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Report
on
Humidity transport in unventilated roofs

1. Short summary:

From 1986 til 2011 we have analysed strength and physical properties of unventilated roof elements produced by Lett-Tak A/S in Norway. The reason for the study was obtaining general approval for use in Iceland. In march of 2000 the **Icalandic Building Research Institute**, now **Nýsköpunarmiðstöð Íslands** issued an approval and renewed it later where unventilated Lett-Tak roof elements are allowed over swimming pools.

In Iceland the summers are short and there was considerable scepticism that humidity accumulated during winter inside unventilated roof would dry out during the short and rather cold summers.

The results are positive. Unventilated roofs are suitable for Icelandic conditions. Sunshine plays an important role in heating the roof surface.

The study has continued in collaboration with the the **Icelandic Building Research Institute**, **Línuhönnun Consulting Engineers** and the **Icelandic Meterological Institute**. In this report we summarize the results.

2. Measuring humidity in plywood:

Specimens of plywood from the top of the roof element were taken and %humidity by dryweight was measured. When humidity goes over 22% to 24% the risk of rotting of wood begins when the temperature is over 5°C.

Results:

2.1

Time	Building	Sample no.	Humidity % of dryweight	How roof is built
January 1999	Shopping center Kringlan Built 1986	KR1K	12,4%	Lett-tak roof elements of type II (See table 2 on page 11)
		KR2K	12,8%	
		KR3K	13,7%	
		KR4K	13,5	

2.2	Time	Building	Sample no.	Humidity % of dryweight	How roof is built
	January 1999	Sportshall Smárinn built 1993	SM1K	13,2%	Lett-Tak roof elements of type I (see table 2 on page 10)
			SM2K	13,3%	
			SM3K	14,7%	
			SM4K	15,1%	
			SM5K	14,8%	
			SM6K	15,4%	
	August 1999	Sportshall Smárinn built 1993	SM1	11,4%	
			SM2	9,2%	
			SM3	10,5%	
			SM4	10,5%	
			SM5	10,2%	
			SM6	9,7%	

2.1 and 2.2 measured by Línuhönnun Consulting Engineers

The measurements from January and August 1999 are in the same roof elements and therefore give actual winter and summer values for the roof. The moisture in the outer part of the roof moves closer to the inside on summer days. 6 years after the building period, the roof is in equilibrium with the surroundings at the measured points.

2.3	Time	Building	Sample no.	Humidity % of dryweight	How roof is built
	July 1993	Shopping center Kringlan Built 1986	1	11,9%	Lett-Tak roof elements of type II
			2	11,0%	
			3	12,2%	
			4	12,2%	

2.3 Measured by The Icelandic Building Research Institute

2.4					
	April 1999	Sportshall KR built 1998	IKR1K	23,5%	Lett-Tak roof elements of type II
			IKR2K	12,6%	
			IKR3K	12,4%	
			IKR4K	11,8%	
	May 2002	Sportshall KR built 1998	IKR1K	11,6%	Lett-Tak roof elements of type II
			IKR2K	10,1%	
			IKR3K	9,4%	

2.4 Measured by Línuhönnun Consulting Engineers

The measurement from 1999 had humidity from the building period. A new measurement 3 years later shows that the roof has dryed out 4,7 % on the average, from 15,1% to 10,4%.

In may 2002 the outside temperature was 13°C on a sunny day, and the temperature under corrugated steel was 19°C. The sun must have had a large role in the fast drying.

The results of a report from Linuhönnun Consulting Engineers "Lett-Tak þakeiningar, útreikningur á rakabúskap" (Lett-Tak roof elements, calculations of moisture behaviour), was that for such a roof it would take 21 years to dry out from 20% to 12%, when no humidity was added from inside.

Those calculations, according to Ficks law, used monthly average outdoor temperatures, measured in Reykjavik by the Icelandic Meterological Institute in 1971-1980.

On a sunny day the temperature over the roof surface is higher than assumed in the calculations and therefor the moisture dryout is faster which makes the calculations rather on the safe side.

Under the elements there is a vapour barrier; but also, 40% of the area is covered with steel plates. There are indications that only the remaining 60% of the area transport moisture into the elements. ***Enclosure 1*** shows a section of a Lett-Tak roof element.

3. Indoor climate

Indoor temperature and humidity was measured in a number of buildings. The result is that those buildings are warm and dry. All those buildings have ventilation systems where air from the outside is warmed up and blown into the house. On ***chart 2*** on page 4, one can see the effect during a 3 hour power outage. Of course this is harmless for such a short time but it also shows that the ventilation is vital.

