STUDY ON HUMIDITY ENVIRONMET IN CRAWL SPACE OF DWELLING HOUSE

A. IWAMAE, Ph.D., M. MATSUMOTO, Ph.D.

ABSTRACT

Many houses in Japan have crawl space between the lowest floor and the earth ground which is about 50 cm in height. This is considered as protection against corrosion of wood materials in the floor. Japanese building codes recommend ventilation with outdoor air in this space. In our field research, we found condensation in the crawl space in summer. This is due to low temperature of the ground and high humidity of the outdoor air which is typical of the Asian climate. To prevent this condensation and ensure long-term durability, we estimated the effect of a humidity-controlling soil cover which absorbs moisture into itself and desorbs during the dry season. The estimation is performed by field experiments and numerical analysis based on simultaneous heat and moisture transport process, which is validated by experimental results. The numerical analysis also clarifies the effect of ventilation.

1. INTRODUCTION

Modern houses in Japan have crawl space under the first floor which is about half meter in height. Traditionally, to prevent flood disaster which is caused by concentrated precipitation once in several years, the floor level is higher than surrounding ground. As shown in Figure 1 the modemization of the house and it's building system changes the shape of the foundation from a series of columns to wall of concrete. Temperature and humidity in the space are greatly affected by this enclosure. To ensure durability of wood materials that compose the first floor, the hurnidity must be kept under control **in** some range. Generally, it is said that the suitable range for preventing wood from rotting is below 85% Rh.

Figure 2 shows the standard construction of the crawl space in Japanese houses which is dictated by Japanese architectural codes. The vapor barrier is set on the earth ground in order to prevent evaporation from ground soil and to decrease humidity in the space. This is done in the underground space in many other countries as well. We have studied the effect of this vapor barrier which had not been adequately estimated quantitatively. (Matsumoto et al. 1993) The estimation is composed of field measurement and numerical analysis. In this paper, we take up the crawl space with vapor barrier.

Ventilation by holes set in foundation wall once every several meters is also recommended by the codes. It may be decided to simply follow old traditional stile, and ventilation effect on the space humidity is another problem which is not estimated adequately.

In modem houses, antiseptic is poured into the wood material in the crawl space. This treatment ensures wood durability even if surrounding air is extremely humid. But from the point of human health and environment pollution, the use of antiseptic should be reduced. To keep crawl space humidity low, we estimated the effect of ventilation and soil cover.

2. PRE-EXAMINATION FOR CONDENSATION IN CRAWL SPACE

In summer of 1994, we measured the hygro-thennal environment in the crawl space in which

film of water has been detected as shown in Figure 3.

The water spread over the plastic sheet which works as vapor barrier to reduce evaporation from underground. Moreover, there were water droplet on the surface of the floor facing the crawl space shown in Figure 4. In the wet part, wood materials adsorb water and become so soft that one can d lines with a nail.

We monitored the variations of temperature and humidity in the crawl space and temperature on surface of surroundings. Figure 5 shows the measuring point. Temperature was monitored thermocouples and humidity was monitored by an electronic sensor which was based on electr resistance of the vapor adsorption film.

Figure 6 and 7 show measured variation in temperature and humidity. Figure 8 shows the variatio vapor pressure obtained by calculation with the following equations.

$$PV = Pvfl)\ Rh / 100 \qquad (1)$$

$$loglo(PVAT)) = 12.78614 + 10.79574\ (1 - 273.16 \qquad 5.028\ \log,o(T / 273.16$$
$$\cdot\ 1.50475EA(1\_\ {}_{10\text{-}8.2969(T/273.16\text{-}1}$$
$$\cdot\ 0.42873E\text{-}3(1\ {}_{(4.76915(1 - 273.161\ T)\_} \qquad (2)$$

Figure 6 also shows the dew point temperature of the crawl space air.

It is obvious that temperature at the under ground surface is lower than crawl space dew point, w leads naturally to condensation during the measuring period. Condensation also occurred on the surf of the concrete foundation intern-fittently. Generally, in this measurement, the temperature in the c space was so low that it was easy to bring out condensation with just a little difference in temperat Though it is common for vapor to condense on the surface of walls and/or floors in underground room summer, which is due to outdoor air as a humidity source and underground temperature as a heat sin is unusual that the sai-ne phenomena occurred in the crawl space, at least in Japan.

In fall and winter of 1994, we found that there was no water in the space and the daily average hum went down to 60%, which is the annual minimum as a result.

3. FIELD TEST FOR EFFECT OF SOIL COVER ON HUMIDITY CONTROL IN CRAWL SPACE

We tried humidity control by using soil cover which adsorbs and desorbs moisture of attached sp Soil cover in this trial was a c. 5 mm high layer of granular silica gel, which was specially manufacture have a larger pore than normal desiccant.

We set the soil cover on May 1995, the next year of pre-examination, and monitored variation temperature and humidity in the crawl space as mentioned above.

Figures 9 - 11 show the monitored results on temperature, relative humidity and vapor pres respectively. Vapor pressure is calculated by eq. (1). The gray line shows the variation in outdoor and the black bold line shows that of the crawl space.

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$$P_v = P_{vs}(T)\, Rh / 100 \qquad ($$

$$\begin{aligned}\log_{10}(P_{vs}(T)) = {} & 12.78614 + 10.79574\,(1 - 273.16/T) - 5.028 \log_{10}(T/273.16) \\ & + 1.50475\text{E}^{-4}(1 - 10^{-8.2969(T/273.16 - 1)}) \\ & + 0.42873\text{E}^{-3}(10^{4.76955(1 - 273.16/T)} - 1)\end{aligned} \qquad ($$

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It is considered theoretically that the effect ot'soll cover on thermal variation is not so LTreal. This result on temperature also indicates the same trend as obtained by pre-examination, Froin to summer, the crawl space temperature increased with time lag to outdoors. Peak val tie in this year was a few degrees Celsius lower than that of outdoor dire to the thermal capacity ofthe -round, Outdoor air temperature started to gradually decrease in September and the relation between the crawl space and outdoors upset. Monthly average temperature of the space in September **was 1** de,-rec hl,),her than that of outdoors.

The variation in relative humidity of the crawl space air showed the effect ot'soll cover. The frequency of an extremely high level, above 95%, became lower than the uncovered condition ill the previous year.

From May to June, the daily average space humidity coincided to outdoor air the same as temperature variation did. In July, the two apart from each other and the under floor space became humid, corresponding to the decrease in space temperature. Space humidity Gradually increased and, in last week of July, it was above 95%, which designates condensation where temperature 'IS just a little lower than the space. In this period, it is confirmed that there was no water film on the soil cover or **on** the ground.

Vapor pressure of the crawl space in May and June was slightly lower than that of outdoors. This seems to be due to time lag in annual variation, or to the effect ot'soll cover. We estimated this

by numerical analysis which is described in next section.

Daily average vapor pressure of the space was lower than outdoors frolil May to July, while

c. 2 mmHg higher than outdoor air in August. The space should need some kind of beat source and vapor source such as adequately wet materials to maintain vapor pressure level which is higher than surroundings. Since there is no heat source in the crawl space, and because the Rh sensor we used became unreliable once it had experienced condensation on itself', we regard the high vapor pressure in August as a sensing error due to the Rh sensor.

Figure 12 shows the variation from fall to winter. Humidity level in the crawl space goes down with the decrease in that of the outdoor air, and this means the soil cover -radually desorved the humidity. Since the daily average vapor pressure in this period nearly equals that of outdoor air. it can be said that the soil cover's effect will continue next year.

4. NUMERICAL ANALYSIS

In this section. we describe the validation of a numerical model we propose for the crawl space humidity. Then, using this model, we estimate the contribution of component factors, which are the effect of soil cover and ventilation rate on exchanging space air with outdoor air.

We propose a numerical model which consists of two parts. One is for hygro-thermal variations in soil cover, while the other is for the conservation of enthalpy and mass of vapor in the crawl space. We consider the vapor barrier on the ground and floor are perfectly impermeable, thus. vapor flux is equal to 0 on the boundary under the soil cover and on the surface ofthe concrete wall and floor facin. the space.

In the soil cover, the simultaneous heat and moisture equations are applied as follows. When there are two phases of moisture in porous material. vapor as a gas phase and water as a liquid cl phase, from mass conservation, the next two balance equations are derived for each phase.

We neglect liquid water movement in the soil cover, since it i's not so (Yi-cat **under** liv(@,i-osco

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condition (*Rh* is below 95%

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One can oet the heat balance equation of a small divided area in porous material, hy taking 11110

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It is well known empirically that vapor inoves related to the vapor pressure gradient in poroll,' materia This fact means vapor movement can be expressed by gradients of temperature and absolute humility i one regards vapor as a function of these two physical parameters. Thus, fluxes are

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By the way, it is well known that water content of porous material correspond to the relative humidity of surrounding air and it's value is constant under invariable pressure. Thus, o *F(Rh)*

Fv(LY) From this relation,

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Here, we use the following, notations

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Then, we can derive as follows.

