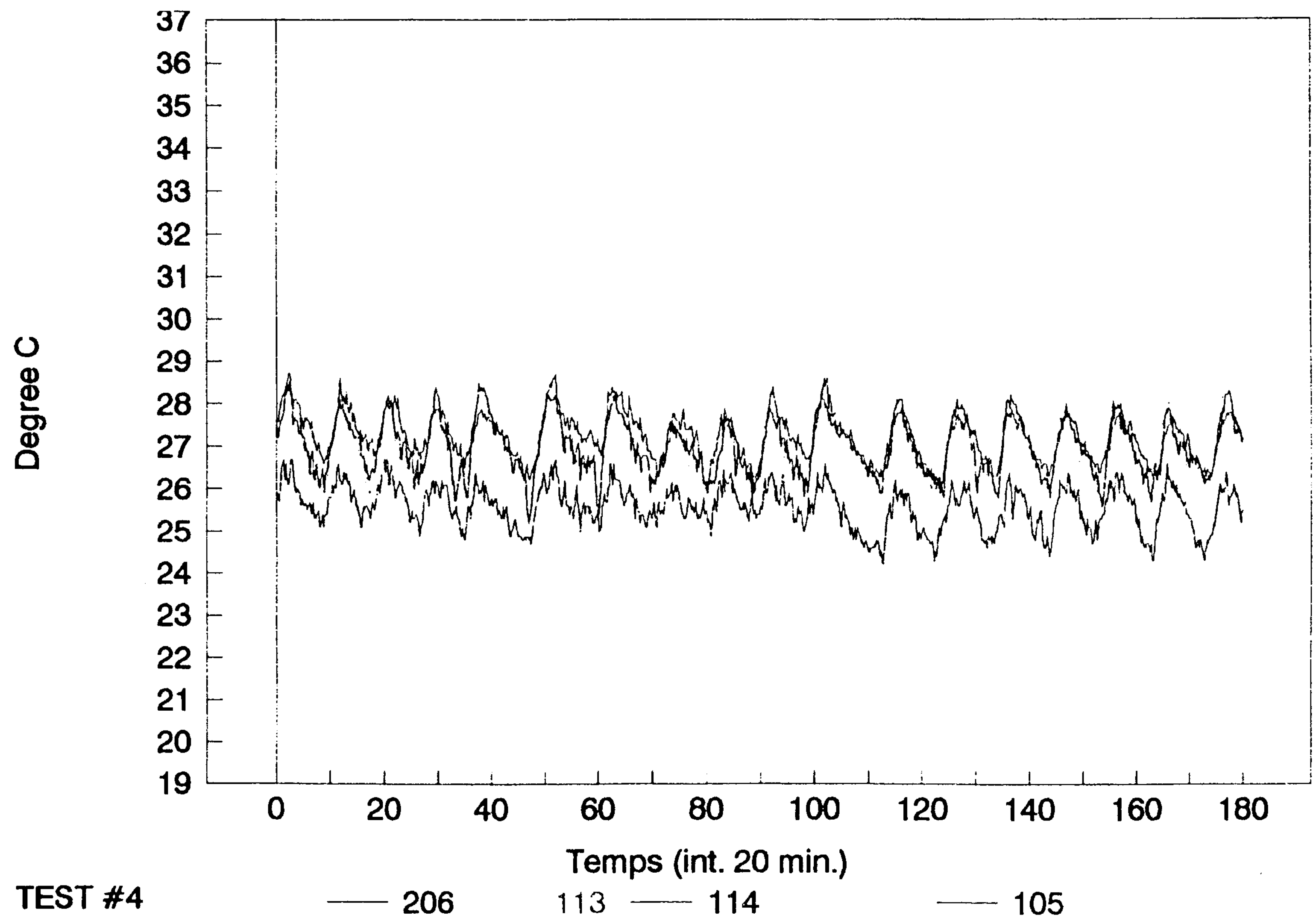


Figure 9. Temperature, central section, test #4, heater on at 26.9°, off at 27.2°, set point at 27.7°, recirculation "off".