Chart 1
Indoor climate, Shopping center Kringlan

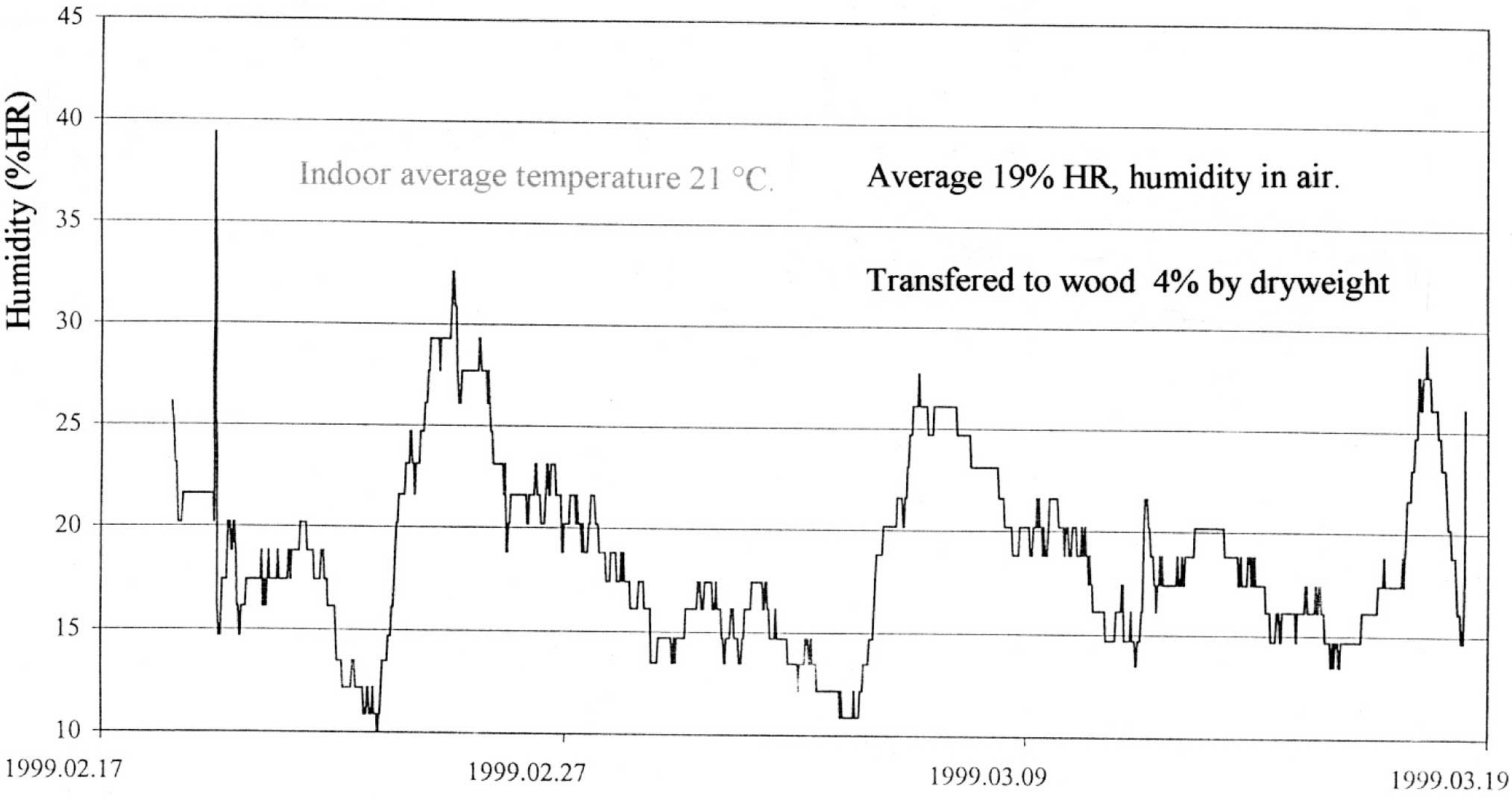
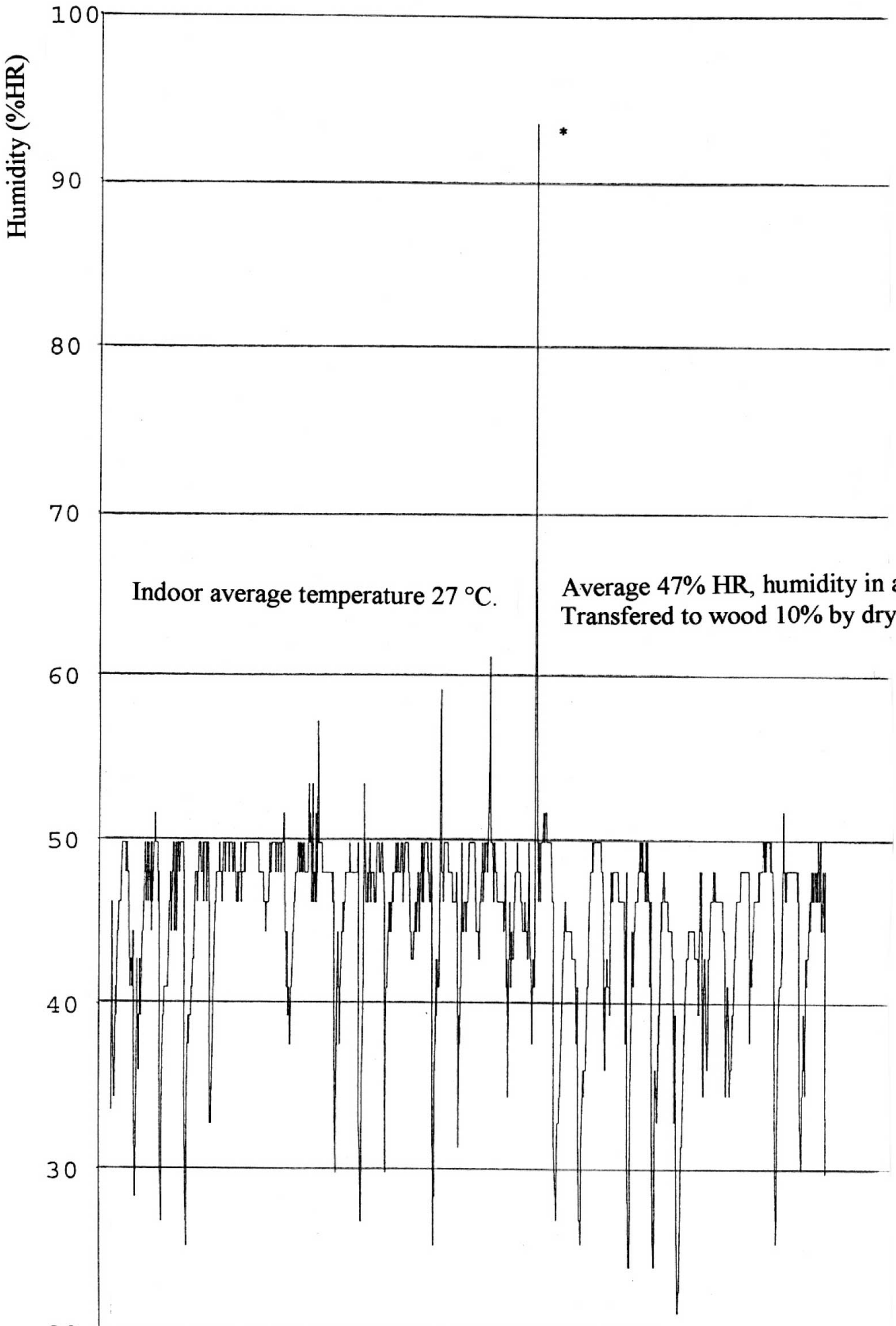


Chart 2

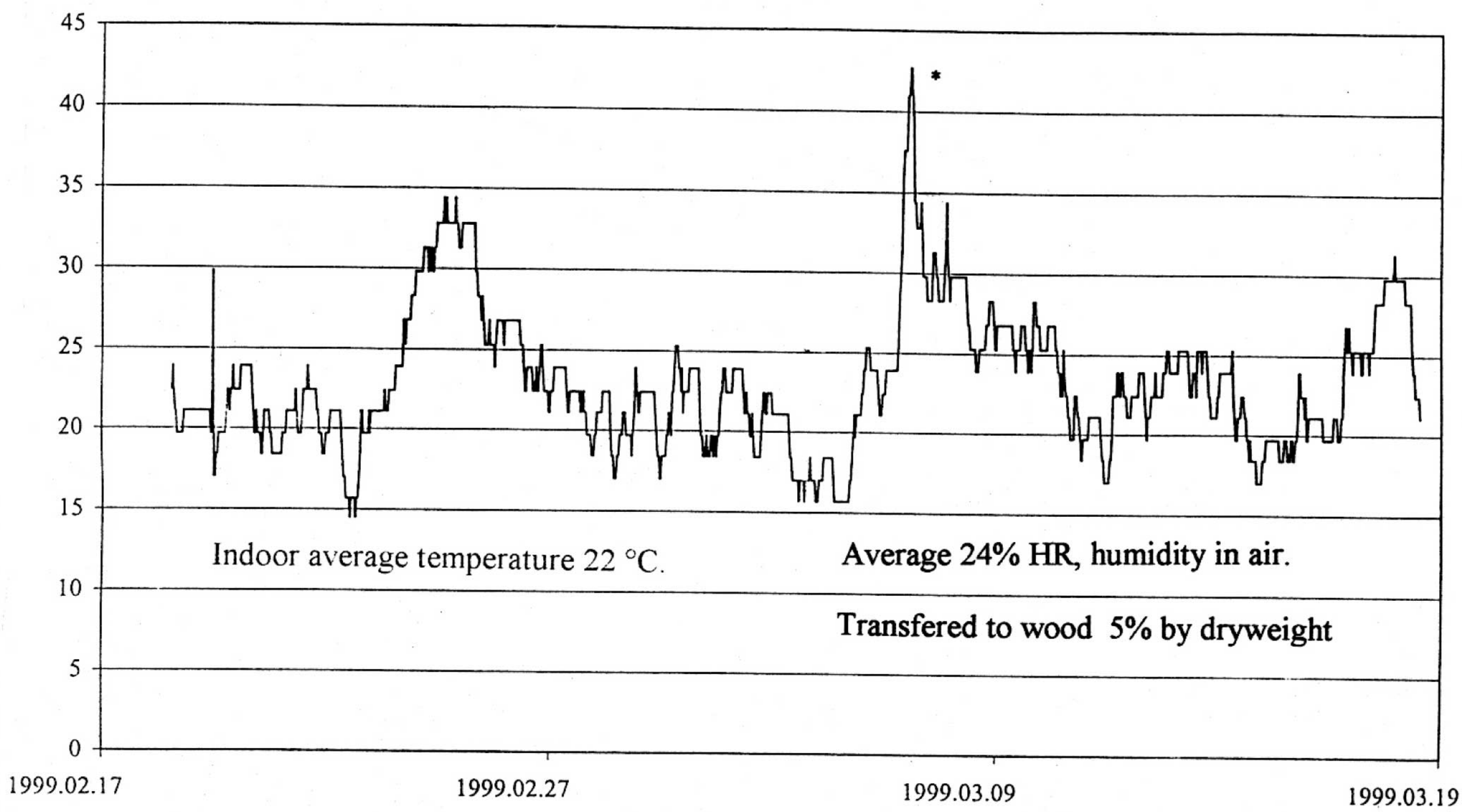
Indoor climate, Swimming hall, Háleitisbraut 11-13 Reykjavík



** 3 hour power outage*

Chart3

Indoor climate, Sportshall Kaplakriki



** Feast day of Hafnarfjörður town with dance and drinks*

Measurements show an indoor temperature on the average over 20C°, perhaps because of the relatively cheap thermal heating available in Iceland

Examples of humidity measurements:

	Humidity % HR (humidity in air)	Transfered to Wood (% of dryweight) *
Sportshall	24%	5%
Shopping center	19%	4%
Swimming hall	47%	10%

* See ***Enclosure 2*** for transfering % in air to % in wood.