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$$\frac{\partial \phi \rho_w}{\partial t} = -\nabla J_{2w} + W$$

$$\frac{\partial (\Phi_0 - \phi) \rho_v}{\partial t} = -\nabla J_{1w} - W$$

$$J_w = J_{1w} + J_{2w}$$

From Eq.(5) and the sum of Eq.(3) and Eq.(4), we obtain the following.

$$\frac{\partial}{\partial t} [(\Phi_0 - \phi) \rho_v + \phi \rho_w] = - \nabla J_w$$

One can get the heat balance equation of a small divided area in porous material, by taki account the phase change heat,

$$\frac{\partial C_p T}{\partial t} = - \nabla q + rW$$

It is well known empirically that vapor moves related to the vapor pressure gradient in material. This fact means vapor movement can be expressed by gradients of temperature an lute humidity if one regards vapor as a function of these two physical parameters. Thus, flu as follows.

$$J_w = -\lambda'_X \nabla X$$

$$q = -\lambda \nabla T$$

$$W = \rho_w \frac{\partial \phi}{\partial t}$$

The next two equations can be derived from Eqs.(6) and (7) with the approximation of $\Phi_0 - \phi$

$$\Phi_0 \frac{\partial \rho_v}{\partial t} + \rho_w \frac{\partial \phi}{\partial t} = \lambda'_X \nabla^2 X$$

$$C_p \frac{\partial T}{\partial t} = \lambda \nabla^2 T + r\rho_w \frac{\partial \phi}{\partial t}$$

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$$\frac{\partial \phi}{\partial t} = \frac{\partial \phi}{\partial X}\frac{\partial X}{\partial t} + \frac{\partial \phi}{\partial T}\frac{\partial T}{\partial t} = \frac{\partial F_X}{\partial X}\frac{\partial X}{\partial t} + \frac{\partial F_X}{\partial T}\frac{\partial T}{\partial t}$$

Here, we use the following notations

$$\kappa = \rho_w \frac{\partial F_X}{\partial X}$$

$$\nu = - \rho_w \frac{\partial F_X}{\partial T}$$

Then, we can derive as follows.

$$\rho \frac{\partial \phi}{} = \kappa \frac{\partial X}{} - \nu \frac{\partial T}{}$$

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at P Tt

(17)

Finally we get the following two equations.

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il@, p' + K Tt v Tt A ',v V- (1 8)

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CP+ /-V) Tt - 1-K Tt = AVT 19)

From enthalpy and vapor mass conservation, one can derive the next two equations **for** crawl space all'.

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Wherein,

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q,@1) = o@I, (TS1,1,1 T) (23)

1 P, (24)

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1 1 + R III + 1/(x) (25)

To add to these equations, we use heat transmittance with the upper **room** Ihi-ou-Lh the floor, as follows.

aT

C,, Tt = A V-T (26)

For the thermal boundary condition, we use **measurement** results on _**ground** temperature at 1 0 cut depth, upper room temperature, and the variation in outdoor **all..** which is **linearly** interpo~ lated with a series of recorded data taken at one ho intervals.

Figure 13 shows the calculation result compared to measurement. Table 1 shows the illonthly average of both results.

Table 1 Monthly average measurement and calculation results

Temperature ['C]	Relative **humility**	'Vapor pressure [Pa]

	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.
May	16.50	16.36	71.90	66.66	1352	1244
June	17.79	17.88	78.55	81.05	1608	1668
July	21.99	21.69	91.49	95.52	2428	2482
August	24.24	23.96	88.75	83.70	-2688	2489

The difference **in** vapor pressure **in** August is conspicuous. The **measurement** result, how-

c,

ever. was affected by the sensor error as mentioned earlier. It is evident that this numerical **model** can express hygro-thermal variation in the crawl space practically. **In** this case, the ventilation rate c, is 7.2 times per hour, which we regard as the standard condition **in** following estimations.

$$\frac{\partial \rho_v}{\partial t} = \rho' \frac{\partial X}{\partial t} \qquad (1$$

Finally we get the following two equations.

$$(\Phi_0 \rho' + \kappa) \frac{\partial X}{\partial t} - \nu \frac{\partial T}{\partial t} = \lambda'x \nabla^2 X \qquad (1$$

$$(C_p + r\nu) \frac{\partial T}{\partial t} - r\kappa \frac{\partial X}{\partial t} = \lambda \nabla^2 T \qquad (1$$

From enthalpy and vapor mass conservation, one can derive the next two equations for crawl :

air.

$$C_p \frac{\partial T}{\partial t} = \frac{q_{SU} + q_{SD}}{h} + C_p V_n (T_{out} - T) \qquad (2$$

$$C'_p \frac{\partial X}{\partial t} = \frac{J_{WSD}}{h} + C'_p V_n (X_{out} - X) \qquad (21$$

Wherein,

$$q_{SU} = K_{floor} (T_{room} - T) \qquad (22$$

$$q_{SD} = \alpha_c (T_{surf} - T) \qquad (23$$

$$J_{WSD} = \alpha'_p (P_{v\,surf} - P_v) \qquad (24$$

$$K_{floor} = 1 / (1/\alpha_c + R_{floor} + 1/\alpha) \qquad (25$$

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1 1 Figure 14 shows the variation in the case ot'\,ariou,,,, ventilation rate. The gray, bold and th in li desi-nate results from the standard, 1/3 tinies rate and 3 tinies rate, respectively. Table 2 shows monthly average for two months.

Table 2 Ventilation effect on monthly average

	July		August	
ventilation rate [times/h]	2.2	21 .6	2.2	22 1 .6
Temperature ['C]	21 1.2 8	22.48	23.59	24.70
Relative humidity [%]	94.87	91.83	88.59	79.01
Vapor pressure [Pa]	18.04	18.75	19.32	1 8.39

It is shown that the increase in ventilation rate improves humidity in August because of temperature difference between the crawl space and the outdoor air. But, it's effect on vapor pressur not so large. It increased in the first week of July, which lead to higher relative humidity,. The decre in ventilation rate improves humidity in July, especially in the first week of July. Thus, it is found in crawl space that actual ventilation rate, the standard rate ill the estlillation, is the most undesirable. also note that the increase in ventilation rate up to 3 tin-les has not enough effect to ensure the dura of wood.

F12ure 15 shows the variation in relative humidity in the case of various thickness of soil cover. array, bold and thin lines designate results for 5 mm (standard), 7 mm and 0 trim thickn respectively. The difference between the 5 nim and 7 **ruin** cases is very little, only remarkable **in** the week of July. But, the difference between covered and uncovered is bib, ill July. This means the cover effect on humidity control of the crawl space all- is validated to the
end of July. In August. the daily average ofthe covered cases is higher than that of the uncovered cases. This is due to evaporation from soil cover.

It is shown that soil covet- decreases the frequency of extremely **high** humidity by leveling the dally variation, but it does riot decrease the amplitude of the daily average in annual variation. Thus, cover is confirmed to improve condensation occurring only at night.

5. CONCLUSIONS

It is found that there is condensation in crawl space in summer due to ventilation exchame outdoor air. What we presented in this paper is an example and a numerical model for this phenom and the effect of soil cover and ventilation for the improvement.

The effect of the soil cover is not enou-h to keep dry in all summer-. It is shown that it decreases daily variation and it does not let be humid in winter.

It is shown that chanae in ventilation rate more or less makes humidity decrease, but in these estimations, we cannot find out the optimal solution that means low enough to ensure the durability of wood material without pouring antiseptic. Optimal ventilation rate depends oil local weather condition. So, we should desicn humidity environment **ill** the crawl space of every house by usliiL, a numerical mo which can express locality, such as the model we validated

REFERENCE

M. Matsumoto et al. 1993, ---An Analysis of Temperature and Humidity Variation **in** Underfloor Space - Comparing with Experimental Results-". CIB/W40 meeting in Sopron

SYMBOLS

CP	heat capacity [Pm3K]
C'	moisture capacity of air [kQ/in'(kc,/k-c,')]

17 height of crawl space [m]

j moisture flux

PO pressure of standard air [Pal

PI vapor pressure [Pal

PIN saturated vapor pressure related to temperature 1 Pal

q heat flux

Rllo(,i thermal resistance of floor [M2 K/W]

Rh relative humidity [%]

1, latent heat from liquid to vapor [J/ko]

In

T temperature ['C]

t time [S]

v *it* ventilation rate [tliiies/s]

W moisture weight of phase changed

X specific humidity [k-/kg'] 0.622 *P,I(P, - P)*

· total heat transfer coefficient [W/in'K]

a(convective heat transfer coefficient [W/in'K]

a' vapor transfer coefficient [k-/m'-s(k(,1k-,,')]

Pit w C

0, maximum pore size

· water content related to volume

K humidity derivative for equivalent water content

heat conductivity [J/m'K]

moisture conductivity related to specific humidity -radiant [k-/iii,@(kL,/kg')]

c

temperature derivative for equivalent water content

p@,. density of water

p, density of vapor

p' density of dry air

SCRIPT

room: upper room

out outdoor air

surf surface of soil cover facine crawl space

lw gas phase

2w liquid phase

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SYMBOLS

C_p	:	heat capacity [J/m3K]
C'_p	:	moisture capacity of air [kg/m³(kg/kg')]
h	:	height of crawl space [m]
J	:	moisture flux
P_0	:	pressure of standard air [Pa]
P_v	:	vapor pressure [Pa]
P_{vs}	:	saturated vapor pressure related to temperature [Pa]
q	:	heat flux
R_{floor}	:	thermal resistance of floor [m²K/W]
Rh	:	relative humidity [%]
r	:	latent heat from liquid to vapor [J/kg]
T	:	temperature [°C]
t	:	time [s]
V_n	:	ventilation rate [times/s]
W	:	moisture weight of phase changed
X	:	specific humidity [kg/kg'] (= 0.622 $P_v/(P_0 - P_v)$)
α	:	total heat transfer coefficient [W/m²K]
α_c	:	convective heat transfer coefficient [W/m²K]
α'_m	:	vapor transfer coefficient [kg/m²s(kg/kg')]
Φ_0	:	maximum pore size
ϕ	:	water content related to volume
κ	:	humidity derivative for equivalent water content
λ	:	heat conductivity [J/m³K]
λ'_x	:	moisture conductivity related to specific humidity gradient [kg/ms(kg/kg')]
ν	:	temperature derivative for equivalent water content
ρ_w	:	density of water
ρ_v	:	density of vapor
ρ'	:	density of dry air

SCRIPT

room	:	upper room
out	:	outdoor air
surf	:	surface of soil cover facing crawl space
lw	:	gas phase

(a) **Traditional house in Nara prefecture**

(b) **under floor structure**

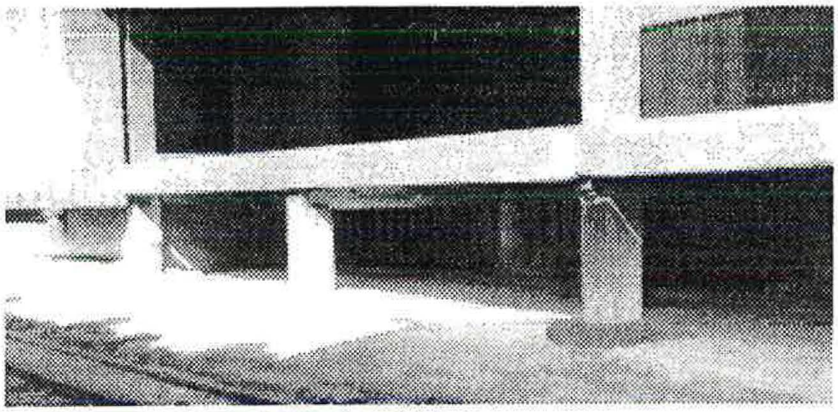
(c) modern house

holes on concrete foundation are for ventilation

Figure 1 Typical traditional house and modern house in Japan

It is well known that our ancestor have made house with wood and soil. Japanese houses have greatly changed with deriving insulation and wood board in last three decades. These make void space between inside and outside, which has original environment of various physical factors.