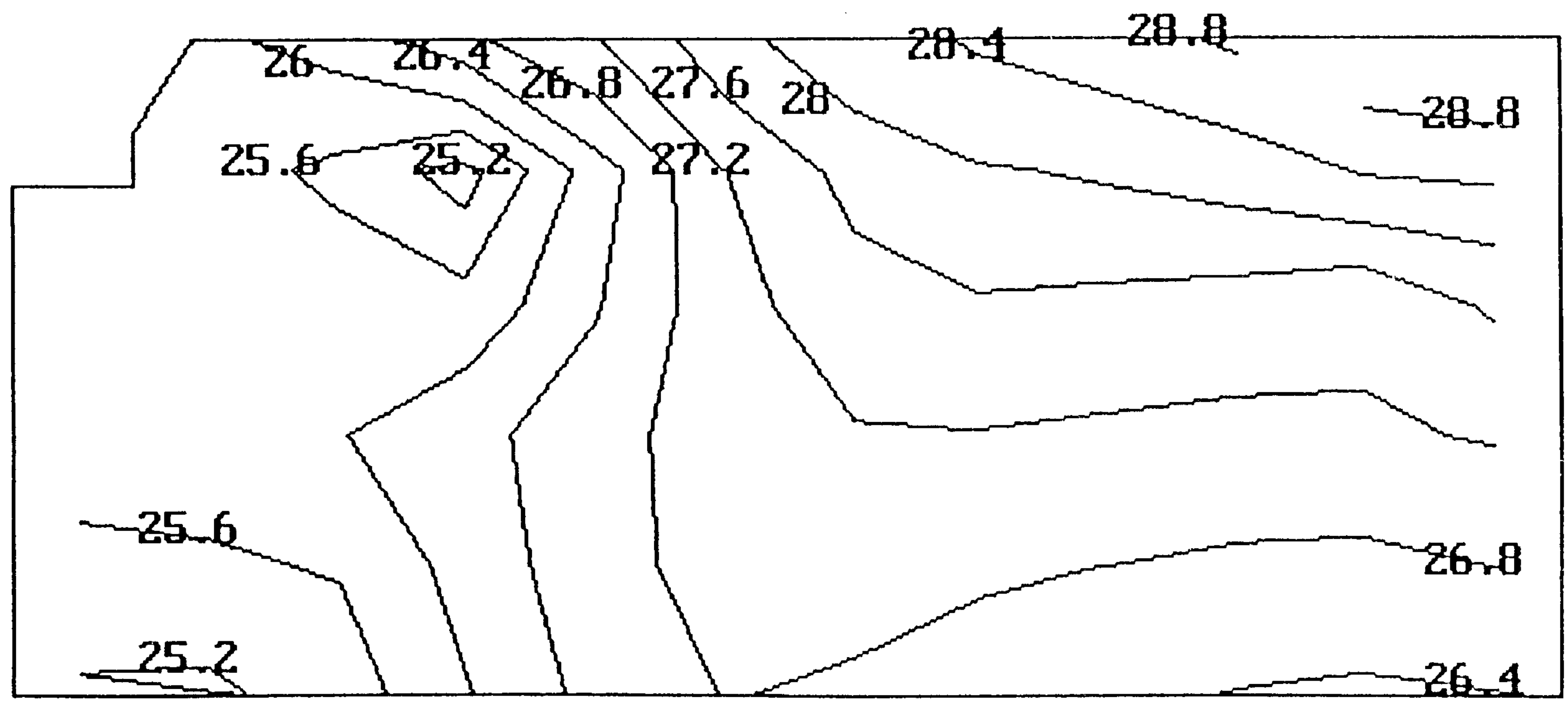


Figure 10. Isotherms, central section, test #4, average over 3 h.