See ***chart 1***, ***chart 2*** and ***chart 3*** as an example of results.

The Icelandic Building Research Institute has measured the indoor climate in apartment buildings.

Reference 1.2, "Rakamælingar í íbúðum " (Humidity measurements in apartments). These buildings are ventilated by opening windows. (Or not ventilated if windows are kept closed .) The measurements showed very high humidity in some instances such as when windows were kept closed for a long time, sudden cooling by opening windows, etc.

Chart 4 and chart 5 below show an example of measurments in an apartment. In the report from 1999 ,"Loftræstingar í íbúðarhúsum" page 5 the conclusion states: *From the measurements it seems prudent to calculate 2 g/m^3 moisture addition in (icelandic) apartments in wintertime.*

Chart 4 Indoor climate, apartment

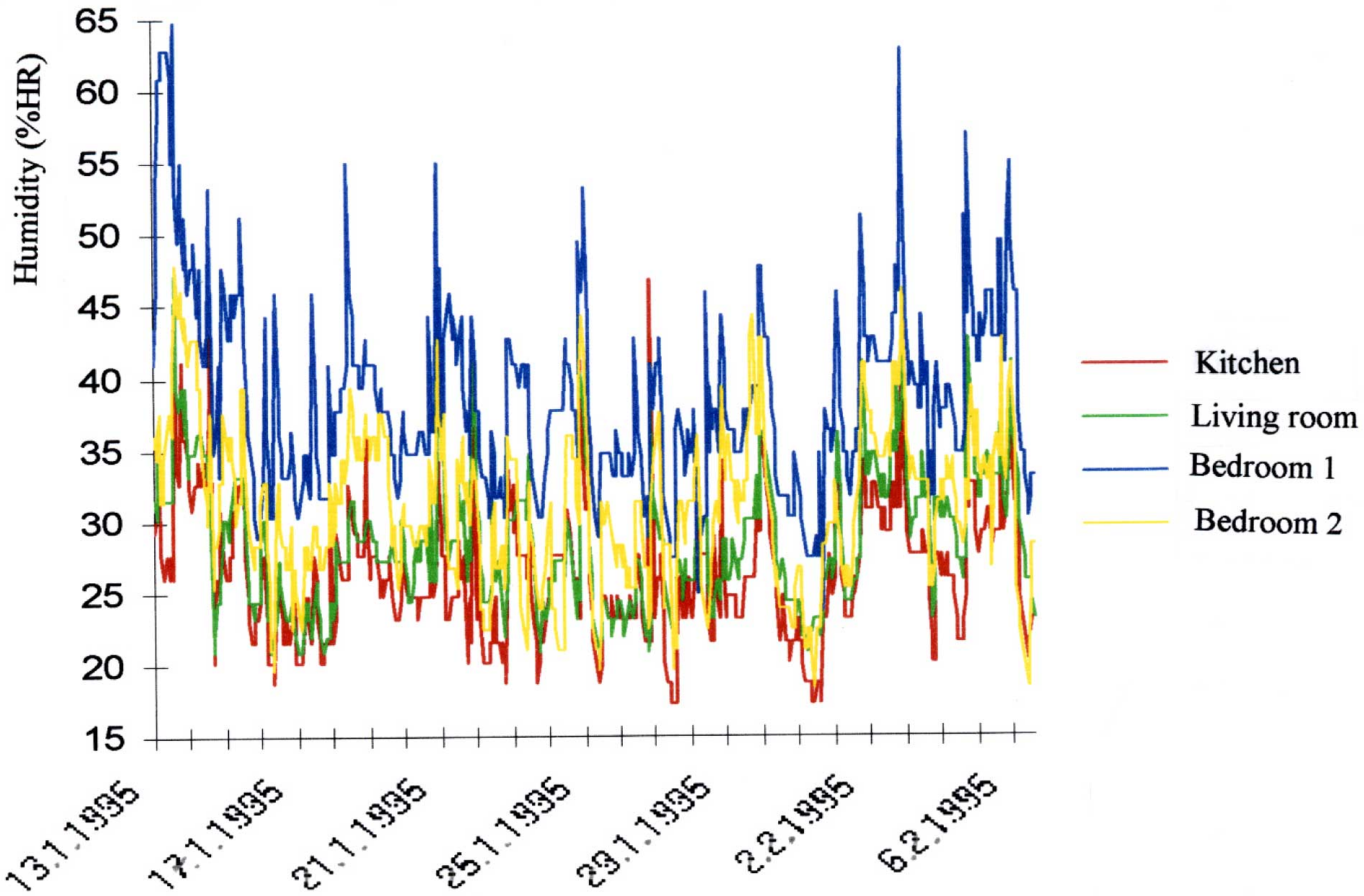
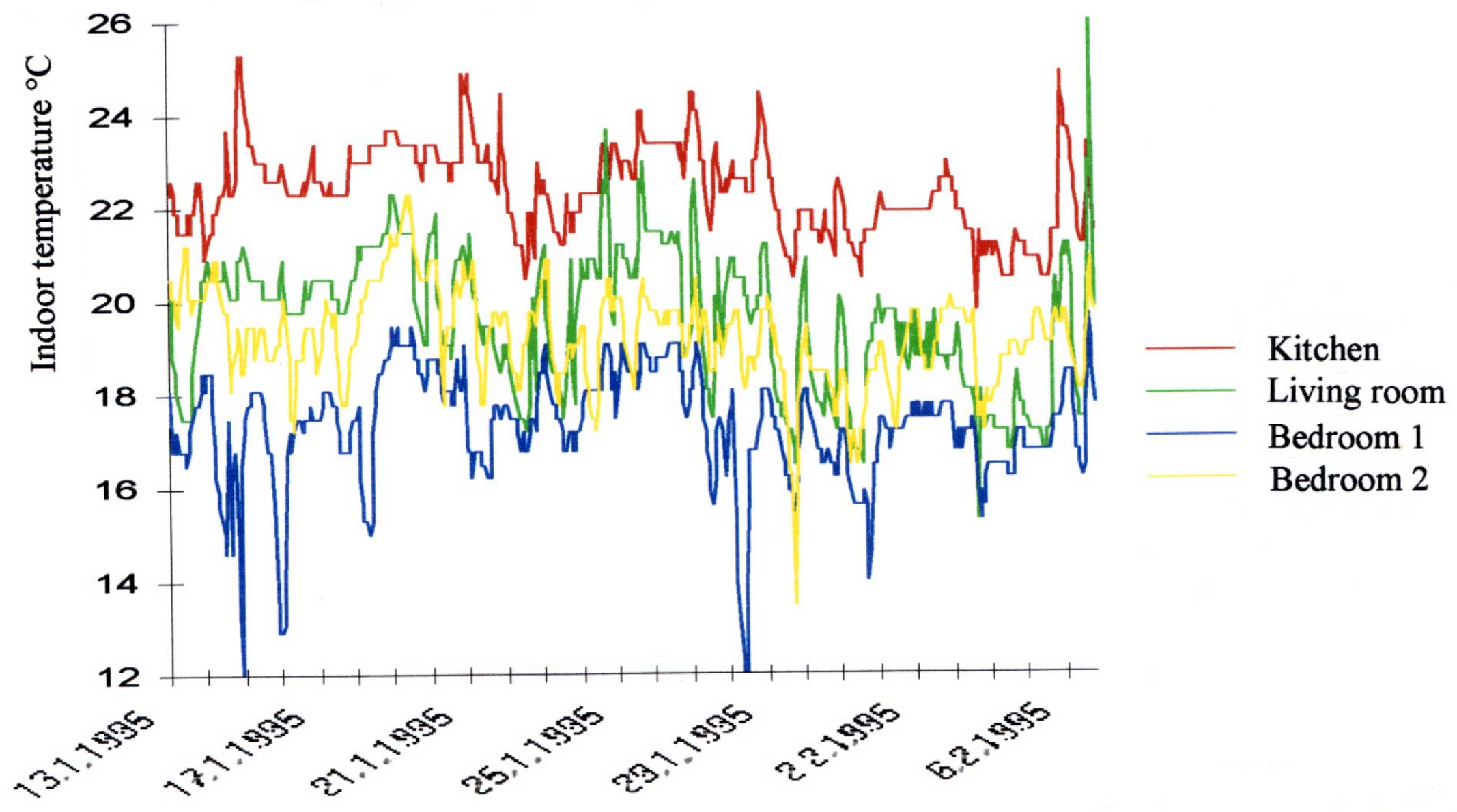