(a) Traditional house in Nara prefecture



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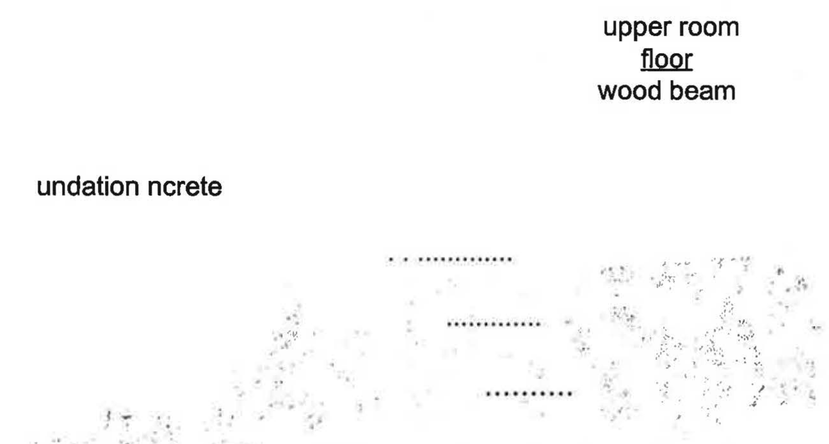


Figure 2 Standard construction of crawl space

Japanese architectural codes dictate vapor barrier on the ground and ventilation with outdoor in order to ensure durability of wood material

Figure 3 Water on vapor barrier

These scene is continued to whole over the house. Wood material in the crawl space are poured preservative against corruption, but it is difficult to enssure a long-term effect under the wet condition shown in this figure.

Figure 4 Water drops on surface of floor

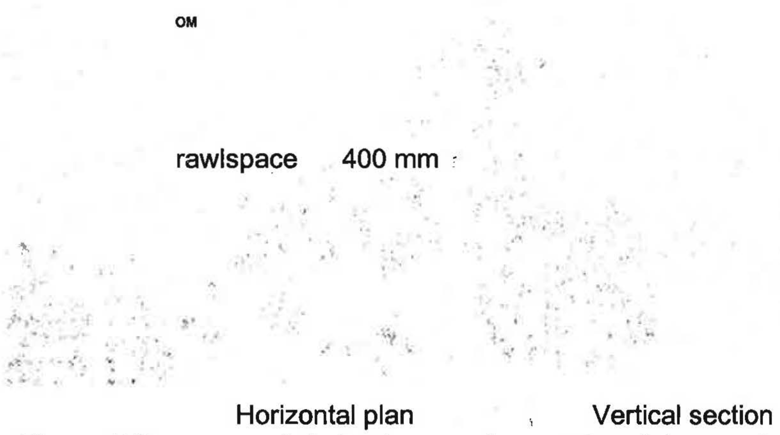
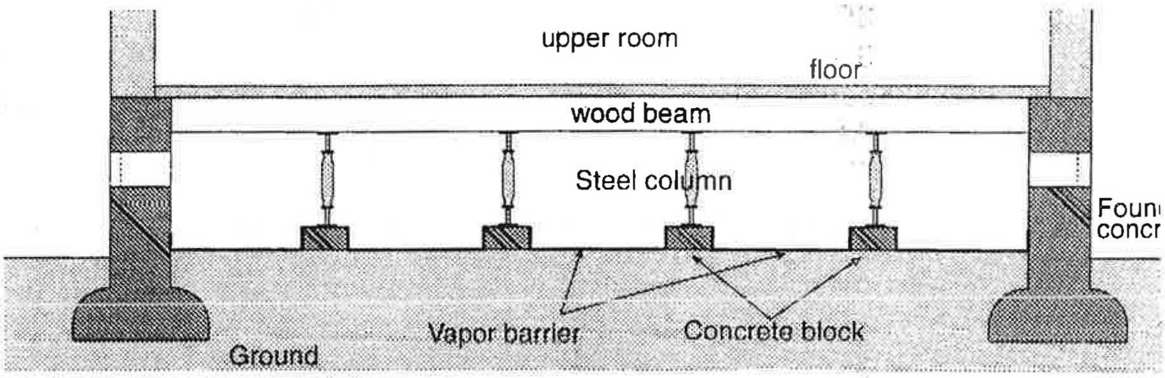


Figure 5 Measure points for temperature and moisture variation in crawl space



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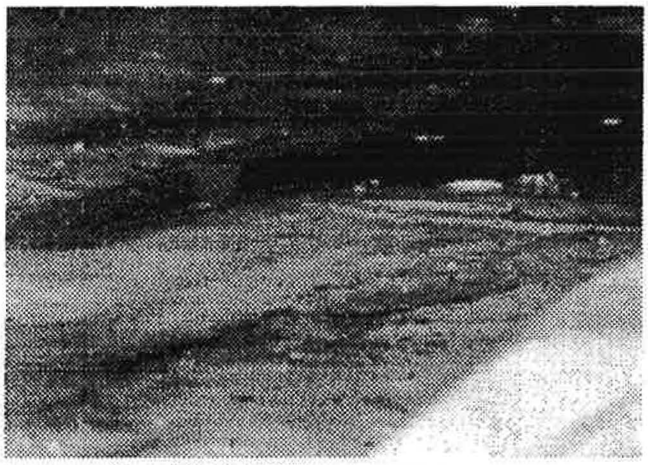

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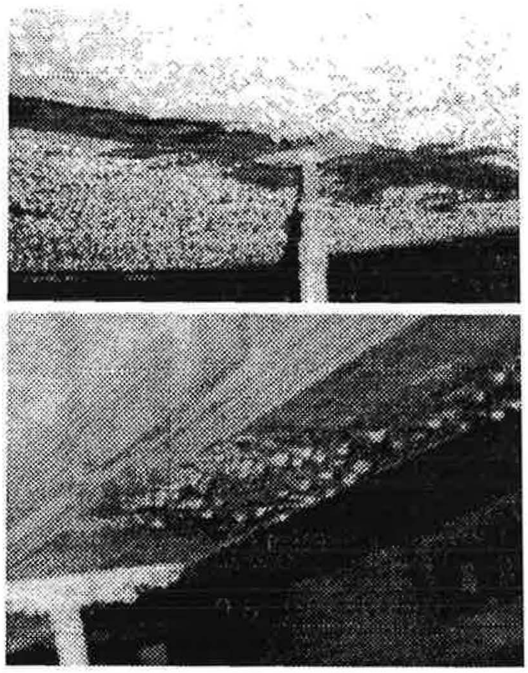
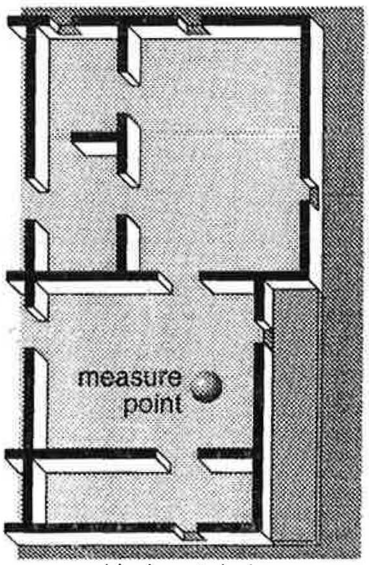
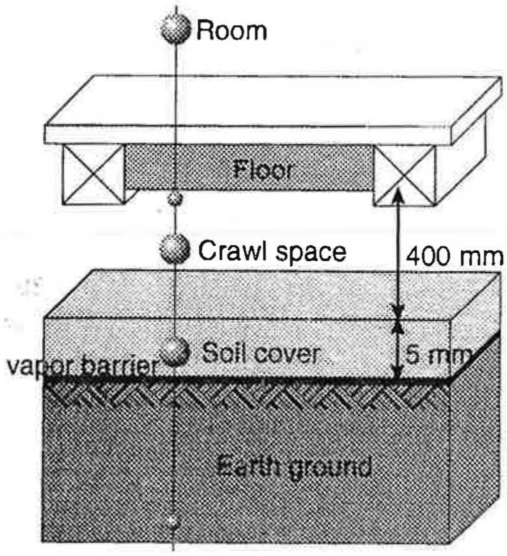