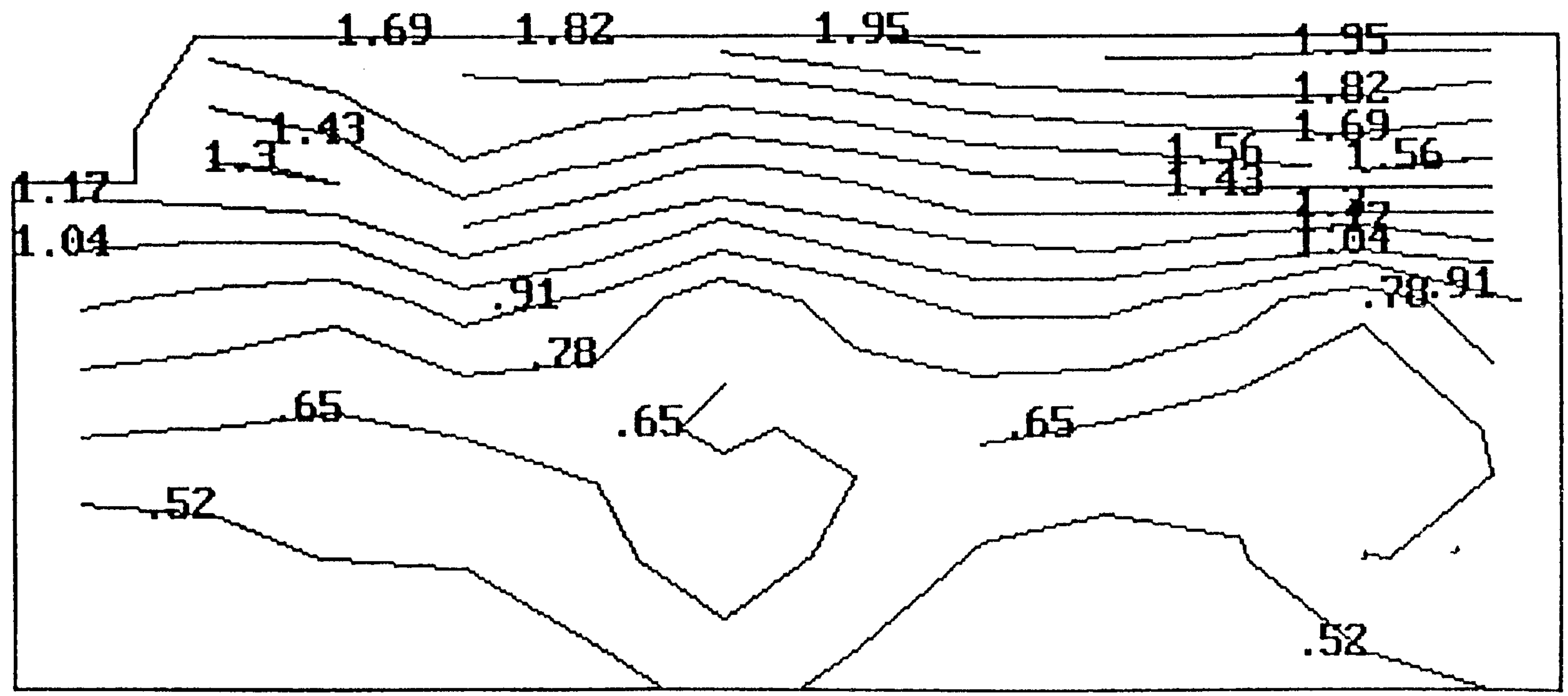


Figure 11. Standard deviation profile, central section, test #4, average over 3 h.

APPENDIX 1

TEST#1 16 MARS,94 PORC = 7Kg. CHAUF. ON = 80.5 OFF 81 F
CONSIGNE = 82 F, RECIRC. ON, 1080 MESURES A 10 SEC. D'INTERVAL.
SONDE UNIQUE PRESSION STAT. 30 Pa