Chart 5 Indoor climate, apartment



4. <u>Humidity inside the roof</u>

Mesurements inside the roof show humidity transfer, especially when the sun heats the surface. On ***chart 6*** below one can see that during winter the sun heats the light grey surface 1,7°C over outdoor temperature.On ***chart 7*** (see page 8) one can see that the average temperature under dusty black bitumen is 8°C higher than the average outdoor temperature and the temperature of the dark bitumen reaches up to 48°C on a sunny day when the measured outdoor temperature is about 10°C. C***hart 8*** (see page 9), shows summer values compared to winter values on ***Chart 8*** and there is nearly the same difference or 8,7°C instead of 8°C. *The sun has the same effect the whole year.*
On ***chart 9*** , (see page 10) one can clearly see how quickly humidity conditions, move from the outer to the inner part of the roof when the sun shines and back again when the surface cools off at night.

Chart 6 Roof in Reykjavík (Ármúli 8)
Lett-Tak roofelements, unventilated Heat transfer

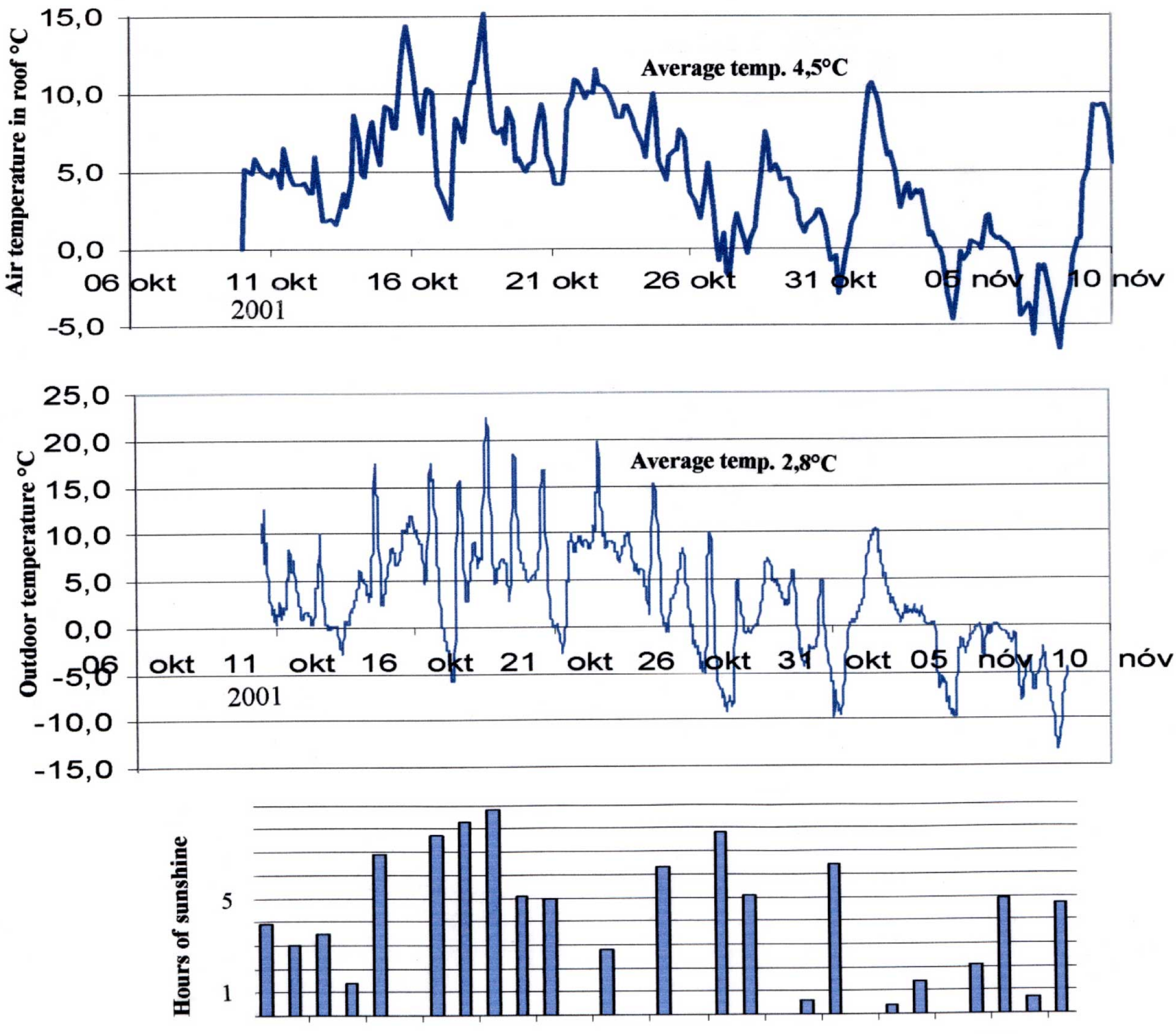
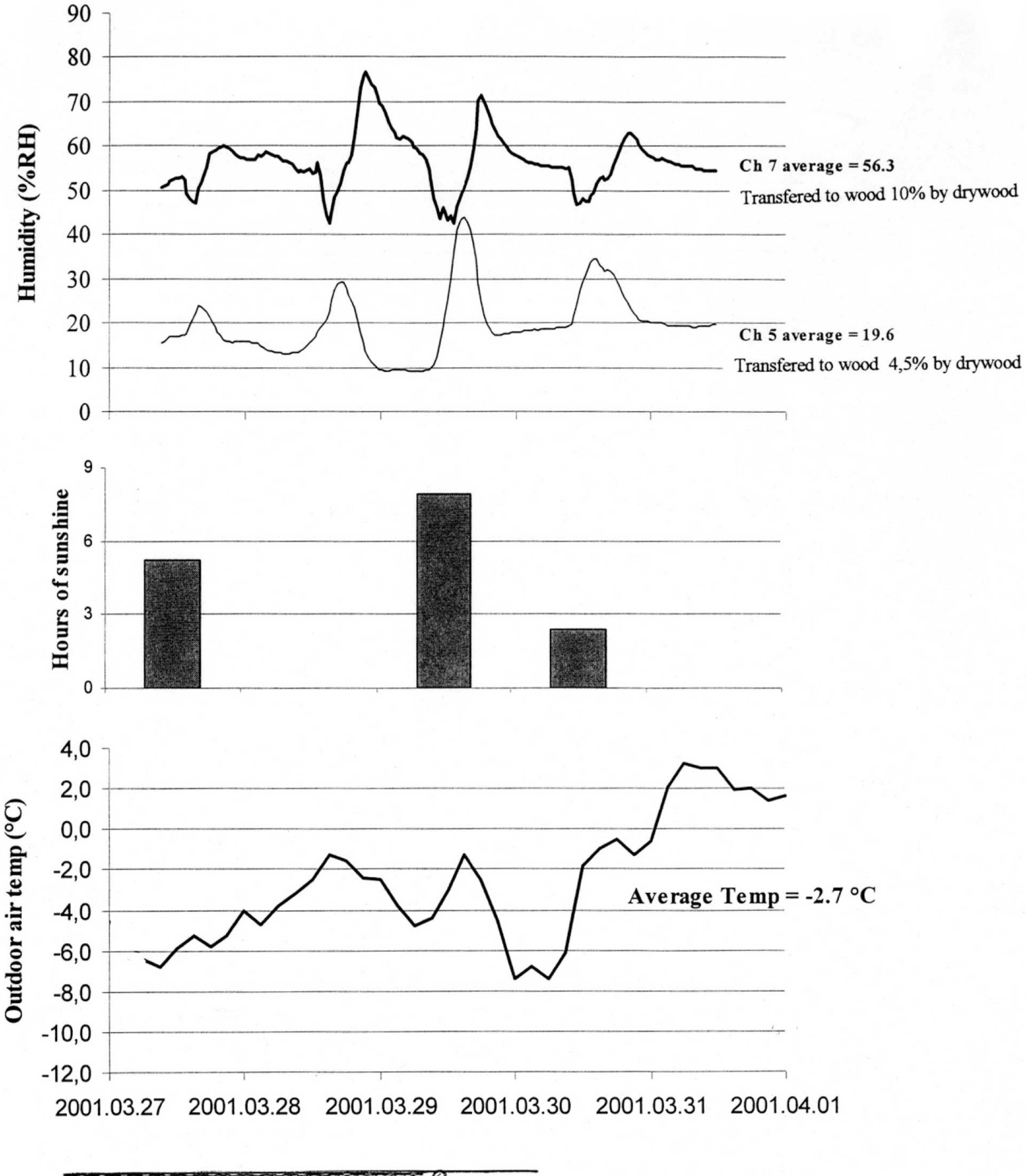