Figure 4 Water drops on surface of t





Horizontal plan

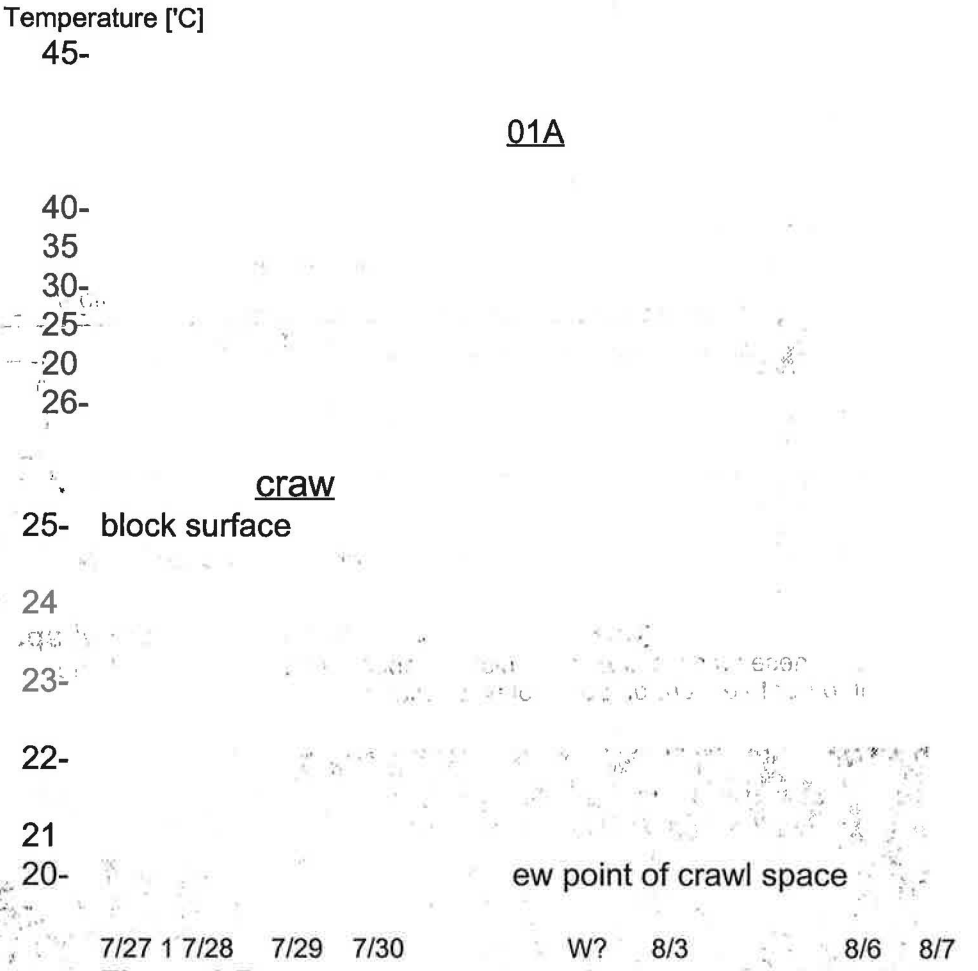


Figure 6 Pre-measurement result : temperature variations

Abscissa shows time elapse. One scale means one day. Ordinate shows temperature in degree Celsius scale. Dew point temperature is calculated bye recorded temperature and humidity of the space, by using relation between saturated vapor pressure and temperature.

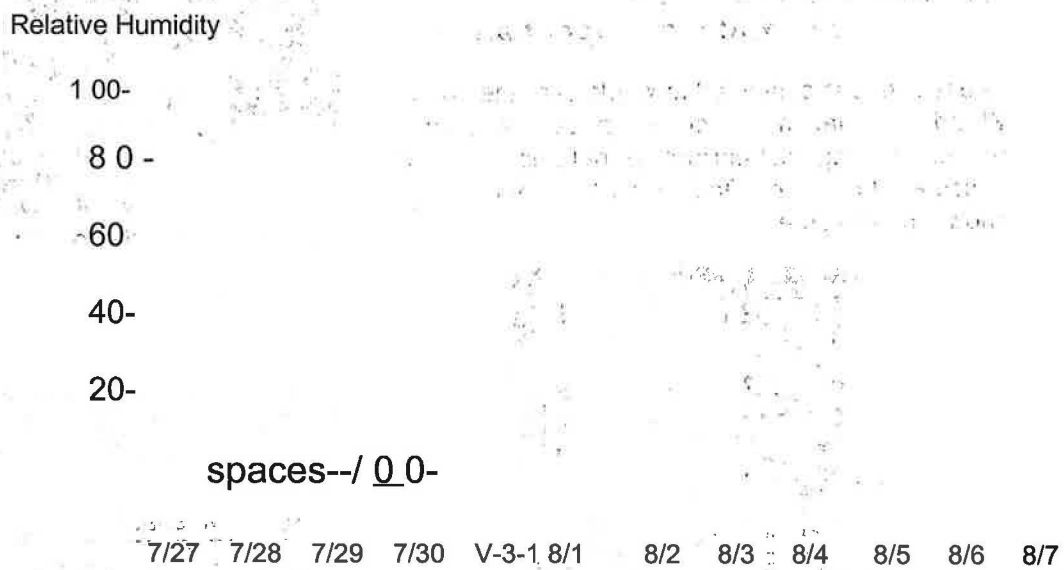


Figure 7 Pre-measurement result variations of relative humidity

Ordinate shows relative humidity. In contrast to variation of outdoor air whose daily average varies in c. 60 - 70 % range, crawl space humidity goes above 90 % and achieves to 100 % in first week of August. Values of over 1 00 % are due to sensing error.

Vapor pressure [Pa]

3500-

3000-

2500-

2000-

1500-

1000-

500-

0

7/27 7/28 7/29 7/30 7/31 8/1 8/2 8/3 8/4 8/5 8/6 8/7

Figure 8 Pre-measurement result variations of vapor

Ordinate shows vapor pressure, which is calculated by recorded temperature and humidity

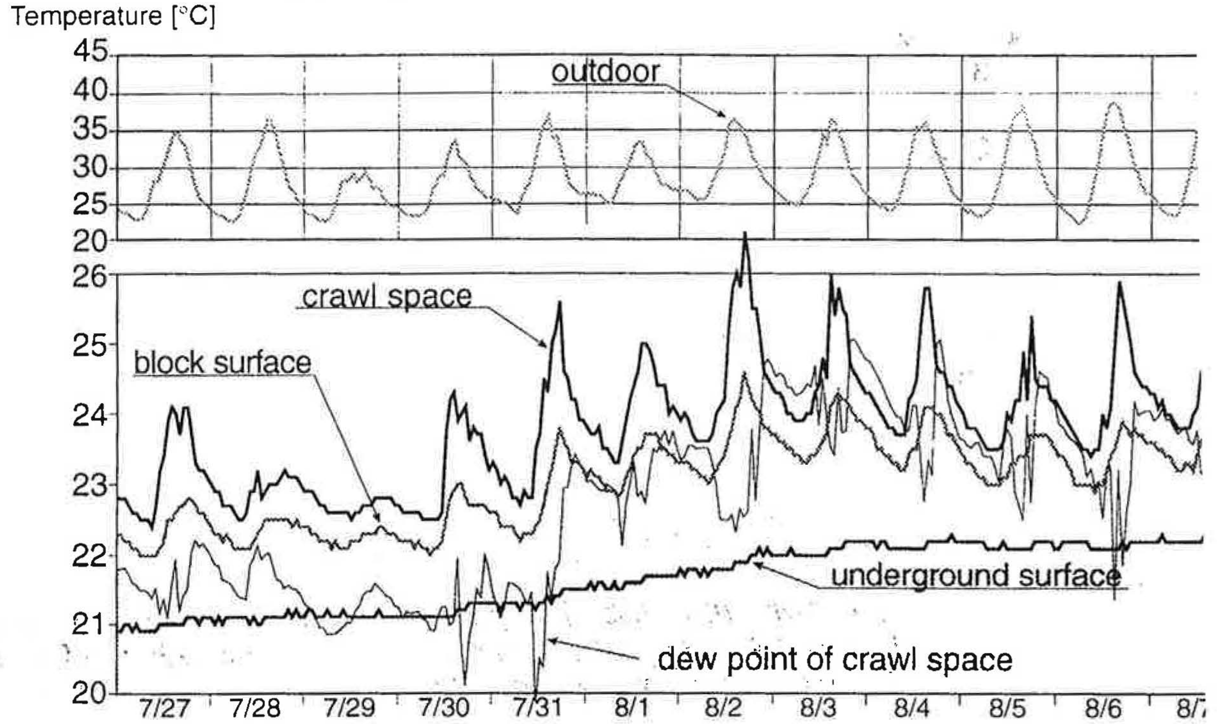
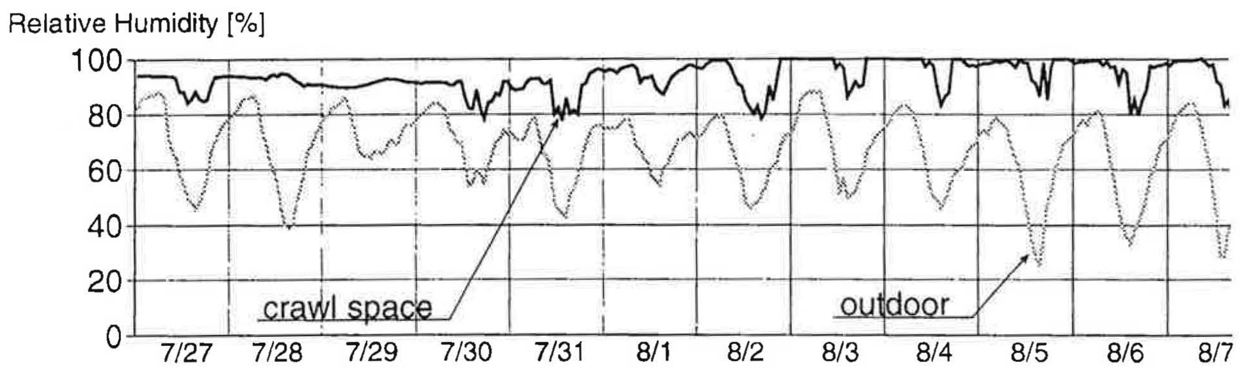


Figure 6 Pre-measurement result : temperature variations

Abscissa shows time elapse. One scale means one day. Ordinate shows temperature in degree scale. Dew point temperature is calculated bye recorded temperature and humidity of the space, t relation between saturated vapor pressure and temperature.