Canal	101	102	103	104	105	106	107
moyenne	25.59	26.00	26.39	26.16	26.32	26.60	27.46
ecart tp	0.53	0.57	0.58	0.50	0.57	0.65	0.60
Canal	108	109	110	111	112	113	114
moyenne	26.14	26.83	26.26	26.55	25.27	26.83	26.85
ecart tp	0.52	0.59	0.56	0.55	0.45	0.52	0.51
canal	304	116	201	202	203	204	205
moyenne	25.80	28.53	27.51	27.73	25.80	25.91	24.33
ecart tp	0.88	0.57	0.53	1.30	0.44	0.37	0.46
canal	206	207	208	209	210	211	212
moyenne	25.37	25.97	26.05	27.21	27.30	28.21	26.21
ecart tp	0.38	0.47	0.76	0.66	0.48	1.28	0.90
canal	213	214	215	216	301	302	303
moyenne	25.42	0.68	0.17	0.03	-1.49	21.53	56.66
ecart tp	0.74	0.17	0.19	0.21	0.28	0.37	1.67
canal	305	306	307	308	309	310	311
moyenne	43.08	27.44	2.41	0.41	0.00	2.62	0.12
ecart tp	2.26	0.24	0.09	0.00	0.00	0.12	0.00
canal	312	313	314	315	316		115 HEURES
moyenne	26.41	26.84	26.95	27.40	93.68		17:30:50
ecart tp	0.43	0.62	0.42	0.70	5.27		20:30:40

PRODUCTION D'HUMIDITE= 2.41 Kg/Hr
ECART TYPIQUE= 0.09 Kg/Hr
VENTILATION= 93.68 L/s
ECART TYPIQUE= 5.27 L/s
HUMIDITE RELATIVE INTERIEUR 56.66 %
DEVIATION STANDARD= 1.67 %
CONSOMMATION PROPANE= 0.41 Kg.
ENERGIE DES VENTILATEURS = 0.356833 Kw/Hr

APPENDIX 2

TEST #2 16 MARS,94 PORC = 7 Kg. CHAUF. ON = 80 OFF = 80.5 F
CONSIGNE = 82 F, RECIRC. ON, 1080 MESURES A 10 SEC. D'INTERVAL.
SONDE UNIQUE PRESSION STAT. 30 Pa

Canal	101	102	103	104	105	106	107
moyenne	25.3	25.7	26.1	25.9	26.1	26.3	27.0
ecart tp	0.58	0.60	0.60	0.56	0.61	0.67	0.71
Canal	**108**	**109**	**110**	**111**	**112**	**113**	**114**
moyenne	25.9	26.5	25.9	26.3	24.9	26.6	26.6
ecart tp	0.57	0.63	0.63	0.59	0.51	0.59	0.58
canal	**304**	**116**	**201**	**202**	**203**	**204**	**205**
moyenne	25.3	28.0	27.1	27.5	25.7	25.6	24.1
ecart tp	0.80	0.60	0.58	1.41	0.51	0.42	0.49
canal	**206**	**207**	**208**	**209**	**210**	**211**	**212**
moyenne	25.29	25.78	26.26	27.00	27.04	27.88	26.26
ecart tp	0.43	0.53	0.76	0.73	0.57	1.33	0.94
canal	**213**	**214**	**215**	**216**	**301**	**302**	**303**
moyenne	25.32	0.31	-0.20	-0.35	-3.50	20.82	51.08
ecart tp	0.86	0.28	0.30	0.32	1.11	0.14	1.49
canal	**305**	**306**	**307**	**308**	**309**	**310**	**311**
moyenne	35.24	27.16	2.39	0.41		2.70	0.12
ecart tp	2.08	0.26	0.08			0.15	0.003933
canal	**312**	**313**	**314**	**315**	**316**	**115 HEURES**	
moyenne	26.13	26.52	26.68	27.21	98.17		20:32:40
ecart tp	0.47	0.65	0.49	0.81	3.40		23:32:30

PRODUCTION D'HUMIDITE = 2.39 Kg/Hr
ECART TYPIQUE = 0.08
VENTILATION = 98.17 L/s
ECART TYPIQUE = 3.40
HUMIDITE RELATIVE INT. = 51.08 %
DEVIATION STANDARD = 1.49
CONSOMMATION PROPANE = 0.41 Kg.
ENERGIE DES VENTILATEURS = 0.349819 Kw/Hr

APPENDIX 3

TEST#3 17 MARS,94 PORC = 7Kg. CHAUF. ON = 80,OFF = 80.5F
CONSIGNE = 82 F RECIRC. OFF, 1080 MESURES A 10 SEC. D'INTERVAL.
SONDE UNIQUE PRESSION STAT. 0 Pa