Chart 7

Roof in Akureyri (Rúmfatalagerinn), northern Iceland
Lett-Tak roofelements, unventilated.

Humidity transfer



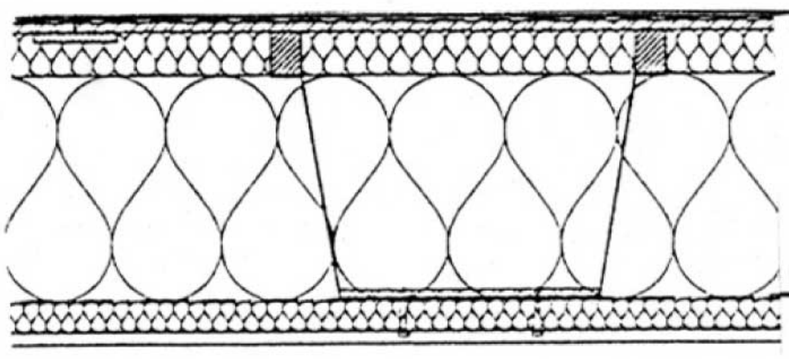
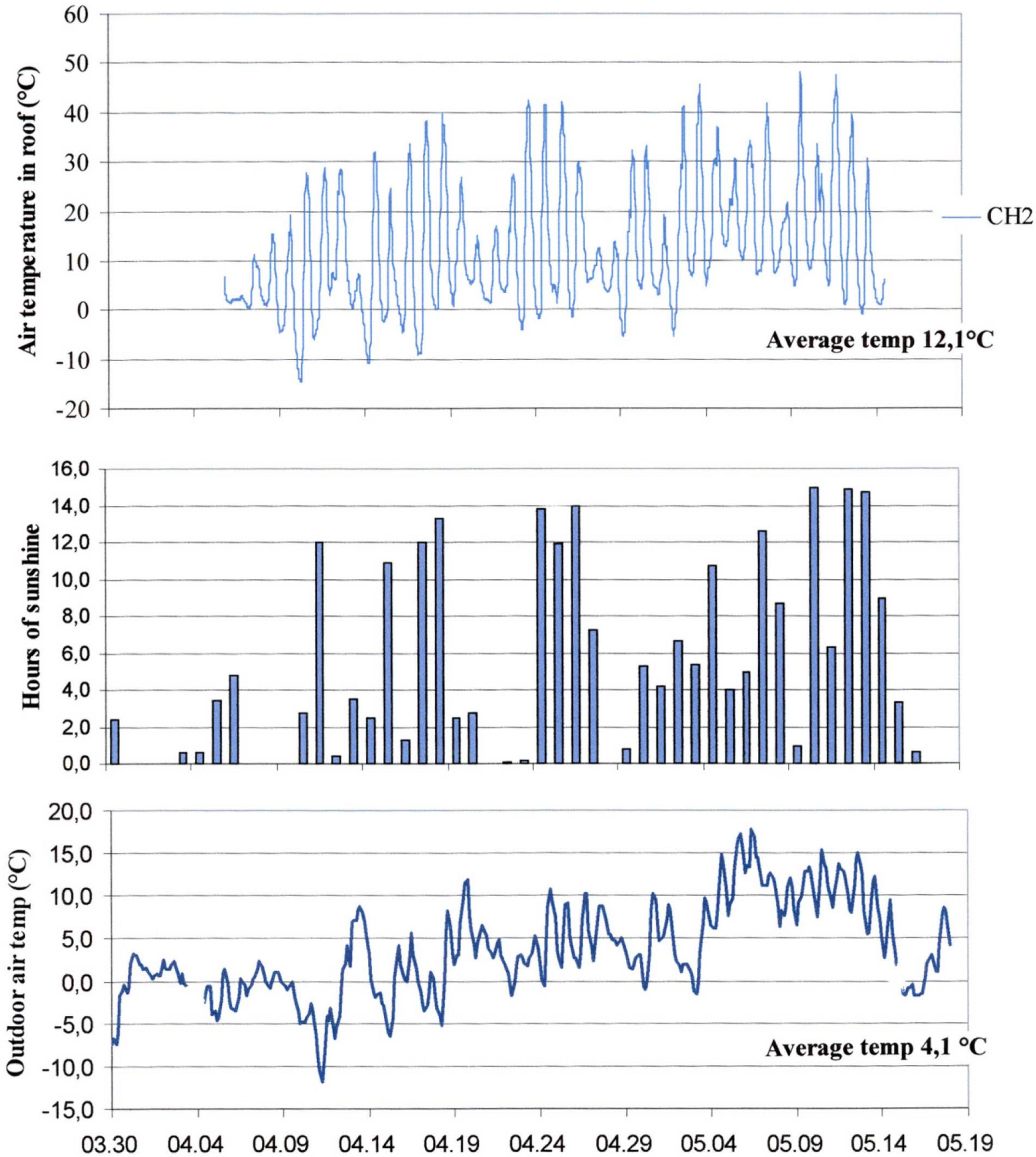


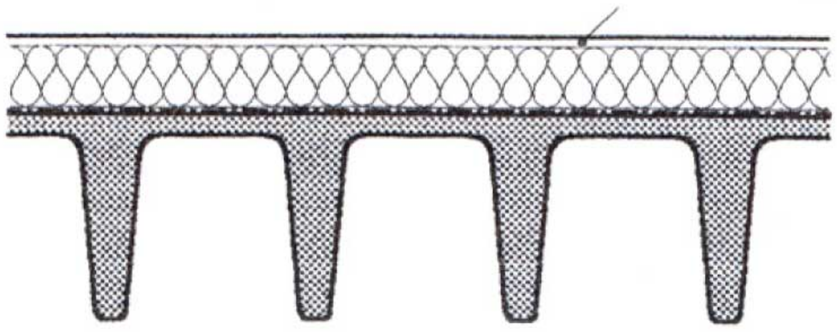
Chart 8

Roof in Akureyri (Kea – Nettó), northern Iceland
Bitumen-roof, unventilated.