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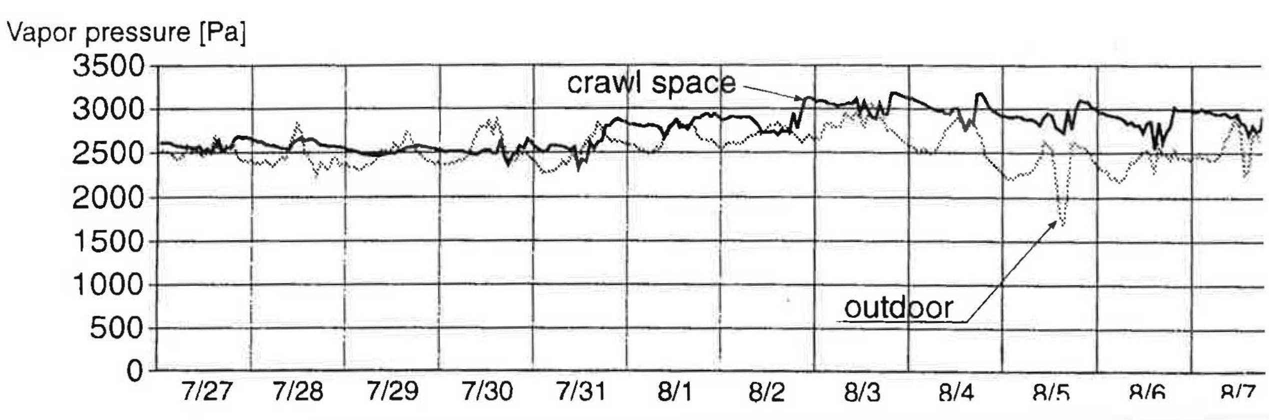


Temperature [OC]
35

30 1

25

20

15

10

TT cra@

5 May Jun. Ay. Aug. Sep.

Figure 9 Monitored result with soil cover Variation of temperature

Relative humidity [%]

100 crawl

90

80

70

60

50

40

30 -

20

MaAl Jun. Ay. Aug. Sep.

Figure 10 Monitored result with soil cover Variation of relative humidity

Vapor pressure [Pal

3500

space

3000

2500

2000

1500

1 0

5

r air

May Jun. Aug. Sep.