Canal	101	102	103	104	105	106	107
moyenne	26.19	26.58	28.34	25.89	27.05	28.73	25.83
ecart tp	0.60	0.47	1.57	0.60	0.50	1.93	0.54
Canal	108	109	110	111	112	113	114
moyenne	26.54	28.46	26.14	26.70	28.39	26.65	26.69
ecart tp	0.53	1.55	0.67	0.64	1.54	0.62	0.57
canal	304	116	201	202	203	204	205
moyenne	28.93	27.28	27.13	29.61	25.15	25.34	23.14
ecart tp	1.79	0.55	0.52	1.62	0.43	0.53	0.44
canal	206	207	208	209	210	211	212
moyenne	25.67	25.76	26.82	28.11	26.59	30.07	24.45
ecart tp	0.38	0.74	1.59	0.80	0.62	2.02	1.46
canal	213	214	215	216	301	302	303
moyenne	25.00	0.03	-0.31	-0.45	-5.31	20.53	46.57
ecart tp	1.70	0.47	0.50	0.54	1.19	0.15	1.81
canal	305	306	307	308	309	310	311
moyenne	2.90	27.09	2.33	0.52		2.62	0.12
ecart tp	0.25	0.24	0.13			0.13	0.0042
canal	312	313	314	315	316		115 HEURES
moyenne	26.80	28.15	26.43	26.17	98.55		0:36:10
ecart tp	0.44	1.04	0.48	1.03	3.66		3:36:00

PRODUCTIO D'HUMIDITE=	2.33 Kg/Hr
ECART TYPIQUE=	0.13
VENTILATION=	98.55 L/s
ECART TYPIQUE	3.66
HUMIDITE RELATIVE INTERIEUR	46.57 %
DEVIATION STANDARD=	1.81
CONSOMMATION PROPANE=	0.52 Kg.
ENERGIE DES VENTILATEURS =	0.348728 Kw/Hr

APPENDIX 4

TEST#4 17 MARS,94 PORC = 7Kg. CHAUF. ON = 80.5 OFF = 81 F
CONSIGNE = 82 RECIRC. OFF, 1080 MESURES A 10 SEC. D'INTERVAL.
SONDE UNIQUE PRESSION STAT. 0 Pa

Canal	101	102	103	104	105	106	107
moyenne	26.77	26.94	28.71	26.60	27.26	29.17	26.12
ecart tp	0.91	0.59	1.80	0.69	0.59	2.35	0.62
Canal	108	109	110	111	112	113	114
moyenne	26.82	28.96	26.55	27.06	28.66	26.99	26.99
ecart tp	0.55	2.14	0.74	0.65	1.71	0.72	0.62
canal	304	116	201	202	203	204	205
moyenne	29.38	26.98	27.07	30.19	25.22	25.47	23.19
ecart tp	2.11	0.73	0.64	2.35	0.50	0.56	0.51
canal	206	207	208	209	210	211	212
moyenne	25.58	25.93	27.26	27.77	26.66	30.17	25.35
ecart tp	0.50	0.76	1.44	1.04	0.77	1.91	1.46
canal	213	214	215	216	301	302	303
moyenne	24.63	0.18	-0.12	-0.25	-4.57	20.13	43.09
ecart tp	1.62	0.60	0.65	0.71	0.92	0.12	0.45
canal	305	306	307	308	309	310	311
moyenne	24.23	27.40	2.30	0.49	0.00	2.63	0.11
ecart tp	0.59	0.30	0.31	0.00	0.00	0.15	0.0046
canal	312	313	314	315	316	115 HEURES	
moyenne	27.19	28.50	26.30	26.24	96.73		4:39:50
ecart tp	0.48	1.32	0.66	1.06	5.22		7:39:40

PRODUCTION D'HUMIDITE= 2.30 Kg/Hr
ECART TYPIQUE= 0.31
VENTILATION= 96.73 L/s
ECART TYPIQUE= 5.22
HUMIDITE RELATIVE INTERIEUR 43.09 %
DEVIATION STANDARD= 0.45
CONSOMMATION PROPANE= 0.49 Kg.
ENERGIE DES VENTILATEURS = 0.339531 Kw/Hr