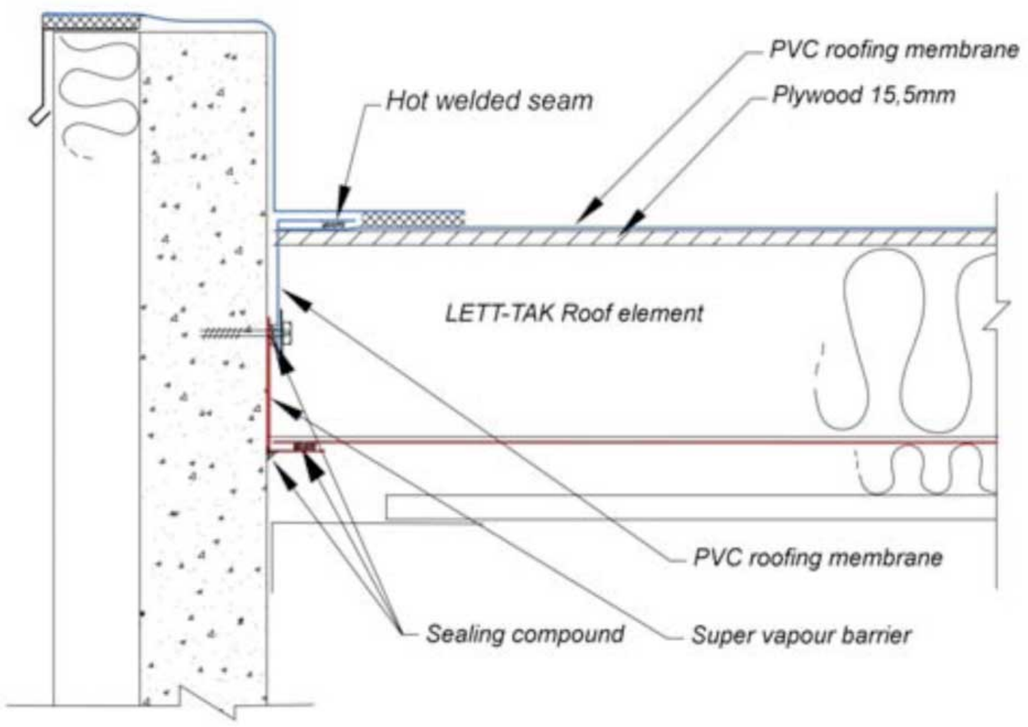
Heat transfer



Measuring head Ch2, under dusty black bitumen



Drawing 1



When Lett-tak roof elements are used over swimming pools the roof shall be made airtight by combining the roofing membrane to the vapour barrier along the surrounding walls. *Drawing 1* shows an example. Before mounting the element a stripe of wapour barrier and a stripe of roofing membrane are fastened and seald to the wall with metal bar. After mounting the roof element the stripes are velded/seald over and under before finishing the roofing over the parapet and finishing with an aluminium flashing inside.