Figure 11 Monitored result with soil cover Variation of vapor pressure

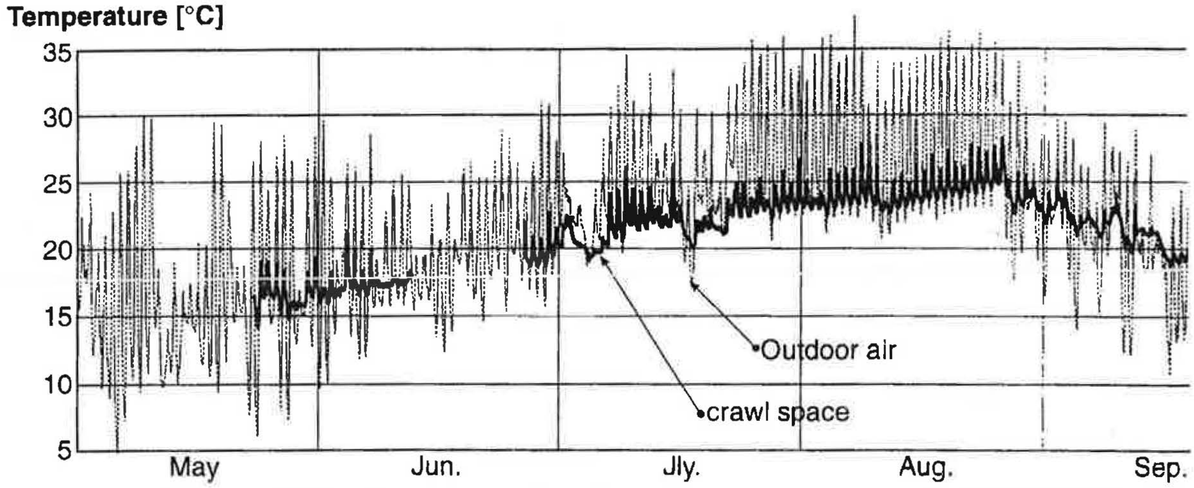


Figure 9 Monitored result with soil cover : Variation of temperature

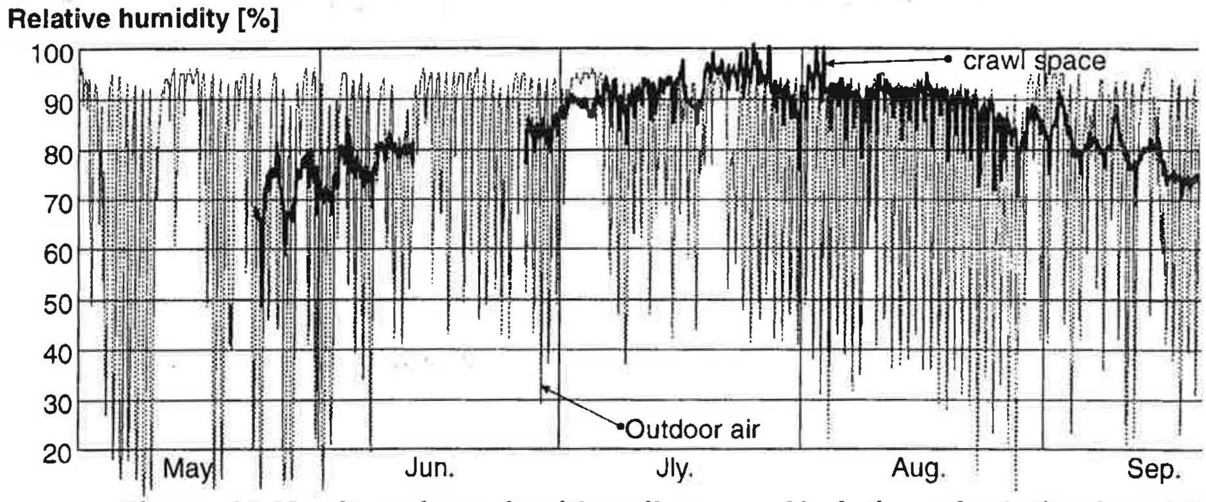


Figure 10 Monitored result with soil cover : Variation of relative humidi

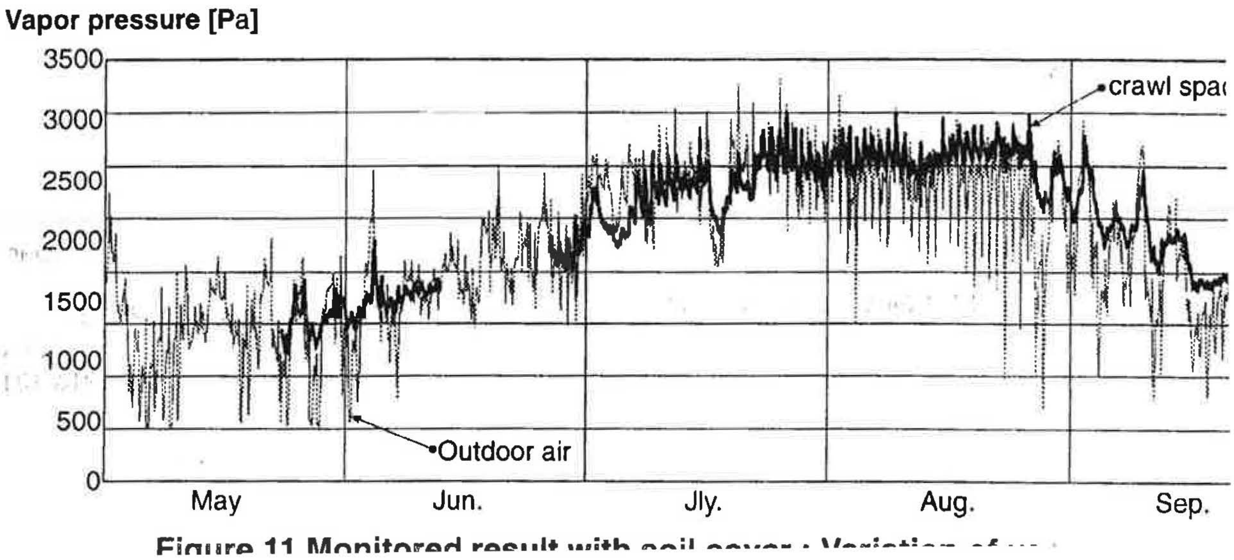
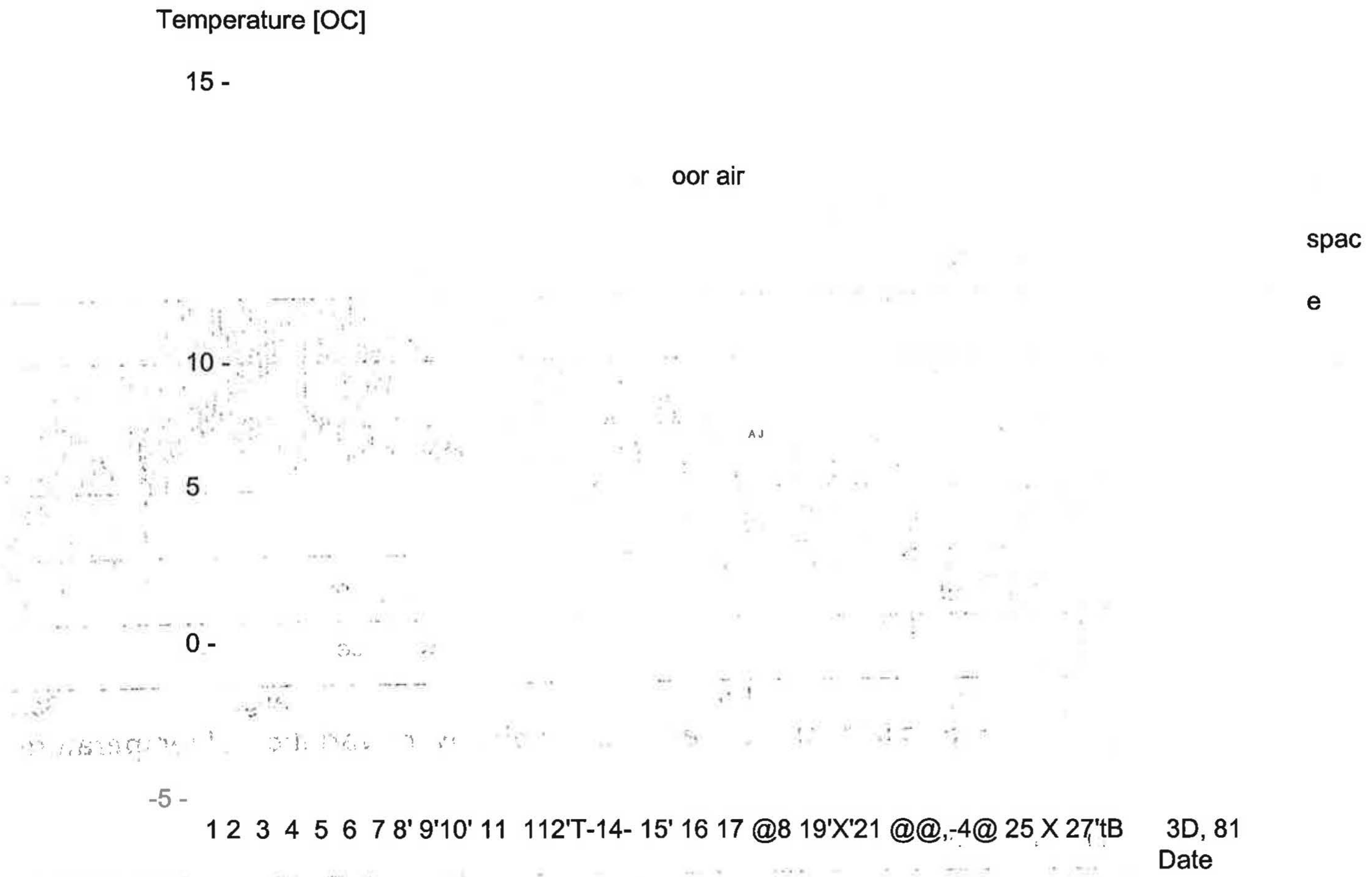
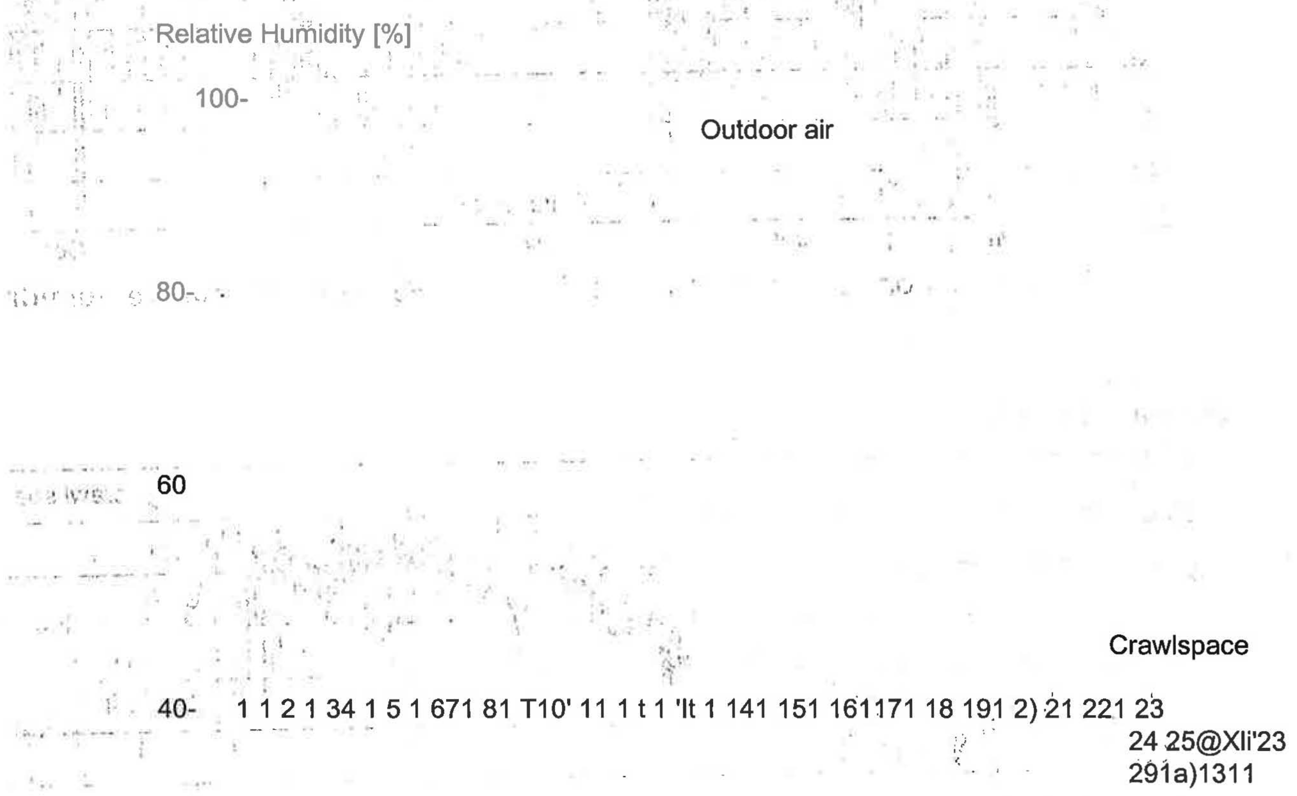


Figure 11 Monitored result with soil cover : Variation of



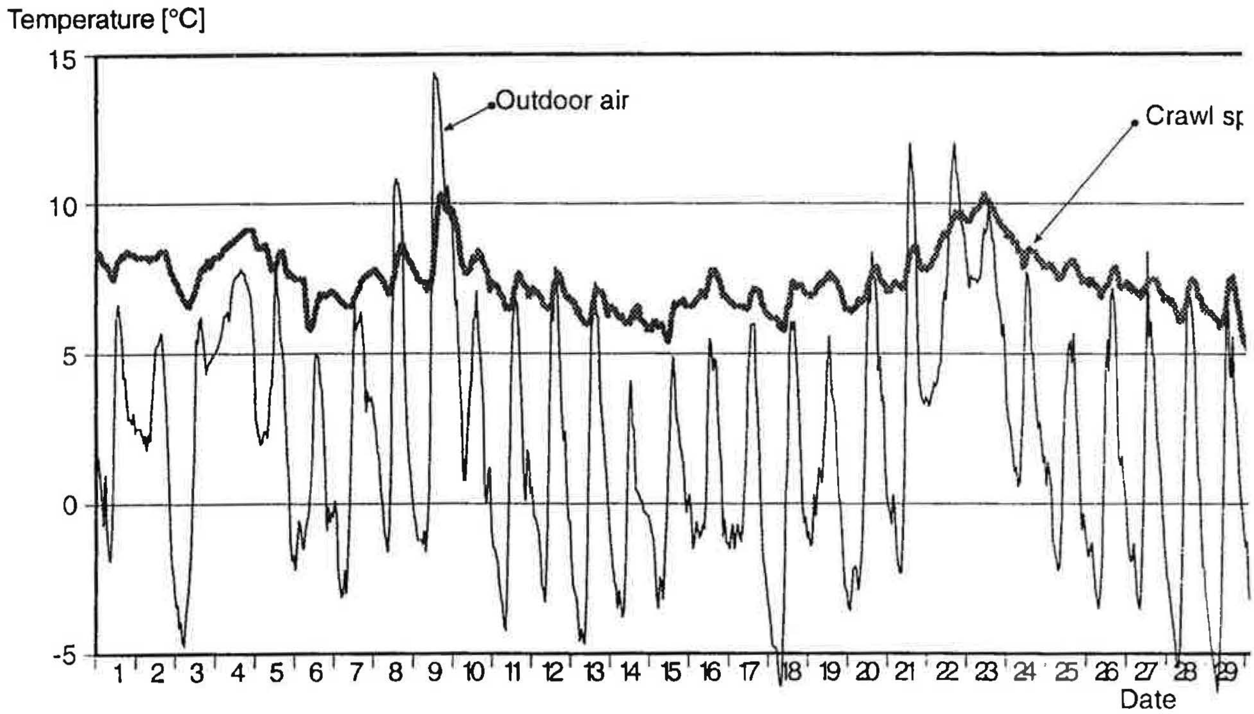
(a) Variation in temperature



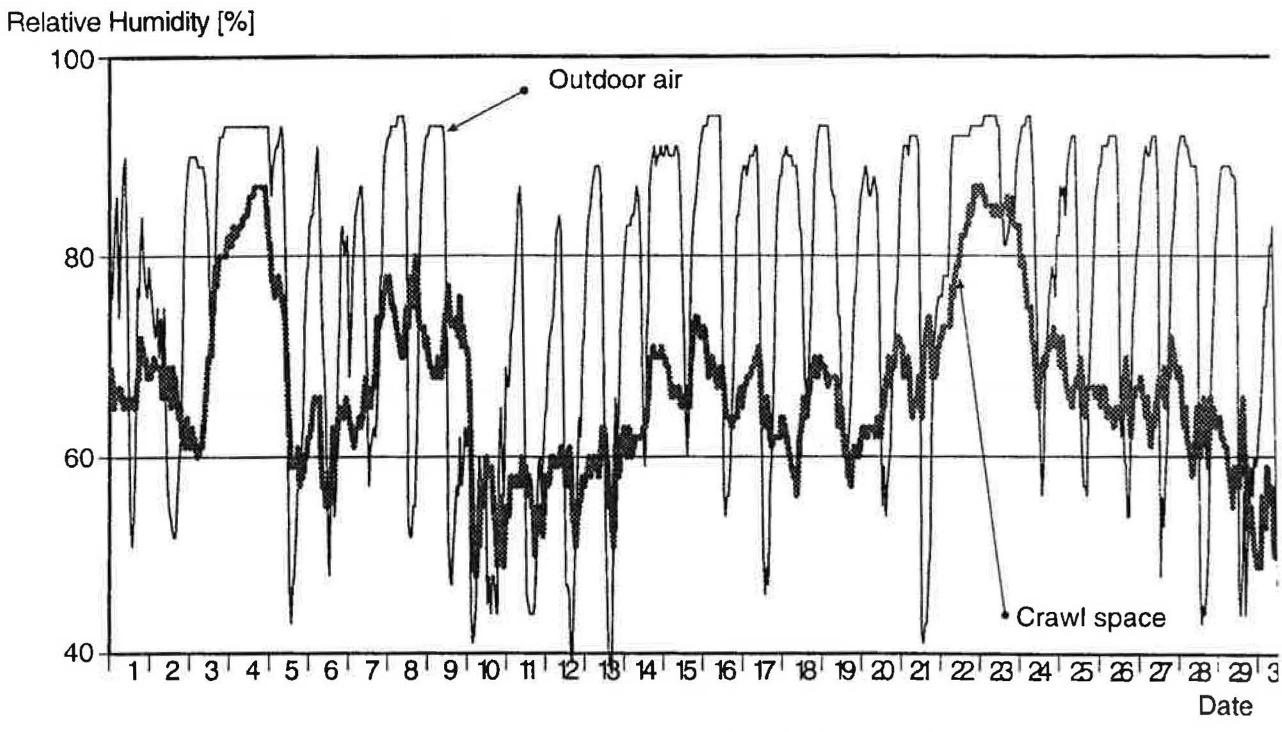
Date

(b) Variation in relative humidity

Figure 12 Monitored result with Soil cover : January 95



(a) Variation in temperature



(b) Variation in relative humidity

Figure 12 Monitored result with soil cover : January 95

Temperature [OCI

30

Measur

25
20

Ca culated
Jun. Aug.