Chart 9

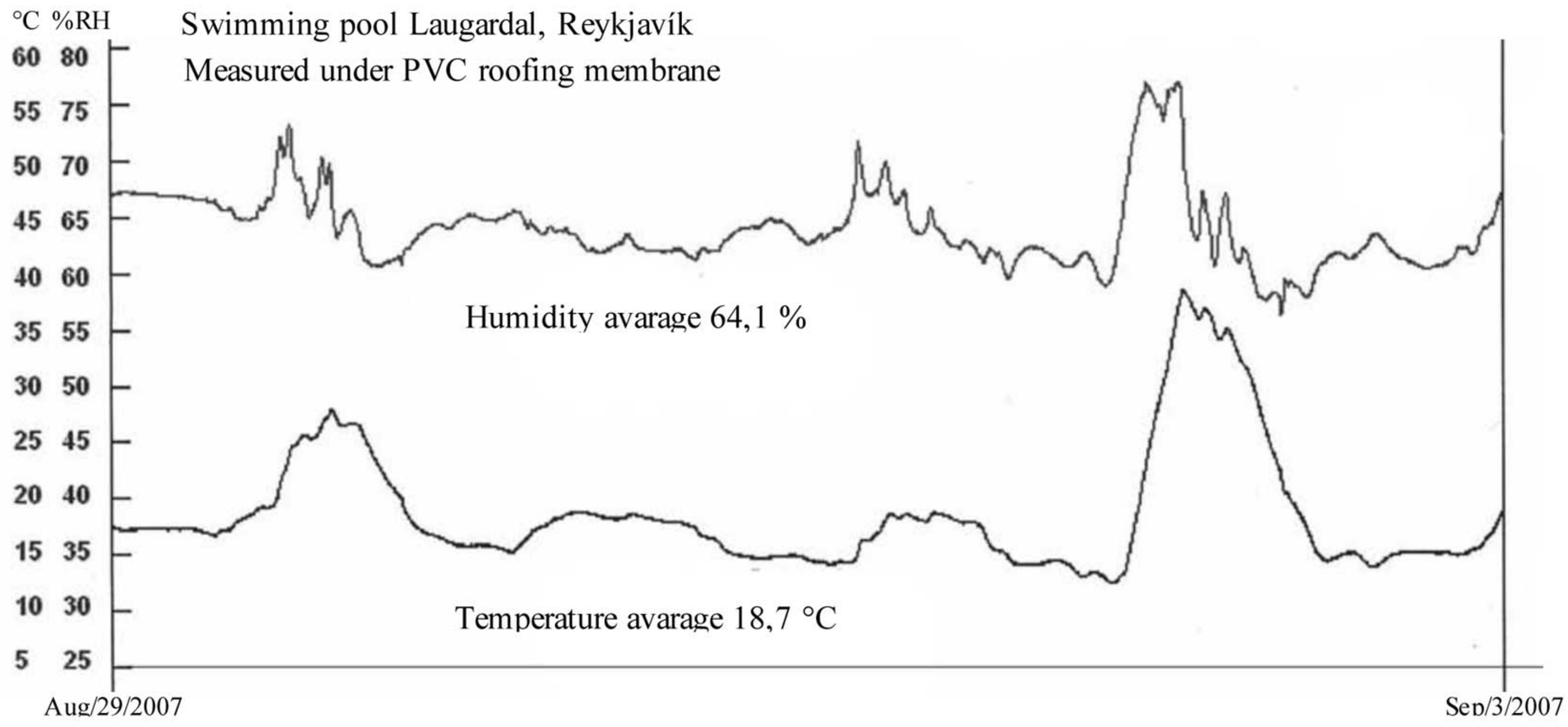


Chart 10

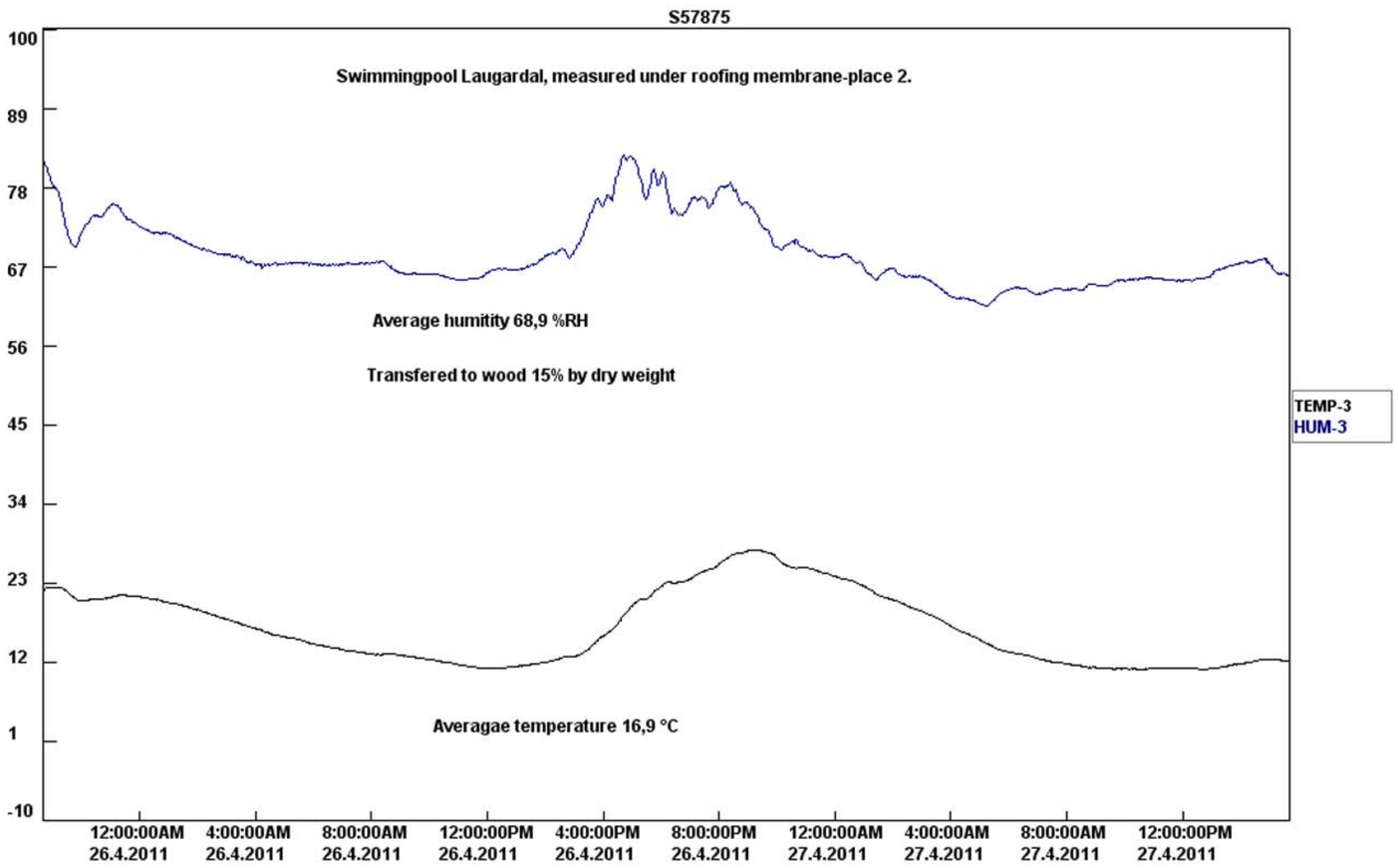


Chart 9 and 10 show clearly that Lett-Tak elements over swimming pool built 2003 are in good condition. The elements are of type V, see table 2 on page 11. Four other roofs over swimming pools in Iceland are without problems with same type of roofs.

5. Lett-Tak elements and Icelandic approval, valid until March 3, 2005.

Calculations of humidity transfer through differnt types of Lett-Tak elements were used to define what kinds of elements are allowed on different kinds of buildings.
Table 1, ***table 2*** and ***table 3*** show the results .

Table 1 ***Type of building***

Group	Example of type of building	Mean relative moisture indoors at 20°C %
A	Offices Retail stores Service centers "Dry" storage	< 25
B	Residential Industrial Schools Recreational	25 - 35
C	"Wet" Industrial Baths, locker rooms	35 - 45
D	Swimming pools	45 - 55

Table 2 ***Types of Lett-Tak roof elements***

Nr.	Roofing Membrane	Moisture Barrier
I	PVC-membrane, Protan SE 1,2, $Z \approx 80$	PE-membrane 0,2 mm, $Z \approx 445$
II	One layer asphalt membrane, 2 kg/m^2, under corrugated metallic cladding $Z \approx 500$	PE-membrane 0,2 mm, $Z \approx 445$
III	One layer asphalt membrane, 2 kg/m^2, under corrugated metallic cladding $Z \approx 500$	Super-Barrier (PE-aluminum foil-PE), $Z > 10000$
IV	Two layers asphalt membrane, 8,3 kg/m^2, $Z \approx 2250$.	Super-Barrier (PE-aluminum foil-PE), $Z > 10000$
V	PVC-Membrane $Z \approx 80$	Super-Barrier (PE-aluminium foil-PE), $Z > 10000$
VI	Ventilated roof, any membrane.	Super-Barrier (PE-aluminum foil-PE), $Z > 10000$

Table 3 ***Where to use different types of roof elements***

Group	Mean relative moisture indoors at 20°C	Example of type of building	Lett-Tak roof element Type
A	<25 %	Offices Retail stores Service centers "Dry" storage	I, II, III, IV, VI
B	25 - 35	Residential Industrial Schools Recreational	I, III, IV*, VI
C	35 - 45	"Wet" Industrial Baths, lockerrooms	V*, VI*
D	45 - 55	Swimming pools	V*, VI*

*** There shall be independent control on workmanship regarding vapour barrier. Over swimming pools there shall be ventilation over the roof elements. (If there is a separate ceiling under the roof elements and controled humidity in between, the type of elements is depending on that humidity and other conditions.)**

When working with rooftype V in building of group D the roof shall be made airtight by combining the roofing membrane to the vapour barrier.

There has not been a failure in Lett-Tak elements in Iceland yet. It is likely that there will be failures with time but such failures will most likely be attributable to temporary leakage than to the physical conditions.

<u>But one must also consider good workmanship when installing the roof and connecting the vapour barrier</u>. Figure 1 shows how the vapour barrier is sealed to the steel and the sealing is going up to the double tape (adhesive on both sides) waiting for the next Lett-Tak roof element to be pulled into the sealing.

Fig. 1

6. Thanks for cooperation

We thank Mr. Björn Marteinsson at the Icelandic Building Research Institute, Mr. Jón Viðar Guðjónsson at Línuhönnun Consulting Engineers og Mrs. Guðrún Gísladóttir at the Icelandic Meterological Institute for their part in this work.

Reykjavík, 26.04.2011
Hallgrímur Axelsson

References:

1. From The Icelandic Building Research Institute:

1.1 1999 Ástandskönnun þakeininga
1.2 1999 Rakamælingar í ibúðum
1.3 Unpublished measurements

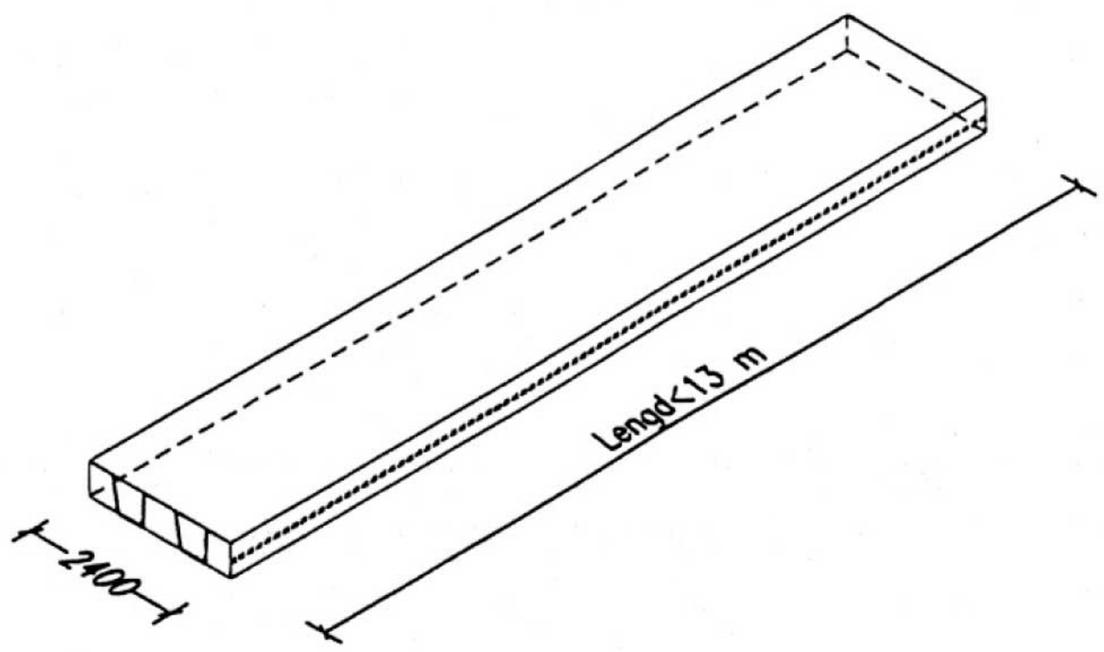
2. From Línuhönnun Consulting Engineers

2.1 1999 Lett-Tak þakeiningar, útreikningur á rakabúskap
2.2 Unpublished measurements