Figure 13 (a) Comparison between calculated and measured temperature

Relative humidity [%]
1OC

90 sm

50

May Jun. Ay. Aug.

Figure 13 (b) Comparison between calculated and measured relative humidity

Vapor pressure [Pal
3000

2500

2000

1500

1000 Caict

Tay Jun. Au

Figure 13(c) Comparison between calculated and measured vapor pressure

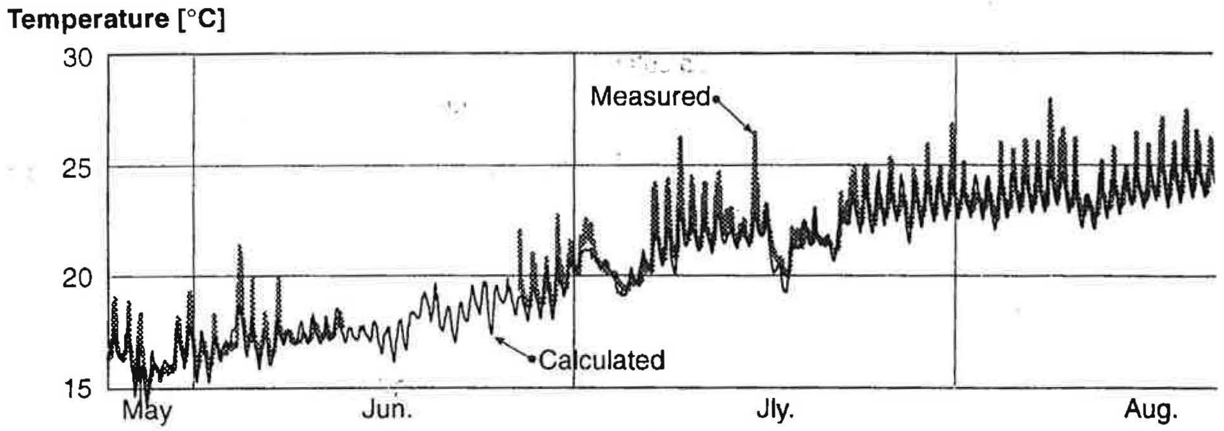


Figure 13 (a) Comparison between calculated and measured temperat

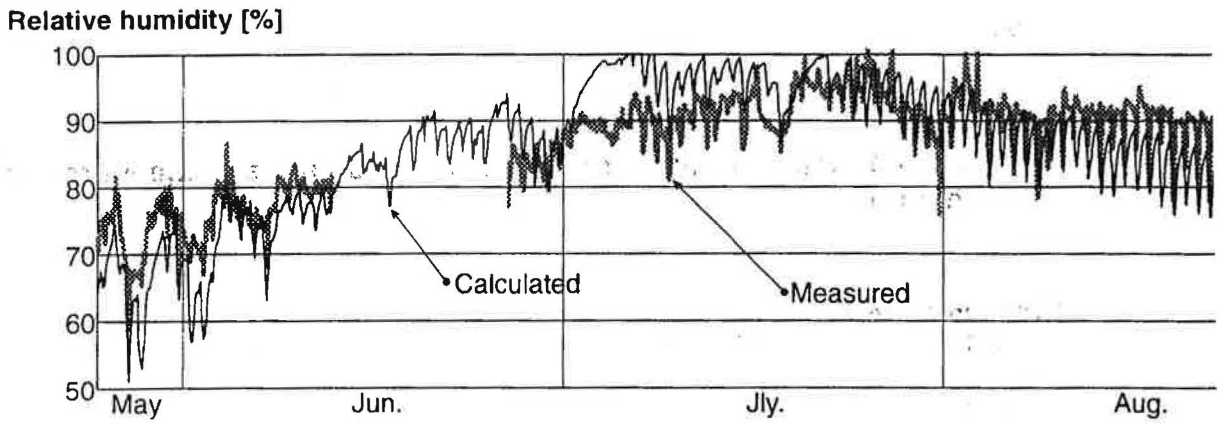


Figure 13 (b) Comparison between calculated and measured relative humi

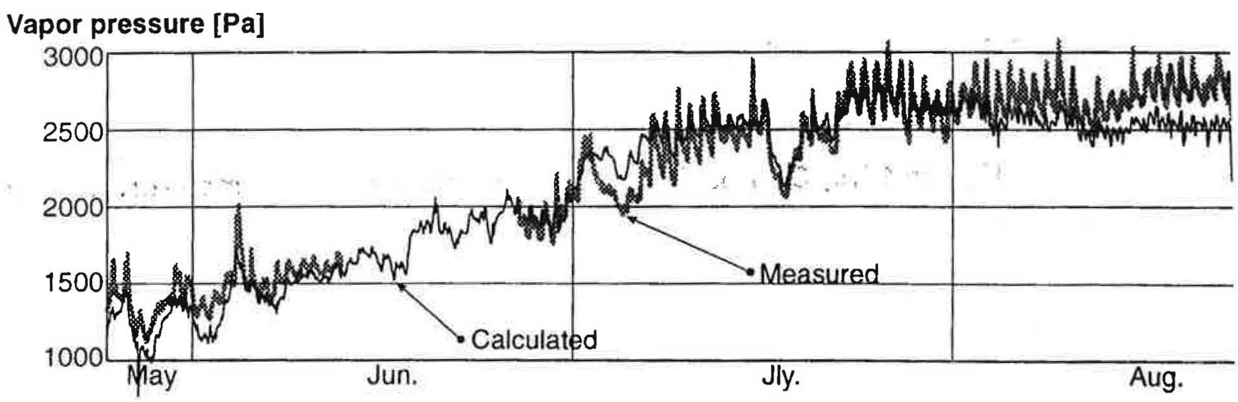


Figure 13(c) Comparison between calculated and measured vapor pressur

Figure 14 (a) Effect of ventilation Variation in temperature

Figure 14 (b) Effect of ventilation Variation in relative humidity

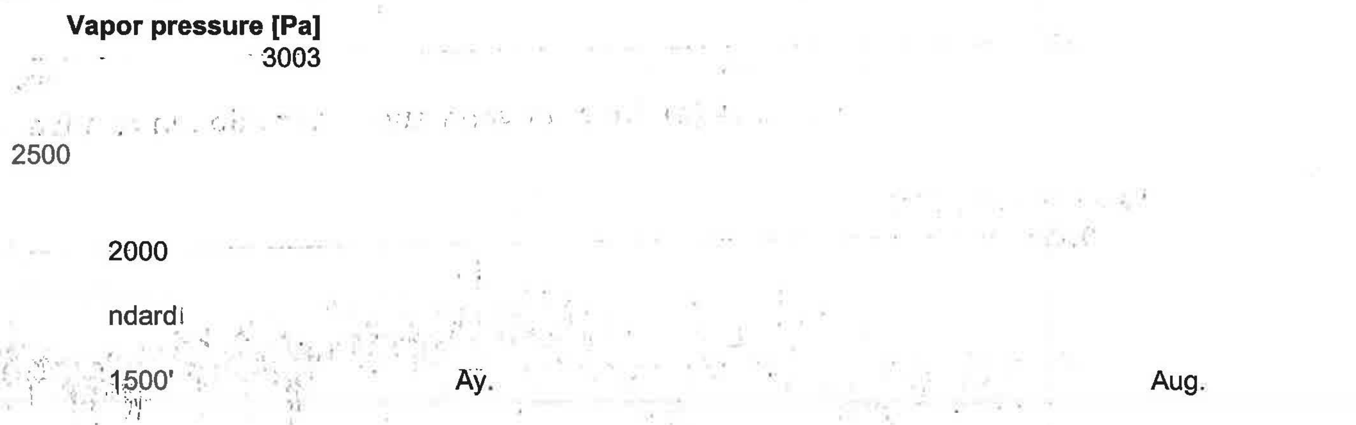


Figure 14 (c) Effect of ventilation Variation in vapor pressure

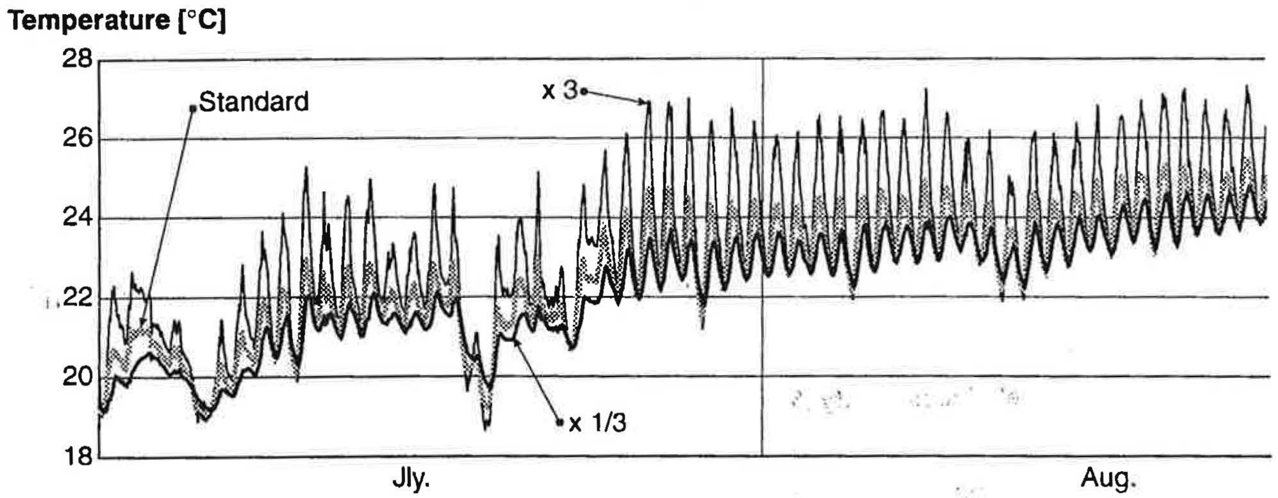


Figure 14 (a) Effect of ventilation : Variation in temperature

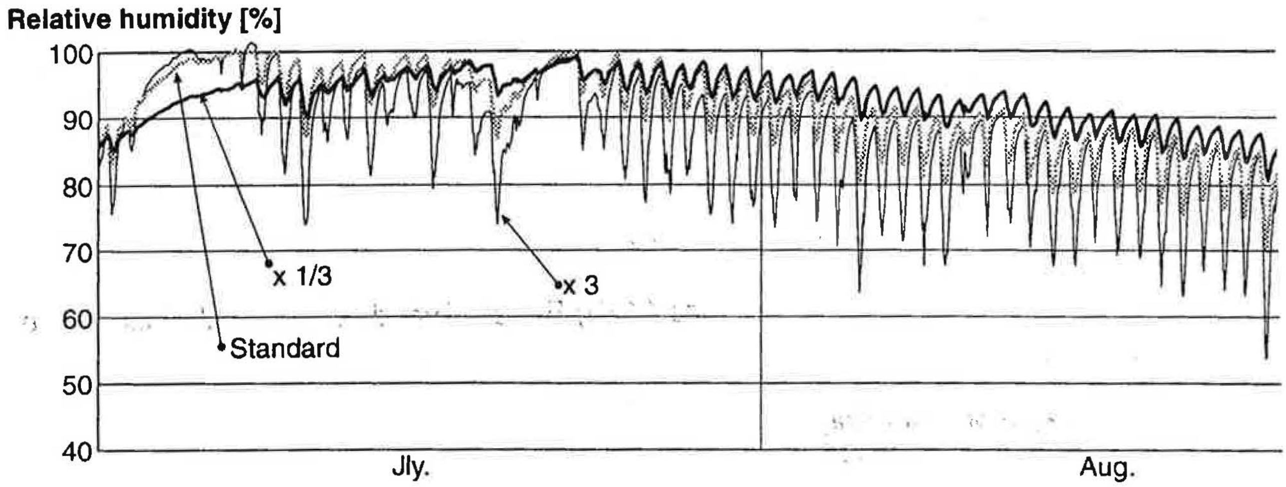


Figure 14 (b) Effect of ventilation : Variation in relative humidity

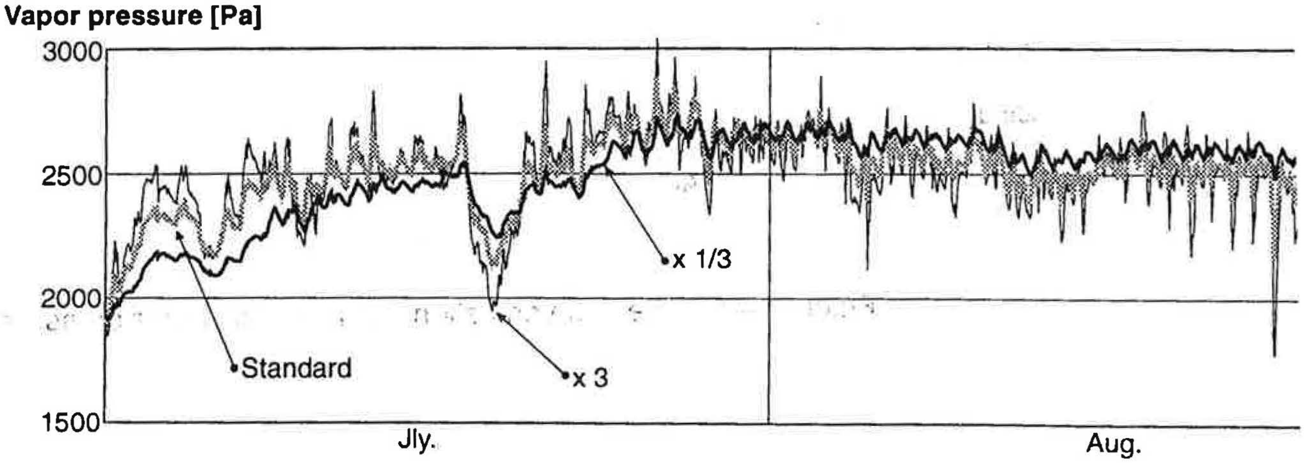


Figure 14 (c) Effect of ventilation : Variation in vapor pressure

Relative@h,A4

1 00

90

80

Omm

70

5mm Standard)

60

\7.5mm

50

40

30 1 2' 3' 4 5 6' 7' 8' 9 ' 10' 11' 12' 13'14' 15' 16' 17 22'23' 24

July

Relative humid ty

loo

7.5

J

90

80

70

60

50

40

m

nclard

30 'I'2'3'4'5 6'7'8' 27'28'22 301 31

Figure 15 Effect of thickness of soil cover

Ordinate shows relative humidity. In this numerical model, vapor mass conservation of crawl space is only affected by outdoor air through ventilation, if there is no soil cover. Thus, the variation in vapor pressure is almost equal to that of outdoors.

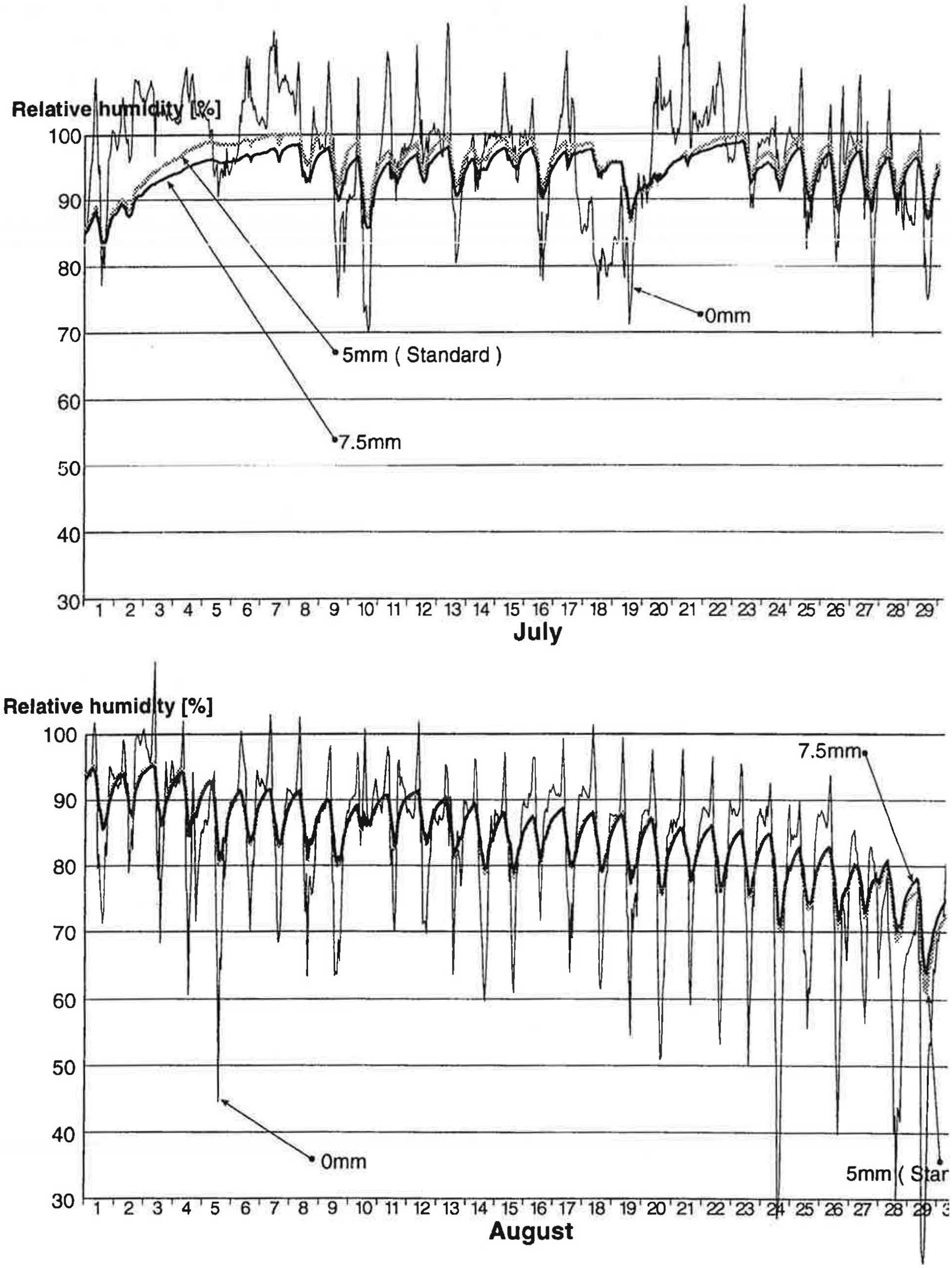


Figure 15 Effect of thickness of soil cover

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