3. 1991 Tagpappbranchens opplysningråd (TOR), no. 21

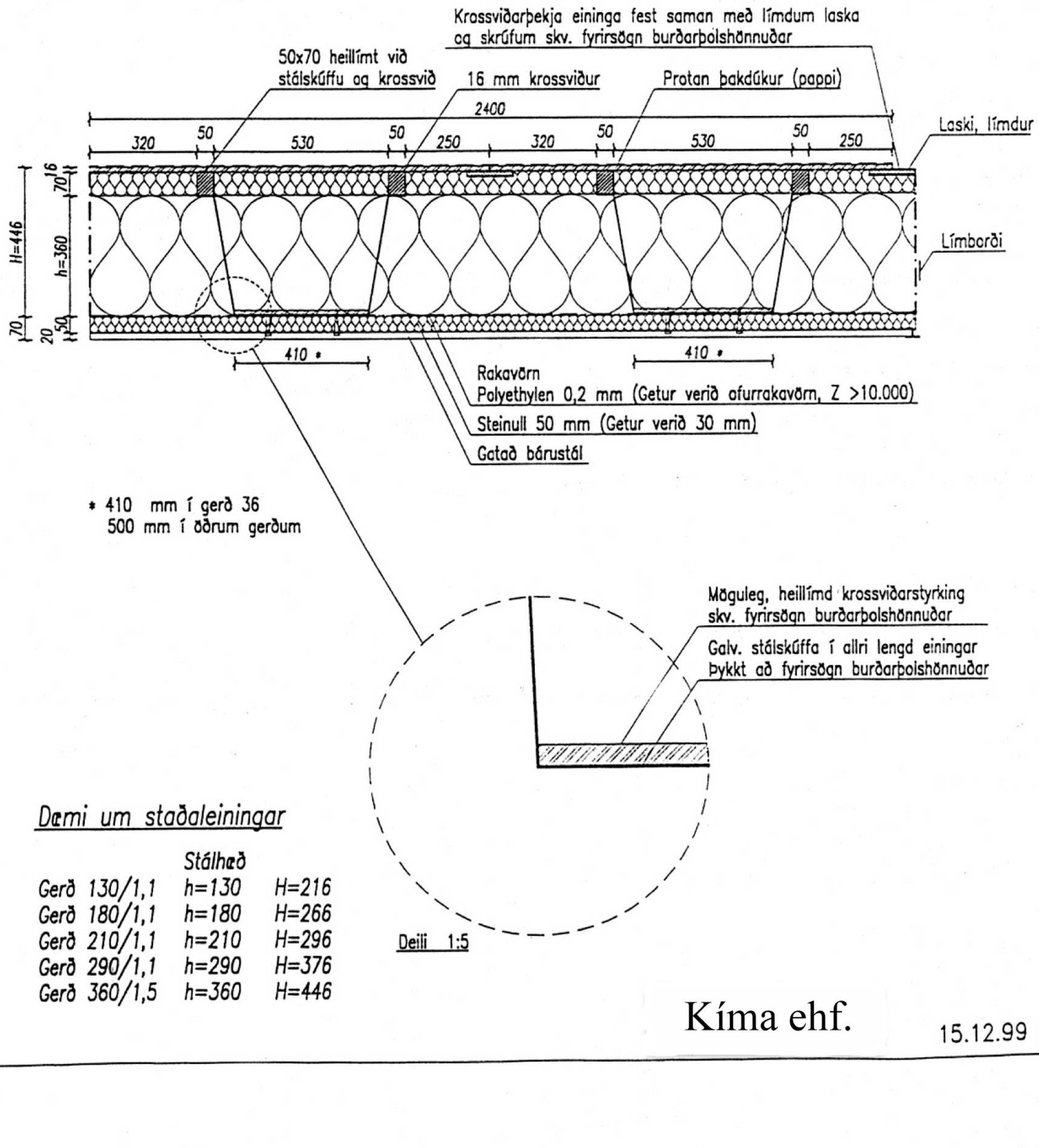
LETT–TAK þakeiningar

Kennisnið 1



Þversnið í staðaleiningu af gerð 360/1,5 1:20

Að ofan: Þakdúkur (getur verið tjörupappi)
Að neðan: 50 mm steinull og gataðar bárustál



Dæmi um staðaleiningar

	Stálhæð	
Gerð 130/1,1	h=130	H=216
Gerð 180/1,1	h=180	H=266
Gerð 210/1,1	h=210	H=296
Gerð 290/1,1	h=290	H=376
Gerð 360/1,5	h=360	H=446

Kíma ehf.

15.12.99 HA RG

Enclosure 2

(From reference 3, TOR no. 21)

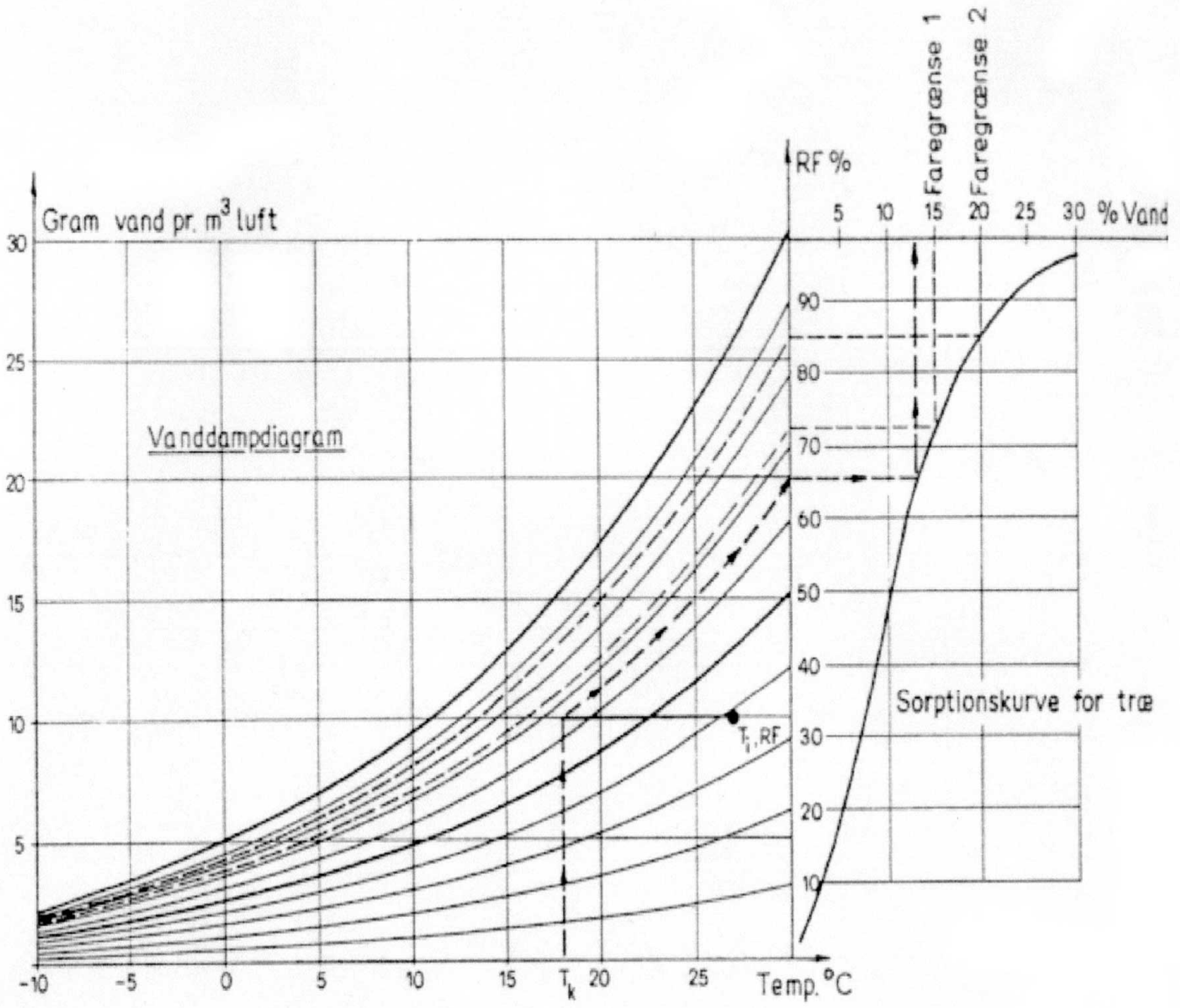


Diagram til bestemmelse af træfugtighed